Quaternary Ecological Studies

A Session in Memory of Prof. Paul Brönnimann

Chaired by Barun Sen Gupta

This session was designed to accommodate diverse studies on environmental relationships of modern or Pleistocene forams. The presentations are on field or laboratory investigations concerning autecology or synecology, or on ecological principles or modeling, of all foraminiferal habitats, whether marginal marine or full marine. The geographical coverage range between narrowly local to widely regional. Topics include (but are not limited to):

(1) diversity, ecology, paleoecology, and biological oceanography of Quaternary forams in both oligotrophic and eutrophic seas;

(2) community changes in historical or geological time;

(3) effects of natural or anthropogenic stresses on foraminiferal species or associations;

(4) taphonomic problems with sedimentary records of forams; and

(5) novel investigative or analytical techniques.
Paul Brönnimann died on January 7, 1993 in Geneva (Switzerland). He was 80 years old. He was born in Biel (Bern, Switzerland) on February 11, 1913. Paul Brönnimann studied at the University of Basel where he obtained a diploma of pedagogical studies in 1938 and a doctorate in Geology and Paleontology in 1939, prepared under the direction of Manfred Reichel.

Just after the beginning of World War II he was called into the army. He stopped most of his research, but was able to carry out some works about larger Tertiary foraminifera in Lausanne University. After the war, he became Privat-Docent at Bern University until December 1945. During this period he obtained his PhD and published articles on Tertiary Orbitoids, Moroccan Miogypsinids and Discocyclina. Unfortunately, he could not find work after the war in Switzerland and had to leave his country.

**Trinidad, 1946-1952**

In January 1946, Paul Brönnimann began his international work as a micropaleontologist. He began as “Paleontologist and Senior Stratigrapher with the Trinidad Leaseholds Ltd.” at Pointe-à-Pierre, Trinidad, B.W.I. During this period, he began his works on planktonic foraminifera, while always publishing papers on Tertiary large foraminifera. In Trinidad, he also discovered mangrove foraminifera and began to collect and study them. His passion for Recent foraminifera will last all his life. His last paper was published in 1992 (*Revue de Paléobiologie, 11*).

In Trinidad, he met new colleagues, some of them becoming faithful friends. Among them Walter H. Blow, Hans Bolli, Hans G. Kugler, Hans H. Renz. His work on mangrove foraminifera led him to initiate fruitful collaborations with Joseph A. Cushman whom he will meet later at Sharon (Massachusetts) and with Ruth Todd.
Cuba, 1952-1959

In Havana, Paul Brönnimann took up the post of “Head of Geological Laboratory, Cuban Gulf Oil Co” in 1952 and was attached to Esso Standard Oil in 1957. This period of his life was the one he talked about the most frequently.

In Havana, he met a good friend who unfortunately died too early: Noel K. Brown. He also appreciated the companionship of many colleagues, particularly Pedro Bermudez, and Danilo Rigassi with whom he prepared the “Contribution to the Geology and Paleontology of the Area of the City of La Habana” published in 1963.

During this period, he published many papers about planktonic foraminifera, but kept on studying Orbitoids and extended his field of study to other groups: Calpionellids, planktonic crinoids and nannofossils. He established a biozonation based on Nannoconus in 1955. He also began his studies about coprolites, that would intensify as he came back to Europe.

He had to leave Cuba reluctantly on December 6, 1959, when the Cuban revolution started. He kept a terrible recollection of this event.

Libya, 1960-1962

After Cuba, Paul Brönnimann and his family, Helen his wife and Martin his only son, went to Tripoli. He took up the post of “Senior Paleontologist and Head of Geological Laboratory, Esso Standard Libya, Inc.”.

France, 1963

In France, Paul Brönnimann spent his last year in the oil industry as “Senior Research Associate, Jersey Production Research Co, European Laboratories, Bordeaux”

Back to Switzerland, Geneva University, 1964-1982

At the end of 1963, Paul Brönnimann got a position at Geneva University as professor of paleontology. He kept this position until 1982. He had the opportunity to develop the teaching of a rising field in industrial sector: micropaleontology.

At the same time, he received strong financial support from the Swiss National Science Foundation that allowed him to carry out his research in good conditions. He collaborated with many colleagues, among them Marc A. Conrad, Adrien Jayet, Norbert Steinhauser, Louisette Zaninetti and Jean Charollais, with whom he struck up a solid friendship and published papers about the micropaleontology of the lower Cretaceous of the Geneva region. Still working...
on planktonic foraminifera, he organized the First International Planktonic Conference in Geneva in 1967, and took part in the JOIDES project in 1969.

With Louisette Zaninetti, his assistant, he began a new chapter of studies, beginning to work on Triassic foraminifera, an almost unexplored domain at that time. They traveled over alpine Europe, Iran, Pakistan and Turkey to collect material. Together, they also went back to work on mangrove foraminifera that he had left when leaving the Caribbean. This work led them to United States, Australia, Pacific islands, and mainly to Brazil where they carried out some fundamental works about mangrove foraminifera in collaboration with D. Dias-Brito, M. Arai, P. Casaletti, S. Silveira, E. Koutsoukos, G. Beurlen and J-A. Moura.

Recent agglutinated foraminifera became increasingly more fascinating for Paul Brönnimann who began a new collaboration with John E. Whittaker, whom he met for the first time in Geneva in 1973.

**Retirement 1982-1993**

In 1982, Paul Brönnimann retired, but remained emeritus professor of Geneva University and continued his work until the day before he died. His scientific work is considerable and encompasses a wide range of topics with great international value. He supported the setting up of the Revue de Paléobiologie published by the Museum of Geneva. In 1984 he received, at the same time as Hans Bolli, the “Joseph A. Cushman Award” and in 1986, was honorary president of Benthos’ 86. Many scientists had the privilege of coming into contact with this man of great learning who had a strong personality. He demanded a lot of himself and of his assistants, but was a very generous person, always happy to pass his knowledge down to younger generations.

After his death, the Paul Brönnimann Foundation was set up for awarding young scientists working on foraminifera.
We use a multidisciplinary approach in the study of marine sediment cores from a SW Greenland fjord, the Ameralik Fjord, near Nuuk (Godthåb), in order to determine the Holocene hydrographic history of the fjord as a proxy for the climate development of the region. For that purpose we have studied the sedimentology (colour scans, XRF-intensity, and grain size), benthic foraminifera and diatoms in an 8 m long piston core, a 3.5-m long gravity core, and a short box core from the same station. The chronology of the long cores is based on calibrated AMS 14C-dates, while the box core was 210Pb-dated. Ameralik is a 75-km long, up to 700 m deep multi-basin fjord in the Godthåbsfjord complex, where melt-water rivers from the Inland Ice drains into the fjord, but no glaciers terminate into the fjord at present.

The cores reach back to the early Holocene. The record of the last 4400 cal. years has been studied in detail, while the analysis of the early Holocene section is ongoing. From app. 4400-3200 BP fine-grained sediments with a high Fe content were deposited during a period of high sedimentation rates, representing a proglacial deposit, where large quantities of sediments were washed out from the melting of nearby inland glaciers. The diatoms indicate stable surface-water conditions with winter sea-ice formation in sheltered areas and with a steady influx of oceanic species associated with inflow of surface waters from the Labrador Sea. The benthic foraminifera indicate a high-energy, stable bottom-water environment with normal-marine or only slightly reduced salinities. We believe that this time interval represents the final part of the Holocene Thermal Maximum.

For the last 3200 years (approximately), conditions have been much more unstable. Significantly lower sediment accumulation rates and lower iron contents indicate a reduced output of terrestrial material. This was presumably linked to the general cooling of the area, resulting in a decreased melt-water outflow. The diminished melt-water outflow may have allowed an increased
influx of oceanic (sub)surface water, presumably from the comparatively warm West Greenland Current (WGC). However, the largest changes are illustrated in the benthic foraminiferal assemblage. The diverse, calcareous fauna found prior to 3200 BP, is replaced first by the opportunistic *Elphidium excavatum* and later at 2800 BP it disappears altogether, only leaving an assemblage of agglutinated species. This indicates a bottom-water condition that prevented the formation of calcareous foraminiferal tests; this was presumably linked to brine formation and reduced subsurface influx of oxygenated and saline WGC water in combination with sea-ice formation. During most of the approximately 2000 following years, the agglutinated fauna continues to dominate the foraminiferal assemblages.

A new significant change in the hydrographic regime occurred at about 750 BP (AD 1200), possibly linked to the initiation of the Little Ice Age. A decrease in oceanic diatoms and a rise in sea-ice diatoms indicate a significant drop in surface-water temperatures, more extensive sea-ice formation and a decreased influx of WGC surface water. The reintroduction of a calcareous foraminiferal fauna suggests a return to increased fjord ventilation related to enhanced subsurface inflow of saline WGC water (Irminger Water). A low Fe-content from app. 600-250 cal. yr BP (AD 1350-1700) suggests a reduced melt-water outflow and thus lower atmospheric temperatures. After app. 250 BP (AD 1700) increased influxes of benthic diatoms and a higher Fe-content suggest an increased melt-water outflow and thus increasing atmospheric temperatures, while the diatoms suggest enhanced inflow of WGC surface water.
Distribution of modern benthic foraminiferal assemblages in the Ariake Sea, Kyushu, Japan

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The Ariake Sea is a major producer of laver (red algae), which trades at a high price in Japan. In December 2000, most laver was bleached, and the laver processing companies consequently suffered great economic loss. In addition, muddy sediments with hydrogen sulfide odor covered extensive areas of the sea floor (Akimoto \textit{et al.}, 2004a, b) delineated environmental change in the Ariake Sea over the past 40 years, based on the relationship between foraminifers and the oceanic conditions reported from other bays around Japan.

Four previous studies have characterized the distribution of modern benthic foraminiferal assemblages in other bays around Kyushu, including Omura Bay (Shuto, 1953), Kagoshima Bay (Oki, 1980) and the Yatsushiro Sea (Kobayashi, 1992; Rifaldi & Oki, 1998). Modern assemblages in the northern Ariake Sea differ from those in these areas (Tanaka & Akimoto, 2004). Thus, data on the assemblages present in the Ariake Sea are needed for detailed paleoenvironmental reconstruction. This study describes the distribution of the assemblages in the Ariake Sea, and examines environmental factors related to that distribution, based on 212 sediment samples collected from the uppermost centimeter of the sea floor sediments.

Factor analysis (Q-mode) with varimax rotation was used to reduce the data into meaningful groups, and was performed to detect major environmental factors that likely controlled the distribution of benthic foraminifers. The data matrix for this analysis is composed of 209 samples represented by 20 or more individuals in each sample, and by 84 species that occurred as 6 or more individuals in one sample. Factor analysis identified seven factors that account for 87.4 \% of the variability of the data.

Seven foraminiferal assemblages were identified. These are characterized by predominant species (more than 20\% in one sample at least) including \textit{Ammonia beccarii} (Linne), \textit{Trochammina cf. hadai} Uchio, \textit{Elphidium advenum} (Cushman), \textit{Eponides cribroconcameratus} (Asano and Uchino), \textit{Elphidium somaense} Takayanagi, \textit{Textularia orbica} Lalicker and McCulloch, and \textit{Neoeponides mira} (Cushman).
The assemblages have the following spatial distributions and environmental associations:

1) *A. beccarii* inhabits coastal waters influenced by fresh water.

2) Three assemblages (*N. mira, T. orbica* and *E. advenum*) are distributed in the middle bay, where intermediate water contains more than 100% dissolved oxygen and salinity is greater than 3.2% (Kamata, 1967; Tanaka & Akimoto, 2004), and in association with coarse grained sediments (Akimoto et al., 2004a). *N. mira* coexists with sea plants, algae and colonies of *Modiolus comuptus* Sowerby. *T. orbica* has a thick, heavy agglutinated test, and thus is only present in the granule-sized sediments deposited from fast bottom currents. *E. advenum* occurs in the coarse sandy sediments.

3) *E. cribroconcameratus* occurs in samples from outer bay areas, where bottom waters are warmer than 12°C in winter.

4) The distributions of the *T. cf. hadai* and *E. somaense* assemblages are restricted to the boundary area between the intermediate and coastal waters. Because abundant organic matter is supplied to this boundary area, the dissolved oxygen content of bottom waters decreases rapidly in July, and falls to near zero in August (Takikawa et al., 2005). At the same time, pH of the bottom waters in the area occupied by *T. cf. hadai* also shifts to 7.3, whereas that in the area of *E. somaense* only reaches 7.8 at minimum. Thus, *T. cf. hadai* and *E. somaense* are indicators of rich supply of organic matter.

The above species also occur in other areas influenced by coastal waters in the East China Sea (Wang, 1988) and around Japan (Kosugi et al., 1991). They can therefore be used as environmental indicators in modern coastal and bay areas influenced by pollution originating from human activity.
Contributions of foraminifera to the production of carbonate sediments in recifal areas of Abrolhos, Bahia, Brazil

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The coral reefs of Abrolhos region in Brazil occupy an area of nearly 6,000 m². They constitute the richest and most extensive coralline complex of the South Atlantic Ocean. In contrast with the predominance of carbonate sedimentation observed in most reefs of the tropical seas, the Abrolhos reefs developed in a predominantly terrigenous sedimentary province. The production of carbonate sediments from the reefal organisms results in a change of sedimentary facies. The terrigenous sediments, dominant in the seashore zone, are gradually replaced by carbonate layers of offshore origin. Thus, carbonate sediments are concentrated on middle and outer shelves and in the areas that surround the reefs. With the goal of evaluating the contribution of foraminifera to the production of the carbonate sediment that surrounds the Abrolhos reefs, 38 samples of surface sediment were collected from the bottom, including reefs that extend along the coastline between the cities of Corumbau and Nova Viçosa, down to the isobath of 30 m. The analyses of the samples have revealed that, among the carbonate particles identified, only five components (coralline algae, molluscs, Halimeda, foraminifera and bryozoans) constitute >5% of each sample. The contributions of foraminifera and Halimeda are about equal, exceeded only by those of incrusting coralline algae and molluscs. Tests of foraminifera are absent only in two samples (22 and 23). More than 20% foraminifera tests was found in five samples, all of them from seashore reefs. In the mud fraction, the foraminifera are the biggest contributors, represented mainly by the species Ammonia beccarii, Elphidium discoidale, E. poeyanum, P. bulloides, P. elongata, Pyrgo subsphaerica, Quinqueloculina angulata, Q. disparilis curta, Q. lamarckiana, Q. polygona and Triloculina trigonula.
Benthic foraminifera of the “Parrachos” of Maracajaú, Rio Grande do Norte State, NE Brazil: Preliminary assessment

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The so-called “Parrachos” belong to the Maracajaú Coral Reef Protected Area, located about 7 km from shore in the northern Touros-Natal area, 60 km north of Natal, in Rio Grande do Norte State, northeastern Brazil. The Maracajaú reefs are a characteristic coral-algal reef community, dominated by reef-building branching and head corals and calcareous algae. A preliminary field survey was carried out in May 2004 when 35 surface sediment samples were collected with scuba diving. The study aims at a detailed reconstruction of the distribution patterns of the benthic foraminifera assemblages, in order to evaluate their application as bioindicators in coral reef health assessment and monitoring. Among 39 foraminifera genera recorded, Amphistegina lessoni, Pyrgo subsphaerica, Spiroloculina depressa, Peneroplis pertusus, Glabratellina arcuata, Cibides, Discorbis, Triloculina and Quinqueloculina are dominant in the area. A thorough SEM study is currently being carried out in order to evaluate the degree of bioerosion on selected specimens and investigate its probable causes.
Diagnostic tool to evaluate the benthic habitat quality in lagoons and estuaries of southern Brazilian coast

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Benthic organisms are affected by environmental conditions at multiple levels of organization including individuals, populations, assemblages and communities. Since different stressors can have variable effects on the biota, responses to changes in the environmental conditions can be reflected at any of these levels and, perhaps, simultaneously at multiple levels. The structure of benthic communities is widely used as indicator of the ecological health of a system. Therefore, it is desirable to choose a method to characterize their components and integrate multiple quantitative descriptors. The aim of this study is to present a relatively simple and fast multimetric biological index to evaluate ecological aspects of estuaries and lagoons from Santa Catarina (Brazil). The dataset used encompasses much of the southern Brazilian physiographic and environmental variability of mixohaline environments. Among the studied areas the most expressive are the lagoonal complex of Southern Santa Catarina, Lagoa da Conceição and Itapocu estuarine-lagoonal system.

