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Effects of a Major Dredging Program on the Sedimentary Environment of Miramichi Bay, New Brunswick

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by

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ABSTRACT

Kranck, K. and T.G. Milligan. 1989. Effects of a major dredging program on the sedimentary environment of Miramichi Bay, New Brunswick. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 112: iv + 61 pp.

Comparison between the natural sedimentary environment and the sediment distribution after the dredging of 6.3 million m^3 of sediment from the central navigation channel of Miramichi Estuary with a trailing hopper dredge demonstrates the behaviour and fate of the dredge spoils. Nearly three quarters of the weight of material pumped into the hopper was spilled into the surrounding water with the dredge overflow. Initially the lost sediment dispersed over much of the bay but within less than a year after the end of the principal portion of the dredging the overflowed sediment had become concentrated in the vicinity of the turbidity maximum as a low density bottom deposit. The material dumped on the major dumpsite was reduced in volume by compaction or erosion to about one quarter of its original amount by volume.

RÉSUMÉ

Kranck, K. and T.G. Milligan. 1989. Effects of a major dredging program on the sedimentary environment of Miramichi Bay, New Brunswick. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 112: iv + 61 pp.

Une comparaison du milieu sédimentaire naturel et de la répartition des sédiments après dragage de 6,3 millions de m^3 de sédiments à la drague suceuse porteuse dans le chenal central de navigation de l'estuaire de la Miramichi, illustre le comportement et le devenir des déblais de dragage. En poids, près des trois quarts des matériaux pompés dans le puits à déblais étaient rejetés dans les eaux avoisinantes avec l'eau évacuée. Initialement, les sédiments perdus se dispersaient sur une bonne partie de la baie, mais moins d'un an après la fin de la portion principale des travaux de dragage les sédiments rejetés s'étaient concentrés aux environs du maximum de turbidité sous forme de dépôt de fond de faible densité. Le volume des matériaux déversés au principal emplacement de déversement avait été réduit du quart par compaction et érosion.

Table of Contents

LIST OF TABLES

1. INTRODUCTION

The Miramichi Estuary is a large, shallow, barrier bar estuary on the Gulf of St Lawrence coast of New Brunswick (Fig. 1). The bay is an important centre for lobster, herring, salmon and smelt fisheries. The other major economic activities within the bay are centered in the towns of Newcastle and Chatham, the sites of several forest products industries as well as shipping terminals for iron ore, oil and construction materials.

Until recently, shipping through the bay used a channel of 5 metre draft which was largely natural and had required very little maintenance since 1939. In 1981-83 a major dredging program was undertaken and the channel was deepened to 7.6 metres (Philpott, 1978). 6.16 million metric tons of dredge spoils (scow measured volume) were disposed of at three designated dumpsites, (Fig.2) (MacLaren Plansearch Ltd., 1985). This report discusses the impact of the dredging program on the marine environment and the apparent long term fate of bottom sediment dislodged to deepen the shipping channel.

The study is based largely on sediment samples collected during two sediment studies. In September and October, 1973, as part of a study of suspended sediment dynamics and flocculation mechanisms associated with the fresh-salt water transition of an estuary, bottom and suspended sediment samples were collected throughout Miramichi Bay (Kranck, 1981). These data in conjunction with other existing sedimentological information and relevant physical oceanographic data are used to describe the natural sediment regime of the Bay. In 1983 a study of bottom stability and sediment movement associated with the channel dredging activities was initiated. The study was partly sponsored by the Ocean Dumping Research Fund of the Department of Environment. Most of the field work was carried out under contract with Geomarine Associates Ltd., N.S. Additional data were collected in 1983 and 1984 by the Coastal Oceanography Division, Bedford Institute of Oceanography. Based on comparison between the pre-dredging and the post-dredging information the effects of a major dredging program carried out in a relatively pristine marine environment are evaluated.

2. PREVIOUS WORK

Miramichi Bay is one of the most intensively studied bodies of water on the Canadian East coast. Early work included research on water movement, fauna and sediments. Chalmers (1888, 1894) described Pleistocene deposits of marine and fresh water alluvium along the shores of the Miramichi. Fothergill (1953) surveyed tidal currents in the Miramichi and Bousfield (1955) in a comprehensive study of the Bay described the temperature and salinity distribution and current patterns as well as a map of surficial bottom sediments of the outer bay. The river runoff and fresh water sediment load in the Miramichi River was described by Ambler (1976), Krauel (1975) and Krauel and Birch (1979). Vilks and Krauel (1982) discuss the physical oceanography based on modern current metre surveys and modeling techniques. Recent sediment related studies of the Bay include work on foraminiferal stratigraphy (Schafer and Smith, 1983), geochemistry, (Rashid and Reinson, 1979; Buckley and Winters, 1983), suspended sediment (Winters, 1981 and Kranck, 1981) and bottom sediments (Reinson, 1976).

