Geo-Marine Letters (1993) 13: 212–218

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Patterns and variability in sediment accumulation rates, Fraser River delta foreslope, British Columbia, Canada

Received 4 June 1993 / Revision received: 10 September 1993

Abstract Minimum sediment accumulation rates on the Fraser River delta foreslope exhibit a high degree of spatial variation, with accumulation rates ranging from 0.50 to 3.0 cm/yr. Accumulation rates generally increase towards Sand Heads channel, the active foreslope depocenter. Sedimentation rates and patterns and micropaleontological assemblages are interpreted to reflect reintroduction of older sediment from upslope via slumping and sediment-gravity flow processes. Such processes account for the bulk of sedimentation in much of the subaqueous delta. These processes provide a mechanism for sand bypassing of the delta plain and foreslope and for delivery of coarse-grained sediment directly to prodelta and basinal environments.

Introduction

Minimum sediment accumulation rates have been calculated for selected piston cores collected from the Fraser River delta foreslope during a 1989 research cruise of the *CSS Vector*. In addition, a qualitative assessment of sediment remobilization has been determined through analysis of micropaleontologic assemblages from cored sediment. Specific objectives of this study were to present a first approximation of the sources, rates, and patterns of sedimentation on the delta slope and to analyze their implications for sediment stability conditions.

Previous studies have focused on the subaerially exposed portion of the delta, on Holocene accretion of the delta (Clague et al. 1991; Hart et al. 1992), and on diurnal to annual fluctuations in sediment dynamics. This study focuses on patterns and variations in sediment accumulation rates over the 36-year period from 1953 to 1989, as determined from cesium-137 profiles. These results shed light on identifying and predicting the specific mechanisms and frequency of sedimentation events on this and other subaqueous deltaic environments.

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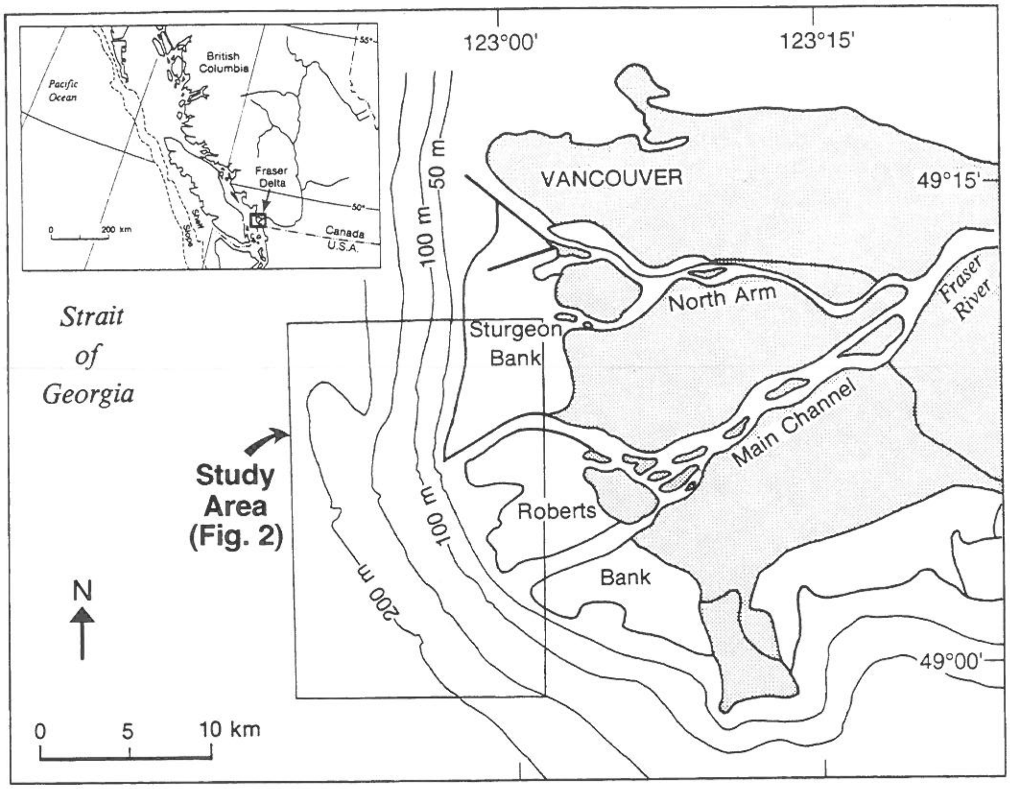
Geologic setting