The major stressors in these areas are domestic waste discharges that locally induce organic enrichment. The habitat quality indicator developed is the Benthic Index of Biotic Integrity based on euryhaline foraminifera populations descriptors (Forams B-IBI). This index evaluates the ecological condition of a sample by comparing values of key benthic community attributes to reference values expected under non-degraded conditions in similar habitats. The Forams B-IBI was calculated by scoring each attribute of foraminifera community structure according to the principles of Multicriteria Evaluation techniques. To select the attributes it was determined:

1) the ability of each attribute to distinguish among samples,
2) the level of correlation among attributes, and
3) the variability of each attribute across estuarine zones.

Six attributes were valuable in discriminating sites: total species abundance; percent abundance of the dominant taxon; percent abundance of tolerant taxa (e.g. *Cribroelphidium gunteri* and *Ammotium* spp.); percent
abundance of living individuals; average size of tests; and percent abundance of tests with abnormal development. Measures of richness and diversity were not included in the index because they are strongly correlated with other attributes (e.g. values of dominance). The thresholds were determined based on values obtained from reference site data and calibrated separately for oligomesohaline zones and poly-euhaline zones. The scores range from 1 to 5, 1 being related to the most degraded sites. This lower value was found in less than 10% of the evaluated samples. Following the same classification proposed by the Chesapeake Bay Benthic Monitoring Program, the benthic community condition was grouped in four levels: meets goals (good habitat quality), marginally degraded, degraded, and severely degraded. Forams B-IBI values of 3.0 were considered as the breakpoint between degraded and non-degraded conditions. The majority of the evaluated sites presented values above this limit. In general, areas under stronger marine influence, i.e. near to inlets, scored better (values above 4) than more confined areas. Although more testing and evaluation of this index are warranted, the obtained results showed that it provides a reliable and sensitive indicator for evaluating the ecological significance of sediment-associated stressors. It also should be considered as a component of wider environmental quality index in coastal management studies.

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Pleistocene glacial-interglacial dynamics at ODP Site 1198 (Australia): Micropaleontological and geochemical evidence

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Ocean Drilling Program Leg 194 drilled at Site 1198 (Marion Plateau) a sedimentary succession particularly suitable for high-resolution micropaleontological and geochemical studies. Our research is based on quantitative analyses of planktonic foraminifera, calcareous nannoplankton, stable isotopes of foraminiferal tests, and phosphorus and carbonate concentrations in bulk sediments to obtain a multi-proxy paleoceanographic reconstruction of the Late Pleistocene Northeastern Australian margin.

The bulk carbonate record obtained on board Leg 194 (Page, 2004. Scientific Results, 194:1-9) and the isotope stratigraphy performed in this research indicate that the upper 15 meters of the sedimentary sequence at Site 1198 span the glacial-interglacial cycles from Marine Isotope Stage 12 (approximately 460 kyr) to MIS1. Additional biostratigraphic information is provided by the first occurrence of *E. huxleyi* in sample 194-1198A-2H-2, 12-14 cm, which marks the base of Zones NN21 of Martini (1971. Proceedings of the II Planktonic Conference, Ed. Tecnoscienza, Roma, 739-785.) and by the *E. huxleyi* acme Zone, which is identified in the interval from sample 194-1198A-1H-1, 6-8 cm, up to the end of the section. In tropical regions, the base of this acme zone is equated to about 85 kyr (e.g., Thierstein *et al.*, 1977. Geology, 5:400-404).

Our results indicate that the increasing values observed in the curves of aragonite and Mg-rich calcite starting from the base of the section (460 kyr) may correlate with the onset of a carbonate platform along the Australian margin and near the Marion Plateau, very reasonably the Great Barrier Reef, as also indicated by Meyer *et al.* (2006. Evidence for the initiation of the Great Barrier Reef in Pleistocene sediments from Marion Plateau, NE Australia: 22-23).
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Pleistocene glacial-interglacial dynamics at ODP Site 1198 (Australia):
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The glacial MIS 6 is very well characterized in our section. In particular, we observe that the percentages of detrital phosphorus and the minor amount of quartz recall the curves of iron, possibly suggesting an increased input of terrigenous material into the ocean during this glacial stage. In the same time interval, we record higher abundances of *Globigerinoides ruber* (up to 25%). High abundances of this species were also observed in glacial stages by Reiss & Hottinger (1984. *Ecological Micropalenology*. Springer-Verlag: 354). The increase in detrital phosphorus would suggest an increase in either eolian or fluvial input that may have produced environmental conditions conducive to the proliferation of *G. ruber*.

Detrital input of nutrients from the continent could also have boosted productivity in surface waters as indicated by relative abundances of *Globigerina bulloides* (foraminifera), and created nutrient-poorer but optimal conditions for *Florisphaera profunda* (calcareous nannoplankton) in the lower photic zone.

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Foraminifera from the continental shelf and slope of the northern coast of Rio Grande do Norte state (NE Brazil): Microbiofacies and evaluation of their use as local bioindicators of environmental quality

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The present study was carried out on the continental shelf and slope off the northern coast of Rio Grande do Norte State (northeastern Brazil). The aims of this study were to characterize the area based on the benthic foraminiferal assemblages, and to evaluate their potential use as local bioindicators of environmental quality. Active exploration and production of oil and gas, and two submarine outfall pipes from petrochemical industry are present in the area. Forty-five localities were sampled by box cores, van Veen grab and Scuba diving, and three replicates from each locality were studied. More than 300 benthic species were documented. Based on total foraminiferal assemblages, the following biofacies were identified:

1. **biofacies 1** – recorded at several sites where siliciclastic sediments dominate, most of them located close to the shore;
2. **biofacies 2 and 3** – recorded at sites located near the outfall pipes from the Guamaré petrochemical complex and inside the Açú River paleocanyon, dominated by siliciclastic sediments with higher silt and total organic matter content, with a high standing stock of foraminifera;
3. **biofacies 4** – transitional, recorded at sites with siliciclastic to carbonate bottom sediments;
4. **biofacies 5** – recorded at sites dominated by carbonate bottom sediments, with abundant coralline algae and/or macroforaminiferal bioclasts;
5. **biofacies 6** – recorded at sites located on the continental slope, with abundant planktonic tests and well-diversified benthic foraminiferal assemblages.
Biofacies maps are presented based on total and living foraminiferal assemblages. It is important to note that other studies have shown low values of total organic matter on the bottom sediments of the area, but these small variations are important and usually perceived by the smaller heterotrophic foraminiferal species. The area is basically oligotrophic and has symbiont-bearing calcareous foraminifera. The results demonstrate that two foraminiferal groups deserve special attention concerning applications to environmental assessment and monitoring:

1) the opportunistic heterotrophic foraminifera that show high standing stock near the outfall pipes and other areas with higher silt and organic matter content; these are normally species adapted to episodic anoxia or low-oxygen (dysaerobic to quasi-anaerobic) bottom conditions (e.g., *Bolivina* spp.) and anthropogenic pollution;

2) the symbiont-bearing foraminifera (e.g., *Amphistegina* spp., *Heterostegina* spp. *Laevipeneroplis* spp., *Archaia angulatus*), which require particular environmental conditions (e.g., warm water, low nutrient water with normal marine salinities and water column transparency).

Locally, there are large bottom heterogeneities which reflect on the distribution of the benthic foraminiferal assemblages. The FORAM Index – FI (Foraminifera in Reef Assessment and Monitoring Index) was tentatively applied on the local foraminiferal data. The results demonstrate that, integrated with other available biotic and abiotic data, the FORAM Index can be successfully applied to the environmental characterization and ecological monitoring of the area.
Living foraminifera of the São Sebastião Channel (Brazil): A comparison between two areas subject to petroliferous waste and urban sewage

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Depending on the type of impact on aquatic organisms, pollutants may be ranked in the following order of increasing hazard:

1) those causing mechanical impacts (suspensions, films, solid wastes);
2) those provoking eutrophic effects (mineral and organic compounds);
3) those having saprogenic properties (sewage with a high content of easily decomposed organic matter);
4) those causing toxic effects upon physiological processes (heavy metals, chlorinated hydrocarbons);
5) those with mutagenic properties (benzo(a)pyrene and other polycyclic aromatic compounds – PAHs, biphenyls – PCBs).

São Sebastião Channel, located along the Atlantic Coast of São Paulo State, has environments varying from well preserved to highly polluted. The north-central part of the channel is the site of one of the largest petroleum terminals in Brazil (Dutos e Terminais Centro Sul - DTCS). Since 1967, when this terminal was built, numerous oil spills have occurred. Near this terminal is the Araçá Submarine Outfall (ASO), which dumps almost all of the domestic sewage from São Sebastião into the sea.

In this study the living foraminiferal response to contaminated effluents from the DTCS and the ASO was assessed based on a detailed geochemical and foraminiferal study of 20 point samples. For determination of foraminifera, samples were fixed with 70% alcohol and then stained with Rose Bengal. One hundred stained individuals were identified and the absolute number per unit volume of sediment calculated.

The assessed quality of the sediments is different in the two areas. Hydrocarbon concentrations and mud percentages in sediments collected near DTCS are higher than those around the ASO. Sediment in the DTCS area is largely mud with a high content of organic carbon (1–2.3%), nitrogen (0.04–
0.23%) and sulphur (0.12–0.47%). Sediments around the ASO were mostly sandy with high calcium carbonate content (24-29%). The highest percentages of fines, nitrogen (0.02–0.1%) and sulphur (0.1-0.2%) were displayed on the eastern portion of the Araçá Bay.

A total of 50 living species of foraminifera were identified in DTCS and ASO regions. Dead tests heavily outnumber live individuals in DTCS area. Living densities and richness are extremely low. More than 100cm³ of sediment were necessary in order to find 100 live specimens. The density values are higher in the ASO region. For example, just 20 cm³ of sediment were sufficient for the majority of the samples. *Ammonia tepida* dominates both the DTCS and the ASO assemblages, but *Buliminella elegantissima*, *Bolivina* spp., *Pararotalia cananetaensis*, and *Discorbis williamsoni* are also very common.

The lower density and richness values of the DTCS region may be related to oils spills and illegal cleansing of oil tanker containers. Living specimens are rare because of the noxious effect of petrochemical discharges. Oil and oil products comprise a complex and diverse group of pollutants that cause various impacts on living organisms, persist for long periods of time in sediments, and are subject to biomagnifications in the food web.

Generally, domestic effluent components decrease the abundance and diversity of foraminiferal assemblages in the Araçá Bay, but when the organic content is moderate and toxic components (such as PCBs) are absent, foraminiferal assemblages benefit from the nutrients (e.g., 179 individuals in 10 cm³ - station 8). These results confirm that foraminiferal assemblages respond more negatively to petrochemical discharges than to sewage outfall.
Foraminifera as indicators of marine pollution in the inner shelf of the SW Atlantic Ocean

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Quantitative analyses of foraminiferal assemblages and environmental parameters (e.g., salinity, temperature, dissolved oxygen, pH, total coliform bacteria, sand, silt, and clay) near an outfall at Mar Grosso Beach (Laguna, Santa Catarina, Brazil) demonstrate that Foraminifera can be used as indicators of domestic sewage. Surface-sediment samples were collected with a bottom snapper at twenty-four sites (water depths 5-20 m). Overall, the foraminiferal fauna is dominated by Elphidium spp., followed by Pseudonion atlanticum and Buccella peruviana. The generally low species diversity in the area may be due to the surf that prevents settlement on or in the substrate. A somewhat higher diversity is noted close to the mouth of the Laguna estuarine system where reduced salinity and higher temperatures show freshwater influence, and suggest a relationship between increased diversity and greater availability of terrestrial food. The silt and clay content correlates well with the total coliforms at three stations (5, 6, and 15 m). The study area can be separated into two regions. The region that includes stations closer to the estuary mouth and is under the influence of the outfall exhibits higher foraminiferal diversity and higher mean values of total coliforms and silt-clay content. In general, the characteristics of the foraminiferal assemblages show that the environment is in the initial stages of eutrophication. Apparently, the nutrient enrichment of the water by the organic waste has induced changes in the benthic foraminiferal community through an increase in species richness. Due to the high energy of the marine environment, however, the particulate organic waste derived from the outfall does not settle down on the seabed; our study supports the hypothesis that the material derived from the 12-m deep outfall is accumulated on the southwest part of the beach.
Population dynamics of foraminifera as indicator of estuarine environmental health

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Foraminiferal population dynamics provide a useful proxy of environmental health in two estuaries with similar configurations: Rehoboth Bay (Delaware, USA) and the estuarine system of Laguna (Santa Catarina, Brazil). Both estuarine systems have similar geomorphology, are connected to the ocean via one entrance, and have restricted water exchange due to long water residence times at least in the most inner parts. Both have shallow water depths, are microtidal, and have variable winds. Both estuaries share susceptibility to eutrophication, pollution, and sediment infilling, particularly in more restricted areas away from the ocean connection. Hydrographic data and sediment samples for analysis of foraminifera and thecamoebians were collected in the summer. Our measurements showed higher salinities overall in Rehoboth Bay compared to Laguna at the time of sampling. In Rehoboth, surface salinity varied from 14.8 and 28.6 per mil and bottom values from 19.5 to 28.7 per mil; in contrast, in Laguna surface salinity varied from 0.0 and 15.0 per mil and bottom values from 1.0 to 20.0 per mil. The lower salinities noted in Laguna suggests it may be better flushed and, because of this, less susceptible to eutrophication. The range of dissolved oxygen values in bottom waters is greater in Rehoboth Bay than in Laguna, ranging between 0.8 and 9.2 mg/l in the former and between 1.3 to 7.4 mg/l in the latter. The low oxygen values noted at specific sites in both study areas suggests locally poor mixing and a resulting higher risk of bottom water hypoxia and eutrophication. Given these physical parameters, we would expect Rehoboth Bay to be more susceptible to eutrophication. The faunal results suggest that Rehoboth Bay is, indeed, more affected by eutrophication. Rehoboth Bay presents lower diversity, with more than 50% of living specimens distributed in 10 foraminiferal species (4 Rotaliina, 1 Milioliina, 5 Textulariina) and one thecamoebian species. The bloom of Elphidium spp. and Ammonia spp., which tolerate hypoxia, reveals that the strategy of the population is to rapidly reproduce when conditions are favorable in a small period of time, suggesting a stressed environment. In contrast, Laguna presents higher diversity with very few living specimens (less than 10%)
distributed in 24 foraminiferal species (12 Rotaliina, 2 Milioliina, 10 Textulariina) and 8 thecamoebian species. The higher diversity, larger tests and lesser abundance of living species comprise a more stable fauna that suggest Laguna is an environment less susceptible to eutrophication. These differences may be due, in part, to stresses imposed by the wide range of seasonal change in temperature at the Rehoboth Bay sites, in contrast to the more stable subtropical climate of Laguna. However, it may also reflect a greater anthropogenic stress causing eutrophication in Rehoboth Bay. This suggests that the Laguna estuarine system is susceptible to degradation of environmental quality, particularly in the north where water circulation is less efficient, if no coastal management plans are implemented for stresses such as municipal and industrial wastes.
Freshwater influence and water masses interaction on the foraminifera along the SW Atlantic continental shelf