From 1975 on, much of the work was inspired by environmental and engineering considerations for the proposed Miramichi Channel Study. Philpott (1978) has summarized the numerous studies completed prior to the commencement of the channel modification. During and after the dredging, monitoring of the environmental effects of the dredging and dredge spoil dumping was carried out by Maclaren Plansearch on contract to the Department of Public Works, Canada. The results are in interim reports and summarized in MacLaren Plansearch, (1985).

3. PHYSICAL ENVIRONMENT

3.1 Geographical Setting

Miramichi Bay is the largest of many river estuaries bounded by the system of sand barriers running along the eastern coast of New Brunswick (Fig 1). The Miramichi River and several smaller rivers drain into the Bay from a total drainage area of about 13,000 square kilometres. Miramichi Bay may be subdivided into three parts (Fig 2): The Outer Bay is the portion outside the barrier bars which is open to the Gulf of St. Lawrence and at its outermost edge has depths down to 60 metres. The Inner Bay lies between the barrier system and the narrow river channel. Most of the Inner Bay is relatively shallow with depths between 2 and 8 metres. The 5 to 6 metre shipping channel runs through the middle. At the shoreward end of the Inner Bay depths increase to 10 metres at the mouth of the Miramichi River. The deep channel between the Inner Bay and the town of Newcastle referred to as the River Channel in this report, is 10 m deep in many areas and is subjected to tidal effects of up to 1.75 m range at Newcastle. It forms an integral part of the Miramichi estuarine system.

3.2 Underlying Sediment

The Bay lies within the New Brunswick Lowland Physiographic Province (Rampton et. al., 1984) which is underlain mainly by relatively flat Pennsylvanian sandstone with minor siltstone and conglomerates. Late Wisconsin morainal sediment consisting of sandy, gravelly and boulder tills form the surficial sediment of the land draining into Miramichi Estuary. Only the Bay itself and the lands close to the coast are underlain by younger Wisconsin and early Holocene marine sediments, mainly sand and silt, with minor mud and clay deposited by the late Pleistocene inundation of the coastal lands by the Goldthwait Sea. The barrier islands at the mouth of the Inner Bay have formed from Holocene and recent sands.

3.3 Physical Oceanography

According to Vilks and Krauel (1982) as well as earlier studies, the river channel portion of the estuary conforms to a salt wedge estuary during high river discharge conditions and alters to a highly stratified two layer flow system during low inflow conditions. The Inner Bay on the other hand is slightly stratified to well mixed. The vertical dependence of residual currents appears to follow a typical estuarine circulation with a seaward flow at the surface and a landward flow along the bottom.

Maximum salinity intrusion extends over 40 km up the river estuary as far as Newcastle, and tidal effects beyond. During high river discharge the salt water is almost expelled from the river portion of the estuary. Varying fresh water inflow causes a change in the lateral salinity gradient in the Inner Bay. During low inflow, lower salinity water occurs to the right of the ebb flow, while under high inflows low salinity water occurs to the left of the ebb flows (Fig. 3). Under low discharge conditions the normal tidal circulation is cyclonic. When the momentum of the discharge from the river becomes more important than the Coriolis force this effect is suppressed and the fresh water jets out along the north side of the Inner Bay.

The Outer Bay is dominated by a coastally confined southerly longshore residual flow along the coast which is partly responsible for maintaining the sand barriers and beach system. The Outer Bay is subject to considerably more wave and wind action than the relatively protected Inner Bay.

4. METHODS

4.1 Field Observations

A Van Veen type grab was used to sample the bottom sediment. Sediment cores were collected with a gravity corer. Water samples for suspended sediment determinations were collected using Niskin bottles. The bottles were shaken on deck prior to being subsampled and the water samples placed in plastic bottles for later processing. During the pre-dredging survey light attenuance measurements were made using an optical beam attenuance metre calibrated against total concentration of suspended particulate matter (Larsen, 1984). Water temperature and salinity were measured with a Beckman RS-5 induction salinometer and a Guildline conductivity, temperature and pressure (CTD) profiling system. An Ott Arkansas current metre was used to measure current.

4.2 Laboratory Analysis

A Model T or TA2 Coulter counter was used for particle size analysis of the bottom and suspended sediment samples following the methods of Kranck and Milligan (1979). To remove organic matter the bottom sediment samples were oxidized by boiling in hydrogen peroxide or ashing in a low temperature asher. Pre-treatment for analysis of suspended sediment consisted of filtering a known volume of water through a Millipore membrane filter and ashing the filter in a low temperature asher. In some analyses the residue was also boiled in hydrogen peroxide.

