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A SIMPLE TECHNIQUE FOR FINE-SCALE, VERTICAL SECTIONING OF FRESH SEDIMENT CORES[1]

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INTRODUCTION

Biogeochemical processes occurring at the sediment-water interface and within the very near-surface sediments are known to affect or control what occurs above or below the sediment surface (see reviews of Nowell 1983; Jumars and Nowell 1984; Nowell and Jumars 1984; Grant and Madsen 1986; Butman 1987; Rumohr et al. 1987). Studies of these phenomena often require vertical sampling of the variables of interest over very fine (e.g., millimeter) spatial scales. Existing techniques for such fine-scale vertical sectioning of fresh sediment cores were developed primarily for studies of porewater chemistry (Craven et al. 1986; Jahnke et al. 1986; Reimers and Smith 1986) and of the distributions of meiofauna or microbes (Boaden and Platt 1971; Joint et al. 1982; Palmer and Molloy 1986), where only very small samples (cores ≤3.0 cm in diameter) are required. Furthermore, in most cases, the vertical-sectioning technique requires subcoring a much larger sediment sample (e.g., a box core) *after* it is taken. This potentially introduces error (contamination between layers) when sectioning at millimeter intervals, because near-surface sediments within the sample may mix vertically or horizontally on transit to the water surface (Rutledge and Fleeger 1988).

We here describe a technique for fine-scale vertical sectioning of fresh sediment cores that operates on the same general principle as many previously described core extruders but that can be used on larger cores. We also describe a technique for subcoring a box core while it is taking a sample, to avoid errors which may be introduced by subsampling on deck. The precision (in terms of vertical positioning, contamination between adjacent layers, and smearing) of this extruding technique is discussed, based on results of laboratory calibration experiments using muddy sediments.

EXISTING TECHNIQUES FOR FINE-SCALE VERTICAL SECTIONING

Existing techniques to extrude and section fresh sediment cores at scales of millimeters (1–50-mm sections) involve the use of small (10–50 ml), disposable or reusable syringes (Boaden and Platt 1971; Joint et al. 1982; Craven et al. 1986; Jahnke et al. 1986; Palmer and Molloy 1986; Reimers and Smith 1986). In most cases, the syringe barrel was used to subcore a larger sediment sample (box core or grab), exceptions being Boaden and Platt (1971) and Joint et al. (1982), where intertidal

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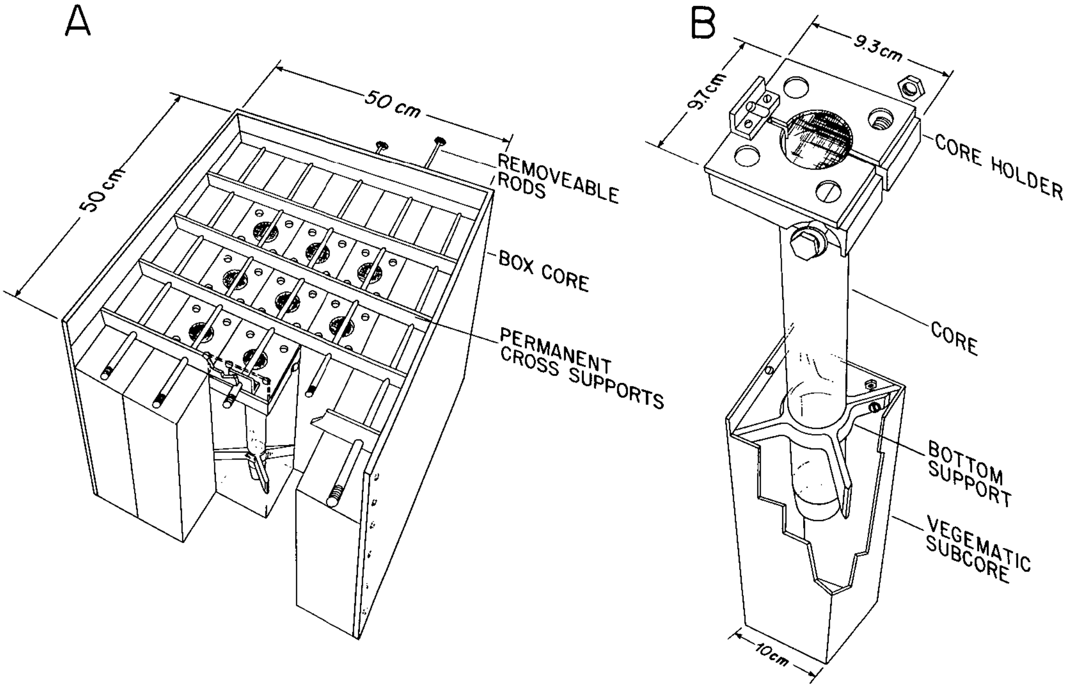


