

CBBLSRP FY 95 YEAR-END REPORT

Physical and Biological Mechanisms Influencing the Development and Evolution of Sedimentary Structure

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Introduction

Research work during 1995 included completion of Eckernfoerde analyses and collection of data/samples in the Dry Tortugas/Marquesas study area. The results of Eckernfoerde studies were presented at the CBBL workshop during summer 1995 and in two preliminary papers as part of the *Geo-Marine Letters* special volume. Preparations of two final research papers and an integrated summary paper of Eckernfoerde work were started. These include modeling of strata formation, which is highlighted in this annual report. We participated in two research cruises to the Dry Tortugas and Marquesas, and collected over 200 cores in coordination with boundary-layer and acoustic observations. These data will help us to contrast strata formation in a carbonate setting with that observed in siliciclastic settings. Analyses of these new samples started in 1995, as described below.

Results and Conclusions Regarding Modeling in Eckernfoerde Bay

Previous studies have proposed that the subtle laminations in the silty-clay sediment of Eckernfoerde Bay are a function of alternating storm and fair-weather sediment transport and accumulation (Milkert, 1994; Friedrichs and Wright, 1995), overprinted by shallow bioturbation (Bentley et al., 1996). 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:

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

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 is the accumulation rate (cm/yr). Excess ^{234}Th activities permitted estimates of D_b ($\sim 0.7 \text{ cm}^2 \text{ yr}^{-1}$) in central basin sediments, using a solution to the steady-state advection/diffusion equation (Aller and Cochran, 1976).

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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. 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.

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. 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.

The aim of the biological component in Eckernfoerde Bay was to characterize the role of the benthic community in vertical particle mixing and sediment transport. Functional-group analysis was used to determine the successional status of the benthic community and the potential role in vertical mixing, defined here as the vertical displacement between feeding and defecation, of the functional groups present in this system: surface deposit feeders, head-down deposit feeders, carnivores/scavengers, and suspension feeders. The benthic community of Eckernfoerde Bay was dominated by opportunistic surface deposit feeders, particularly the spionid polychaete *Polydora ciliata* and the tellinid bivalve *Abra alba*. Head-down deposit feeders such as capitellid polychaetes were the next most abundant group. Bioturbation experiments and radiochemical analysis indicate that this community mixed the top 0.5-1.0 cm of the sediment on rapid time scales (< 14 days) (D'Andrea et al., 1996; Bentley et al., 1996). Particle bioturbation is best incorporated into models as a biological mixing or "biodiffusion" coefficient (Berner 1980; Aller 1980; Guinasso and Schink 1975; Goldberg and Koide 1962). The biodiffusion coefficient estimated in particle mixing studies can be decomposed into the following form: $D_b = \delta^2/2\Omega$, where D_b represents the biodiffusion coefficient, δ the mean step length, and Ω the mean rest period (Wheatcroft 1990). Our results indicate that the vertical

displacement between ingestion and defecation of particles is important in determining the step-length portion (δ) of the biodiffusion coefficient, and is directly related to the functional group (Table 2). In Eckernfoerde Bay, the step length is controlled primarily by head-down deposit feeders such as capitellid polychaetes, despite the numerical dominance of surface deposit feeders. The benthic community is maintained at a low level of complexity due to a regular disturbance, most likely seasonal hypoxia/anoxia.

The sizes and abundances of deposit feeders and the fecal pellets they produce were used to determine whether the fecal pellet sizes and abundances were capable of being produced by the resident population in the central basin. Deposit-feeder fecal pellets are typically aggregates of finer particles, and can be fairly robust to decomposition and breakage. They are then subject to benthic-boundary-layer processes such as bottom stress, resuspension and transport. We concentrated on determining if the spatial distribution of fecal pellets was a good indicator of sedimentary processes occurring in Eckernfoerde Bay. The primary fecal pellet producers identified for this system were the tellinid bivalve *Abra alba*, capitellid polychaetes, and tubificid oligochaetes. Fecal pellet abundance increases almost exponentially with water depth; the greatest abundances were found in the central basin (Fig. 1). Pellet size is significantly greater in the central basin than along the shallower flanks of the bay (Fig. 2). The largest fecal pellet producers, however, were found at the shallowest stations where the smallest pellets and lowest abundances of fecal pellets were found (Fig. 1). Our results indicate that there is a winnowing of robust fecal pellets from the steep slopes along the flanks of Eckernfoerde Bay into the central basin. The abundance of fecal pellets follows the pattern of sediment transport and deposition in Eckernfoerde Bay and supports the hypothesis that the central basin is a sink for fine particles. Our results indicate that the spatial distribution of robust fecal pellets may be a good biogenic indicator of sedimentary processes in some shallow coastal systems.

