Quarterly Report to the Naval Research Laboratory

PHYSICAL AND BIOLOGICAL MECHANISMS INFLUENCING THE DEVELOPMENT AND EVOLUTION OF SEDIMENTARY STRUCTURE

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PROGRESS DURING SPRING 1995

This spring, we have focused our research on completing laboratory analysis on the Eckernförde data and preparations for the Gassy Mud Meetings in June. We are integrating sedimentological, radioisotopic, and benthic biological results with benthic boundary-layer physical data to quantitatively assess the processes controlling sedimentary fabric in the central basin of Eckernförde Bay. The summaries of these results are attached and are the actual abstracts sent in for the Workshop on Modeling Methane Rich Sediments of Eckernförde Bay.

For the Key West experiment, we are in the early stages of radiochemical and faunal analysis of box core samples.

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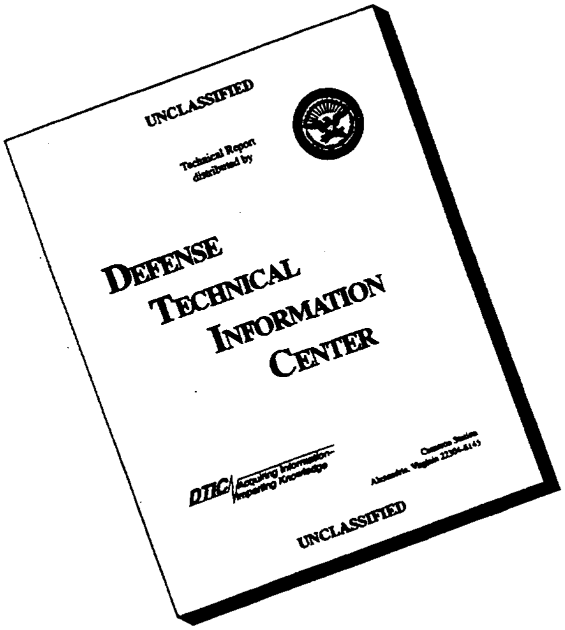

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Benthic macrofauna and bioturbation in Eckernfoerde Bay

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The purpose of this study was to characterize the benthic macrofaunal community of Eckernfoerde Bay, southwestern Baltic Sea, in terms of abundance, functional groups, and bioturbation potential. Bioturbation by macrofauna modifies sedimentary characteristics; rates and styles of bioturbation are partially controlled by macrofaunal abundance and functional group distribution.

Functional groups describe organisms that do things in similar ways. Functional group analysis of benthic communities indicates successional status and timing of prior disturbance events such as storms and anoxic events. In this study, analysis of benthic fauna was coordinated with sedimentological and boundary layer studies to identify processes controlling sediment structure in Eckernfoerde Bay.

Benthic faunal samples were taken during four ten-day cruises during spring 1993 and summer 1994. Sampling was focused around the acoustic tower sites (Old Tower, New Tower) in the central basin of Eckernfoerde Bay. Other samples were taken from the landward and seaward ends of the bay to develop a more regional perspective of the benthic community. These included muddy sites (Eckernfoerde Navy Base, Hausgarten), and one sandy site (Mittelgrund). Collected animals were identified to the lowest taxonomic group (usually species). Each taxonomic group was assigned to one of the following functional groups: surface deposit feeder, head-down deposit feeder, suspension feeder, or carnivore.

A bioturbation experiment was conducted in spring 1993 to compare vertical particle mixing rates in different sediments and benthic communities. Cores maintained in a running seawater sytem were marked at the surface with fluorescent particles, incubated for two weeks, then vertical distribution of fluorescence was determined.

Results

Macrofaunal abundance was high throughout the bay during spring 1993. Dominant macrofauna consisted of 16 species (90% of total species) and 4 functional groups. Muddy areas were dominated by small surface deposit feeders, especially the polychaete *Polydora ciliata* and the tellinid bivalve *Abra alba*. Mittelgrund supported a distinctly different fauna with significantly lower abundance than the muddy stations. Mittelgrund had relatively more head-down deposit feeders, suspension feeders and carnivores, and less surface deposit feeders than the muddy sites (Fig. 1).

Animal abundance was nearly an order of magnitude lower in June 1994 than in spring 1993 (Fig. 2). Decrease in abundance was coupled with a shift in community composition. Surface deposit feeders were proportionately less important, and mobile carnivores, especially *Harmathoe* sp., were more important in June 1994 than in spring 1993 (Figure 2). *Diastylus rathkei*, a surface deposit feeding amphipod, was numerically important in June 1994.

The bioturbation experiments showed that fluorescent particles were mixed 0.5-1.0 cm into the sediment over a two week period, regardless of station and functional group dominance. The benthic fauna of Eckernfoerde Bay is dominated by small, surface deposit feeders (Figs. 1 and 2). This functional group feeds and defecates at the surface, and is discretely mobile, so it is not likely to mix particles deeply into the sediment. Small head-down deposit feeders such as *Capitella* sp. may be more important bioturbators than surface deposit feeders in Eckernfoerde Bay, and bioturbation may be advective at a small scale.

The southwest portion of Kiel Bight is subjected to periods of bottom water hypoxia and anoxia in late summer. This causes a regular disturbance that controls the complexity of benthic community structure. Ecological succession of the benthic community after anoxic events begins with early opportunists, or pioneers; most species in Eckernfoerde Bay are classified as enrichment opportunists or as tolerant to low oxygen. If the benthos experiences summer anoxia every year, then the community will not progress beyond the pioneering stage. Pioneering species feed near the sediment-water interface or from the water column and occur in dense aggregations. Bioturbation by pioneers does not penetrate deeply into the sediment. The sediment structure tends towards laminar stratification dominated by pelletization and an oxic zone confined to a thin layer just below the sediment-water interface (<2 cm).

Conclusions

All measured components of Eckernfoerde Bay - abundance, diversity, animal size, functional groups, particle mixing - point to a system dominated by a regular or recent disturbance which reduced the complexity of the community structure and sediment reworking by the benthic fauna. The description of the benthos is consistent with the study of sedimentary strata of Eckernfoerde Bay and with numerous studies of Kiel Bight.