The Fraser River delta, offshore Vancouver, British Columbia, is the largest delta on Canada's Pacific coast (Fig. 1). The Fraser River drains approximately 250,000 km^2 of mountainous terrain with peak discharge during the snowmelt freshet in late spring and early summer (Milliman 1980). Within the Fraser River estuary, a pronounced tidal influence is superimposed on the fluvial regime; semidiurnal tides at the river mouth can approach 5 m (Kostaschuk et al. 1989). Tidal range within the estuary decreases upstream and with increasing discharge, and, in conjunction with fluvial discharge, produces a pronounced salt wedge that strongly affects local sedimentation rates and mechanics (Kostaschuk and Luternauer 1989).

The Fraser River delta plain consists of a series of broad tidal flats up to 9 km wide with average slopes of less than 0.1°. The delta foreslope extends a further 5–10 km seaward at an average slope of 1.5°. The study area consists of 150 km^2 in the delta foreslope (Fig. 2). Water depths in the study area range from less than 50 m to greater than 250 m. Average gradient of the slope in the study area is approximately 3.0°, but locally exceeds 6°.

Several submarine channels dissect the delta foreslope. These channels have up to 10 m relief and extend from the seaward terminus of the tidal flats or distributary mouth, to water depths in excess of 200 m (Fig. 2). The largest, and currently active, of these is the Sand Heads channel.

Fig. 1. Study area location map. Area enclosed within rectangular box is detailed in Fig. 2. (Modified from Moslow et al. 1991; Kostaschuk et al. 1992)



Data base and methodology

Cesium-137 is a radiogenic isotope produced as a by-product of the testing of nuclear weapons. Global distribution of ^{137}Cs in surface sediments represents fallout from atmospheric testing. Vertical accretion rates of undisturbed recent sediments worldwide can be calculated based on the first appearance and maximum concentration of ^{137}Cs in recent sediments.

Detailed sedimentologic descriptions show that the cored intervals used in this study are essentially non-burrowed (Moslow et al. 1991). The assumptions made in calculating sediment accumulation rates in this study were thus: (1) first appearance of ^{137}Cs represents the initiation of widespread atmospheric testing in 1954, and (2) tailing effects of relatively low concentrations due to bioturbation are negligible in the cores selected.

Five piston cores collected during this investigation were selected for analysis (Fig. 2). The sites chosen represent a variety of different subenvironments believed to reflect the probable range of sedimentary processes and sedimentation rates in the area. Sedimentary characteristics of these cores are summarized as Table 1. Both the main cores and their trigger cores were logged to ensure that reduction of the section due to coring was minimal.

The cores were sampled continuously across 5- to 10-cm intervals and analyzed for ^{137}Cs content. With the exception of core VEC89A-03, all cores were sampled and counted from the sediment–water interface until at least one barren core increment that was not sand-rich was encountered. This ensured that the cores were sampled through the first appearance of ^{137}Cs. This provides a quick and simple method to determine the maximum depth to which ^{137}Cs is present. As sample intervals exceed annual sedimentation rates, only minimum sediment accumulation rates can be calculated. Cesium analyses for this study were conducted at the Saskatchewan Institute of Pedology, University of Saskatchewan, following the methodology of DeJong et al. (1982).

A total of 28 subsamples were taken from four piston cores (Fig. 2). Arcellacean and foraminifera populations from the sampled intervals were isolated, identified, and counted. The total number of specimens recovered in 19 of the 28 samples collected was too low to place statistical significance on the population counts; however, samples that contain limited populations are of qualitative value where allochthonous specimens from radically different environments are present.