FIG. 1.—A) Diagram of a 0.25-m² MK-3 Hessler-Scandia box core, showing core holders in the central nine sections of the vegematic. The front panel of the box core has been removed to expose the vegematic sections; a cut-away view of one section shows the core tube inside. B) Expanded view of core holder and bottom support in a vegematic section of a box core; see text for detailed description.

sands were cored with the syringe barrel directly. In all cases, the syringe plunger was inserted into the bottom of the syringe barrel containing sediments, and the sample was extruded through the top of the barrel, either by turning a micrometer screw (Joint et al. 1982; Palmer and Molloy 1986) or by simply pushing on the plunger (Boaden and Platt 1971; Craven et al. 1986; Jahnke et al. 1986; Reimers and Smith 1986).

The vertical resolution afforded by a given coring technique depends on both the extent of core shortening and the vertical mixing of sediment layers within the cores (e.g., see Wrath 1936; Piggot 1941; Emery and Hulsemann 1964; Hongve and Erlandsen 1979; Lebel et al. 1982; Weaver and Schultheiss 1983; Blomqvist 1985; Rutledge and Fleeger 1988). The most recent results indicate that the depth at which core shortening begins is positively correlated with core diameter, suggesting that the sediment depth to which accurate, fine-scale, vertical resolution may be expected decreases with decreasing core diameter (Blomqvist 1985). Furthermore, the very near-surface sediments tend to concentrate in the center of the samples as they are brought to the water surface (due to inadvertent shaking and jostling of the samples, even when carefully transported by divers) (Rutledge and Fleeger 1988), so subsampling a larger core or grab once it is on deck could introduce error if small-scale vertical resolution is required. The magnitude of both phenomena depends on the sediment-sampling technique, as well as on the sediment texture and environmental conditions at the time of sampling. Particularly vexing, however, is that the existence of clear water above the sediment surface when the sample is brought on deck does not necessarily indicate an undisturbed sample (see Elmgren 1973). Thus, to minimize these potential problems when attempting to discern fine-scale vertical gradients in sediment grain size, porewater chemistry, and organism abundance, we designed a subcoring technique that eliminates the potential error associated with subsampling after the sediments are brought on deck and an extruder that could be used to vertically section relatively large-diameter cores.

THE CORING AND SUBCORING TECHNIQUE

Initially, field cores taken by scuba divers in shallow water (depth, 10 m, Buzzards Bay, Massachusetts) for biological and sedimentological analyses were made of clear-cast acrylic tubing, with an inside diameter of 3.9 cm and a wall thickness of 6.5 mm. The acrylic material and relatively large wall thickness were chosen to minimize distortion of the core during the extruding process. Later we learned that nondistorting, thinner walls were possible if we used polycarbonate (sold under the trade name Lexan), which is more rigid than acrylic, so we currently use polycarbonate cores with a 3.8-cm inside diameter and a 3-mm-wall thickness. The bottom, outside perimeter of the cores are beveled to minimize disturbance to surface sediments when the core is initially inserted into the seabed.