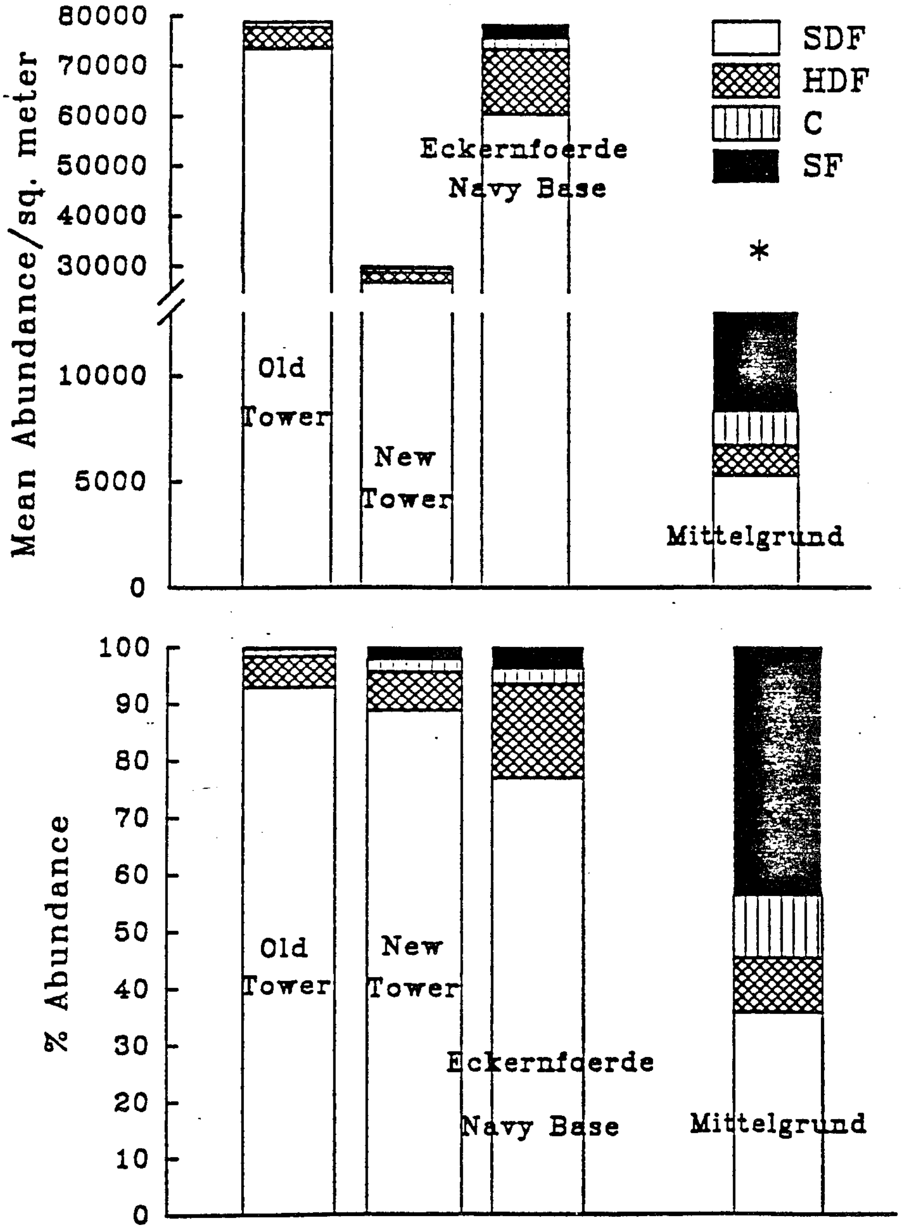

Figure 1. Mean abundance (top) and percent functional group composition (bottom) at spring 1993 stations. SDF = surface deposit feeders; HDF = head-down deposit feeders; C = carnivores; SF = suspension feeders; * = significantly lower abundance than muddy samples ($\alpha = 0.05$).