Sediment accumulation rates

Core VEC89A-03 was collected along the flank of the Sand Heads channel (Fig. 2). Counting was originally stopped at the 75- to 80-cm interval because only trace ^{137}Cs was noted (Fig. 3, VEC89A-03). Based on subsequent experience with coarser-grained intervals, the remaining samples were counted; all contained significant concentrations of ^{137}Cs. The trace interval at 75–80 cm has subsequently been found to be composed predominantly of well-rounded quartz grains with minor mafic rock fragments

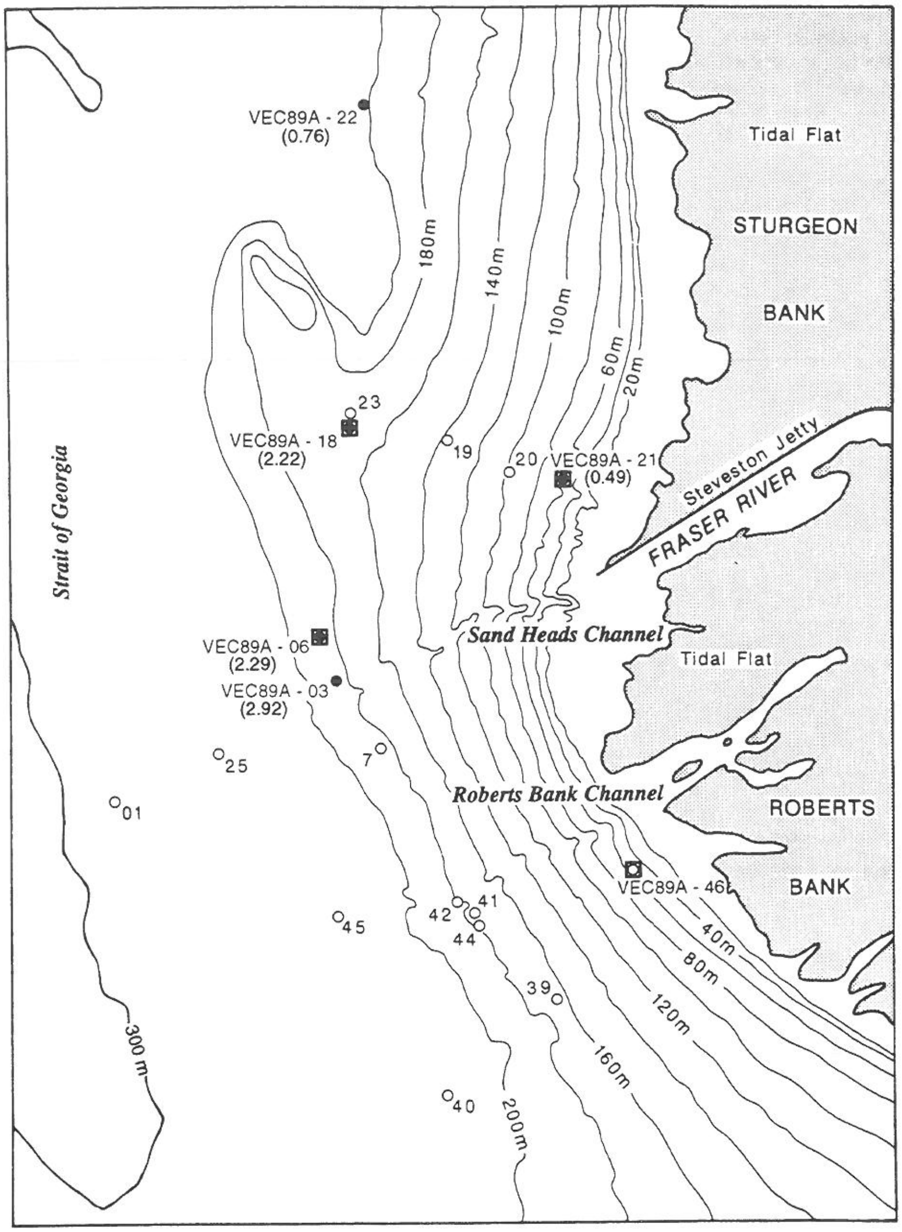


Fig. 2. Detailed bathymetry and piston core locations (open circles) in the study area. Piston core sites with ^{137}Cs data available are represented by closed circles; open squares represent sites with micropaleontologic data