To obtain cores for fine-scale vertical sectioning using a shipboard-operated sampling technique, we modified the vegematic sections of a 0.25-m² MK-3 Hessler-Scandia Box Core (Ocean Instruments, California; see initial description in Hessler and Jumars 1974) to hold our shallow-water core tubes. The 25 vegematic sections each measure 10 cm by 10 cm (outside dimensions) and hang in the box by aluminum rods which run horizontally through tabs at the top of the sections (see Fig. 1A). The rods thread through permanent cross supports which limit the extent to which the sections are pushed up during sampling. Aluminum core holders (Fig. 1B) were machined to fit inside the vegematic sections; the core holders have tabs with holes so that they also hang from the removable rods.

The core holders (refer to Fig. 1B) were designed for our 3.8-cm-diameter polycarbonate cores. Each core holder is a solid piece of aluminum 9.3 cm square and 2.2 cm thick so that it fits snugly inside a vegematic section. The top of the core holder also has a small lip (2 mm wide and 1 mm thick) on two sides so that it can rest on top of the vegematic section, and it has an indentation on one end to fit under the permanent cross supports. The core holder is split in the middle so that it can be slid onto a core and tightened with a bolt. The underside of the core holder contains a 4.4-cm-diameter hole where the core is inserted. A fine-mesh screen (400-μm-square openings) is inserted into this hole to reduce sloshing but also to allow water to escape out the top of the core when the box core is biting. The screen is supported by a 3-mm lip around the periphery of the core hole, so that the diameter of the opening looking down at the top of the core holder is 3.9 cm, slightly larger than the inside diameter of the core. The core holder contains four 1.5-mm-diameter holes in the corners, also for water escape.

For long cores, we also clamp on a cross-bar support (see "bottom support" in Fig. 1B) near the bottom of the core. The most important feature of this cross bar is the beveled end of each strut that fits precisely into the corners of the vegematic section to hold the biting end of the core securely in the center of the vegematic section.

The core holders can be inserted into any or all of the vegematic sections of the box core, depending on the number of samples required. The length of core needed to obtain the required sample depth depends on the depth of penetration of the box core. We usually mount both 13-cm- and 37-cm-long cores on the first deployment; the short cores

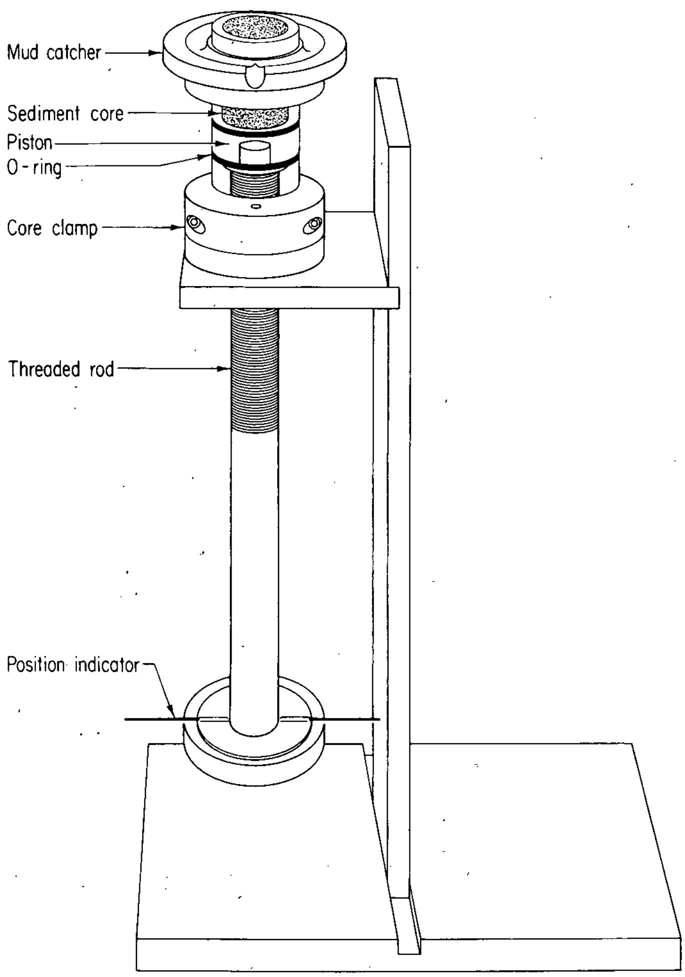


FIG. 2.—Drawing of the core extruder; see text for detailed description.