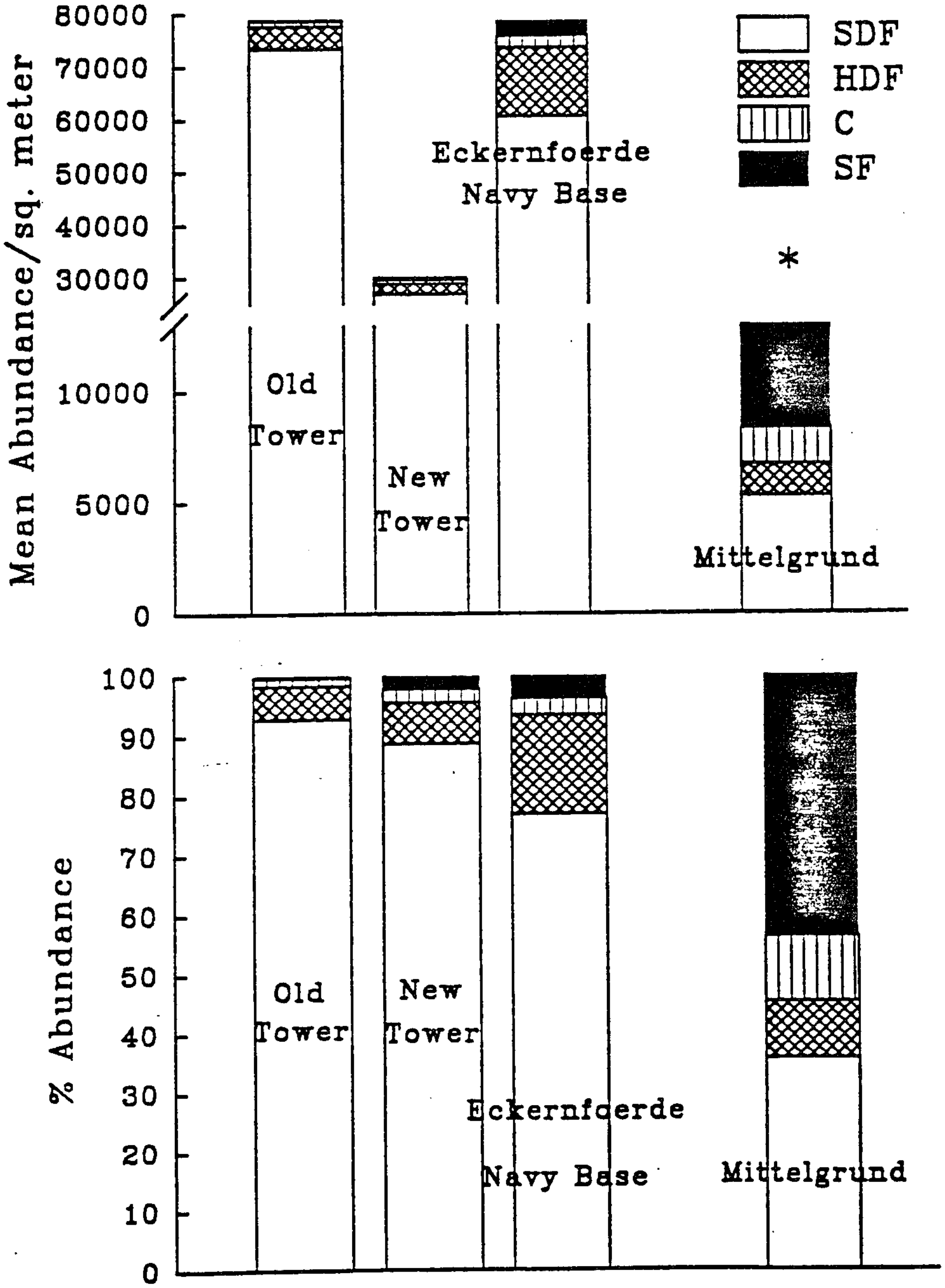

Figure 2. Mean abundance (top) and percent functional group composition (bottom) at muddy stations in spring 1993 and June 1994. SDF = surface deposit feeders; HDF = head-down deposit feeders; C = carnivores; SF = suspension feeders.

Fecal pellets of *Abra alba* as traces of sediment movement in Eckernföerde Bay

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Introduction

Fecal pellets produced by deposit feeders are typically aggregates of finer particles. They can be fairly robust and resistant to decomposition and breakage. They are then subject to benthic boundary layer processes such as bottom stress, resuspension, and transport. We conducted studies to determine the spatial distribution of the tellinid bivalve *Abra alba* and their fecal pellets to determine if fecal pellet distribution is a good biogenic indicator of sedimentary processes in Eckernfoerde Bay. Fecal pellet studies were conducted in coordination with sedimentological, radiochemical, and boundary layer studies.

Background

Eckernfoerde Bay is a shallow, fjord-like embayment in the southwestern region of Kiel Bight in the Baltic Sea (Figure 1). The central basin is relatively shallow (27-29 m) and shoals steeply to wave-cut beaches. Mittelgrund forms a sill at the seaward end of the bay, restricting water exchange through a narrow channel to the northwest of Mittelgrund (Werner et al. 1987).

The sediment is high in organic content and is characterized by laminated bedding (Bentley et al. in press). Microstructure is characterized by a high degree of pelletization. Many of the fecal pellets are the characteristic ovoid pellets produced by the surface deposit feeding bivalve *Abra alba*. *A. alba* is one of the dominant species of the Western Baltic and the characteristic species in muddy portions of Kiel Bight (Arntz and Brunswig 1976, Meyer-Reil et al. 1987, Werner et al. 1987, Weigelt 1991). Their fecal pellets are extremely resistant to breakdown resulting in their preservation.

The hydrographic conditions of Eckernfoerde Bay are dominated by wind-induced currents, internal waves, and seiches (Friedrichs and Wright, in press). Near bottom velocities were approximately 1 cm s^{-1} with periodic bursts from 5 cm s^{-1} to >10 cm s^{-1}. Bottom stress never reached critical magnitude to resuspend fine particles over their study period (April and May) in 1993. Internal waves were of sufficient velocity to advect and deposit suspended material within the bay. They describe a bottom stress gradient from high in the channels and shallows to consistently lower in the central basin, and suggest that the central basin is a sink for fine sediments in this system.

Methods

Benthic samples were taken during a ten-day cruise aboard the *R/V Planet* during late June-early July 1994. Sampling was focused around two acoustic tower stations in the central basin of Eckernfoerde Bay and included a transect from the central basin to the shallower flank and Hausgarten, a muddy site at the seaward end of the Bay (Figure 1).

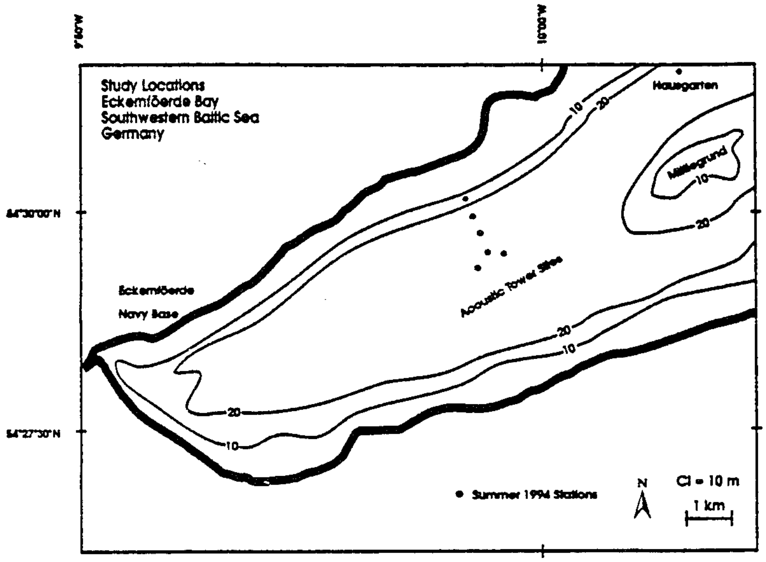

Figure 1. Map of Eckernfoerde Bay showing study areas.