Table 1. Summary of sedimentary characteristics and minimum sediment accumulation rates

Piston core	Length (cm)	Sampling depth (cm)	Sedimentary characteristics	Accumulation rates (cm/yr)
VEC89A-03	220	105	flank of the Sand Heads channel, two coarsening/thickening upward cycles, graded fine to medium-grained sands, wavy and lenticular bedding, containing rafted organics and clay–silt interbeds	>2.92
VEC89A-06	106	90	800 m north of VEC89A-03, poorly defined fining upward cycle, primarily massive silty clay/clayey silt, thin, silty, very fine to fine-grained sands with graded bases and abrupt tops	2.29
VEC89A-18	381	220	dense, compacted, black clayey silt, few shell fragments and minor disseminated organic matter	2.22
VEC89A-21	423	25	onshore background, massive silty clay, rare silty laminations	0.49
VEC89A-22	510	35	offshore background, structureless silty clay to clayey silt, rare silty lamination, minor rafted organic debris	0.76

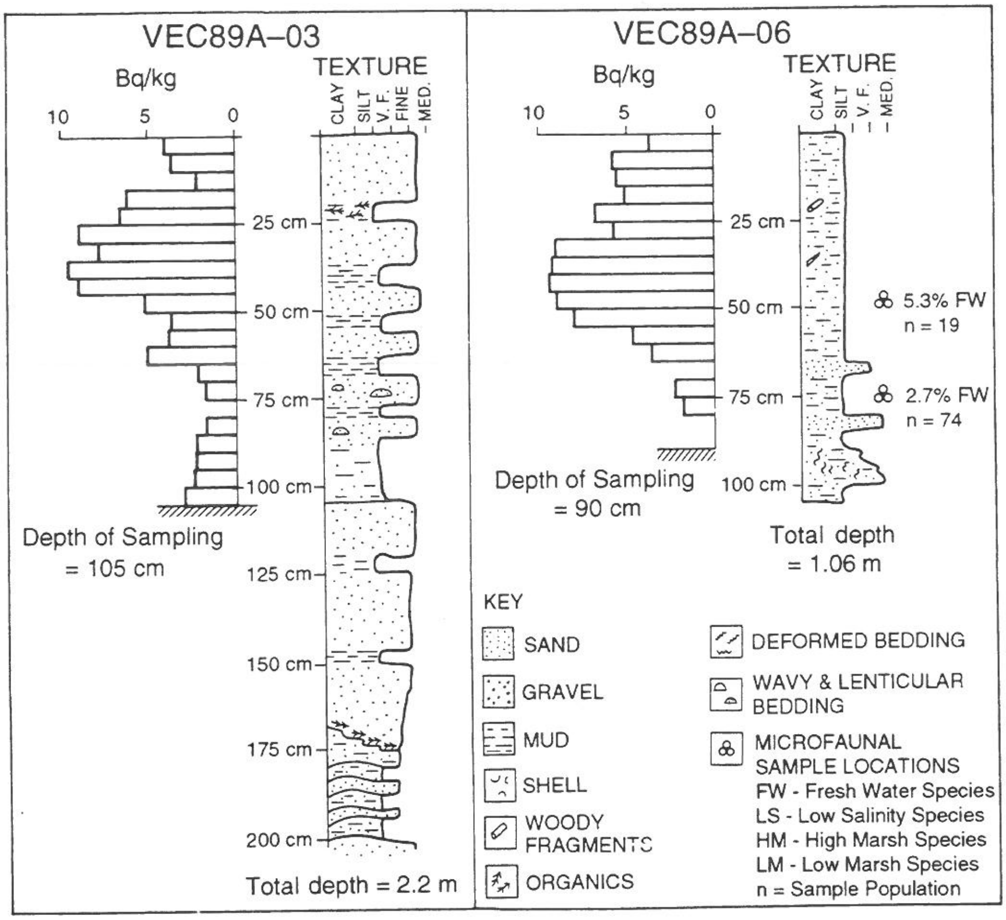


Fig. 3. Sedimentologic logs and ^{137}Cs sediment profiles for piston cores VEC89A-03 (left) and VEC89A-06 (right) with allochthonous micropaleontologic species distribution

and lesser feldspar and mica; clay minerals are virtually absent. Other intervals of similar characteristics commonly show a suppression of ^{137}Cs values. Accumulation of 105 cm of sediment between 1954 and 1989 requires a minimum sedimentation rate of 2.92 cm/yr.

The base of detectable ^{137}Cs concentration in core VEC89A-06 occurs at a depth of 80 or 85cm (Fig. 3). The reason for this uncertainty is that the barren interval at 80–85 cm is predominantly fine quartz sand. Minimum accumulation rate for the interval is 2.29 cm/yr.