The samples were suspended in filtered 3 percent NaCl solution or, in the case of coarse bottom samples, in a 30 percent glycerine and 1 percent NaCl mixture. Aggregates were dispersed using a sapphire tipped ultrasonic probe. Suspensions were kept sufficiently dilute to avoid coincidence errors. Each sample was counted with a minimum of three different orifice tubes. This gave a series of overlapping distributions which were edited so as to produce size distributions or spectra for the single grain, disaggregated particles between about 2 and 400 µm.

The results of particle size analysis are plotted as frequency distributions or frequency spectra of volume vs. diameter. Particle diameter is always plotted on a log scale along the abscissa. The ordinate presents particle volume plotted either on logarithmic or arithmetic scales. The semi-logarithmic spectra show equal volumes as equal areas under curves whereas log-log plotted spectra emphasize similarity in relative distributions over a limited size range in different spectra. Bottom sediment results are presented as percent of total sediment volume analyzed and suspended sediment results as particle volume relative to total sample volume (ppm).

A model developed to explain the genesis of grain size characteristics of sediments is used to interpret the sediment size analysis (Kranck and Milligan, 1985). The model assumes that sediment transport and hydrodynamic sorting produce size distributions which are characterized by equations of the form:

$$C=QD^{m}e^{-K\alpha D^{2}n} \tag{1}$$

where C is the volume concentration of class, Q is the Y axis intercept, D the diameter in μm and m a source slope coefficient which varies for different source areas and usually has a value close to 0. n defines the number of times a sediment has been resuspended and redeposited and α includes all the terms in Stokes' law other than diameter so that is equal to particle settling rate giving K the dimensions of inverse settling rate. K represents the balance between gravitational settling and the maintenance of particles in suspension by turbulence and can be related to shear velocity. When the two are in equilibrium, i.e. there is a steady state balance between turbulent diffusion and gravitational settling, K defines a maximum possible particle size distribution (critical size) which will be maintained in suspension. In a bottom sediment K is related to the energy conditions which have deposited the sediment at some time in the past. Equation 1 can also be used to describe the portion of a sediment deposited as part of flocs. Since each floc contains a proportion of all categories of fine material in the suspension floc settling occurs without any sediment sorting, resulting in deposition of a sediment with the same size spectra as the parent suspension. Most natural sediment populations contain some proportion of both components; a coarse grain settled mode and an unsorted finer floc population. Typically the proportion of floc deposited material increases with decrease in grain size.

By using standard curve fitting techniques and by making certain assumptions about the sediment, the variables in this model may be evaluated from the observed sediment size spectra and the relative amounts of floc and grain settled material may be calculated (Fig. 4). In this study the only variable used is K, the variable dependent on transport energy of the depositional environment. K has the units of time/distance i.e. the inverse of velocity, and it can be shown that if the values of m and n are sufficiently high, K is equal to the inverse of the modal settling rate of the particles making up the size distribution. This relationship establishes a dependency between the energy regime and the most abundant particle size, justifying the use of modal size as a measure of characteristic dynamic size of a distribution.

5. NORMAL SEDIMENTATION REGIME

The 1973 field program, sampling the normal, pre-dredging sedimentary conditions in Miramichi Estuary, consisted principally of a network of bottom samples from throughout the Bay and a series of suspended sediment samples collected from a line of stations along the centre of the Bay (Fig. 1).

5.1 Bottom Sediment

The bottom sample stations were located on a grid with approximately 3 km between stations (Fig. 1). Samples were also obtained from the stations along the central line. These samples were supplemented by a series of samples from the Miramichi Channel Study (Philpott, 1978), situated on a 2 km grid spacing. The resulting bottom sediment distribution (Fig. 5) agreed in general with Bousfield's (1955) earlier map, the first published description of bottom sediment in the Bay. Sand bottom dominated the outer portion of Inner Bay and outside the barrier bar (Reinson, 1977). The inner central portion of Inner Bay consisted of fine mud which coarsened towards the coasts and the outer portion of the Inner Bay. The bottom sediment in the channel portion of the estuary consisted of a heterogeneous mixture of sand and mud.