Description of Preliminary Work in Marquesas/Tortugas

Sedimentological studies were undertaken in the Dry Tortugas and Marquesas islands to elucidate the relationship between physical and biological processes in the benthic boundary layer and resultant preserved sedimentary fabric in a carbonate-shelf setting. More specifically, our sampling program was geared toward three goals: studying temporal and small-scale spatial variability (biological and sedimentological) of the seabed in the vicinity of the VIMS tetrapod during the period of its deployment in the Dry Tortugas; characterizing temporal and spatial seabed variability of the Tortugas study site as a whole ($\sim 30 \text{ km}^2$), and to a lesser extent, the Marquesas study site ($\sim 70 \text{ km}^2$); and establishing a regional framework of benthic-community and sedimentary-fabric distributions over areas south and east of the Tortugas ($\sim 500 \text{ km}^2$) and north and west of the Marquesas ($\sim 100 \text{ km}^2$). To achieve these goals, 210 box cores and 14 gravity cores were recovered.

Cores are being examined by observations of x-radiographs, microfabric (using image analysis techniques), grain size, and ^{234}Th , and ^{210}Pb geochronology. Using the results from these analyses, we plan to evaluate quantitative models of strata formation, such as the Wheatcroft model (1990), discussed above, for applicability to fine-grained carbonate-shelf depositional environments.

Initial results indicate that both the Marquesas and Tortugas study sites are subjected to interacting biological and physical sediment transport and mixing mechanisms. Radiographs of both sites display a thin (2-5 cm) layer of high-porosity sediment blanketing a very shelly, more-consolidated carbonate mud. Cross-stratification is frequently observed in the surface layer of radiographs of Marquesas cores. In contrast, the surface layer of cores from the Tortugas is frequently homogenized by bioturbation. Deeper sediments from both sites are generally intensely bioturbated, containing large vertical burrows (to 1 cm inside diameter, probably produced by Callianassid crustaceans; Tedesco and Aller, in press), deposit-feeding traces (horizontal-meniscate backfilling, characteristic of heart-urchins; Bromley, 1990) as well as numerous small (< 0.5 cm) vertical and inclined burrows (produced by unidentified vermiform organisms). Only rarely are vestiges of primary depositional structure evident.

Excess ^{234}Th was limited to the upper 2 cm of two cores recovered near the VIMS tetrapod. This depth corresponds to the thickness of fluffy surface layer, seen in radiographs taken from the same cores (Fig. 3), and indicates that this layer is probably well-mixed on time scales approaching the half-life of ^{234}Th (Aller and Cochran, 1976). An algal mat blanketed the sediment surface over much of the study area, probably inhibiting sediment remobilization (physical mixing) by all but the most energetic events (ripples were observed to form on disturbed, unmatted sediment, following the passage of a storm in late February 1995). Bioturbation and physical mixing both appear to be important in the surface layer of the Dry Tortugas site.

Although measurable excess ^{234}Th appears to be restricted to a relatively thin surface sediment layer, bioturbation is significant below the surface layer, judging by the well-developed biogenic fabric described above. Vertical zoning of specific biogenic structures is typical of a tiered ichnofabric, and should closely relate to benthic community structure and rates and episodicity of sediment accumulation (Bromley and Ekdale, 1986; Boudreau, 1994; Tedesco and Aller, in press).