Box cores (20x30x50 cm) were taken at each station and were subsampled for fauna and fecal pellets. Five 30 cm subcores were taken from each boxcore for faunal analysis. The subcores were extruded into 0-2 cm and 2-10 cm sections which were sieved using 500 µm mesh. Animals were preserved in ~7% buffered formalin and identified to the lowest taxonomic group (usually species).

Five 3 cm syringe cores were taken from each box core for fecal pellet analysis. Sediment was sieved to 80 µm and preserved in ~7% buffered formalin. *Abra alba* fecal pellets were counted. Length and width of pellets were also measured.

Results and Discussion

Preliminary results indicate that most of the *Abra alba* were juveniles (<2.5 mm) and were abundant in all samples. Adult *A. alba* were absent but their characteristic fecal pellets were abundant, particularly in the central basin. Relative abundance of adult fecal pellets decreased from the central basin to the shallower sites on the transect. Pellets from adults were on average 1.4 mm long and 0.6 mm wide. These dimensions were used to estimate the settling velocity of fecal pellets using a semi-empirical variation of the Stokes equation for cylindrical particles (Komar 1980). The relation is as follows:

$$w_s = 0.0790\frac{1}{\mu}(\rho_s - \rho)gL^2\left(\frac{L}{D}\right)^{-1.664}$$

where w_s = settling velocity
μ = water viscosity = 0.123 g cm^{-1} s^{-1}
ρ_s = particle density = 1.2 g cm^{-3}; a value in the middle of the range of fecal pellet densities described by Taghon et al. (1984)
ρ = density of seawater = 1.031 g cm^{-3} for this system
g = gravity constant = 981 cm s^{-1}
L = length = 0.14 cm
D = diameter of cylinder (here width) = 0.06 cm

The settling velocity estimate based on the above values is 5.1 cm s^{-1}. This sinking velocity is much greater than near bottom velocities in the central basin of Eckernfoerde Bay (1 cm s^{-1}), and even exceeds some of the periodic burst velocities. This indicates that fecal pellets in the central basin would be resuspended long enough to be transported an appreciable distance.

The absence of adult *Abra alba* can be attributed to several factors. *A. alba* are known to have irregular seasonal fluctuations, with maximum standing stock in autumn and minimum in May-July (Meyer-Reil et al. 1987). Our study period (June-July) was during the seasonal minimum for *A. alba*. An alternative explanation is that the area has experienced a recent disturbance such as anoxia; this is supported by functional group distribution studies by D'Andrea et al. (in press). *A. alba* is not resistant to low oxygen and has shown drastic decreases in the southwestern Kiel Bight during major anoxic events (Werner et al. 1987, Weigelt 1991).

Our results indicate that the fecal pellets of adult *Abra alba* follow the pattern of sediment transport and deposition in Eckernfoerde Bay. Our results support the hypothesis that the central basin is a sink for fine particles and is consistent with geological and biological investigations of Eckernfoerde Bay (Nittrouer et al. 1994, Lopez et al. 1994, Bentley et al., in press, D'Andrea et al., in press). Our results indicate that the spatial distribution of robust fecal pellets can be good biogenic indicators of sedimentary processes in this system.

References

Arntz, W. and Brunswig, D. 1976. Studies on the structure and dynamics of macrobenthos in the Western Baltic carried out by the Joint Research Program "Interaction Sea-Seabottom" (SFB 95-Kiel). *Proc. Xth European Symp. on Marine Biology*, **2**:17-42.

Bentley, S., Nittrouer, C., and Sommerfield, C. (submitted) Development of sedimentary strata in Eckernfoerde Bay, southwestern Baltic Sea. Geo-Marine Letters

D'Andrea, A., Lopez, G., Craig, N. (submitted) Benthic macrofauna and bioturbation in Eckernfoerde Bay, southwestern Baltic Sea. Geo-Marine Letters.

Friedrichs, C. and Wright, L. (in press) Resonant internal waves and their role in transport and accumulation of fine sediment in Eckernfoerde Bay, Baltic Sea. Continental Shelf Research.

Komar, P. 1980. Settling velocities of circular cylinders at low Reynolds numbers. *J. Geol.*, **88**:327-336.

Meyer-Reil, L.-A., Faubel, A., Graf, G., Thiel, H. 1987. Aspects of benthic community structure and metabolism, Ch. 3, p. 70-110. *In* J. Rumohr, E. Walger, and B. Zeitzschel (eds.), *Lecture Notes on Coastal and Estuarine Studies*, Vol. **13**, Seawater-Sediment Interactions in Coastal Waters.

Taghon, G., Nowell, A., Jumars, P. 1984. Transport and breakdown of fecal pellets: Biological and sedimentological consequences. *Limnol. Oceanogr.*, **29(1)**:64-72.

Weigelt, M. 1991. Short- and long-term changes in the benthic community of the deeper parts of Kiel Bay (Western Baltic) due to oxygen depletion and eutrophication. *Meeresforschung*, **33**:197-224.

Werner, F., McLean, S., Grafenstein, U. von, Erlenkeuser, H., Sarnthein, M., Schauer, U., Unsöld, G., Walger, E., and Wittstock, R. Sedimentary records of benthic processes, Ch. 5, p. 162-262. *In* J. Rumohr, E. Walger, and B. Zeitzschel (eds.), *Lecture Notes on Coastal and Estuarine Studies*, Vol. **13**, Seawater-Sediment Interactions in Coastal Waters.

Observations of Sedimentary Character and Their Relationship to Environmenal Processes in Eckernfoerde Bay

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Sedimentary characteristics in the marine environment are initially emplaced by physical processes, are subsequently modified by biological reworking, and are ultimately preserved by burial. The characteristics at a location evolve with time and change vertically and horizontally within the seabed. In central Eckernfoerde Bay, southwestern Baltic Sea, sedimentological studies were conducted in coordination with studies of benthic biology, boundary-layer dynamics, and seabed acoustics in order to identify factors controlling the emplacement and evolution of sedimentary strata in the bay. The application of this work is to facilitate modeling acoustic response of the bay floor as a function of sediment type and structure (a primary goal for the Coastal Benthic Boundary Layer Project).