Core VEC89A-18 was subsampled for ^{137}Cs analysis across 10-cm intervals (Fig. 4, left). Base of measurable ^{137}Cs concentration occurs at a depth of 80 cm. Minimum accumulation rate is 2.22 cm/yr. Core VEC89A-21 (Fig. 4, right) represents an onshore background value for the area. Minimum sedimentation rate for the period 1954–1989 is 0.49 cm/yr and represents the lowest accumulation rate in the study area. Core VEC89A-22 (Fig. 5) represents an offshore background value for the area. Minimum sedimentation rate for the period 1954–1989 is 0.76 cm/yr.

Distribution of micropaleontologic populations

Foraminiferal fauna recovered from all samples are predominantly species common in neritic depth waters in the Strait of Georgia (Cockbain 1963), and along the coast of British Columbia (Patterson 1993). Allochthonous foraminiferal species in the sample set include *Ammobaculites foliaceous*, *Jadammina macrescens*, and *Miliammina fusca*. *J. macrescens* is almost exclusively restricted to the high marsh zone, with only a minor percentage in the low marsh environment; very few get washed out onto the tidal flats of the Fraser delta (Patterson 1990). *A. foliaceous* and *M. fusca* are characteristic of the low marsh and are rarely transported out onto the tidal flat sands.

Arcellaceans are generally restricted to freshwater environments in lakes or above highest tide in salt marshes (Patterson et al. 1985). One exception, *Centropyxis aculeata*, is capable of withstanding very low salinity concentrations on the order of 1–2% and is often found in the highest portions of salt marshes where there is limited incursion of brackish water. *C. arculeata* was encountered in cores VEC89A-21 (Fig. 4, right) and VEC89A-46 (Fig. 6). Other arcellacean species (*Centropyxis constricta*, *Difflugia oblonga*, and *Difflugia urceolata*) were found in samples from all cores examined.

Disscussion

Sediment accumulation rates calculated for cores from the Fraser delta foreslope exhibit a wide degree of variation