Biological samples were concentrated around the tetrapod deployment site in the Dry Tortugas study site, but included samples throughout the grid and near Marquesas to get a regional perspective. Overall, benthic samples were taken from 119 box cores. These included 40 box cores from the tetrapod site, 42 from the Dry Tortugas study area, and 37 box cores from the Marquesas and regional stations. Preliminary work on the samples indicate three organisms with the greatest bioturbation potential: Callianassid shrimp, capitellid polychaetes, and sipunculan worms. Callianassid shrimp are commonly selective deposit feeders which live in deep burrow systems. These burrow systems typically include galleries where coarser sediment and fecal pellets are stored. These galleries could affect this system by creating large void spaces in the sediment and biologically graded bedding. The capitellids found in this system (dominated by *Notomastus*) are rather large (up to 10 cm long). This group of polychaetes are head-down deposit feeders that feed at depth and defecate at the surface. Sipunculan worms are active burrowers, although some live in mucus-lined burrows, and are mostly nonselective deposit feeders. These three species should be the dominant bioturbators of this system. Future work will focus on relationships between sediment accumulation rates, benthic community structure, hydrodynamic conditions, and sedimentary structures.

References

- Aller RC (1977) The influence of macrobenthos on chemical diagenesis of marine sediments. Unpublished Ph.D. dissertation, Yale University, 600 pp.
- 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 (1996) Development of sedimentary strata in Eckernfoerde Bay, southwestern Baltic Sea. *Geo-Marine Letters*, 16.
- Berner R (1980) Early Diagenesis, A Theoretical Approach. Princeton, New Jersey, Princeton University Press: 241 pp.
- Boudreau BP (1994) Is burial velocity a master parameter for bioturbation? *Geochimica et Cosmochimica Acta*, 58: 1243-1249.
- Bromley RG (1990) *Trace Fossils: Biology and Taphonomy; Special Topics in Paleontology*, Unwin-Hyman, London, 280 pp.
- Bromley RG and Ekdale AA (1986) Composite ichnofabrics and tiering of burrows. *Geology Magazine* 123: 59-65.
- Crank J (1975) *The Mathematics of Diffusion*. Oxford, Clarendon Press, 339 pp.
- D'Andrea A, Craig N, and Lopez GR (1996) Benthic macrofauna and depth of bioturbation in Eckernfoerde Bay, southwestern Baltic Sea. *Geo-Marine Letters* 16.
- Friedrichs CT and Wright LD (1995) Resonant internal waves and their role in transport and accumulation of fine sediment in Eckernfoerde Bay, Baltic Sea. *Continental Shelf Research* 15: 1697-1721.
- Goldberg E and Koide M (1962) Geochronological studies of deep-sea sediments by the Ia/Th method. *Geochimica et Cosmochimica Acta* 26: 417-450.
- Guinasso N and Schink D (1975) Quantitative estimate of biological mixing rates in abyssal sediments. *Journal of Geophysical Research* 80: 3032-3043.
- Jumars PA and RA Wheatcroft (1989) Responses of benthos to changing food quality and quantity, with a focus on deposit feeding and bioturbation. In Berger WH, VS Smetacek and G Wefer (eds.), *Productivity in the Oceans: Present and Past*, New York, John Wiley and Sons, pp. 235-253.
- Milkert D (1994) Auswirkungen von Sturmen auf Schlicksedimente der westlichen Ostsee. Berichte-Report Geologisch-Palaontologisches Institut Universitat-Kiel 66, 153 pp.
- Tedesco LP and Aller RC (1996) ^{210}Pb chronology of sequences affected by burrow excavation and infilling: Examples from shallow marine sediment sequences, Holocene south Florida and Caicos Platform, British West Indies. *Journal of Sedimentary Research*.
- Wheatcroft RA (1990) Preservation potential of sedimentary event layers. *Geology* 18: 843-845.