Results

X-radiography

X-radiographs of cores from the central basin of Eckernfoerde Bay show laminations in the upper 20-30 cm of the sea floor. Below this depth, methane bubbles disrupt the fabric, obscuring laminations. In the upper (non-gassy) region, laminations typically have diffuse contacts, and are interbedded with thicker beds (several cm thick). The laminations are generally more absorptive of X-rays than the thicker beds (thus appearing dark in positive prints), and may be laterally discontinuous and inclined from horizontal. Discrete traces made by infauna are rare, if present at all, although shells of both gastropods and tellinid bivalves (single and articulated valves, some apparently in life position) are occasionally present. X-rays from several cores in the central basin showed shell layers (1-2 cm thick) of tellinid bivalves about 15 cm below the sediment surface.

Microfabric

Thin-sections representing the upper 15 cm of core BS4-602 were prepared to study detailed correlations with X-radiographs and grain-size variations. Portions of the upper 25 cm of four other cores were prepared also.

Two general types of microfabric were observed in cores from the central basin: pelletal fabrics (pellets > 10% of volume; percentages are approximate) and non-pelletal fabrics (pellets < 10% of volume). Of these, pelletal fabrics are by far the most common, and may be either matrix supported or pellet supported. In addition, thin (<1 mm) laminations of brown amorphous organic material (optically isotropic under crossed polarizers) were observed, especially near surface layers of cores. Transitions from non-pelletal layers to overlying pelletal layers tend to be gradational, whereas contacts between non-pelletal and underlying pelletal layers are sharp. Types of particles visible in thin section include detrital mineral grains, aggregates of clay minerals (probably admixed with amorphous organic matter), and other biogenic particles (such as calcareous and agglutinated foraminiferal tests, diatom frustules, and organic detritus).

Most fecal pellets present (produced by the tellinid bivalve *Abra alba*); are ovoid, tapering slightly to one end, ranging from ~100-500 μm long, and averaging approximately 250 μm. They are encapsulated in mucous sheaths visible in thin section, and may contain mineral grains as large as 100 μm. The color of individual pellets varies from the that of surrounding sediment (shades of light

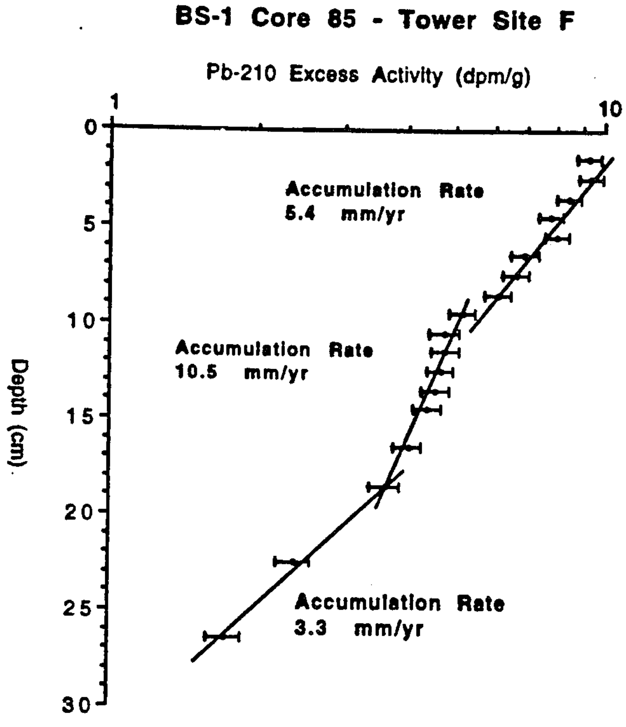

Fig. 1. Excess ^{210}Pb; note changes in accumulation rate through time.

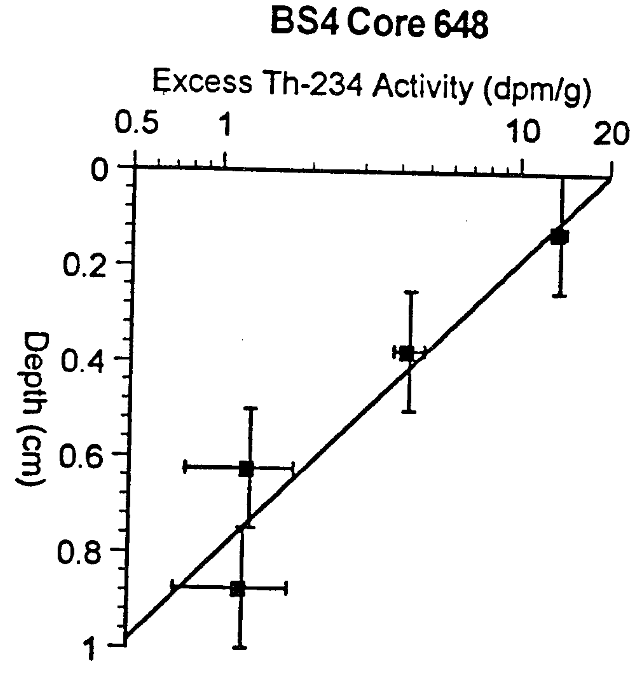

Fig. 2 Excess ^{234}Th; excess activities are restricted to the upper 1 cm.

brown in thin section, under non-polarized light) to blackish, and may be a function of both encapsulated sediment type and of increasing iron monosulfide or organic content. These pellets are extremely resistant to breakdown; heating overnight at 100° C in 30% H_2O_2 was necessary to disaggregate them for grain-size analysis.