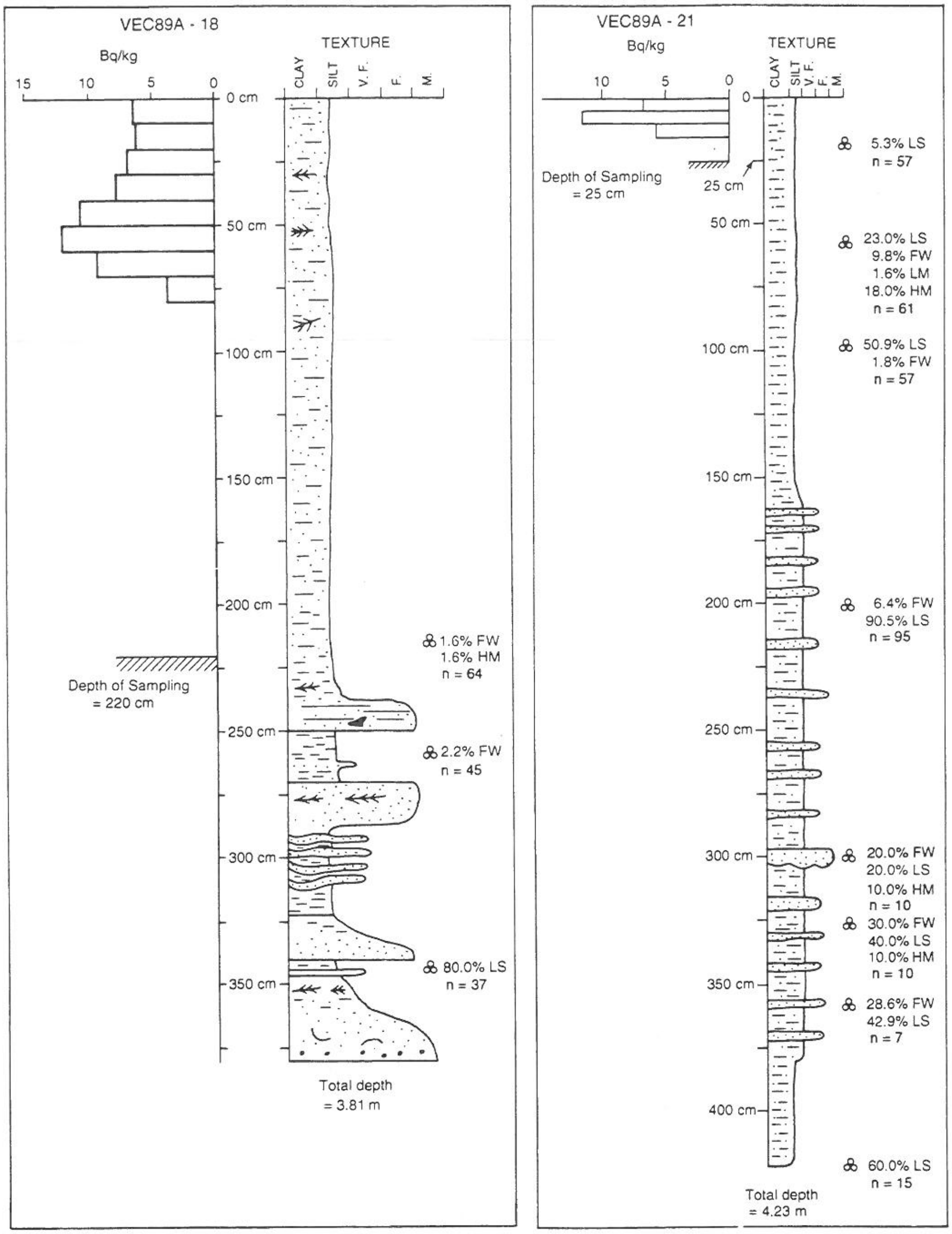


Fig. 4. Sedimentologic log for piston cores VEC89A-18 (left) and VEC89A-21 (right) with ^{137}Cs sediment profiles and allochthonous micropaleontologic species distribution

among locations. This trend becomes more pronounced in the vicinity of the Sand Heads channel. The general spatial pattern evident in the data set shows that accumulation rates increase towards the Sand Heads channel (Fig. 7).