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The focus of this study is the influence of freshwater runoff from Plata River and Patos Lagoon on the distribution of benthic foraminifera along the SW Atlantic Continental Shelf. Surface sediments were collected with a bottom snapper along the 50, 100 and 150 m isobaths from 27º to 38ºS. Analyses of 26 samples from winter and 21 from summer demonstrate that despite the seasonal migration of the Subtropical Shelf Front, a strong influence of SSF on foraminiferal associations persists between 33º and 34.5ºS. Salinity, temperature, and dissolved oxygen show significant seasonal variations, but the geographic distribution of foraminiferal species is related strongly to freshwater runoff, especially that from the Plata River. The species diversity is lower at stations closer to the Plata mouth and higher at those from the Patos lagoon and farther north. Regional relative abundances of dominant species follow clear latitudinal gradients, and three main foraminiferal associations indicate three different water masses. Association A, with >30% Buccella peruviana and Bulimina marginata, indicates the presence of cold Sub Antarctic Shelf Water (SASW) in winter, from 33.5 to 38.3ºS, but mainly in the southern sector. In summer, however, at stations deeper than 100 m, the abundance of this association decreases to <15% around 37.5-38.9ºS where two species of association B (Cassidulina subglobosa, Uvigerina peregrina) take over. Association B, containing C. subglobosa, U. peregrina, and Pseudonion atlanticum, is mainly found at >55 m depths in the northern part of the area (27-33ºS) in both seasons, and is linked with Brazil Current waters. In four areas of the shelf, continental freshwater influence is detected by the presence of Association C (Ammonia beccarii, Bolivina striatula, and Buliminella elegantissima). The strongest signal, between 34 and 35.5ºS, is from the Plata River in winter. The second freshwater signal, from the Patos Lagoon, is observed between 32.9 and 33.2ºS in winter but farther south in summer (33.5-34.5ºS). The third freshwater signal is observed between 29º and 29.8ºS, and marks the influence of the Laguna estuarine system. The northern most fresh water influence is from the Itajaí-Açú River, recorded between 27.3 and 27.5ºS in winter, but extending southward (to 28.8ºS) in summer.
Sensitivity of time-averaged benthic foraminiferal assemblages to temporal variations in environmental conditions

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The basic assumption in paleoreconstructions is that fossil assemblages truthfully mirror the original biocoenosis and underlying environmental signals. This, however, is not true. The major reason is that fossil communities and assemblages contain time-averaged signals, which actually could mainly be driven by a sharp contrast in temporal environmental variations. The ecological imprint of, for instance, seasons with deviating environmental conditions (oxygenation, productivity, etc.) could weigh heavily in the year-average ecological and taphonomical control and thus in the dead/fossil assemblage. In recent years, much data has become available on short-term (scale of months) fluctuations in living (Rose Bengal stained) foraminiferal assemblages in relation to variations in environmental conditions. However, the transition to time-averaged dead assemblages remains poorly understood. Living assemblages are modified during the transformation to a dead/fossil assemblage by processes that vary strongly between taxa and over time: differences in population dynamics (e.g. low standing stocks but short generation length, thus high flux to the dead assemblage), and taphonomical differences between various environmental settings. These processes are difficult to quantify, and long-term (>1 year) time-series of both living and dead foraminiferal assemblages have almost exclusively been studied in intertidal environments. This study investigates a data set based on foraminiferal patterns and environmental variables from stations in two environmentally highly contrasting areas in the Mediterranean Sea, the Adriatic Sea and Levantine Basin. Microhabitat samples of living (Rose Bengal stained) and dead foraminifera were collected over a period of two years.
Salinity dynamics and living foraminifera assemblages at Caminha tidal-marsh (northern Portugal)

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The Caminha tidal marsh is located in northern Portugal, by the left bank of Minho river, at the confluence with Coura, a small tributary. The Minho watershed drains the rainiest region of Portugal, with marked characteristics of a wet Atlantic climate. The estuary is very shallow due to widespread siltation which, associated with the river discharge, prevents extensive penetration of a salt wedge and frequently allows the complete flushing out of sea water during ebb tide. Measures of salinity of interstitial waters in marsh sediment have shown low salinity conditions 4 km upstream from the river mouth. Our representative transect (Pedras Ruivas - PR) shows five different settings which were distinguished based upon foraminiferal assemblages:

1) channel –PR1- strongly dominated by s: Miliammina fusca (Brady) and Psammosphera sp.;
2) tidal flat –PR2, PR3– foraminifera absent;
3) low marsh –PR4, PR5– strongly dominated by M. fusca, associated with Psammosphera sp., Haynesina germanica (Ehrenberg) and Sacammina sp.;
4) high marsh -PR6, PR7- strongly dominated by M. fusca, associated with Psammosphera sp., Pseudothurammina limnetis (Scott & Medioli) and Haplophragmoides wilberti Andersen;
5) upper high marsh –PR8, PR10- showing a strong presence of Haplophragmoides manilaensis Andersen, which dominates PR10 assemblage, associated with M. fusca, P. limnetis and H. wilberti.

Salinity is a main environmental constraint in the Minho estuary. The strong gradient found in estuarine waters at the river mouth between consecutive low water (2‰) and high water (35‰) led to a study of salinity dynamics of both interstitial and flood driven near-bottom marsh water over the PR transect, during the rise of the tide, under Spring (April) and Fall (October) conditions. Measures of salinity were repeated approximately each 15 min. in water leaking inside perforated PVC tubes, previously inserted into the sediment to a depth of 40cm below surface. The results suggest that:
1) salinity of surface water flooding the marsh is not homogeneous, a decreasing gradient being found across the 110m-long transect, from channel to highest high-marsh (Spring – 24‰ to 6‰; Fall – 30‰ to 10‰);  
2) interstitial water salinity increases from Spring to Fall, as a result of salt concentration during the dry season;  
3) at the beginning of marsh flooding in Spring and before the arrival of marine water, interstitial water is diluted by lower-salinity water resident inside the estuary, with a consequent salinity reduction (the elevation of the highest high-marsh making it an exception to this pattern); and  
4) salinity of marsh interstitial waters displays a smaller range of variation than estuarine waters (PR1 - channel).

Salinity can reflect the stability that the marsh biotope offers to the foraminiferal assemblages under extreme variations of estuarine environment, allowing in the case of Caminha tidal-marsh the development of a low-salinity association.
Environmental constrains of living foraminifera distribution in the Caminha tidal-marsh (northern Portugal)

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Sixty surface sediment samples were collected in April and October 2002 in the Caminha tidal marsh in order to study the present-day distribution of foraminiferal assemblages. This marsh is developed on the left margin of the Minho River at the confluence with a small tributary, the Coura River. The Minho River defines the political border with Spain along the Galicia region. Its watershed drains the rainiest region of Portugal, with an average annual precipitation of 1600 mm, characteristic of a wet Atlantic climate, and develops in an area dominated by acid igneous and metamorphic rocks, producing carbonate-depleted water and sediment. From the group of potentially toxic metals Cu, Pb, Zn, Ni and Cr, only Ni exhibits concentrations (in 14% of the sediment samples) associated in the literature with frequent incidence of toxic effects on benthic communities. The estuary behaves essentially as “partially mixed” and presents a semi-diurnal, high-mesotidal regime, where the amplitude of the astronomical spring tide reaches 4m, and is further amplified by storm surge. The dynamic tidal effects are felt up to a distance of around 40 km upstream, as a consequence of both the tidal regime and the smoothness and low gradient of the Minho’s outlet. The estuary is very shallow due to widespread siltation which, associated with the river discharge, prevents extensive penetration of a salt wedge and frequently allows the complete flushing out of sea water during ebb tide. Considering the short distance to the river mouth (around 4km), an unusual low-salinity foraminiferal assemblage has been found in Caminha tidal-marsh that may be grouped in five associations.
Three main features of these associations stand out:

1) the low-salinity tolerant species *Haplophragmoides manilaensis* Andersen, *Psammosphera sp.*, *Miliammina fusca* (Brady) are dominant under Spring and Fall conditions;

2) *Pseudothurammina limnetis* (Scott & Medioli) occurs also as a dominant species in high-marsh zones IA2 and IB;

3) the hyaline foraminifera are present in very low proportion (<5%) in both the low-marsh and tidal flat associations; in addition, they exhibit very thin tests often lacking the carbonate layer, in accordance with geochemical conditions of interstitial water, namely strong undersaturation in calcite.

The geological setting of the Minho River basin indicates sea water as the main source of CaCO$_3$. However, climate, bottom morphology and hydrodynamics impose a short penetration distance and a small residence time of sea water inside the estuary. Therefore, the Caminha tidal-marsh environment is simultaneously constrained by both low salinity and CaCO$_3$ depletion.
Response of benthic foraminifera assemblages to pollution variation detected in cores from Guanabara Bay, RJ, Brazil

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Guanabara Bay is a large estuary (coordinates 22°40’ to 23°00’ S; 43°00’ to 43°20’ W) in Rio de Janeiro State, Brazil, between Rio de Janeiro and Niterói cities. Important mangrove areas are still found around the bay, but these represent only a minor part of the original mangrove extent. The largest mangrove region is located in Guapimirim Environmental Protection Area (APA). The degradation of Guanabara Bay was intensified during the 20th century, but the original ecosystem has been changing since Brazil’s discovery time. Sewage and drainage infrastructure services did not keep pace with the needs of the ever growing human population. Benthic foraminifera are used as pollution indicators in coastal areas, because they are very sensitive to environmental changes. This study presents the response of foraminifera assemblages to anthropogenic environmental impact and its recorded history. The foraminifera have been recovered from six cores collected near Paquetá Island and in the NE part of Guanabara Bay, which includes mangrove areas in Guapimirim APA and São Gonçalo district.

The analyzed cores were collected in November 2001. One 135 cm long core was collected near São Gonçalo. Two cores, 169 and 130 cm long, were collected in Guapimirim APA. Three other cores, 222, 242 and 283 cm long, were collected next to Paquetá Island. The methods used in this research are standard for calcareous microfossils.

Benthic foraminifera species diversity in these regions is low. Density values are low within the first centimeters of the cores, but increase downwards. Total Organic Carbon (TOC) values are high in all samples, and increase upwards along the cores. Agglutinated species (*Haplophragmoides wilberti*, *Textularia earlandi* and *Trochammina inflata*) are abundant close to the mangrove regions. Other common species (*Ammonia tepida*, *A. parkinsoniana*, *Buliminella elegantissima* and *Elphidium* spp.) are common in sediments with high concentration of organic matter, characterizing impacted environments.
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Response of benthic foraminifera assemblages to pollution variation detected in cores from Guanabara Bay, RJ, Brazil

Brígida Orioli Figueira; Mariana Nunes Cardoso; Franco Borges Quadros & Claudia Gutterres Vilela

The agglutinated species abundances, high TOC values and low Shannon-Wiener diversity indicate that mangroves occupied the region close to São Gonçalo in past times (based on evidence from the basal to middle parts of the core). These data are in accordance with the researched bibliography. With the elapsing time one can observe a gradual increase in organic matter accumulation rates and the disappearance of characteristic mangrove species. At the same time, there is an increase in the abundance of abraded and small species (top half of the core). The region next to Guapimirim APA does not show any abrupt upcore reduction in the proportion of mangrove characteristic species, but it displays a significant increase in the number of species characteristic of degraded environment, like Ammonia tepida, A. parkinsoniana, Buliminella elegantissima and Elphidium spp. The cores next to Paquetá Island indicate that the region has been subject to environmental impact processes as clearly seen from the microfaunal changes, like the abundant presence of Ammonia tepida and A. parkinsoniana.

The results show a progressive increase in the pollution toward the present, with variation in abundance of Ammonia tepida, A. parkinsoniana, Buliminella elegantissima, Elphidium spp., Haplophragmoides wilberti, Textularia earlandi and Trochammina inflata.
Relationships between primary productivity and oxygen conditions off NW Africa during the last deglaciation: Inferences from benthic foraminifera, diatoms and terrigenous sediments

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The Cape Blanc region off Mauritania, NW Africa, forms an important site for investigating paleoproductivity responses to past oceanographic changes, due to its location under the intersection of several characteristic water masses. Today it sits at the boundary between cool, temperate, subpolar water masses in the north and warm, tropical water masses to the south and west. In addition, the region is characterised by extensive, year-round upwelling and high terrigenous input, leading to high primary productivity. Slight changes in the direction of the trade winds and in the location of the boundary between the water masses can potentially have a large impact on the productivity of the region. In order to study productivity changes during deglaciation events, we have investigated the relationship of a range of variables such as aeolian input, species composition of diatoms and benthic foraminifera, and stable oxygen and carbon isotopes of planktonic and benthic foraminifera. Here we present the first results of the benthic foraminiferal assemblage studies, foremost from the Younger Dryas and the Bølling/Allerød, and compare with other variables. The grain-size record suggests that during the Younger Dryas the terrestrial conditions were drier and windier, resulting in a higher transport of aeolian dust to the Cape Blanc offshore area. The amplified fertilization and/or more intense upwelling resulted in elevated primary productivity as indicated by the very high concentration of diatoms during these times. The increased primary production resulted in low-oxygen conditions at the seafloor, and the benthic foraminiferal community could not benefit from the increased food supply. This is illustrated by the low concentration of benthic foraminifera and the complete dominance of the benthic foraminifera Bulimina exilis. These conditions stand in sharp contrast to those during the Bølling/Allerød and the rest of the Holocene.
Test malformation in foraminifera

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Malformed foraminiferal tests are known from the geological record, in modern stressed marine environments, and in laboratory cultures with higher than normal salinity levels. The deformities include aberrantly coiled tests, addition of small misshapen chambers, multiple apertures, twinned specimens, chamber misplacement to one side or the other of the plane of coiling, and edge fluting. They typically constitute a relatively small percentage of the total number of foraminifera and occur in both calcareous and agglutinated species. Hence, such malformations may indicate the health of these ecosystems. Although numerous studies have correlated malformations with specific environmental factors, such relationships are inconsistent and not well understood.

We examined this problem at seven sites ranging in age from Paleocene to Recent. Indian early Paleocene inter-trap shallow-water sediments within the Rajamundy Magmatic Province contain few foraminiferal species but with up to 10% malformed specimens. The sediment, deposited over long intervals, may have been exposed to volcanic contaminants directly or from runoff. However, at Deception Island, Antarctica, foraminifera live in a flooded active volcanic caldera, yet malformations occur in less than 1% of the specimens. In California, San Francisco Bay (SFB) experienced increased pollution and sedimentation due to mining, agricultural, industrial, and urban development for 150 years, yet malformed tests comprise less than 5% of its fauna. In Pleistocene SFB deposits, malformations are rare. A marsh adjacent to SFB was contaminated with heavy metals from roasted pyrite ore and Lake Merritt, a lagoon isolated from SFB by developers in 1861, is surrounded by the city of
Oakland. The heavy metals and urban runoff resulted in high concentrations of organic and chemical pollutants. Malformed foraminifera comprise less than 5% of the fauna in both of these highly polluted marginal environments of SFB. On the marsh, agglutinated species (Trochammina, Miliammina, and Haplophragmoides) were malformed whereas in the Lake calcareous species were affected (Ammonia, Haynesina, Elphidium, and Cribrorhaphidium). The 1978 Amoco Cadiz oil spill (223,000 tons of crude oil) affected the mouth of the Morlaix River, France, where malformed and parasitized Protelphidium paralium occurred in up to 10% of the fauna, considerably more than the 1% or less that occurred before the spill. In contrast to these coastal localities, deformed tests are absent or very rare in deep benthic environments and in Tertiary deposits unaffected by volcanism.