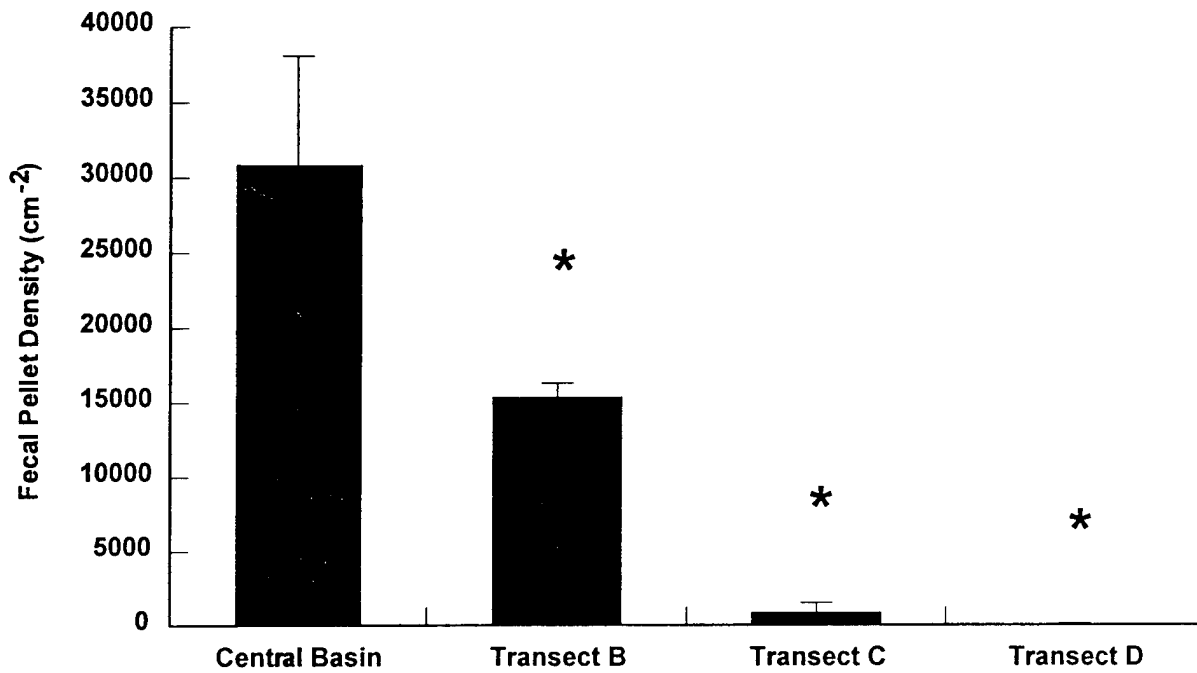
Table 1. Model results: degree of pelletization of a storm layer with resumed accumulation and bioturbation. $C_0 = 100$, $D_b = 0.7 \text{ cm}^2 \text{ yr}^{-1}$, $w = 7 \text{ mm yr}^{-1}$.

Initial depth (mm) from 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)

SURFACE DEPOSIT FEEDERS (SDF)		Vertical Displacement (δ)
<i>Polydora ciliata</i>	polychaete	~0 cm
<i>Abra alba</i>	bivalve	~0 cm
<i>Diastylus rathkei</i>	crustacean	~0 cm
HEAD-DOWN DEPOSIT FEEDERS (HDF)		
<i>Capitella</i> sp.	polychaete	~1 cm
<i>Heteromastus filiformis</i>	polychaete	~1 cm
tubificid sp.	oligochaete	~1 cm
<i>Pectinaria koreni</i>	polychaete	2-3 cm
<i>Scoloplos armiger</i>	polychaete	2-3 cm
CARNIVORES/SCAVENGERS (C)		
<i>Anaitides maculata</i>	polychaete	~0 cm to 1cm (burrowing)
syllid sp.	polychaete	~0 cm to 1cm (burrowing)
<i>Nephtys</i> sp.	polychaete	~0 cm to 1cm (burrowing)
<i>Hermathoe</i> sp.	polychaete	~0 cm to 1cm (burrowing)
<i>Sigambra</i> sp.	polychaete	~0 cm to 1cm (burrowing)
SUSPENSION FEEDERS (SF)		
<i>Mytilus edulis</i>	bivalve	~0 cm
<i>Cerastoderma</i> sp.	bivalve	~0 cm
<i>Corbula gibba</i>	bivalve	~0 cm

Table 2. Rank order of dominant macrofauna in Eckernfoerde Bay and vertical displacement between feeding and defecation for individual species.