Piston core VEC89A-03 represents a thick channelized sequence (Table 1) and reflects the highest sedimentation rates in the study area. The Sand Heads channel is the active depocenter for the Fraser Delta, and greater accumulation rates might therefore be anticipated. The base of ^{137}Cs accumulation was not sampled in this interval; as a consequence the accumulation rates may be significantly greater than those calculated. The top of the interval may also have been lost due to flowage of unconsolidated sand out of the core barrel or reduced by erosion. Evidence in support of erosional reduction of the sedimentary record includes the documentation of large-scale sediment-gravity flows that have moved up to 1,000,000 m^3 of sediment in a single event approximately 5 km up-channel from the core site (McKenna et al. 1992; Kostaschuk et al. 1992).

An increase in ^{137}Cs concentration in the upper two sample increments of the core is atypical of sediment profiles in the Fraser River delta. This is interpreted to represent the reintroduction of slightly older sediment from upslope via sediment-gravity flow processes. Further evidence in support of the reintroduction and remobilization of sediments in the Fraser River delta area is the presence of abundant allochthonous foraminifera and arcellacean populations in other piston cores collected in this vicinity.

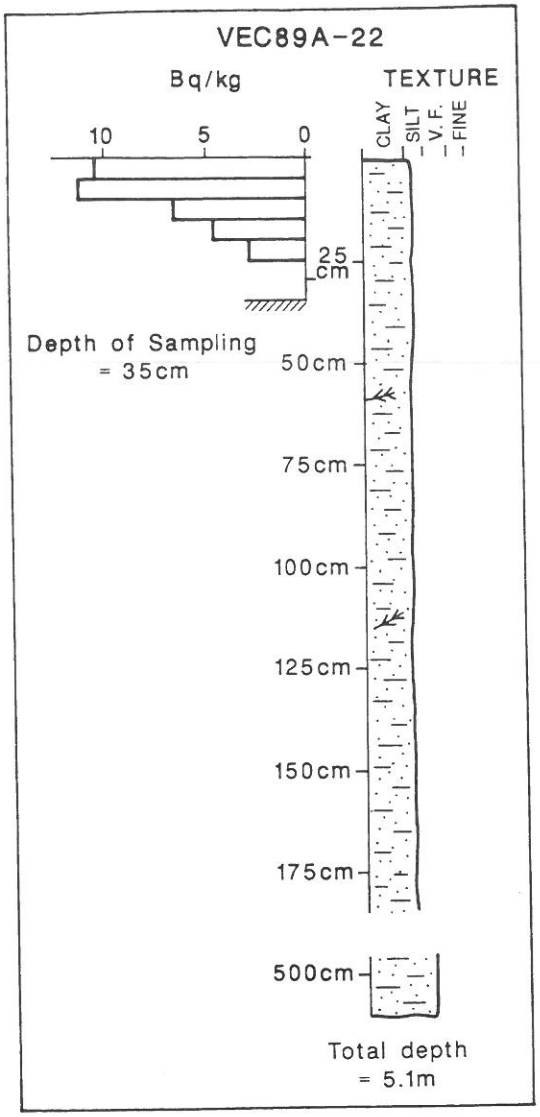


Fig. 5. Sedimentologic log for piston core VEC89A-22 with ^{137}Cs sediment profiles

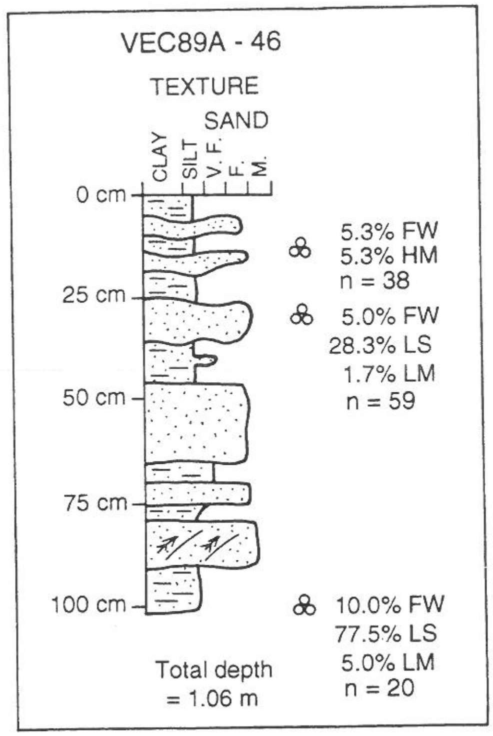


Fig. 6. Sedimentologic log for piston core VEC89A-46 with allochthonous micropaleontologic species distribution