are preferable, to minimize sample processing time, if the box-core sample is deep enough. As each vegematic section of the box core is removed after sampling, the cores are capped on the bottom (by digging out the mud from below) before the core holder is removed. Thus far, we have successfully used this technique for obtaining fine-scale vertical sections of bottom sediments at depths between 80 m and 400 m along the southern California coast, where sediments ranged between almost entirely sand to almost entirely mud.

THE CORE EXTRUDER

The core extruder is shown in Figure 2. It consists of a stand and clamp to hold the core vertical, a tight-fitting piston which is pushed up by turning a threaded rod, and a "mud catcher" for washing the extruded sample into a collecting vessel. M. H. Bothner and M. C. Woodward provided valuable advice on the design and construction of the core extruder.

The piston is a clear-cast acrylic rod slightly smaller than the inside core diameter. O-rings are set in grooves near each end of the piston to ensure stability and a tight seal between the piston and the core. The piston is pushed up through the core by a threaded rod which turns freely in an indentation in the bottom of the piston. The rod is machined so that one complete turn pushes the piston up 2 mm. A pointer attached to a washer sits on top of the screw knob at the bottom of the rod to indicate the rod position. The pointer is free to rotate around the rod so that it can be zeroed when the sediment surface is flush with the top of the core; then the pointer is clamped in place so that it rotates with the screw knob. The rod threads through a tapped plastic collar which is mounted on the extruder stand. Attached to the tapped collar is another plastic collar that fits around the core and tightens with set screws to hold the core in place.

Near the top of the core is a polycarbonate mud catcher, which is donut shaped and fits snugly around the outside of the core. A tight seal, made by an o-ring set in a groove very close to the upper edge of the mud catcher, prevents any loss of the sample and also holds the ring in place. The mud catcher has a hollowed-out trough and spout to catch the sample. A thin (~1-mm-thick) but rigid sheet of aluminum, held vertically to minimize smearing of the sample, is used to slice the extruded sediment off the top of the core into the mud catcher. The sample is then washed down the spout of the mud catcher into a collection container.

This extruder was designed for the cores used in our field studies (see Butman and Grant 1986; Grant and Butman 1987) but is not limited to use on relatively small cores as are the more delicate, syringe-type extruders. The rugged construction of the screw assembly allows for precise, fine-scale sectioning even at sea. Virtually any core of reasonable size can be sectioned using this technique, as long as the piston fits tightly inside a sufficiently inflexible core tube.

CALIBRATION EXPERIMENTS

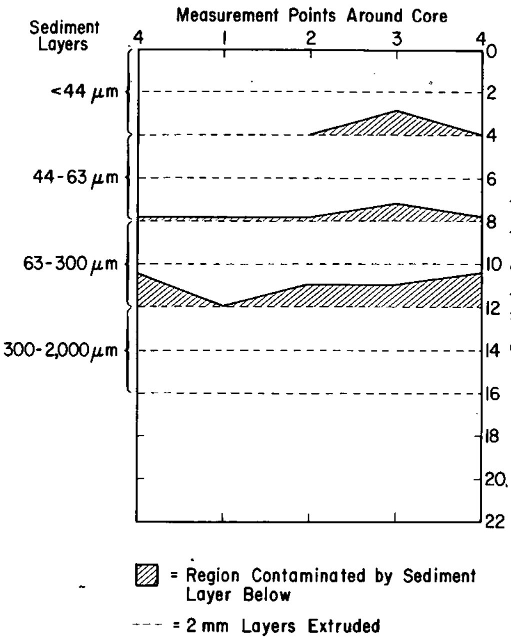
Calibration cores consisting of sediment layers increasing in grain size downcore were assembled and extruded in the laboratory in an attempt to define the precision of this core-extruding technique. The sediments were collected from the field (intertidally from Sippewissett Marsh, Massachusetts, in the first experiment and at 10-m depth from Buzzards Bay in all others), frozen at least overnight, thawed and wet-sieved through nested screens. Since there were no live animals to rework the sediments, and thus change the layering of the mud, these calibration cores indicate the maximum error introduced by the extruder itself (e.g., by smearing of the sample along the core wall) and by laboratory technique (sieving and layering).