Malformed tests have been attributed to physical damage, highly fluctuating environmental parameters, or elevated levels of natural or human pollution, or any combination thereof. Although traces of toxic chemicals detected in tests could affect shell formation, little is known about the cellular process of test formation. Comparison of previous studies reveals that cause-and-effect is inconsistent between localities. Malformations are associated commonly with marginal marine environments such as marshes, mangrove swamps, estuaries, and lagoons, which are naturally stressed habitats primarily because of wide fluctuations in salinity, temperature, and dissolved oxygen levels. Environments in or near urban or industrial areas may be polluted by chemicals, organic matter, and increased sediment, resulting in higher frequencies of malformed tests. The occurrence of teramorphic tests in deep-water environments and their absence in some highly polluted environments is perplexing. Hence, environmental foraminiferologists must view each faunal locality as unique when attempting to relate teratological specimens to local environmental parameters.
Live foraminiferal faunas from the lower part of Cap-Ferret Canyon (Bay of Biscay): Composition, microhabitats, stable isotopes

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A 2800 m deep station from the lower part of Cap-Ferret Canyon (Bay of Biscay) was sampled in January 1999, June 1999 and April 2000. This station is characterised by fine-grained sediments and by important inputs of reworked organic matter in an intermediate state of decay. Diagenetic reactions within the sediment follow the well-established depth sequence resulting from the aerobic and anaerobic degradation of organic matter. At our station, live benthic foraminiferal faunas differ strongly from faunas previously collected at nearby open slope sites at a comparable water depth. Spectacularly high densities of deep infaunal species are observed in the deeper parts of the sediment for all three sampling periods. In our opinion, these high deep infaunal densities are a direct response to the massive flux of partially degraded organic matter, which is slowly introduced into the deeper parts of the sediment, where it induces a rather stable succession of redox gradients. *Melonis barleeanus* lives in the dysoxic part of the sediment whereas *Globobulimina affinis* thrives preferentially around the zero oxygen boundary. The investigation of the stable isotopes of dominant taxa reveals that there is no systematic relationship between foraminiferal microhabitat and the offset of foraminiferal δ¹⁸O and equilibrium calcite δ¹⁸O. The δ¹³C values of most foraminiferal taxa are not correlated to bottom water δ¹³C_DIC and seem to echo a “microhabitat effect”. As commonly documented, only the δ¹³C of *Cibicides wuellerstorfi* is very close to bottom
water $\delta^{13}$C$_{DIC}$. The peculiar fauna found at this lower canyon station, with its uncommonly high proportions of deep infaunal species complicates the use of these taxa for paleoceanographic reconstructions. Very often, fossil assemblages dominated by these taxa are interpreted as characteristic of highly eutrophic (important input of labile organic matter) or severely dysoxic bottom water conditions. The formation of such an assemblage in a well-oxygenated environment with important focusing of partially degraded organic matter shows that such fossil assemblages can also be formed in rather well-oxygenated settings without a strong vertical flux of labile organic matter.
The 1995 flood in the Vilaine estuary (France): Consequences on bathymetry, sedimentation and living foraminifera

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In January 1995, the flood of the century occurred in the Vilaine estuary (South Brittany, France). Numerical data from surface sediment samples can be used to estimate the consequences of this flood on the bathymetry, sedimentation and living foraminifera assemblages. Sedimentary (clay, organic carbon and carbonate contents) and foraminiferal (living assemblages) studies were performed with surface sediment from three stations in the Vilaine estuary. Surface sediments and cores (forty centimetres in length) were collected monthly from October 1992 to September 1996. Before the flood event, *Elphidium excavatum* made up more than 80% of the living assemblages and lived from the surface to 15 cm depth in the sediment. The complementary 20% was represented by *Ammonia tepida*, *Haynesina germanica* and *A. beccarii*. The surface sediments were characterized by a physicochemical gradient: high organic carbon and clay contents in the fluvial part and high carbonate content in the marine part. During the flood in January 1995, the fluvial current eroded the top of the estuarine sediments that contained all living foraminifera. This flood has led to the transfer of $3 \times 10^6$ m$^3$ of flood material from the upper part of the estuary to the Vilaine bay. The thickness of erosion is estimated at 50 cm, and the deposited flood material (rich in organic carbon) is up to 75 cm thick. From February to July 1995, the estuarine sediments were recolonized by *E. excavatum*, *H. germanica*, *A. tepida* and *A. beccarii*, but also by six species commonly observed on the inner shelf: *Leptohalys scottii*, *Bulimina aculeata*, *Nonionella turgida*, *Fursenkoina fusiformis*, *Bolivina variabilis*, and *Cribrononion magellanicum*. This recolonization was associated with a deposit of clay rich in carbonates and organic carbon. Nine months after the flood, the Vilaine estuary had recovered its previous bathymetry, sedimentary characteristics and living assemblages. The six inner shelf species which appeared during the recolonization had survived only temporarily. In cores collected in the estuarine zone, the indicator of this flood event is the occurrence of inner shelf species.
Holocene ice shelf stability:
A foraminiferal record from the bottom up

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The catastrophic collapse of Larsen-B Ice Shelf in early 2002 and its subsequent disintegration has resulted in the exposure of ~5700 square km of surface area formerly covered by either grounded glacial ice or ice shelf. During cruises NBP00-03, NBP01-07 and LMG05-05 surface sediment and core samples were collected to determine spatial and temporal distributions of foraminifera in the regions of Larsen-A (LIS-A) and Larsen-B (LIS-B) ice shelves.

Results of foraminiferal distribution analyses indicate distinct spatial and temporal variability between LIS-A and LIS-B. We suggest that these differences are the result of rapid faunal turnover related to changing conditions in primary productivity, sediment input and evolving glacial conditions on the continental shelf. LIS-A exhibits a faunal transition from ice shelf edge to outer shelf related to a slight primary productivity gradient. A similar trend is observed in LIS-B but with taxonomic differences. Temporally LIS-A and LIS-B differ greatly. LIS-A reveals a record of foraminiferal presence/preservation restricted to the latest Holocene and related to the ultimate collapse of LIS-A. However, LIS-B exhibits a record of planktonic and benthic foraminifera persistent throughout the Holocene. This indicates the sub-ice shelf presence of foraminifera in the absence of primary productivity throughout the Holocene. In addition, planktonic and benthic foraminiferal δ18O indicate progressive melting of the LIS-B accelerated in the mid- to late Holocene culminating in its recent collapse.
Marine pollution signatures on bioindicators of parts of southeast coast of India: A multidisciplinary tool in metal pollution monitoring

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Pollution signatures on foraminiferal biomarkers have been examined along the southeast coast of India. Analysis of surficial sediment samples shows environmental enrichment in heavy metals (Cr, Cu, Pb and Zn). The recorded high and low values were as follows:

1) Cr: 225.3 ppm (station 5) and 4.8 ppm (station 10);
2) Cu: 128.4 ppm (station 2) and 2.1 ppm (station 18);
3) Pb: 121.5 ppm (station 5) and 3.8 ppm (station 6); and
4) Zn: 196 ppm (station 5) and 4.3 ppm (station 10).

At present, the coastal environment in the study area is so lethal to benthic foraminifera that a minimal number of living species (4-7) can be concurrently found in sediments in <5 fathom water depths. The following species appear to be sensitive to metal pollution: *Elphidium advenum* (diminishing ornamentation), *Elphidium* sp. (thinning of final chamber), *Ammonia* sp. (deepening of groves), and *Textularia sagitulla* (highly corroded surface). The morphological abnormalities serve as pollution proxies in the study area. The investigation shows that the study area on the east coast of India is gradually turning into a garbage bin.
Abundance of *Globocassidulina subglobosa* in piston cores from the Salvador submarine canyon - Preliminary environmental inferences

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The Salvador Submarine Canyon is located along the northeast coast of Brazil, between latitudes 13°15’ and 13°30’ S, and longitudes 38°50’ and 38°35’ W. Foraminifera were recovered from samples of two piston cores of Quaternary sediments, drilled during the IX Geomar Expedition. The cores are from near the head (core #4– 154m depth, 305cm length,) and medium (core #9– 1460m depth, 161cm length) portions of the canyon. Physiographically, these depths correspond to the upper and lower slope of the continental margin in this region. Beyond the canyon head, the sediments are composed predominantly of muds, varying from terrigenous to calcareous muds towards the canyon mouth. The absolute abundance of foraminifera show opposite downcore trends in the two cores, increasing and then stabilizing in the shallower one, but decreasing in the deeper. The percentage planktonic/g of samples is in direct correlation with the water depth and distance from coast. The most common benthic species, in both cores, are *Globocassidulina subglobosa* and *Bolivina* spp., with about the same relative abundance. *Globocassidulina subglobosa* is an opportunistic, epifaunal/shallow infaunal species, typical of low productivity settings, where all organic carbon oxidation occurs near the sediment/water interface. The marked occurrence of *Globocassidulina subglobosa*, at least 50% of the total benthic microfaunal assemblage in both cores, suggests an environment with low organic carbon flux. The mixed size specimens of *Globocassidulina subglobosa*, with localized abundance peaks of small sized specimens, suggest moderately oxygenated depositional settings, and perhaps localized variable low-oxygen condition.
Foraminiferal indication of climatic variability off North Iceland during the last 2000 years

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The North Icelandic Shelf is a boundary region between water masses of Atlantic and Polar water masses, and is therefore a sensitive area to oceanographic and climatic changes. The present position of the Polar Front separates Arctic surface waters of the East Greenland and East Icelandic currents from branches of the North Atlantic Current in the area. Furthermore, sedimentary basins on the North Icelandic Shelf have the advantage of high sedimentation rates, allowing a sufficient temporal resolution for important information on past oceanographic and climatic changes. The present study focuses particularly on the last 2000 years, a time interval which includes both the historical time in Iceland and the time when the anthropogenic forcing became significant. The presence of historical and terrestrially dated air-fall tephra markers from Icelandic volcanoes makes it possible to construct reliable age models for the marine cores, minimising the problem of variable marine reservoir ages.

Benthic and planktonic foraminiferal assemblages and stable isotopes have been investigated in a series of sediment cores from the North Icelandic shelf. Two of the cores, IMAGES cores MD992273 and MD992275, attain sedimentation rates of between 300 and 500 cm per 1000 years during the late Holocene. The planktonic and benthic faunal distributions have been used for the reconstruction of paleoceanographic shifts during the last 2000 years, and the sea surface and bottom water temperatures have been reconstructed based on the oxygen isotopes of Neogloboquadrina pachyderma (sinistral), Melonis barleeanus and Islandiella norcrossi. The dominant planktonic species is Neogloboquadrina pachyderma (sinistral), while the most important benthic species are Islandiella norcrossi, Melonis barleeanus, Nonionellina labradorica, Cassidulina neoteretis, Cassidulina reniforme, Pullenia bulloides and Cibicides lobatulus.

The assemblages and the isotopes show increased influence of the Atlantic water masses of the Irminger Current during the time interval between ca. 1200 and 700 cal yr BP (Medieval Warm Period). The interval between ca.
700 and 100 cal yr BP (encompassing the Little Ice Age), on the other hand, was characterised by decreased sea-surface temperatures, presumably due to intensified influence of the East Icelandic Current in the area north of Iceland. It is interesting to note that the opportunistic species *Elphidium excavatum* immigrated to the entire North Icelandic shelf area at around 1200 cal yr BP. During the last century, an amelioration of the temperature is suggested by benthic as well as planktonic foraminiferal data. The foraminiferal results have been compared with high resolution sedimentological studies and diatom data from the same area and with the Greenland ice core record as well as with similar data from the time interval 8000-6000 cal yr BP in core MD992275 (the Holocene Climatic Optimum). Future high resolution foraminiferal studies from the North Icelandic Shelf are expected to contribute important data for a better understanding of the natural climate variability during the last millennium.
The role of *Amphistegina lobifera* as environmental health proxy in coastal ecosystems: 
A case study from Kastro and Korthi Gulfs 
(Andros Island, Middle Aegean Sea, Greece)

Olga Koukousioura; M. V. Triantaphyllou; Th. Tsourou; M. Dimiza & M. D. Dermitzakis

A study of Recent epiphytic benthic foraminiferal assemblages was conducted in August 2001 and July 2003 at Kastro and Korthi gulfs, Andros Island, Greece. Sampling was completed by collecting different algal species.

The response of benthic foraminifers to stressed environmental conditions was demonstrated by a change in the microfauna; *Amphistegina lobifera* has been replaced by miliolids (*Quinqueloculina berthelotiana/Q. bicarinata*) and small rotalliids (*Rosalina globularis*). This is documented by relative abundances of the foraminiferal species. Q-mode cluster analysis and Principal Component Analysis verified the presence of three different biofacies (Normal (NE), Declining (DE) and Stressed (SE) Environment Biofacies). In particular, the SE biofacies in the coastal environments of Andros Island is characterized by the very low frequencies of *A. lobifera* (<15%), whereas the NE biofacies is represented by great accumulations of *A. lobifera* (35-54.6%). The DE biofacies is characterized by intermediate frequencies of *A. lobifera* (21.22-38.33%). The SE biofacies has been mainly detected in areas affected by domestic sewage outfall, revealing the total absence of *A. lobifera*, abundance of miliolids (45-82%) and small rotalliids (7-21.5%), and a severe decrease in diversity.

The paucity of *A. lobifera* can, therefore, be used to recognize diverse unhealthy environmental conditions caused by natural influence (e.g. wave action and fresh water inputs, Korthi Gulf) and anthropogenic stress (e.g. sewage outfall, Kastro Gulf). Consequently, the large symbiont bearing benthic foraminifer *A. lobifera*, a species considered as a healthy conditions biomarker in coral reefs (associated with a high diversity of foraminifera), has proven to be a sound healthy conditions indicator in the coastal environments of the middle Aegean Sea.
Easter Island, a small volcanic island with an area of approximately 106 km², lies 2,230 miles west of the Chilean coast at latitude 27°10'S. As the easternmost outpost of the Polynesian region, and one of the most isolated islands in the Pacific Ocean, Easter Island has a marine fauna with an Indo-Pacific affinity. Characteristically, there is a high level of endemism for several taxonomic groups, including foraminifera (e.g., Adelosina pascuaensis), ostracods (e.g., Cytheroloides keji pasquaensis, Macrocyprina rattrayi, Neonesidea supercaudata, Loxocorniculm mayburyae, Quadracythere alloios, Tenedocythere titanikos, Triginglymus nesiotes, Cleocythere nautes, Xestoleberis polys, Xestoleberis tetragons and Aglaiocypris cylindratas; all described in R. Whatley, R. Jones & K. Woutrs, 2000. Revista Española de Micropaleontología, 32 (1): 79-106) and micromolluscs (dominated by microgastropods of the families Hipponicidae and Caecidae).