Pelletal fabrics tend to be anisotropic: fecal pellets and detrital mineral grains show little preferred orientation or location, except for occasional small aggregates of pellets that appear to have filled small voids in the sediment. Non-pelletal laminations sometimes display graded bedding; other laminations may show no obvious grain-size variations between layers, and thus no graded bedding. In general, microstructural laminations correspond to laminations observed in X-radiographs, and pelletal fabrics in thin section are associated with thicker, homogenized beds seen in X-radiographs.

Grain-size distribution

Grain-size analyses were performed at 1-cm intervals for the upper 25 cm of cores from the central basin, above the zone of gas disturbance. Analyses for samples deeper in cores were performed at 2-4 cm intervals. Distributions tend to be polymodal, with the primary mode centered between 9.5 and 11.5 ϕ and a secondary mode, less than 10% by mass, centered between 3 and 6 ϕ. Subtle coarsening in the median grain size of each mode is commonly associated with laminations observed in X-radiographs, and non-pelletal, graded bedding in microfabric. The coarsening associated with these laminations is accompanied by a 2-4% increase in the mass percentage of particles in the 3-6 ϕ size range.

Radiochemistry

Sediment accumulation rates in the central basin determined by ^{210}Pb geochronology range from 3 to over 10 mm per year (Fig. 1). Excess ^{210}Pb is present in the seabed to depths of 30-40 cm. Excess ^{234}Th is restricted to the upper centimeter of sediment (Fig. 2), indicating that mixing (i.e., the surface mixed layer, or sediment layer influenced by mixing processes) is restricted to this thin veneer in the sea floor. No significant seasonal variability in sediment mixing depths was observed over winter, spring and summer cruises, although intensity of mixing may change. Lateral variability of accumulation rates within the central basin was minimal.

Shallow penetration of sediment mixing results in the preservation of a detailed environmental record (cm-scale) in central-basin sediments. Long-term variations in ^{210}Pb profiles were observed in central-basin cores (Fig. 1), indicating historical shifts in either ^{210}Pb flux in coastal waters or changing sediment supply.

Conclusions

The sedimentary input to the central basin is controlled by pulsed supply of fine particles from both proximal and distal sources. Time-series benthic-boundary-layer observations indicate physical sediment mixing to be insignificant. Biological mixing is intense, but presently limited to the upper centimeter of the seabed. Sediment pulses (storm layers) exceeding the mixed-layer thickness may be preserved as individual laminations. Slower deposition results in intensely reworked and pelletized sediment (pelletal fabric). Particle and chemical tracers reaching the seafloor may be vertically resolved to increments of ~5 mm, preserving a detailed stratigraphic record in the upper 25 cm, above levels of microbial gas formation.

Fluctuations in the frequency of sediment pulses cause variations in ^{210}Pb accumulation rates (3-10 mm yr^{-1}). Similarly, sedimentary fabric (mm and cm scales) displays subtle gradients in grain size and bioturbation (including pelletization) that correlate to fluctuations in sediment supply rate.

Measurement of progressive bioturbation in event layers, Eckernfoerde Bay, southwestern Baltic Sea.

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Sedimentological studies were undertaken in the central basin of Eckernfoerde Bay to determine the relationship between physical and biological processes in the benthic-boundary layer and resultant preserved sedimentary fabric (Bentley et al., in press; Nittrouer et al., 1994). This paper compares the degree of bioturbation in central basin sediments, inferred from intensity of sediment pelletization, with results of a biodiffusional model based on signal-dissipation theory (Wheatcroft, 1990).

Radiographic and microfabric examinations of central basin sedimentary fabric show it to be characterized by clay-rich pelletal laminae alternating with slightly siltier, non-pelletized laminae, sometimes displaying basal graded bedding. Sediment-transport studies indicate that the laminated bedding is caused by alternating deposition of storm-suspended sediments from adjacent shallow-water areas and fair-weather supply of fine suspended material advected from the open Baltic. Physical reworking of the seabed in the central basin is minimal (Friedrichs and Wright, in press; Wright, 1994). Bioturbation does not extend far downward into the seabed, but is intense (~ 1 cm depth of reworking: Bentley et al., in press; D'Andrea et al., in press), reaching depths comparable to annual sediment accumulation as measured by ^{210}Pb geochronology (5-11 mm/yr: Bentley et al., in press; Nittrouer et al., 1994). Small, ovoid, mucous-encapsulated fecal pellets (~ 500 μm) are produced in abundance by the two dominant taxa in the benthic community (Bentley et al., in press; D'Andrea et al., in press). Slow accumulation of sediments during the fair-weather regime thus results in near-complete pelletization of the mixed layer. Sedimentary-event layers (such as storm deposits) thicker than the mixed layer may overwhelm the benthos, resulting in preserved primary depositional fabric characterized by sharp basal contacts, graded bedding and unpelletized sediment (Bentley et al., in press). Biological disturbances, such as anoxic events, may eliminate burrowing temporarily (D'Andrea et al., in press); primary depositional fabric would be preserved under these conditions as well, however, the sedimentological signatures of such events would lack the graded bedding of storm layers.

In order to assess quantitatively the relationship between pulsed sediment deposition and rate of bioturbation, we examined laminations in thin section for evidence of progressive bioturbation with age, and compared these results with calculated values of disruption using the transit time/dissipation time model of Wheatcroft (1990). This model, derived from Crank (1975), addresses the diffusional modification of an event layer (of some initial concentration C) undergoing bioturbation during transit through the mixed layer, as follows:

$$C = 0.5\, C_0\, erf\,[L_s/(2(D_b T_m)^{1/2})]$$

where C_0 is initial tracer concentration in the event layer, *erf* is the error function, a tabulated mathematical function, L_s is the event layer thickness (cm), and D_b is the biodiffusion coefficient. T_m is the event layer transit time through the mixed layer, given in simplest form by L_b/w, where L_b is the mixed layer thickness (cm), and w the accumulation rate (cm/ yr).