Error introduced by our wet-sieving technique was estimated by resieving a subsample of each presieved size class of sediment for use as controls. Error introduced by our sediment-layering technique was estimated by measuring the height of each sediment layer at several points around the outside perimeter of the core, assuming that the interface between sediment layers, as viewed from the outside of the core, was representative of the sediment interface in the core interior (the validity of this assumption will be discussed later).

All sediment sieving was done very gently by the same individual, using prefiltered seawater (particles >5 μm were removed), and care was taken to minimize breakage of natural aggregates. This sieving technique was chosen for the grain-size analyses, as opposed to a more classical grain-size analysis technique (e.g., using a disaggregant, such as Calgon, and pipette analysis; see Folk 1980), because it would be used in subsequent applications of the core extruder for sediment-transport studies, to determine the size of natural particulates in the very surface sediments (i.e., in the "resuspendable" fraction; see Grant and Butman 1987). Sediments were sieved into the following fractions: <45, 45–63, 63–300, ≥ 300 μm (Expt. 1); and <20, 20–45, 45–63, 63–90, 90–180, 180–300, ≥ 300 μm (Expt. 2). The second set of sieve sizes was chosen to maintain an approximately constant fall-velocity interval; if the 45–63- and 63–90-μm-size classes are combined, then successively larger size classes represent about a four-fold increase in fall velocity, with the exception of the largest- and smallest-size-class intervals. The 63-μm sieve was used to divide the 45–90-μm classes in two, for comparative purposes, because 63 μm is the cutoff between silt and very fine sand.

In these experiments, the sediment fractions were added to the cores in layers ~4 mm thick, except for the bottom layer next to the piston, which was ~8 mm thick (to separate the analyzed sections from the piston). Each layer was carefully introduced by a pipette held just beneath the seawater surface. Generally each layer was allowed to settle several hours before adding the next layer, but in Experiment 2, each layer sat for only one hour before addition of the next sediment layer. In one experiment, a thin marker layer of white kaolin china clay was sprinkled on top of each layer to identify clearly the interface between layers. These marker layers were useful for qualitatively assessing the extent of smearing during the extrusion process, but they contaminated the sediment fractions by settling into pore spaces between all layers, so only results of Experiments 1 and 2 will be discussed quantitatively.

Before a core was extruded, it was photographed, and the depth of



Percent of Each Size Class (μm) Per 2mm Layer (Expected Percent Contamination)

<44	44-63	63-300	300-2000
99.6	0.4		
99.6	0.4 (15.0)		
23.6	69.0	7.4	
4.3	83.6	12.1 (17.5)	
0.9	1.3	96.9	0.8
0.4	0.4	53.9	45.3 (43.0)
0.1	0.1	20.4	79.4
0.1	0	2.8	97.0