Fecal Pellet Density in Eckernfoerde Bay, Summer 1994



Fecal Pellet Producer Abundance Along Transect

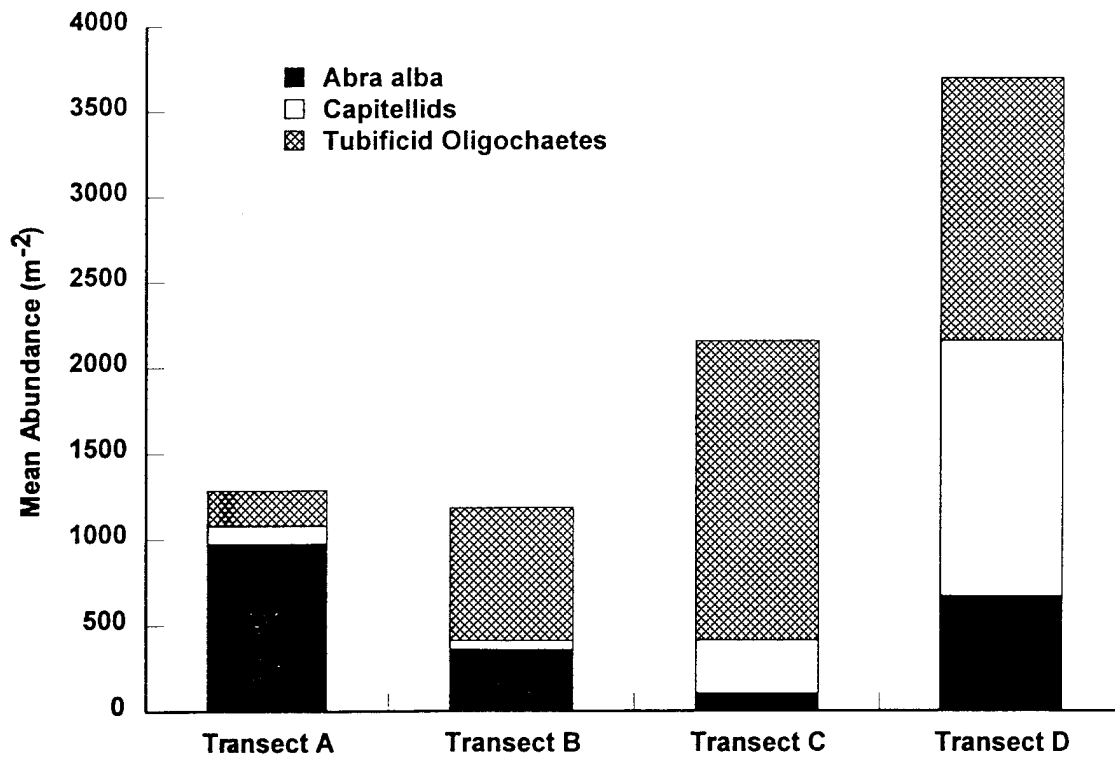


Figure 1. Fecal-pellet density (top) and fecal-pellet-producer abundance (bottom) from the central basin to the shallowest transect station (Transect D = 14m).