Excess ^{234}Th activities (Fig. 1) were used to estimate D_b (~ 0.7 cm^2 yr^{-1})in central basin sediments, using a solution to the steady-state advection/diffusion equation (Aller and Cochran, 1976),

$$D_b = \lambda(z/ln(C_0/C_z))^2$$

where λ is the ^{234}Th decay constant (10.5 yr^{-1}), z is depth in the seabed (cm), C_0 is excess activity at the surface (DPM/g), and C_z is excess activity at depth z (DPM/g). Because of the rapid mixing rates (Lopez et al, this volume) and the short half-life of ^{234}Th, we assume that biological mixing controls the penetration of excess ^{234}Th into the seabed.

A method useful for assessing appropriate length and time scales for modeling is the decomposition of the biodiffusion coefficient into a mean step length and rest period (Wheatcroft et al., 1990) using the form $D_b = \delta^2/2\Omega$, where δ is mean step length , and Ω is mean rest period (yr). Assuming a step length of 2 mm (a value appropriate to the benthic community), the rest period is ~10 days. To advect a 1 mm event layer through the 8 mm mixed layer in less time than the rest period (and so preserve the layer) would require rapid deposition at rates equivalent to 35 cm yr^{-1}, far higher than the mean accumulation rates in the central basin (~7 mm yr^{-1}). Event layers exceeding the mixed-layer thickness satisfy these conditions.

The few laminations clearly preserved in thin sections prepared from central basin sediments (Fig. 2) have sharp lower contacts, and grade upward into progressively more pervasively-pelletized sediment. The thicknesses of unburrowed sediment are on the order of 3-5 mm, and progressively pelletized layers are similar. Each preserved lamination must have been initially thicker than the sediment mixing depth in the central basin (~8 mm), otherwise the lower boundary would not have been preserved. For application of the model, we considered percent pelletization of sediment to approximate the extent of bioturbation undergone by an event layer. Reingestion and microbial decay of fecal pellets are assumed to have negligible effect on pellet concentration, and oxic water-column conditions are assumed as well, allowing rapid recolonization of the substrate surface. Table 1 compares modeled and observed layers of pelletization in a storm layer 10 mm thick.

Table 1. Model results: degree of pelletization of a storm layer with resumed accumulation and bioturbation. $C_0 = 100$, $D_b = 0.7 \text{ cm}^2 \text{ yr}^{-1}$, $w = 7 \text{ mm yr}^{-1}$.

Initial depth (mm) from sediment surface	Transit time to historical layer (yr)	% Pelletized sediment in historical layer, modeled results	% Pelletized sediment estimated from BS4-602, 6.4-7.1 cm depth
1	1	71	70
2	0.86	69	60
3	0.71	67	40
4	0.57	64	30
5	0.43	60	20
6	0.29	56	15
7	0.14	51	10 (basal contact)

Model results can be interpreted as either progressive bioturbation of a single storm layer through time, or as measurements of bioturbation under fluctuating accumulation rates (as indicated by varying transit times: recall that $T_m = L_b/w$). Computed results indicate that fluctuations in sediment input will influence the degree of bioturbation and thus of pelletization, both at high depositional rates, represented by the short transit times in the 5-7 mm depth range, and at intermediate rates (longer transit times, 2-4 mm depths).

Although degree of pelletization increases upward from the basal contact in both modeled and measured results, modeled values of percent pelletized sediment are higher at depth than those determined for corresponding locations in thin sections. This difference may be caused by non-diffusive mixing, while the model assumes diffusive behavior. Capitellid polychaete and ologochaete feeding activities can be advective (albeit at a small scale:T. Forbes, pers. commun);

sediment ingested at depth is deposited on the sediment surface as fecal pellets, resulting in the observed high pellet concentrations near the surface of event layers.

The true measure of bioturbation intensity in these sediments probably exists between model results on the high end, and percent pelletized sediment on the low. Three observations support this assertion. First, observed fecal pellets represent only the contribution of tellinid bivalves and capitellid polychaetes to sediment modification, and do not incorporate bioturbation by other members of the benthic community. Thus, observed degree of sediment pelletization should be a minimum measurement of bioturbation, whereas model results integrate the activities of all organisms mixing the sediment at our scales of observation. Second, the model assumes steady-state biodiffusion, which is not likely when $L_b \leq L_s$; under these conditions, a lag in bioturbation rate not incorporated into the model should occur during the early stages of recolonization (Jumars and Wheatcroft, 1989). Third, organism patchiness and depositional surface irregularities introduce non-uniform gradients into natural microfabric, thus introducing error in correlations of modeled and observed values.

References

Aller RC and Cochran JK (1976) ^{234}Th-^{238}U disequilibrium and diagenetic time scales. Earth and Planetary Science Letters 29: 37-50.

Bentley SJ, Nittrouer CA, and Sommerfield CK (in press) Development of sedimentary strata in Eckernfoerde Bay, southwestern Baltic Sea. Geo-Marine Letters.

Crank J (1975) The mathematics of diffusion. Oxford: Clarendon Press, 339 pp

D'Andrea AF, GR Lopez, and NI Craig (in press) Benthic macrofauna and bioturbation in Eckernfoerde Bay, southwestern Baltic Sea. Geo-Marine Letters.

Friedrichs CT and Wright LD (in press) Resonant internal waves and their role in transport and accumulation of fine sediment in Eckernfoerde Bay, Baltic Sea. Continental Shelf Research

Jumars PA and RA Wheatcroft (1989) Responses of benthos to changing food quality and quantity, withh a focus on deposit feeding and bioturbation. In Berger WH, VS Smetacek, and G Wefer (eds), Productivity in th oceans: Present and Past. New York: John Wiley and Sons, p 235-253.

Nittrouer CA, CK Sommerfield, and SJ Bentley (1994) Formation of sedimentary strata in Eckernfoerde Bay. EOS 75: 180.