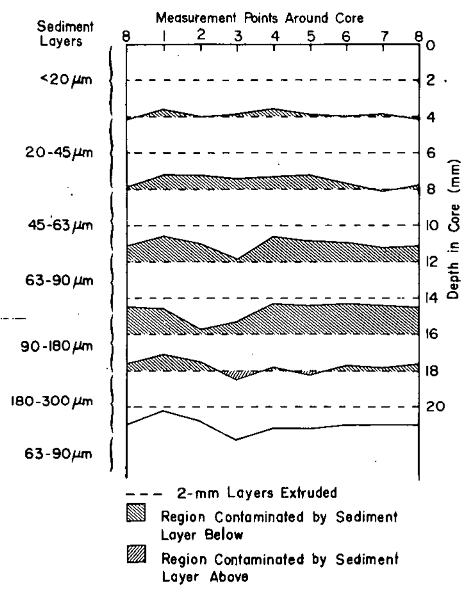
Percent of Each Size Class (μm) for "Control" Sediments

<44	44-63	63-300	300-2000	Control Sediments
99.7	0.3			<44 μm
2.4	95.2	2.4		44-63 μm
0.2	0.3	98.0	1.5	63-300 μm
0	0	0.6	99.4	300-2,000 μm

FIG. 3.—Results of the first calibration experiment, showing initial layering of sediments (left), grain-size distributions recovered in the extruded layers (middle), and grain-size distributions of the control sediments (right). The dashed lines in the diagram on the left indicate the 2-mm sectioning intervals. The shaded regions are the "expected percent contamination" of sediments within a given 2-mm interval by sediments in the layer below, as indicated by measurements of the layer interfaces around the core perimeter. The expected percent contamination (shown in parentheses under the appropriate grain-size class of the extruded sediments in the middle table) was calculated by unrolling the core perimeter into a rectangle of unit width and using simple geometric shapes to represent the contaminated regions. "Uncontaminated" horizons are those 2-mm sections which contain no shading.

each sediment layer was measured at several (four in Expt. 1, and eight in Expt. 2) points around the core to 0.5 mm (using a ruler in Expt. 1) or to 0.1 mm (using calipers in Expt. 2). The seawater above the sediments was removed by pipette before the sediment column was pushed up so that it was level with the top of the core. In these calibration cores, the sediment surface was flat, with irregularities on the order of tenths of millimeters. The core was extruded at 2-mm intervals. Sediments from each layer were gently washed, with 5-μm prefiltered seawater, through the same series of nested screens used to define the size class of the layers for that particular calibration core. The material on the sieves was either vacuum filtered onto preweighed 0.45-μm filters (when very small amounts of a size fraction were collected) and rinsed with distilled water, or was rinsed with distilled water into preweighed aluminum pans. The filters and pans were dried at ~60°C to a constant weight.

Results of the calibration experiments indicate very little error associated with the extruder itself. Since the screw that pushes the piston up the core was machined to an accuracy of greater than 0.001 mm, any inaccuracy in the layer thickness is due to the positioning of the pointer. The pointer can easily be returned to within 5° of its original position, which would result in a maximum error of about one percent for one complete turn of the screw (or 0.02 mm in a 2-mm section).



Percent of Each Size Class (μm) Per 2-mm Layer (Expected Percent Contamination)

<20	20-45	45-63	63-90	90-180	180-300	>300
98.5	1.5					
68.8	29.9 (6.5)	1.3				
9.8 (0.2)	87.1	3.1				
17.7	29.2	51.0 (25.6)	2.1			
6.1	11.0 (0.3)	67.9	15.1			
6.0	4.1	12.6	75.6 (50.0)	1.7		
9.0	3.7	6.6	43.2	36.7	0.9	
7.6	4.9	3.2	18.2	63.9 (65.9)	1.7	0.5
9.6	5.6	3.3	9.0	38.0	33.3 (13.1)	1.3
9.1	6.1	3.9	9.7	16.5 (2.5)	52.7	1.9

Percent of Each Size Class (μm) for "Control" Sediments

<20	20-45	45-63	63-90	90-180	180-300	>300	Control Sediments
97.9	2.1						<20 μm
5.1	92.1	2.8					20-45 μm
3.7	12.6	80.5	3.1				45-63 μm
3.1	3.0	11.7	79.6	2.6			63-90 μm
2.6	1.8	1.5	7.8	85.0	1.3		90-180 μm
6.5	5.6	4.6	5.1	11.6	62.1	4.4	180-300 μm

FIG. 4.—Results for the second calibration experiment; see caption to Figure 3 for explanation.