Nine sediment samples, mainly calcareous in composition and biogenic in origin, with scattered fragments of volcanic rocks, were collected in June 1979 at four different shore sites (water depth less than 1 m at the time of collection): Anakena Bay, Ovahe Bay and La Perouse Cove, on the East coast, and Hanga Roa Cove, on the North coast. Amphistegina lessonii is the dominant species in all the samples. A relatively well diversified miliolid assemblage, represented by 28 species belonging to Adelosina, Amphisorus, Hauerina, Heterillina, Marginopora, Miliolinella, Nodobaculacria, Quinqueloculina, Spiroloculina and Triloculina, is consistently found only in the Anakena and Ovahe bays, typically reflecting the more protected biotopes of these sites,
Distribution of Recent foraminifera, ostracods, and micromolluscs in shore sediments of Easter Island (Isla de Pascua), southeastern Pacific

Eduardo A. M. Koutsoukos; Gerson Fauth; Carla Bender Kotzian & Marly Madeira Falcetta

with low wave energy, finer-grained sediments and sea-grass substrate. This environmental setting is also reflected by the relative abundance in the foraminiferal assemblage of Discorbis mira, Homotrema rubrum, Planorbulina acervalis and P. mediterranensis, together with subordinate numbers of rotaliids, represented by 23 species belonging to Ammonia, Anomalina, Bolivina, Cibicides, Elphidium, Eponides, Fissurina, Glabratella, Gypsina, Heterostegina, Lamarckina, Lenticulina, Loxostomum, Planulina, Poroeponides, Rectobolivina, Reussella, Siphogenerina, Spirillina and Stomatorbina. In addition, the ostracod and microgastropod diversity and abundance are also much higher at these sites. The absence of a well diversified miliolid assemblage in the coves of La Perouse and Hanga Roa (where only rare Amphisorus were recorded), and of the genera Ammonia, Discorbis and Elphidium, points out to less protected biotopes, with moderate to strong wave activity, induced by the high-energy winds prevailing on the SW coast, with steep cliffs, coarser-grained sediments and a rocky shoreline.
Resolution of Holocene climatic and sea-level studies in temperate salt marshes: Implications of sediment mixing

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Ecological studies of marsh foraminifera have focused on providing modern analogs with which fossil foraminifera can be compared and interpreted. One of the characteristic features of tidal marshes is a zonation of species distribution with respect to elevation, where foraminiferal assemblages have been reported to occur within narrowly defined vertical bands, suggesting that these assemblages are accurate sea-level indicators, although many local factors influence the composition of foraminiferal assemblages. Similarly, there is a relationship between elevation and bioturbation where usually high-marsh sediments resolution far surpasses that of the low marsh. However, the study of taphonomy and bioturbation inherently leads to skepticism about the potential resolution of these microfossil-derived signals. The goal here is to quantify the sediment mixing, in an attempt to quantify the degree of stratigraphic destruction in hopes of reconstructing the pre-mixing signal.

Bombay Hook National Wildlife Refuge (BHNWR) is located along the western shore of Delaware Bay near Smyrna, Delaware, and was selected because it is relatively pristine. It has been the subject of recent taphonomic and sea-level studies. The area is characterized by a microtidal range, and the zonation of marsh macrophytes is less distinct than marshes with macrotidal ranges. Three plots, each measuring 1 m², were designated as low, intermediate, and high marsh, based on elevation, aerial exposure, and preliminary analysis of surficial foraminiferal assemblages. Chemically inert glass beads (180-250µm and <105µm; JB Import & Export LLC) color-coded by season were used to monitor the ongoing effects of mixing: red beads were spread in November 1997, yellow beads in July 1998, and green beads in September 1998. Each plot was sampled in February, June, July, and September, 1998, and in April 2005. The cores were sampled to bottom by taking samples of one cm³ volume every
one centimeter after the sides of the cores were cut away to minimize artificial
downcore smearing. Beads were concentrated on 125 µm and 62 µm sieves,
and counted under a binocular microscope.

Short Term Bioturbation — The amount of dispersion of beads tended
to increase from high to low marsh and through time. Bioturbation rates also
tended to increase in the late spring and summer, when the activities of burrowing
invertebrates and macrophyte root growth increased. In the high marsh, red
beads did not exhibit substantial dispersion until July, but by September had
broadened upward somewhat toward the surface. By contrast, there was no
significant increase in dispersion of the yellow beads between July and
September. In the mid marsh, the red beads were already smeared downward
slightly by February. Smearing continued into June. In July, however, they had
shifted back toward the surface, and this pattern persisted into September. In
the low marsh, red beads had also shifted downward by February, but to depths
of 5-6 cm and persisted into June. From July to September, red beads tended to
be concentrated above ~3-4 cm. Unlike the high and mid marsh, the yellow
layer exhibited substantial dispersion in July, although it was concentrated at
the surface by September.

Averaged Bioturbation — The beads dispersion after 7 years shows a
diffusion-like process with a gradient from high to low marsh. We found that
the disturbed layer is three times larger in the low marsh (9.4 cm) than in the
high marsh (3.4 cm). In addition, from the maxima concentrations we can infer
the sedimentation rate, which is up to twice as high in the low marsh (0.91 cm/
yr) than in the high marsh (0.57 cm/yr), in agreement with previous studies in
the area (0.27+0.04 cm/yr from 120-20 yr ago and 0.46+0.05 cm/yr during the
last 20 yr). However, high-marsh sedimentation rates are more constant
while in the low marsh they are more punctuated and highly variable (range
0.09-2.4 cm/yr).
Seafloor sediment was collected by submersible-based observers from four areas of hydrocarbon seepage in the Gulf of Mexico — Farnella Canyon (water depth 2918 m), Alaminos Canyon (~2200 m), Mississippi Canyon (~1070 m), and Green Canyon (~640 m) — in addition to control (non-seep) sites in De Soto Canyon (1848 m), south of Mississippi Canyon (1076 m), Garden Banks (640 m), and Green Canyon (245 m and 680 m). Cluster analysis of foraminiferal data from surface (0-1 cm) and near-surface (1-2 cm) sediment samples allowed us to distinguish between sites of active seepage and sites at which seepage is not active or has not been prolonged. Foraminiferal abundance and species richness data also help in this distinction.

Major species occurring in abyssal non-seep samples include Nuttallides decorata, Eponides turgidus, and Bolivina lowmani, whereas the dysoxia-tolerant infaunal species Praeglobobulimina ovata is common in most seep samples. Epibenthic Cibicides wuellerstorfi and Cornuspira involvens are found attached to vestimentiferan tubeworms at some Gulf of Mexico hydrocarbon seeps, but encysted individuals of the latter species are also found in seafloor sediments. Non-seep samples generally have higher species richness (calcereous 55-73; agglutinated 30-50) compared to seep samples (calcereous 1-53; agglutinated 0-21). Bolivina ordinaria, Cassidulina neocarinata, Gavelinopsis translucens, Osangularia rugosa, and Bolivina albatrossi are important in the bathyal samples, but are absent or negligible in the abyssal samples. Seep assemblages from Mississippi and Green Canyons are generally dominated by Bolivina ordinaria, but Cribromiliolinella sp. and Cornuspira involvens are dominant at one Green Canyon site. Many seep sites support sizeable populations of benthic Foraminifera of wide-ranging environmental adaptations, including several agglutinated species. Species of Hyperammina constitute greater than 90% of the assemblage in several seep samples from Alaminos and Mississippi Canyons. In these samples the foraminiferal abundance may be as high as 586 individuals/ cm³, but species diversity is reduced.
Hydrographic control on the distribution of planktonic foraminifera in the Gulf of Tehuantepec, Mexico

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The distribution of planktonic foraminifera in surface-sediment samples from the Gulf of Tehuantepec (Mexican Pacific), and its relation to hydrographic conditions were studied. Q-Mode factor analysis delineated three main assemblages related to ocean dynamics. The dominant assemblage of the gulf is characterized by *Globigerina bulloides*, which indicates the high productivity, upwelling-influenced surface waters. The *Globigerinita glutinata* assemblage indicates the area of strong instability of the axis of upwelling, and the *Globorotalia menardii-Neogloboquadrina dutertrei* assemblage the warm equatorial waters. The surface sediment distribution of these assemblages reflects the overall ocean dynamics of the Gulf of Tehuantepec, and can be used for paleoenvironmental reconstructions.
Rectilinear benthic foraminifers as tool to delineate oxygen-depleted conditions

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Foraminifers have so far been used in various fields of oceanography including paleomonsoonal variation, sediment movement, pollution effect, sea level changes, etc. by virtue of their extreme sensitivity to the variations in the physico-chemical characteristics of ambient environment. A slight change in any of the parameters of marine environment modifies the foraminiferal assemblages. Thus, specific assemblage from specific set of ecological conditions provides clues for paleoecological or paleoceanographic studies. Several studies have been carried out to document characteristic foraminiferal distribution in oxygen-depleted zones from the world oceans. However, no significant attempts were made to document the benthic foraminiferal response to oxygen concentration in the eastern Arabian Sea, west coast of India, a region marked by well developed oxygen minima zone (OMZ). Further, though a number of authors have reported the invariable abundance of rectilinear benthic foraminifers (RBF) from the OMZs, the collective response of the rectilinear forms has not been investigated so far. The objective of the present study was to document the spatial distribution of benthic foraminifers, especially the RBF with respect to varying oxygen concentration, from the region off central west coast of India.

A total of 103 surface sediment samples were analyzed for benthic foraminiferal study from 15 m to 3300 m water depth, off central west coast of India. A total of 423 benthic foraminiferal species were identified from >100,000 specimens from the study area. Out of the total 405 benthic foraminiferal species identified, 73 species belong to 19 genera of rectilinear bi- and tri-serial benthic foraminifers. The relative abundance of RBF shows strong negative correlation with the oxygen concentration. The abundance of RBF is >40% within the well-established OMZ (150-1500 m) of eastern Arabian Sea. This study shows that the relative abundance of RBF can be applied to delineate oxygen-depleted regions from the present study area. Interestingly, similar increased RBF abundance (>40%) was also noticed within the water depth of 50–60 m. Depleted-oxygen concentration has been noticed from the shallow water regions off the western coast of India, based on physico-chemical investigations. The study shows the importance of RBF to identify geographic and geologic extent of low oxygen concentration zone in the eastern Arabian Sea.
Abundance of *Bulimina denudata*: New sediment toxicity test?

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*Bulimina denudata* Cushman and Parker (= *B. marginata* d’Orbigny) is a valuable taxon as it is present nearly worldwide in outer shelf to upper slope biofacies, is both epifaunal and infaunal, and is quite tolerant of polluted sediments. We compared the abundance of *B. denudata* to amphipod survival and sea urchin fertilization, two tests commonly used to assess the toxicity of sediments, in the vicinity of the Hyperion outfall in Santa Monica Bay near Los Angeles, California, USA. Toxicity patterns suggest that the historical inputs of the 7-mile sludge outfall are the most likely source of the pollution.

We measured amphipod survival, sea urchin fertilization, and the abundance of *B. denudata* in seven box cores using standard analytical methods. The amphipod test used homogenized sediment sampled from 0-6 cm, and every 4 cm section thereafter, continuously for the entire length of the core. The sea urchin fertilization test used the overlying water produced in the amphipod test at the same sampling intervals. In contrast, 1 cm sampling intervals at selected time intervals from replicate cores from the same box core were used for the abundance of *B. denudata*. These time intervals were: pre-pollution conditions (1800 and 1900), beginning of extensive settlement (1945), extreme level of polluted discharge (1970), treated discharge (1985), and the modern record (1997).

In Santa Monica Bay, the amphipod survival test identified toxic samples more often than the sea urchin fertilization tests, whereas the toxicity effect of the latter was more pronounced. These tests suggest that although both are sensitive to pollutants, they each respond to the pollutants in a different manner. Amphipod survival rates negatively correlated with the concentration of silver in the sediment, but not with the high levels of DDT found throughout the bay because the amphipod used in this study [*Grandidierella japonica* (Stephensen)] is tolerant of the pesticide. Poor success with sea urchin fertilization was associated with high concentrations of zinc, silver, copper, cadmium, and total PCBs and PAHs.
Comparison of amphipod survival success and the abundance of \textit{B. denudata} shows that they are generally in good agreement. Both organisms exhibit negative correlations to high levels of pollutants in the sediments. However, in some cases small discrepancies occur between the two records. This inconsistency is particularly evident in core 20 obtained from the middle shelf, approximately 5 m from, and 50 m upslope of, the 7-mile outfall. The unique saw-toothed pattern of both amphipod survival and sea urchin fertilization success is mirrored by the abundance of \textit{B. denudata}, although offset slightly downcore. These offsets may be due to the replicate cores recovering samples that are slightly non-contemporaneous due to gently dipping sediment layers in some box cores. Or, it may be due to the size of the sampling intervals utilized for the different samples: 4-6 cm for the amphipods compared to 1 cm for the foraminifera. As a result, the samples may have different contaminant loads and faunal responses may show generally similar, but not identical trends. Unfortunately, financial constraints precluded us from measuring the contaminant loads for the replicate cores.

This study suggests that the abundance of \textit{B. denudata} positively correlates with the survival success of amphipods. Therefore, the temporal variation of its abundance may be a useful, cost-effective tool for defining and monitoring areas affected by pollutants. The use of \textit{B. denudata} could eliminate the need for the expensive and burdensome laboratory tests required to determine amphipod survival and sea urchin fertilization success. These tests pose an additional problem in that they must be completed shortly (often within a month) after the acquisition of field samples if the results are to be considered valid. Such a time constraint is not an issue when working with foraminifera.
ForamSampler v. 3.0 - Microfossil sample data management software

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Old fashioned paper and pencil micropaleontological data management systems make archiving highly labor-intensive and cumbersome. To simplify this process and increase the efficiency of data collection techniques, the U.S. Geological Survey teamed up with a computer software company, Giavaneers, Inc., to develop ForamSampler, a computerized procedure for microfossil data collection. ForamSampler v. 3.0 allows the researcher to digitally enter and manipulate micropaleontologic (or other) data, thereby dramatically reducing the time previously needed for manual data entry. It also serves as a database.

ForamSampler is modeled after the multisquare specimen slide used by micropaleontologists. When it launches, a blank “sample sheet” with a default 4x4 grid of “specimen boxes” appears. The grid dimensions can be easily customized so that it matches the specimen slide used by the researcher. Any grid layout with up to a total of 60 squares is possible. Header information includes: location, core/site identification, sample, sample interval, floated (yes/no), stained (yes/no), split, total specimen count, size fraction, picked by, and date. Footer information is a checklist of other sample constituents such as diatoms, radiolarians, ostracods, etc. A brief comments section is also provided.

A species selection list on the sheet allows the user to drag a name into a box. Alternatively, the user can type the name directly in the box. The specimen count can then be entered by using any of three options:

1) the up/down arrow keys on the keyboard,
2) the up/down arrow buttons next to the counter (clicker count feature), or
3) by simply typing a number into the number field.

This value can be changed at anytime. The number of foraminifera in the active specimen box is shown. A running total of the number of specimens on the entire sheet is also displayed.

ForamSampler allows the user to personalize the list of species names for the “drag and drop” feature, making the application adaptable to faunas or
floras of any microfossil group, from any geographic region or time period. The species list is a standard ASCII file and can be easily edited or customized.

The standard output (printout) consists of an 8 1/2" x 11" page-size replication of a micropaleontological specimen slide, including species names and counts in each square. ForamSampler can also display digital images of foraminifera or other microfossils in each of the squares, providing useful visual identification.

Entered data are automatically saved to a file containing the contents of all boxes on all sheets, presented as a list of species names and counts both in numeric order of the squares and alphabetically. ForamSampler automatically tallies counts of species appearing in more than one square, the total number of species, and the total specimen count. The file is standard comma delimited ASCII text which can be imported to any spreadsheet program, such as MS-Excel.

ForamSampler is a cross-platform application. The Macintosh version requires a PowerPC, Mac OS X or later; the PC version requires Windows95/98/2000/NT/XP, or Linux. All platforms require Java JRE 1.4.2. On Macintosh, JRE updates are available from Apple. On Windows and Linux platforms, the appropriate JRE is supplied with the installer. The cross-platform feature enables Macintosh and Windows-PC based users to share data collection procedures and files.
Benthic foraminifera as bio-indicators of eutrophicated environments

M. Mojtahid; F. Jorissen; Durrieu & F. Galgani

Foraminifera are among the most abundant protists in marine benthic environments. Because of their short life cycles, high biodiversity and specific ecological requirements, foraminifera react quickly to environmental disturbance, and can be successfully employed as bio-indicators of environmental change, such as ecosystem modifications brought about by anthropogenic pollution. Since foraminifera are commonly abundant, foraminiferal assemblages are easy to collect. They provide a reliable database for statistical analyses, even when only small sample volumes are available. Furthermore, many foraminiferal taxa secrete a carbonate shell, and leave an excellent fossil record, that may be used to characterise baseline conditions, and to reconstruct the state of the ecosystem prior to the onset of pollution. Studies of the effects of pollution on benthic foraminiferal assemblages, and their possible use as pollution indicators were initiated in the early 1960’s. In the last decennia, foraminifera have been increasingly used to monitor pollution in a wide range of marine environments, such as intertidal mudflats impacted by oil spillages, harbours affected by heavy metal pollution, or eutrophicated continental shelves. The aims of our study are to compare different types of eutrophicated environments, both in anthropogenic or completely natural contexts. We use benthic foraminifera as bio-indicators of anthropogenic eutrophication caused by drill cutting discharges (Congo and Gabon), by sewage sludge (Firth of Clyde; Scotland) and by fish farms (Loch Etive; Scotland) and compare the faunal patterns with those observed in the Rhone prodelta, an environment characterised by strong natural eutrophication due to important riverine nutrient input.