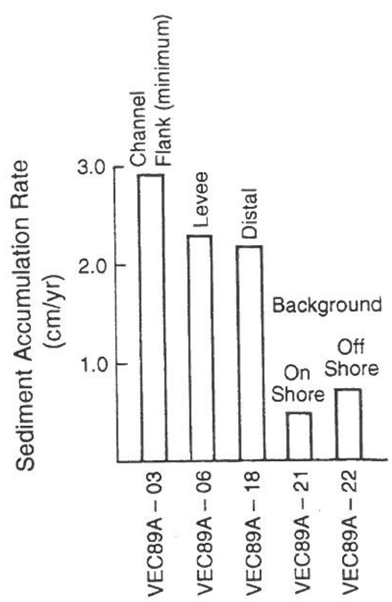


Fig. 7. Histogram plotting variation in sediment accumulation rates from selected sites on the Fraser River delta through the period 1954–1989. Note overall decrease in sediment accumulation rates laterally away from the Sand Heads channel

The most significant concentration of arcellaceans encountered is the interval at 200 cm in VEC89A-21. Greater than 90% of the microfaunal population is comprised of *C. aculeata*, and 92 of the 95 specimens collected were arcellaceans. The overwhelming predominance of arcellaceans suggests that samples hosting these specimens moved downslope relatively intact, picking up only a few foraminifera en route, and cannot be accounted for by simple accidental transport of a few specimens downslope due to tidal current action.

Previous attempts to determine short-term rates of vertical accretion in the Fraser delta have been based on comparisons of historic sounding data and hypsographic curves (Johnston 1921; Mathews and Shepard 1962; Stewart and Tassone 1989). Mathews and Shepard (1962) calculated a vertical accretion rate in excess of 33 cm/yr adjacent to the Sand Heads channel. At our closest sample site to this area, VEC89A-03, we have calculated a minimum sediment accumulation rate of 2.9 cm/yr. Although the margin for error using historic sounding data is significant, we note that there has been an appreciable culturally mediated decrease in net bed load discharge at Sand Heads over recent years as a result of increased dredging activity.

McLean and Tassone (1991) estimate that the average bed material outflow during the period 1974–1983 was less than one third that of the preceding decade. Williams and Roberts (1989), based on radiocarbon dating, have estimated the mean vertical accretion rate over the past 2000 years at 0.12 mm/yr.

Conclusions

Sediment accumulation rates on the Fraser delta foreslope generally increase towards the Sand Heads channel. This appears to be a function of proximity and suggests that the channel is not only an erosional feature, but a depocenter as well. Accumulation rates along the flank of the channel indicate a minimum accumulation rate of 2.92 cm/yr, but the actual sedimentation rate in this area may be significantly greater.

The identification of large scale slope failures at the mouth of the Sand Heads channel, increased ^{137}Cs concentration in the upper sample increments of site VEC89A-03, and the presence of abundant allochthonous microfauna in piston cores from the study area all document evidence for remobilization of sediments in the Fraser River delta. Regional distribution patterns and detailed sedimentary characteristics do not appear to be compatible with storm-related erosion and emplacement. These results suggest that slumping and sediment-gravity flow processes may account for the bulk of sedimentation in the Fraser delta foreslope and likely in the subaqueous environments of other deltas. These processes provide a mechanism for sand bypassing the delta plain and foreslope and delivery of coarse-grained sediment directly to the prodelta environment.

Acknowledgments Funding for this study was provided by EMR and NSERC grants to T.F.M. and R.W.E. (Research Agreement No. 034492), and NSERC Operating Grants to T.F.M. and R.T.P.

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