Virtually no smearing of the core was observed during the experiment where the white clay clearly marked the interface between layers. Furthermore, the mud catcher was effective in ensuring no loss of sample during collection of each extruded layer.

In general, there was excellent agreement in the size-class distributions of the initially layered and extruded sediments; the few large differences can be explained by imprecision in our sieving or layering techniques (refer to Figs. 3 and 4). The size-class distributions in the control sediments indicate the imprecision of our sieving technique. For the first calibration experiment, the error introduced by sieving was less than five percent (i.e., $\geq$95% of the extruded sediments consisted of the initially layered sieve-size class—the sediments were $\geq$95% "pure"). When sediments were separated into smaller-size classes (Expt. 2), the purity dropped to greater than or equal to 80 percent in all but the largest size class (where the purity was only 62%), roughly increasing with decreasing size class. This may reflect the breakdown of natural aggregates during processing. For Experiment 2, all extruded sediment layers and control sediments were refrozen after sectioning, then thawed and sieved several days later, whereas in Experiment 1, the sediments were not refrozen before sieving. Thus, it is possible that refreezing and thawing of sediments contributed to the breakdown of natural aggregates, resulting in lower purity for the larger-sediment-size classes.

The size-class distributions measured in the extruded sediments appear to reflect primarily the imprecision of our sieving technique (and not errors introduced by the extruder), because all size classes represented in control sediments for a given layer also were retrieved in the extruded sediments from that layer. In addition, there was excellent quantitative agreement between extruded fractions and control fractions in the ten layers which were not significantly "contaminated" (see caption to Fig. 3) by the sediment layer below (i.e., layers lacking a shaded region making up >2.5% of the area; see far left in Figs. 3 and 4); 77 percent of these extruded fractions agreed with the control fractions to $\pm$3 percent. Thus, imprecision in sieving as indicated by the control sediments, rather than smearing of the sample during extrusion, accounts for the extruded sediment grain-size distributions in all of the uncontaminated sediment layers.

The control sediment grain-size distributions probably also account for deviations between initially layered and extruded sediments in the contaminated layers; however, the accuracy of our estimated percent contamination of these layers (discussed below) limits the expected quantitative agreement between initially layered and extruded sediments. The expected contamination of each sediment layer by the layer below (shaded regions in far left and values in parentheses in middle of Figs. 3 and 4) indicates the imprecision of our layering technique, insofar as we were able to measure it. In fact, these are only crude estimates of the contamination expected, since we can visually measure the interface between layers only around the perimeter of the core; hence, the extent to which the uneven sediment surface extends to the core interior is unknown. Furthermore, the number of measurement points around the core perimeter limits the resolution of the contaminated sectors within the unit width rectangle used in calculations (see caption to Fig. 3). Given these limitations, it is encouraging that the size-class distribution in some extruded layers can be quantitatively explained by the expected percent contamination alone (e.g., see the 6–8- and 10–12-mm layers in Fig. 3 and the 14–16-mm layer in Fig. 4). In most cases, however, both the expected percent contamination and the percent sediment purity (as determined from the control sediments) are required to account for the observed contamination.

Any remaining disparity between the size-class distributions initially layered and those recovered after extrusion (the 2–4-, 6–8-, 10–12-, and 12–14-mm layers in Fig. 4) is most likely due to small sediments from above settling into pore spaces between the larger sediments below, thus obscuring the interface between sediment layers. Following Experiment 1, we tried to limit this problem by using smaller size-class intervals and to improve our detection of settling by measuring the layer thicknesses more accurately (i.e., with calipers) and at twice as many locations around the core perimeter. In fact, it is difficult to evaluate the effectiveness of these measures in Experiment 2 because of 1) the relatively large impurities of the layered size classes, as indicated in the control sediments; 2) the relatively short period (one hour, compared to several hours in Expt. 1) that each layer of sediment was allowed to settle initially before a smaller-size class was added on top; this may have actually enhanced the settling of small particles into larger pore spaces below, compared to Experiment 1; and 3) the smaller size-class intervals; it was much more difficult to distinguish the interface between two sediment layers.