Our best example of anthropogenic eutrophication is a drill cutting disposal site at the outer continental shelf off Congo, where we observe a zonation of foraminiferal faunas in the 750 m around the discharge point. In the immediate vicinity of the discharge points (within 70 m), faunas are characterised by low foraminiferal densities. Faunas between 70 m and 250 m of the disposal sites
have very high foraminiferal densities, with elevated percentages (about 80%) of opportunistic taxa such as *Bulimina aculeata*, *Buliminata marginata*, *Textularia sagittula*, *Trifarina bradyi* and *Bolivina* spp. Between 250 and 750 m, foraminiferal densities decrease, and the percentages of opportunistic species are lower (40-60% of indicator species). These results show that 4 years after the cessation of oily cutting disposal, strong environmental impact is limited to a zone of 250 m around the disposal sites. We used these data to develop a quantitative pollution index, values of which are strongly correlated with the distance to the disposal site. This foraminiferal index offers the possibility to quantify the impact of anthropogenic eutrophication in continental shelf environments, but its validity must be tested in a wide range of naturally and anthropogenetically impacted marine environments.
Epifaunal foraminiferal zonation of Tagus salt-marshes estuary (Lisbon, Portugal)

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The Tagus River has the second largest estuary of Western Europe, extending across 325 km², of which 40% emerge in the low water of Spring. This region of Lisbon and Tagus Valley exhibits a climate of Mediterranean characteristics. The estuary presents a semi-diurnal mesotidal regime with the average amplitude of the astronomical spring tide reaching 3.2 m. The dynamic tidal effects are felt up to a distance of 80km upstream. This estuary is generally classified as partially mixed, but it also shows a salt wedge structure under low river discharges (<100 m³/s), and develops a well-mixed structure, during peak discharge conditions (>1000 m³/s). Tagus salt marshes develop from the lower to the upper estuary, along 50 km, over an area of 18,760,000 m² (Bettencourt et al., 2003. Estuários Portugueses. Ed. INAG – Ministério das Cidades, Ordenamento do Território e Ambiente. Lisboa). Seventy surface sediment samples were collected in November 2002 and April 2003, along 5 tidal flat and salt-marsh transects distributed in different estuarine domains. Sampling locations were selected to provide information on the foraminiferal assemblages and morphosedimentary zonation, associated with environmental parameters such as temperature, salinity and pH of interstitial water (measured inside perforated PVC tubes inserted into the sediment to a depth of 40 cm below surface), elevation and annual frequency submersion time. The upper estuary transect did not deliver a consistent set of data, so our results will concern the 4 transects located at the middle and lower estuary domains. Nevertheless, none of them is close to the river mouth because no tidal marsh was left by the urban and industrial occupation. A total of 31 species of benthic foraminifera have been identified. They form 4 main associations similar to those recorded in estuaries from the North Atlantic coast of Europe and North America. The salinity of interstitial waters in marsh sediment is close to normal marine, allowing miliolids to flourish and even dominate the faunas in high marsh IB zone. Hyaline foraminifera dominate the assemblages of mud flat and low marsh, extending a significant presence through high marsh IB zone. A remarkable presence of *Jadammina macrescens* association above HHW should also be noted, suggesting that the observed HHW lies above the equivalent astronomical mark, probably as a result of storm surge (Taborda & Dias, 1991. Geonovas, Sp. Nr. 1: 89-97) or tidal distortion.
Experimental evidence of the response of benthic foraminifera to chlorine dioxide disinfected discharge

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Chlorine dioxide (ClO₂) is widely applied in drinking water treatment as an oxidant and primary disinfectant. It is the preferred alternative to chlorine because it is substantially more powerful as a biocide, has a long lasting effect, it does not enter substitution reactions with organic compounds, and is safer for humans because it does not form chlorinated products. Chlorine dioxide generates only chlorite in high chemical yield as its predominant disinfection byproduct, unlike other chemical disinfectants, which produce a multitude of non-predominant byproducts. Therefore, a study of the toxic effects of both chlorine dioxide and chlorite should provide an adequate description of the environmental impact of this disinfection method. Research on bacteria, virus, and fungi has been reported, but there is little information on the effects of chlorine dioxide and chlorite on protozoa and algae.

Thirty live foraminifera [Ammonia tepida (Cushman)] were placed in Petri dishes, each of which was kept covered with a glass lid to limit evaporation and to keep the salinity constant. The water temperature was maintained at 14-18°C, salinity at 31‰, and pH at 8.1 - 8.9. To each Petri dish, 0.5 ml of cultured diatoms (Amphiphora sp.) was added as food. Foraminifera were allowed one week to adapt to their new environment and viewed microscopically for vital signs (visible protoplasm and pseudopodia, clustering of live foraminifera). Following this adaptation period, chlorine dioxide was added to four Petri dishes in the amounts of 0.02, 0.10, 0.40, and 0.84 mg/L, and none was added to another Petri dish to be used as the control. These concentrations were chosen to simulate realistic conditions, although the discharge of chlorine dioxide treated wastewater is very unlikely to contain more than 0.1 mg/L free chlorine dioxide.

During the first two months, the foraminifera and diatom algae developed slowly, i.e. normally. There was no significant difference in the control sample...
and the samples with chlorine dioxide. As the experiment progressed, however, differences became noticeable. In the third and fourth month, algae developed at the lower chlorine dioxide concentrations to the extent that they formed a carpet on the bottom of the Petri dishes and foraminifera were fixed firmly on the algal substrate. In contrast, foraminifera and algae in the control sample were freely lying on the bottom or floating in the water. The diatom bottom “carpet” did not develop in the Petri dishes with higher concentrations of chlorine dioxide and diatoms in those were floating abundantly. Despite the relatively high chlorine dioxide concentrations, foraminifera survived and actually reproduced, although a substantial amount of offspring were deformed, indicating environmental stress. At the present time, it would be premature to assign the type of morphological deformity to the dose of chlorine dioxide. Certainly chlorine dioxide interacts with nucleic acids and is harmful. In addition, being a free radical, it probably permeates the foraminiferal cell, potentially interacting with proteins of the cytoskeleton. Fibers of the cytoskeleton permeate throughout the cell and form a bedding around the membrane, with each part of the cytoskeleton responsible for the development of a certain part of the foraminiferal test. It is possible that in the event that any one part of the cytoskeleton is destroyed by chlorine dioxide, various different types of deformities may be produced.

At lower concentrations of chlorine dioxide (<0.1 mg/L), little influence on foraminifera and diatoms can be seen. This finding is rather unexpected, given the high toxicity of chlorine dioxide to other single-cell organisms (Protista). Concentrations of chlorine dioxide between 0.4 and 0.9 mg/L can cause test deformation in reproduced foraminifera, whereas concentrations between 0.2 and 0.9 mg/L seem to stimulate diatom development, perhaps by eliminating competition and pathogens.
Benthic foraminiferal assemblages of Campos Basin slope, and correlation with South Atlantic water masses

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Benthic foraminiferal assemblages were analyzed from 24 box-core samples collected at water depths ranging from 700 to 2000 m on the Campos Basin Slope. A total of 373 taxa were identified, and cluster analyses of the data led to identification of four distinct assemblages. Assemblage I is represented by high frequency of calcareous species. The presence of *Epistominella exigua* indicates a well oxygenated environment. Assemblages II and III show a similar high frequency of infaunal species (*Uvigerina peregrina*, *Sphaeroidina bulloides*, *Melonis barleeanum*, *Globobulimina affins*, *Bolivina* spp., *Bulimina* spp., *Uvigerina* spp.). Assemblage III shows a distinctly higher species diversity than Assemblage II. Assemblage IV is characterized by a high frequency of agglutinated species. Dissolution of calcareous tests is conspicuous in all samples, but is more intense on Assemblages II and III. A correlation between the distribution of the four assemblages and South Atlantic water masses on the slope is suggested. Assemblage I is correlated with AIW (Antarctic Intermediate Water), a well-oxygenated and nutrient-rich water mass. Assemblages II and III are closely associated with the poorly oxygenated Antarctic Circumpolar Water (ACW). Dissolution rates of calcareous tests, stronger in Assemblages II and III, seem to be related to ACW, which has higher alkalinity (corrosive water). Assemblage IV is influenced by North Atlantic Deep Water (NADW).
Scope for the revision of estimates of life-span of planktonic foraminifera in the Arabian Sea: Sediment traps as a tool

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Determining the life span of planktonic foraminifera is vital in view of their increasing application to paleoclimatic reconstruction. Because of the inability to maintain live specimens in lab culture through their complete life cycle, estimates of life span of planktonic foraminifera are based on the extrapolation of time taken to construct the last few chambers in lab culture experiments, and then back calculating the time taken to construct earlier chambers. There are also reports about the possibility of life span being modulated by lunar cycles. As per present understanding, the life span of planktonic foraminifera is estimated to be of the order of a few days to a few weeks. However, reexamination of foraminiferal data collected through sediment traps from the Arabian Sea indicates the possibility of revision of these extrapolated life span estimates. Sediment trap technique provides time series data of sinking particles (faunal and sediment) from surface to bottom of the sea. Besides many other applications, these data can also be used to estimate the life span of planktonic foraminifera. Sediment trap data show periods (quiescent period, QP), as long as 34 to >100 days, during which total planktonic foraminiferal flux becomes almost zero (and, in certain cases, zero), which is not possible if the life span is of the order of a few days. The argument that this zero flux may arise because of horizontal transport of planktonic foraminifera away from the zone of the sediment trap does not hold, since the trap locations are quite distant from the boundary of the zone of occurrence of planktonic foraminifera. Moreover, there is a rhythmic pattern of seasonal variation in the abundance of larger and smaller fractions of the same species, with peaks of the larger fraction (250 µm to >500 µm) preceding that of the smaller fraction (125 µm to 250 µm). In view of the foregoing, we hypothesize that the life span of certain species is probably of the order of a few months (~6 months) instead of a few weeks or a few days, with a marked dormancy period. However, these estimates for the longevity of certain planktonic foraminiferal species may be specific to the studied region. A fresh approach is required to confirm this hypothesis. If confirmed through more studies, the findings will have far reaching implications in paleoclimatic reconstruction studies.
Deep-sea benthic foraminiferal assemblages from core site GeoB 3388-1 located off northern Chile were investigated to evaluate the relationship between faunal composition patterns and paleoceanographic changes during the last 1 million years (mid- to late Pleistocene). We used multivariate statistics (Principal Component Analysis) to analyze changes in assemblage composition of benthic foraminifers. We use Benthic Foraminiferal Accumulation Rates (BFAR) as a proxy of C, supply and productivity. The dominant species in core GeoB 3388-1 are *Oridorsalis umbonatus*, *Cibicidoides wuellerstorfi*, *Uvigerina peregrina*, *Nutallides umboniferus*, *Epistominella exigua*, *Pullenia bulloides*, *Globocassidulina subglobosa*, *Melonis sphaeroides*, *Gyroidina soldani*, *Ehrenbergina bradyi* and *Melonis formosus*. The first Principal Component (PC1) is associated with the variability in the BFAR of *O. umbonatus*, *C. wuellerstorfi*, *G. soldani*, *U. peregrina*, *M. formosus*, *M. sphaeroides*, *P. bulloides* and *G. subglobosa*. The PC2 is associated with BFAR values of *N. umboniferus* and *P. bulloides* and an inverse relationship with *E. bradyi*. The PC3 is associated with the variability of BFAR of *E. exigua*. The remaining species do not contribute significantly to any of these principal components. Strong fluctuations in BFAR and relative abundance of productivity related species between glacial and interglacial stages after the Mid Pleistocene Revolution (MPR, ~0.9 Ma) indicate stronger seasonal carbon flux fluctuations. The increased abundance of *Epistominella exigua* and *C. wuellerstorfi* during Interval 2 may indicate episodes of enhanced vertical flux of organics (phytodetrital) and increased bottom-water currents, respectively. At Interval 3, the increase of *N. umboniferus* (an Antarctic Bottom Water, AABW, tracer) was probably caused by a decrease or slower inflow of bottom waters from a northern source after the MBE. The almost continuous presence of *Favocassidulina favus* along the core suggests that Pacific Deep Water was present off northern Chile during the last 1 Ma.
Spatial evaluation of fluvial influence inferred from foraminifera distribution and organic geochemistry

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Baía Norte (27°23’ – 27°35’S; 48°33’ – 48°30’W) is a body of shallow marine water located in the southern region of Brazil (Santa Catarina State). Its surface area is 146 km², and its depth is usually lower than 6 meters. It has a connection to the Atlantic Ocean by means of a channel of 12 m maximum depth. Estuaries, mangroves, small sand beaches, river deltas, tidal flats and rocky shores are the main habitats bordering this embayment. Urban developments are also present and are concentrated mainly in and around the cities of Florianópolis, São José and Biguaçu. Among the economic activities developed in this area, tourism, traditional fishing, and oyster and mussel production play an important role. However, the sustainability of these activities depends on local water quality, which should be a constant concern, since sewage treatment is insufficient, and untreated wastes are discharged directly into the creeks and rivers that reach the bay. Fluvial inputs are probably the most important sources of terrigenous constituents and pollutants to Baía Norte sediments. The major freshwater contributors in the area are the Biguaçu, Ratones and Itacorubi rivers. The first one is located on the mainland side of the bay and has the biggest local catchment (383 km²), while Ratones (91 km²) and Itacorubi (28 km²), both located at an island margin, are less important. In this study, irregularities in Recent foraminifera distribution and sedimentary organic matter composition were used as indicators of the sites that are most susceptible site to the influence of fluvial inputs. Thirty eight surface sediment samples were obtained in a 2 km grid resolution and analyzed in relation to their biological and geochemical characteristics (total organic matter as well as carbon, nitrogen, sulfur, biodetritic carbonate, and grain size distribution). The sediments of the area can be described as predominantly muddy, with carbonate contents between 0.3 and 3.8% and total organic matter between 2.5 and 8.3%. High values of C:N ratio (between 9.3 and 19.4) suggest a significant continental contribution at places. Although sediments are relatively rich in organic compounds, the values of C:S ratio (above 5) suggest organic matter degradation under well oxygenated conditions at the bottom. In general,
the values of benthic foraminiferal density and richness are correlated to the depth and negatively to the total organic matter content and increase of clay in the sediments. The suborder Miliolina, as well as the family Nonionidae (mainly *Pseudononion atlanticum*), present a significant negative correlation with organic matter and clay percentage, increasing towards the marine areas less influenced by inner waters. Samples with low density of foraminifera tests, which also show a higher proportion of living forms in the total population and the dominance of the genus *Ammonia*, could be related to local influence of fluvial input into the embayment. Although the families Bolivinidae and Buliminellidae (mainly *Buliminella elegantissima*, *Brizalina striatula* and *Bolivina* sp.) are abundant in all the study area, their occurrences are more important at depths greater than 4 meters, suggesting that these taxa are less tolerant than *Ammonia* to environmental instability induced by mixing processes between fluvial and marine fluxes.