Wheatcroft RA (1990) Preservation potential of sedimentary event layers. Geology 18: 843-845

Wright LD (1994) Benthic transport phenomena in Eckernfoerde Bay (Baltic Sea). EOS 75: 175

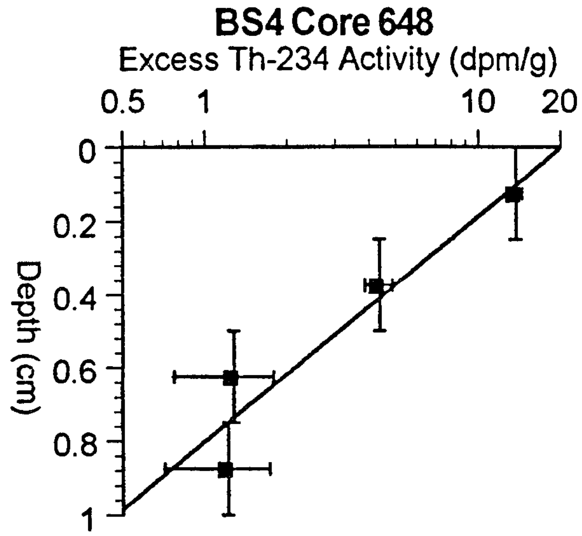

Figure 1 Excess ^{234}Th activity, BS4-648. Db = 0.7 cm^2/yr.

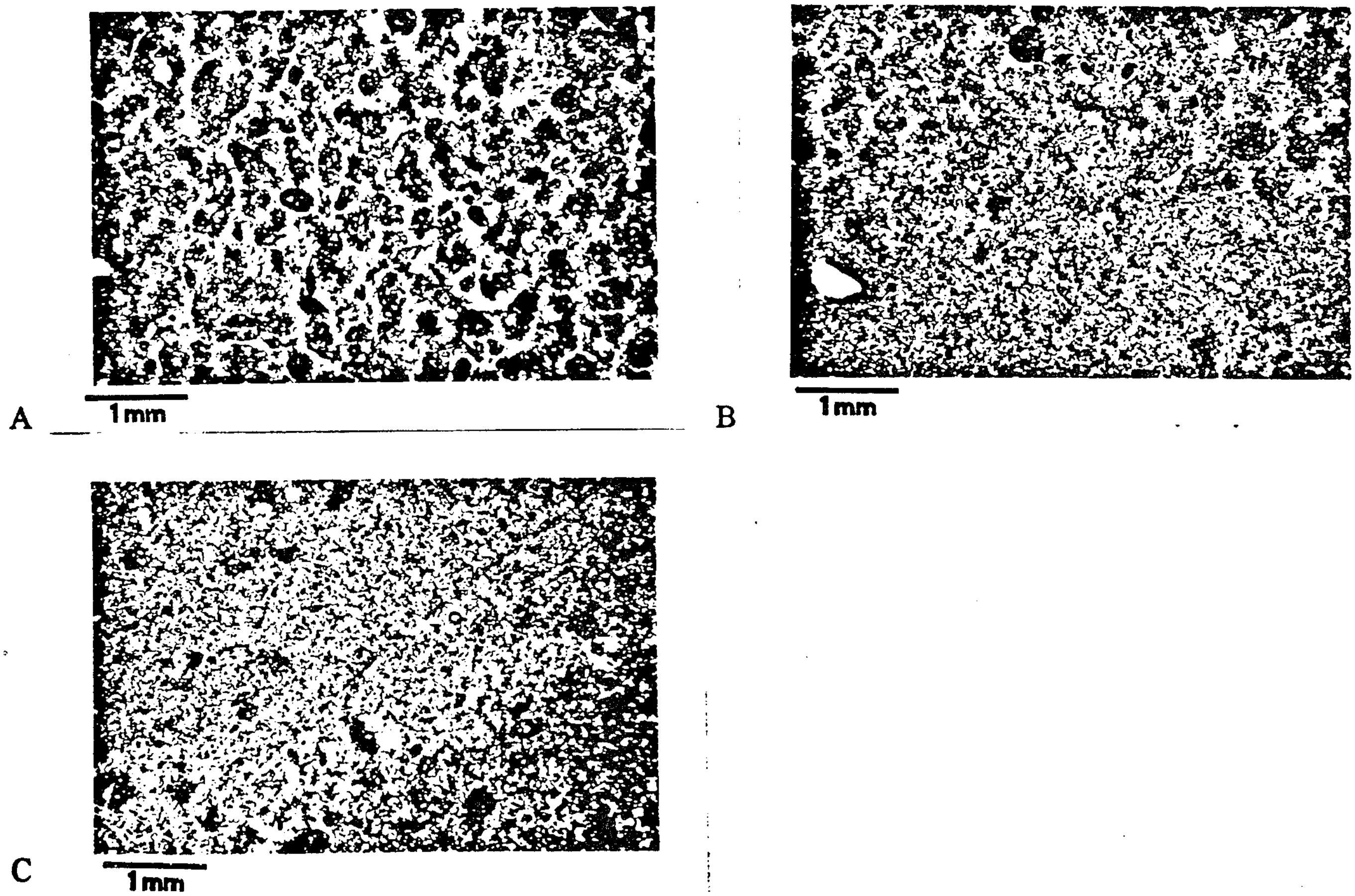

Figure 2 Photomicrographs, BS4-602. Field of view is 5.5 mm wide. A) 2.5-2.8 cm depth, plane light: intensely pelletized horizon, fecal pellets produced by the surface-deposit-feeding bivalves and capitellid polychaetes, B) 6.7-7.0 cm depth, crossed polars: upper portion of event layer showing transition from non-pelletized (lower) to pelletized fabric (upper); C) 7.0-7.3 cm depth, crossed polars: basal contact between non-pelletized event layer and underlying pelletized horizon.

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13. ABSTRACT *(Maximum 200 words)*

This spring, we have focused our research on completing laboratory analysis on the Eckernförde data and preparations for the Gassy Mud Meetings in June. We are integrating sedimentological, radioisotopic, and benthic biological results with benthic boundary-layer physical data to quantitatively assess the processes controlling sedimentary fabric in the central basin of Eckernförde Bay. The summaries of these results are attached and are the actual abstracts sent in for the Workshop on Modeling Methane Rich Sediments of Eckernförde Bay.

For the Key West experiment, we are in the early stages of radiochemical and faunal analysis of box core samples.

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