There is an additional source of error associated with the extruding process, which is difficult to account for quantitatively, but which ultimately limits the vertical resolution afforded by a given sediment texture. This is the dragging of particles across the newly exposed sediment surface when a layer is sliced off the top. Even though we sought to minimize this problem by holding a thin piece of aluminum vertically so that contact between the solid surface and the sediment surface is minimal, it is inevitable that some particles gouge the sediments and can cause mixing as they are dragged across the exposed sediment surface. The maximum error introduced during slicing depends on the maximum particle size that could be dragged by the slicer and where these particles occur along the slicing face. For the 2-mm sediment layers extruded in the calibration experiments, which comprise sediment primarily between 20 and 300 μm, this slicing error ranges between 1 and 15 percent of the layer thickness for each layer interface. However, in field cores with randomly distributed, large, irregular particles such as shell hash, this could be a considerable problem, and we have periodically observed gouges up to 4 mm deep from shells being dragged across the sediments by the slicer. During processing of field cores, we carefully remove these large shells with forceps as soon as they appear during slicing. The problem may be eliminated altogether if slicing is accomplished by a razor-sharp blade (e.g., as used for microtome or rock slicing) that would sever rather than drag the shell hash or large-sediment particles.

SUMMARY

A simple technique for vertical sectioning of fresh sediment cores at scales of millimeters is described, calibrated in the laboratory and used to determine fine-scale stratigraphy of field cores taken by scuba divers or by subcoring a box core while it is taking a sample. The core extruder is specifically designed for studies of sediment-transport phenomena (i.e., to quantify grain-size and organism distributions in the very near-surface sediments), where relatively large-diameter-core samples are required. The core extruder provides vertical resolution in sediment horizons on the order of millimeters, the precision being limited by the maximum grain size at the interface between adjacent sediment layers. Thus, greater vertical resolution is possible in relatively homogeneous, fine-grained environments, which are free of shell hash. The calibration experiments were done for extreme stratigraphic conditions, where cores were layered with sediments increasing in grain size downcore, and thus, certain phenomena (e.g., the mixing of sediments at layer interfaces due to settling of small particles into large pore spaces below) may have been enhanced relative to a more realistic field situation. The extent to which the calibration experiments successfully defined the accuracy and precision of the extruding technique was limited primarily by our ability to measure the volume of the core initially layered by each grain-size fraction and by the imprecision in our sediment-grain-size analysis technique. There was no visual evidence of smearing during extrusion, and the quantitative results do not follow the contamination trends which would be predicted if significant smearing occurred. While it may be possible to reduce further the imprecision associated with the technical errors (e.g., by using X-radiographs to estimate the volume of each grain-size fraction initially layered in the cores), it is unlikely that any new information would be derived from further experiments to calibrate the cores, since nearly all deviations between the grain-size distributions of the initially layered and extruded sediments can be quantitatively explained by the sieving and layering error in these calibration experiments.

The precision associated with grain-size analyses by gentle wet sieving (without addition of a disaggregant) was about 95 percent as long as sediments were not frozen and thawed between sievings. This technique is not proposed to replace standard, well-accepted grain-size analyses (e.g., as in Folk 1980), nor do we suppose that it completely preserves the natural character of all aggregates collected. We have simply defined the precision of a simple technique which may be preferable for scientific questions where the size distribution of intact aggregates is more meaningful than the size distribution of completely disaggregated sediments. More sophisticated techniques for sizing natural aggregates (e.g., see Barth 1984) may eventually confer greater accuracy and precision; however, the most promising methods are still primarily in the developmental stage.

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