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Foraminifera and heavy metal correlation in Guanabara Bay, RJ (Brazil): Pollution proxy

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In developed coastal areas, organisms are exposed to a complex combination of metals, organic compounds, industrial residues and natural elements; the effect is determined not only by ecological but also by biological factors. Foraminifera have been widely studied as proxies of heavy metal contamination. This study shows the results from 26 sediment samples collected during two seasons (summer and winter) in the most polluted bay in Brazil, Guanabara Bay, located in Rio de Janeiro State (22°41’-22°58’S and 43°02’-43°18’W). It describes the foraminiferal assemblage patterns in relation to different parameters, including heavy metal concentration. Together with the sampling of Foraminifera, environmental data on salinity, temperature, dissolved oxygen and organic compounds (C, N, S) were obtained from varied depths. The following metals were determined by atomic absorption and emission spectrophotometry: Zn, Ni, Cr, Cu, Fe and Mn. Distribution patterns and statistical correlations have been investigated both for biological and environmental data. The bottom sediment is predominated by silt and clay, with organic mud contribution from sewage discharge. Inorganic compounds such as heavy metals also contribute, increasing the pollution potential. The pollutant discharge plays an important role in microfauna settlement, limiting or drastically reducing the abundance of foraminiferal fauna in the most contaminated areas. There was a slight seasonal variation in the foraminiferal fauna, which was strongly dominated by a few species such as Ammonia tepida, Buliminella elegantissima, Elphidium excavatum, E. poeyanum and Quinqueloculina seminulum. The lower diversity during the summer may be due to the elevated level of some metals. An enrichment of Cu and Zn is seen in that season, mainly in the inner part of the bay, where the predominance of fine sediment promotes particle retention, including heavy metals and organic matter. The
unsuitability of the northwest area of the bay for faunal settlement was shown by sterile sediment collected there in summer. Correlation analysis between foraminiferal species and heavy metals has shown significance for iron. *Elphidium excavatum* and *Elphidium poeyanum* were not correlated with any metal, but the peak abundance of both species was in the very samples in which concentrations of all heavy metals were the highest. The average value of the most important environmental variables in each group of the Principal Component Analysis during the winter reflects the differences between seasons. The conspicuous delimitation of the groups in the winter was not observed in the summer, when many samples showed anomalous traits, possibly due to intense sewage discharge promoted by rains.
Lagoon to deep-water foraminifera and ostracods from Plio-Pleistocene deposits, Rhodes, Greece

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Nearly 250 species of benthic foraminifera have been identified from the Plio-Pleistocene strata of the Kallithea Bay section on the eastern coast of Rhodes. The section comprises an overall transgressive succession ranging from fluviatile and brackish-water gravel at the base to fine-grained deep-water marl at the top. The marine deposits are referred to the early Pleistocene, while the brackish-water deposits probably are of late Pliocene age. Variations in the abundance and distribution of the benthic foraminiferal species were examined in 61 samples. The brackish water strata contain a low diversity fauna dominated by Ammonia parkinsoniana and A. p. tepida. The marine deposits, in contrast, contain a rich fauna with an average number of species per sample close to eighty. Cluster analyses grouped the marine samples into four biofacies. The distribution of the individual biofacies is closely linked to lithofacies and to changes in the depositional environment. The most distinct environmental change is connected to an increase in water depth caused by a general subsidence of the island. Over a period of less than 500 kyr during the early Pleistocene, the water depth increased from a few meters to more than 400 m. Superimposed on this large-scale subsidence was a series of rapid environmental fluctuations. The fluctuations are shown by repeated shifts between fine-grained, laminated marls and coarse-grained calcarenites, and by parallel shifts in the benthic and planktonic assemblages. The fluctuations were apparently cyclic and they involved shifts between well-oxygenated and low-oxic to anoxic bottom-water conditions. The faunistic and environmental shifts show many similarities to the astronomically driven sapropel cycles from the deeper parts of the eastern Mediterranean, and the laminated beds in the Kallithea Bay section are interpreted as shallow water extensions of sapropels. The shallowest of the laminated beds were deposited at water depth around
75 m. The deposits contain also a diverse fauna of ostracods and nearly 200 taxa have been identified in the marine section.

The coarse-grained deposits in the lower part of the section are dominated by shallow-water and phytal foraminifera species, e.g., *Asterigerinata planorbis*, *Asterigerinata mamilla*, *Cibicides lobatulus*, *Neoconorbina terquemi*, *Elphidium crispum*, and *Reussella spinulosa*. The foraminifera fauna is found together with ostracod species of *Xestoleberis*, *Aurila*, *Callistocythere* and other shallow-water ostracods. The central section is dominated by species that today live mainly on the middle and outer shelf, e.g., *Cassidulina carinata*, *Bolivina spathulata*, *Cibicides ungerianus*, *Melonis barleeanum*, *Bulimina marginata* and *Planulina ariminensis*. They are accompanied by an ostracod fauna dominated by *Acanthocythereis hystrix*, *Bosquetina tarentina*, *Parakrithe dactylomorpha*, *Phlyctocythere pellucida* and *Cytheropteron sulcatum*. The fine-grained deposits in the upper part contain a species rich, deeper water fauna of *Uvigerina peregrina*, *Hoeglundina elegans*, *Gyroidina soldanii*, *G. umbonata*, *Bulimina costata*, and *Hyalinea balthica* associated with deep-water ostracod species such as *Bythocypris bosquetiana*, *Acanthocythereis obtusata*, *Argilloecia acuminata*, *Bosquetina rhodiensis*, *Buntonia textilis*, and *Henryhowella hirta*. The laminated sediments were dominated by foraminifera specimens of *Bulimina seminuda*, *Nonionella turgida*, *Fursenkoina tenuis*, or *Bolivina alata*, *Cassidulinoides bradyi*, *Globobulimina affinis*, *Chilostomella mediterranensis* and *Bulimina elongata*, while the ostracod faunas consist almost exclusively of allochthonous juvenile specimens. According to the ostracods and the foraminifera, the water depth during the deposition of the Kallithea Bay section increased from a few meters to 350–500 m.
Recent foraminifera in Admiralty Bay
(King George Island, Antarctica)

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The Antarctic Peninsula is a region of intense international attention as an important area to monitor any global climate changes. The marine bottom sediment of the Antarctic coastal environments reflects very well any environmental change because it serves as a final destination of the processes that occur in the water column. Within the diverse biota associated with the marine bottom sediment are the foraminifers, which are considered useful environmental biomarkers. The goal of this study was to determine the biodiversity of Recent foraminifera at Admiralty Bay, located off King George Island (South Shetland Islands, Antarctica), a transitional environment between the sub-Antarctic and Antarctic regions. The material was sampled during two austral summers (2002 and 2003). Nineteen stations were selected all over the bay, with a maximum depth of 150 m. For grain size and foraminifera analyses the bottom sediment was sampled with a Van Veen bottom grab. A Go-Flo bottle was used to sample the bottom water to determine temperature, salinity, dissolved oxygen, pH and nutrients. For the foraminifera analyses, a small portion (25 cm³) was stained with Rose Bengal (1g/l) and 4% formalin and washed with fresh water over a sequence of three sieves (250, 125 and 63 µm). All the specimens were picked and identified. The 2002 material showed an average abundance of 297 foraminifers per sample, with 106 live specimens (forms stained with Rose Bengal). On the other hand, the 2003 material presented a lesser average abundance, with 167 foraminifers for sample, with 77 live specimens. They represent 43 taxa at the species level, 23 calcareous and 19 agglutinated. About 26 species occurred in both austral summers (2002 and 2003), 5 species occurred only in samples collected during 2002, and 13 species occurred only in samples collected during 2003. The most abundant calcareous species were: Bolivina pseudopunctata, Cassidulinoides parkerianus and Globocassidulina biora. The most abundant agglutinated species were: Adercotryma glomerata, Miliammina areanacea,
Portotrochammina antarctica, Psammosphaera fusca, Pseudobolivina antarctica, Reophax subfusciformis and Spiroplectammina biformis. The temperatures in 2002/2003 favored such species as Bolivina pseudopunctata, Adercotryma glomerata, Portotrochammina antarctica and Pseudobolivina antarctica. The temperature average during 2002/2003 was higher than those registered in 2003/2004, and it caused some changes in environmental parameters that influenced directly the foraminiferal assemblages. In 2003/04, a period with lower temperatures, the species Cassidulinoides parkerianus, Globocassidulina biora, Miliammina areanacea, Psammosphaera fusca, Reophax subfusciformis and Spiroplectammina biformis were favored by the increase of silt concentrations in the bottom sediment. The analyses of the foraminiferal assemblages collected during two austral summers showed that they were affected by annual temperature variations and consequent changes in other environment parameters. These preliminary analyses confirm the importance of foraminifera as potential Recent climatic biomarkers, indicating new possibilities to monitor world environmental changes. We are still working with the material sampled and new data will help us to better understand the interaction between foraminiferal assemblages and environmental parameters and its relation to climate change.
Study of sedimentary dynamics by means of foraminiferal analysis in Gran Canaria (Canary Islands-Spain)

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The Canary Islands, Spain, are located in the eastern subtropical region of the Atlantic Ocean. Quaternary sedimentary deposits of the Canary Islands include extensive aeolian deposits and beaches. A good example is Las Canteras beach, located in the inner part of El Confital Bay, on the northeastern coast of Gran Canaria Island. This is an urban sandy beach, nearly 3 km long, and constitutes the main tourist area of Las Palmas de Gran Canaria city. For that reason it has a great socio-economic importance. In this context, the building of the town has affected the natural dynamics of the sediments, which arrive from the bottom of the Confital Bay pulled by waves and currents; after drying on the beach, grains are blown towards the south by trade winds. Since 1960 the beach front was rebuilt, and a new seawall and higher buildings were constructed. The result is that the wind is not able to blow the sediments over such fence, and therefore grains accumulate on the beach face. Due to the shoreline configuration and the presence of a natural offshore sandstone bar, the north sector of the beach is very well sheltered from prevailing northern waves. Nevertheless, this bar is not continuous along the whole beach, and the south end of the beach is completely exposed to incident waves. This sandstone bar separates the upper shelf environment and the submerged beach. Until now, coastal dynamics studies of Las Canteras beach have considered the dynamics of the system based on its sedimentology and geomorphology, while the present work is the first one that uses foraminiferal analysis for the study of the sediment dynamics. Sediment samples from three different coastal environments were collected for this study:

1) from upper shelf offshore of the sandstone bar, collected by means of a box corer, which allows the recovery of sediments with minimal disturbance,

2) from the submerged beach collected by scuba-diving, and

3) from the foreshore collected with a hand-held corer.
Samples were washed through a 63 μm sieve and treated with Rose Bengal to differentiate living individuals. The remaining dry sediment was floated using CCl₄. Foraminifera were picked from the dried float, separated, and identified. In order to determine relationships between the three environments we have used the foraminiferal content of the samples as natural tracers of sediment transport. The degree of relationship between different samples has been considered by means of a quantitative cluster analysis, performed by NTSYSpc2 program. This technique yields a very good knowledge of the sedimentary system since it considers the upper shelf, submerged beach, and foreshore integrated as a whole.
Hydrography of the Davis Strait since the Last Glacial Maximum

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The Davis Strait forms a threshold between the deep basins of the Baffin Bay and the northern Labrador Sea. It thus holds a key position for the study of the water exchange between the two areas. The surface circulation is characterised by the West Greenland Current (WGC), which flows northwards along the Greenland coast, entraining relatively ‘warm’ and saline Atlantic water from the Irminger Current as well as cold, low-salinity surface water originating from the East Greenland Current. There is also a significant freshwater (and ice) input to the WGC directly from the Greenland ice sheet. On the western side of the basin, the Baffin-Labrador Current system transports cold, low-salinity Polar Water south along the Canadian coast and into the Labrador Sea. The Labrador Sea plays a key role in the modern THC system, as it is one of the major areas of deep-water formation in the global ocean. The deep circulation over the northern slope of the Labrador Sea is made of two main components: a more baroclinic current with its centre between 2000 m and 1000 m, and a more barotropic current centred near the 2500 m isobath, the latter being part of the large-scale North Atlantic subpolar gyre circulation also transporting overflow waters originating from the Nordic Seas (the Western Boundary Undercurrent, WBUC).

We are carrying out a multi-proxy study of four cores forming a N-S transect across the Davis Strait in order to establish its palaeoceanographic history since the last Glacial Maximum. For that purpose we study sediments (incl. colour scans, XRF-intensity, water content, grain size and IRD content), benthic foraminifera, diatoms and dinoflagellates. The chronology of cores is based on calibrated AMS ¹⁴C-datings on benthic foraminifera and molluscs.
Initial results reveal that in the deep northern Labrador Sea (2300 m depth), high percentages of the polar, planktonic foraminiferal species *Neogloboquadrina pachyderma* (sinistral) indicate very cold surface water from app. 25300 ¹⁴C yrs BP until app. 16800 ¹⁴C yrs BP. During the same interval, the benthic foraminifera record shows significant changes in bottom water conditions. Polar water reached the deep basin, but after app. 19600 ¹⁴C yrs BP the area was influenced by the occasional influx of more saline water, possibly due to brine formation. At app. 16800 ¹⁴C yrs BP (just prior to 20000 cal. yrs BP) an influx of oceanic benthic foraminifera, which are often found linked to Atlantic water masses (*Alabaminella weddellensis*, *Nuttalides umbonatus*, *Pullenia bulloides* and *Cassidulina neoteretis*) become dominant, indicating the existence of a strong influx of the Western Boundary Undercurrent until 14400 ¹⁴C years BP (17700 cal. years BP), i.e. in the period prior to H1, after which the influence of Atlantic Water to the deep basin decreased. This may be linked to a gradual opening of the Arctic Gateway. Surface-water conditions seem to have gradually ameliorated after 16800 ¹⁴C yrs BP as documented by an increased influx of sub-polar planktonic species.

In the shallower areas (600-700 m depth) of central Davis Strait, Atlantic Water may first have reached the area during the Younger Dryas, when we see the first indications of a strengthening of the West Greenland Current in this area. The Holocene period is only represented by very condensed sections (10-20 cm) in most of our records.
As one of the major areas of deep-water formation, the Labrador Sea is an important component of the present-day North Atlantic thermohaline circulation (THC) system. Furthermore, the Labrador Sea is particularly sensitive to freshwater forcing, as enhanced freshwater fluxes will favour sea-ice formation and lead to a reduction of deep-water convection. The surface circulation is characterised by the West Greenland Current (WGC), which flows northwards along the Greenland coast, entraining relatively “warm” and saline Atlantic water from the Irminger Current as well as cold, low-salinity surface water originating from the East Greenland Current. There is also a significant freshwater input to the WGC from the Greenland ice sheet. On the western side of the basin, the Baffin-Labrador Current transports cold, low-salinity Polar Water south along the Canadian coast and into the Labrador Sea. The deep circulation over the northern slope of the Labrador Sea is made of two main components: a more baroclinic current with its centre between 2000 m and 1000 m, and a more barotropic current centred near the 2500 m isobath, the latter being part of the large-scale North Atlantic subpolar gyre circulation also transporting overflow waters originating from the Nordic Seas (the Western Boundary Undercurrent, WBUC).
Within the framework of the DASAG project, we reconstruct sea-surface conditions and deep-water circulation variability in the Baffin Bay - Northern Labrador Sea region off the coast of West Greenland in relation to climate change since the Last Glacial Maximum. Particular attention is given to the influence of the West Greenland sea-ice and iceberg environment and possible linkages with large-scale North Atlantic thermohaline circulation. We use a multi-disciplinary approach based on a variety of proxy data (sedimentological, magnetic and micropalaeontological) from a series of cores reaching from Nuuk in the south, across the Davis Strait and into the Disco Bay in the north. We will here present results, which highlight the paleoceanographic and paleoclimatic history of the region since the last Glacial maximum, while detailed records of each locality are presented separately.