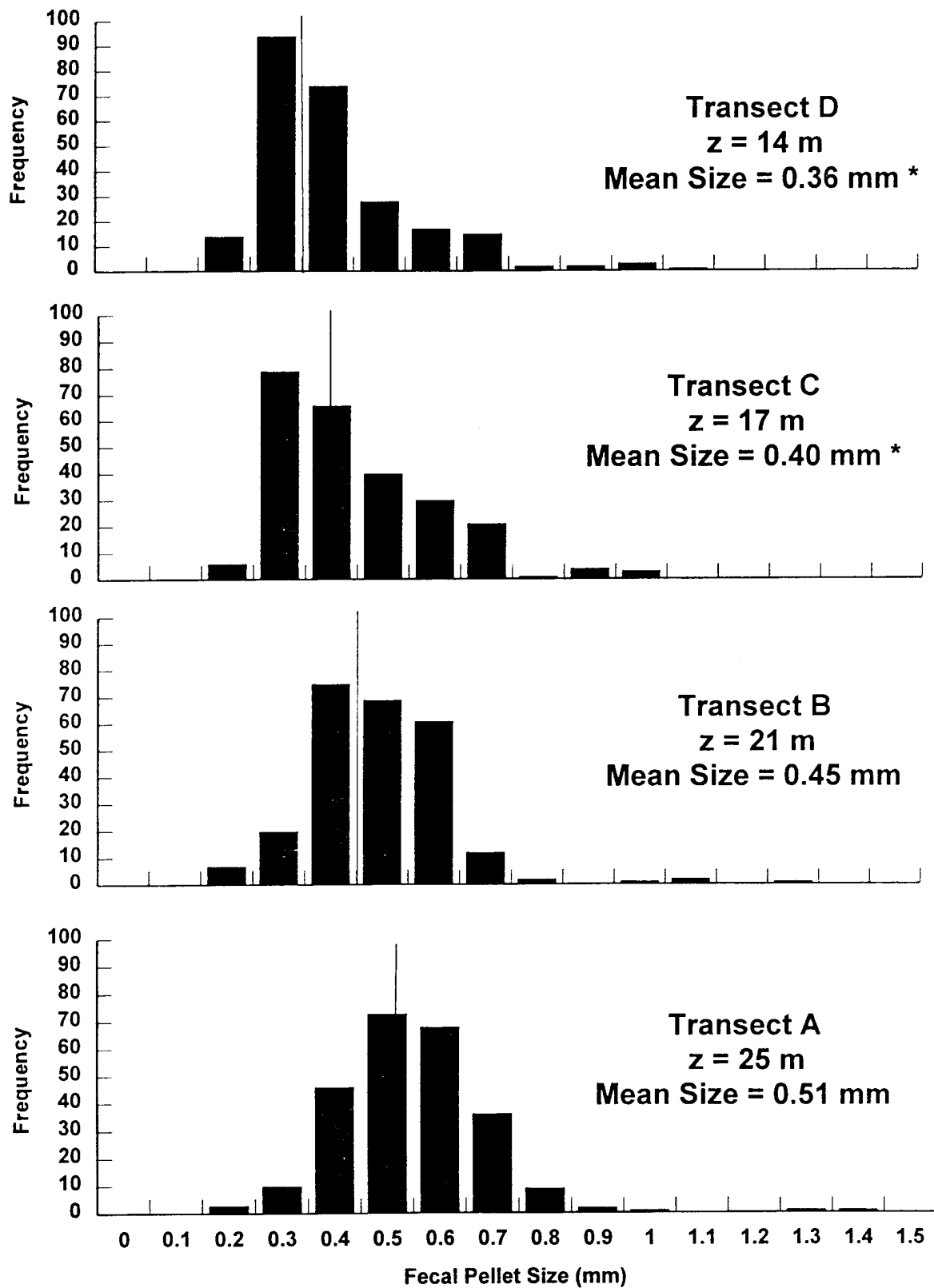


Figure 2. Size frequency of fecal pellets from the shallowest transect station (top) to the central basin (bottom). Mean pellet size is indicated by a single vertical line in each distribution. * = significantly lower mean length than the central basin ($\alpha =$

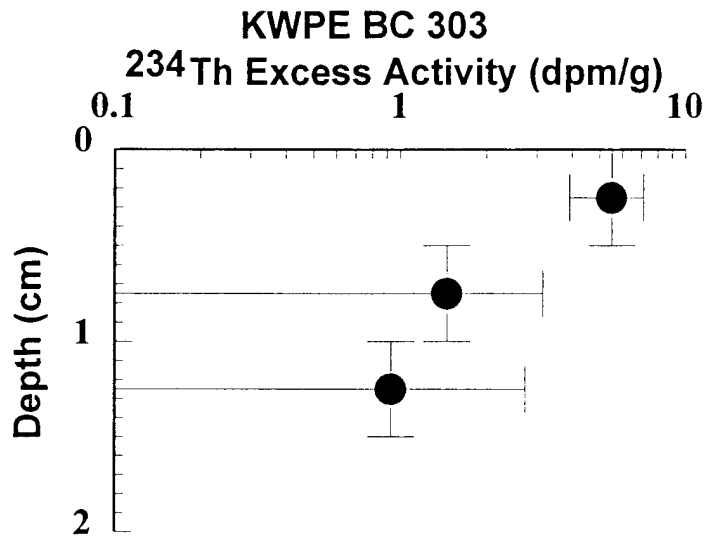


Figure 3. Excess ^{234}Th activity profile from KWPE BC-303. Note that the thickness of the layer containing excess ^{234}Th corresponds to the surface layer seen in x-radiographs.

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