Sediment cores from the deep northern Labrador Sea and the Davis Strait reveal a high resolution record of the water exchange between the Baffin Bay and the Labrador Sea. During the Last Glacial Maximum, Atlantic deep water (WBUC water) masses were found in the northern Labrador Sea. The WBUC activity was enhanced immediately prior to H1. During the Younger Dryas, Atlantic water entrained by the WGC reached the shallower central Davis Strait. Cores from fjords near Nuuk and Disko Bay give a detailed record of the Holocene period, particularly the late Holocene. At about 3200 cal. years BP neoglacial cooling started to influence the area, and since that time the WGC repeatedly displayed major changes both in surface water transport and subsurface entrainment of Atlantic water.
Holocene evolution of Fortaleza and Flamengo Bays, Ubatuba, Brazil, inferred from benthic foraminífera and sedimentological data

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Sedimentological, geochemical and foraminiferal data were obtained in two semi-confined marine bays, located off the northern coast of São Paulo state, Brazil. Thirty-two surface sediment samples were collected by Petersen grab to study the present spatial distribution of the species related to hydrographic and sedimentological parameters. Also, 85 samples were selected from 3 cores which have a well-constrained absolute chronology for the last 7500 years, enabling us to study in detail the development of the foraminiferal assemblages during the Holocene. Two of these cores were collected in Flamengo Bay (UB1 – 2.22 m; Flt1 – 3.76 m) and the other in Fortaleza Bay (3.40 m). Surface-sediment analyses indicate that sandy mud, medium-sized tests (250-125µm) and indicator species of the inner shelf water mass called Coastal Water (CW) dominate the whole bay. Large tests (250-500 µm) and Tropical Water species are rare. Small tests (<125 µm) are rare at the bays’ mouths, but increase in number towards inner areas that have high mud and organic matter contents. These results indicate that Flamengo and Fortaleza bays are environments of moderate hydrodynamic energy, which decrease gradually from the mouth towards the inner parts. The inner areas are low depositional energy sub-environments. The base of the FLT1 core is sandy and azoic indicating an ancient backshore. The upper part of this sandy packet shows evidence of the intertidal crustacean *Callichirus* sp. tubes, which probably indicates an ancient intertidal region. Overlapping this sandy base, there is a muddy sand sequence with low foraminifera diversity and abundance. Sparse foraminifera occurrences are observed at approximately 7500 years, indicating harsh environmental conditions with more local hydrodynamic intensity. The muddy sand sequence is observed in the three cores and represents the gradual infill of the bays with sediments that came from the continental shelf. Gradually, the sandy mud...
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Deposition becomes rich in foraminifera. High foraminifer abundance peaks were useful in recognizing a transgressive maximum sea level period. This peak was observed at 60 cm (Flamengo) and 90 cm (Fortaleza). Radiocarbon dating related to this abundance peak yielded a date of $5040 \pm 40$ years BP. These results are in agreement with literature data, which mention a maximum transgressive period called the Santos Transgression at 5100 years BP. The upper part of the muddy sand sequence at the coretops represents the sea level fall and its subsequent stabilization. Upper parts of the Flamengo’s cores have different faunistic characteristics when compared to UB3 core. In FLT1 and UB1 cores there is a slightly decrease in richness and abundance of foraminifera, but in the UB3 core there is an increase of the foraminifera to the top. Lower foraminifera abundance may be related to a detritic influx increase in the inner part of the Flamengo Bay. Presently the sampled sites of the FLT1 and UB1 have restricted deep circulation. There is a predominance of medium tests in the three cores, but the small ones tend to be more abundant at the top at Flamengo bay. The species found in the muddy sand sequence of the three cores are typical of the inner shelf and very similar to the Recent species analyzed. The benthic foraminifera with geochemical and sedimentological data allowed reconstruction of the changes in the Flamengo and Fortaleza Bays over the last 7500 years.
Benthic foraminiferal paleoecology of the upper Holocene of Sepetiba Bay, Rio de Janeiro, SE Brazil

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The Sepetiba Bay is a semi-confined body of water, and a part of the Sepetiba-Guaratiba Coastal complex in the southwest region of Rio de Janeiro. The study is based on the classification and distribution of benthic foraminiferal assemblages recovered from six cores drilled in the Guaratiba Mangrove and from five cores in the Sepetiba Bay. A total of 108 species were recorded. The Fisher’s alpha diversity indices for most samples from cores BS-02 (located in the middle of Sepetiba Bay) and BS-03 (near the Guaratiba Mangrove) indicate a normal marine salinity environment for the Sepetiba Bay during the late Holocene. The occurrence of characteristic cold-water species in core BS-02 point to the influence of cold currents (Malvinas’ currents) in the bay, whereas the occurrence of a transitional microfauna suggests the mixing of immigrant species from different geographical provinces, most probably related to episodes of water-mass mixing by coastal ocean currents. The foraminiferal record of the core BS-03 section demonstrates the local history of sea-level changes during the late Holocene. A rapid transgressive event in the lower part of the section, associated with a maximum of species richness and number of individuals, is followed upwards by a shallowing episode, with a progressive decrease in species richness and number of specimens, which continues up to the present day with the advance of the tidal-flat setting of the Guaratiba Mangrove.
Holocene foraminifera from the reefs surrounding
Viti Levu, Fiji Islands: A test of the FORAM Index

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The FORAM Index is a technique developed by Hallock et al. (2003, Environmental Monitoring and Assessment 81(1-3):221-238) that uses foraminifera, particularly the “larger” foraminifera, those that possess endosymbiotic algae, to assess water quality in coral reef environments. However, development of the technique took place largely in the Caribbean, and Hallock et al. (2003) admit that more testing in Indo-Pacific reef environments is needed. With an aim to determine whether the FORAM Index can be utilised to assess the health of reefs outside of the Caribbean, particularly in the south-west Pacific region, coral reefs surrounding the main island of Fiji, Viti Levu, were systematically sampled for foraminifera. Viti Levu was chosen as reefs surrounding the island are in clear decline due to anthropogenic pollutants and activities (Zann, 1994, Marine Pollution Bulletin, 29:52-61) and the coral and foraminiferal fauna that inhabits the region is typical of reefs throughout the south-west Pacific. Samples were collected from six transects surrounding Viti Levu, and from a series of spot localities to the north-west and south-east of the island.

A total of forty-nine species of foraminifera were recovered from collected samples. The faunal assemblage is typical of reef faunas throughout the south Pacific, composed of predominantly miliolid and rotaliid taxa, with agglutinated taxa inferior in both diversity and abundance.

FORAM Index values calculated for the collected samples range from a high of 9.75 to a low of 3, but only in exceptional circumstances do calculated values fall below the required value of 4 that indicates water quality conducive to coral reef growth (Hallock et al., 2003). The calculated values obtained suggest that water quality in much of the region surrounding Viti Levu is suitable for coral reef growth and that, therefore, the corals surrounding the island should be unaffected by anthropogenic influences. However, field observations show an inverse relationship to that expected, with a decrease in hermatypic coral cover and diversity coinciding with an increase in calculated FORAM Index values and vice versa. All decreases in coral cover observed directly correlate with an increase in macro-algal abundance.
It is possible that, rather than reflecting coral diversity and abundance, as should be the case if the index functions as intended, results obtained from Fiji appear to be more influenced by macro-algae cover. This could possibly be attributed to the fact that many “larger” foraminifera live epiphytically on the surface of macro-algae and thus, increased macro-algae abundance, often the direct result of anthropogenically driven eutrophication, will result in increased absolute abundance of these taxa, thereby skewing the FORAM Index value obtained.
Study of the influence of submarine sewage outfall upon foraminifera assemblages in Santos Bay, Brazil

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Santos, in southeastern Brazil, has the largest commercial harbor in South America and an important industrial complex (Cubatão). The city also receives about 100,000 tourists during the summer and holidays, all of which contributes to increases in the volume of domestic sewage and pollutants discharged by submarine sewage outfall. The present study analyzed the influence of submarine sewage outfall upon foraminifera assemblages on a regional (macro) scale and local (micro) scale in Santos Bay. Twenty four samples were analyzed at the macro scale and ten from Santos Bay. The samples were collected in winter 1997 and summer 1998. At the micro scale, ten samples were collected close to sewage outfall diffusers in Santos Bay in April 2004. At each station hydrographic and sedimentological data were obtained. Spatial and seasonal variations in the composition of foraminifera assemblages were related to environmental variables. Analysis of the influence of oceanic sewage disposal at the macro scale was inconclusive due to the low density of live foraminifera. Thanatocoenosis (taphonomic and morphometric analyses) and sedimentological analyses revealed two morphosedimentary sectors in Santos Bay, one in the western portion of the study area with sandy sediments, low C and N, low density and low richness of foraminifera, and the other in the east-central portion, with predominance of mud, higher C and N, higher density and richness of foraminifera. C/S ratios permitted detection of anoxic sediments near sewage outfall in Santos Bay in both the winter and summer. At the micro scale, hydrogeochemical and sedimentological data indicated that the area close to the diffusers is highly eutrophicated, with high contents of C, N, P and S in both the water and the sediment. The low C/S ratios of the sediment indicated highly reducing conditions. At the micro scale the biocoenosis composition and distribution indicated that environmental characteristics of Santos Bay directly influence the foraminifera assemblages. The results also suggest that the (pre) treatment of Santos sewage is inefficient, transforming the area of the diffusers into one more major focus of pollution in the bay.
An assessment of stress levels by the use of A/E index in cores in the Guanabara Bay, Rio de Janeiro

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A numerical index using the common foraminifera Ammonia and Elphidium (A/E index) was computed for sub-samples from cores collected in northeastern Guanabara Bay, Rio de Janeiro. The A/E index was first used along the Louisiana continental shelf to estimate the oxygen depletion caused by anthropogenic influence. The A/E index was calculated by the absolute abundance of A. tepida and E. cf. excavatum in the core sub-samples. The index co-varies with the Total Organic Carbon percentages (Sen Gupta et al., 1996, Geology 24/3: 227-230).

Guanabara Bay, in Rio de Janeiro, is an important tourist and economic center in the southeastern Brazil and is one of the most polluted regions on the Brazilian coast. Several districts of Rio de Janeiro and Niterói as well as three other cities surround its margins, which receive domestic and industrial sewage. Four cores collected in 2001 in northeastern Guanabara Bay from 1 to 7 m water depth were analyzed in one-centimeter samples. Core lengths vary from 130 to 280 cm. Occurrence and dominance of A. tepida and E. cf. excavatum are very important in these cores. Relations between occurrences of A. tepida and E. cf. excavatum in core sub-samples can be used to assess the anthropogenic pollution. A. tepida is considered, from previous work on surface samples, as an environmental pollution bioindicator. It is more abundant than E. cf. excavatum in surface sediment samples. In core sub-samples, A. tepida is more conspicuous in the shallower samples than in the deeper ones. E. cf. excavatum is absent in several shallow sub-samples, but it is dominant in the deeper sub-samples. C-14 dates were obtained in two cores. In Core 8, at the depth of 222 cm, the age is 4210 +/- 40 yrs BP; in Core 4, at the depth of 122 cm, the age is 1760 +/- 50 yrs BP, and at the depth of 90 cm, the age is 530 +/- 25 yrs BP. In Core 4, sediment rates increased from the 90 cm depth to the top, i.e., after the 15th century, with the beginning of the colonization period.
Foraminiferal results were compared with TOC values before, during and after the colonization period. TOC values increased in this core, at least three times, from the 90 cm depth to the top of the core (Recent). A large increase can be observed in the other analyzed cores, from 90-100 cm depth to the top. Below that depth, the TOC values increased more slowly in all four cores. In sub-samples of core 4 where *E. cf. excavatum* is present, the A/E index shows a rising trend from the bottom (1760 yrs BP) to the top (Recent). Above 90 cm depth (530 yrs BP) the A/E values are higher; thus, after the 15th century, there was a rising stratigraphic trend of the A/E index. The record in Core 8 is longer, and is marked by the absence of the *E. cf. excavatum* in the shallower sub-samples until 50 cm; therefore no valid A/E index could be calculated. However, the bioindicator *A. tepida* is abundant at the shallow intervals until 30 cm. This significant result, comparable with the surface sample results, suggests that pollution stress rises from the 30 cm depth to the top. Foraminifera are absent at the bottom of the core, at a lithologic unconformity just below 222 cm, C-14 dated as 4210 yrs BP. Previous works on Holocene sea level changes in the Guanabara Bay may be considered in accordance with this lithologic unconformity and the absence of microfauna. Core 11, like Core 8, is marked by the absence of *E. cf. excavatum* in the shallower sub-samples. This species is dominant from 70 cm to the bottom, together with *A. tepida*, which dominates in all sub-samples in the core. The A/E values are high on average and do not show any trend. In Core 10, the A/E values are higher from 110 cm to the top, with low abundance of *A. tepida* and *E. cf. excavatum* until 100 cm depth. The results based on ratios and abundance of *Ammonia tepida* and *Elphidium cf. excavatum* in core sub-samples confirm their use in the anthropogenic pollution assessment in the Guanabara Bay.
Sediment characteristics and foraminifera test morphology relations in intertidal sediments of the Halong Bay, Northern Vietnam

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Sedimentological features and the distribution of foraminifers along several traverses of intertidal sediments in the Halong Bay, Vietnam, are presented. Every traverse was from the lowest to the highest water line; the distance between the single sample points was 30–50 m. The geographical position of the first traverse, the HL profile, is 12 km west of the town of Bây Cháy. The position of the DC profile is on the island Hong Gai, near a coal shipping harbour. The third investigated traverse is the DS profile near the village of Dô SoI. The research describes the grain size distribution, TOC, DC and N content, the mineral composition, the clay minerals and the distribution of main and trace elements. The grain size ranges from silty to fine sandy. Most sediments are poorly sorted, the coarser ones having a higher sorting grade than the finer ones. In grain size fractions over 63 µm, quartz is the most common mineral. All traverses have a low content of feldspars, biotite and muscovite. The <63 µm fraction also contains quartz, muscovite, biotite and feldspars. Quartz is not as common as in the coarser fraction. In addition, the sediment in both fractions contains carbonate, produced by biogenic sources. Its distribution in the traverses is irregular and depends on the fauna. The heavy minerals are a combination of amphiboles, apatite, barite, epidote, garnet, pyrite, rutile, titanite, ilmenite, tourmaline and zircon. The sediments are characterized by a high content of organic matter. The TOC ranges from 0.8 to 6 wt%. The distribution is not regular. The geochemistry of major and trace elements shows that the sediments are partly polluted. The foraminiferal abundance and distribution in the sample localities can be correlated to the sediment properties. Several taxa of mostly cosmopolitan rotaliid foram genera (Ammonia, Elphidium, Discorbia and Asterotalia) seem to be sensitive in-situ monitors of marine pollution. The highest diversity exists in fine-grained sediments with a high content of organic matter. Those sedimentation areas are characterized by stable salinity and...
nutrient supply. In coarser-grained sediments with lower TOC, the foraminifers show a lower diversity, and the tests are smaller sized. In all traverses the foraminifera show test deformations (up to 15% of total content) which can be correlated to the occurrence of heavy metals. The source of those metals is anthropogenic pollution, mainly produced by industry and farming. The resulting foraminiferal morphological deformities include wrong coiling, aberrant chamber shape and size (particularly inflated last chambers), poor development of the last whorl, twisted chamber arrangement, additional chambers, protuberances, multiple apertures, irregular keel, twinning and lack of sculpture. Further investigations aim to quantify the mutation rate according to sediment pollution.