Grain size analysis showed modal sizes ranging from 12 to 200 μm (Fig 5.). From semi-log plotted size spectra for samples from the central line of stations it can be seen that the sediment conforms to the typical pattern of mixed single grain and floc deposited sediment (Fig 6). The sand samples consisted predominantly of clean well sorted material which formed a sharp symmetrical peak but all sand samples contained some floc deposited mud. This fine tail becomes progressively more prominent with decrease in modal size, and in the muddiest samples no single grain deposited modal peak occurred. In the central channel the sediment was occasionally bimodal, indicating fluctuation in depositional conditions. A compound plot of the bottom sediments collected from throughout the Inner Bay demonstrates the similarity in the slope of the fine grained floc settled tail portion of the spectra (Fig. 7). There is an apparent lack of samples with modal sizes around 100 µm, resulting from a break at the boundary of suspended sediment transport and bedload transport.

The value of K was estimated for each of the Inner Bay samples by assuming that the grains represented by the coarse end of each size spectrum were deposited only as single grains. The relationship between K and an average current velocity derived for each station from a two dimensional mathematical model of the Bay (Krauel and Birch, 1979) demonstrates a close relationship between sediment texture and current energy (Fig. 8) and indicates that sedimentation within the Bay is closely controlled by present tidal current dynamics.

The action of currents is also apparent in the distribution of modal grain sizes (Fig. 5). The zone of fine mud with less than 50 µm modal size is situated in the zone of lowest current energy in the Bay, between the region of high tidal currents around the openings in the sand barrier bar and the river channel characterized by strong estuarine flows. Net sediment transport paths, inferred from the contour pattern of sediment modal sizes by assuming transport in direction of decreasing grain size and perpendicular to the concavity of the contours, show an anti-clockwise pattern (Fig. 5). This conforms with the cyclonic circulation in the Bay and indicates that the low river inflow conditions, prevailing over most of the year, control the long term sedimentation rather than the more transient high flow events (Vilks and Krauel, 1982).

5.2 Suspended sediment

During the pre-dredging study each suspended sediment station along the central line was sampled at least twice. Each station was sampled as part of a series during which more than half of the stations were sampled consecutively on the same day. Spot samples were also taken from these stations whenever possible to give a more random distribution to the central line data. Three stations (P, K, and A) were sampled over a complete 13-hour tidal cycle from an anchored vessel (Fig.1). Samples were collected from one metre below the surface, one metre above the bottom and at least one intermediate depth. Temperature, salinity and current were measured in conjunction with most water sampling. To obtain some seasonal coverage, all the central line stations were resampled during a three day interval in May 1973 and one station (N) hourly for 18 hours.

The most prominent feature of the suspended sediment distribution (Fig. 9) is the well developed turbidity maximum at the seaward end of the River Channel east of Point aux Carr (Fig 2). Here suspended particulate matter (S.P.M.) concentrations were 5 to 10 times higher than the values found in the river and the open sea. In May the landward limit of this maximum had shifted seaward along with a seaward shift in the fresh water boundary. The seaward limit of the turbidity maximum however had not shifted but again occurred where the narrow channel opens out into the Inner Bay.

Suspended sediment in the turbidity maximum was characteristically flocculated with about equal proportions of organic and inorganic material. In contrast the material at the landward, low salinity end had lower ash loss values, consisting largely of terrestrial erosional products. The more oceanic water seaward of the turbidity maximum contained relatively high proportions of combustible material as a result of higher organic productivity in the marine environment (Kranck, 1981).

Continuous profiles of light-attenuance recorded over complete tidal cycles (Figs. 10 and 11) showed the pronounced estuarine character of the natural suspended sediment distribution. Especially at station K in the turbidity maximum, the two layer flow which helped to maintain the turbidity maximum (along with flocculation) was well developed (Fig. 10). At the start of high water slack (2230 hrs., Fig 10) the surface sediment concentrations were low due to the presence of relatively clean sea water and the bottom water was very turbid due to sediment entrainment by the strong flood currents. During slack and most of the ebb the bottom water cleared due to sediment settling and replacement by cleaner river water. The surface water became more turbid as fresher water carrying river sediment replaced the cleaner sea water. With the start of the flood strong bottom currents again advected bottom derived sediment past the station while the surface cleared concurrently with increase of salinity. The most prominent feature in the sediment cycling was the strong dominance of an inward directed bottom current which supplies the turbidity maximum with river sediment settling out of the diminishing river speed as well as any sediment entering the bay with the flood current. This balance between seaward directed and shoreward directed transport is responsible for the long term trapping of sediment within the estuary.

Station A showed a much less distinct pattern of sediment cycling and no clear conclusions on net effects could be drawn from the measurements (Fig 11). Minimum currents coincided with high and low tide but no conforming suspended sediment variation could be discerned.

5.3 Bottom-Suspension Interaction

Grain sizes between the modal size and the coarse end of the size distribution represent the material which is in equilibrium with the hydrodynamic environment or is actively settling (Kranck,1986). To examine the relationship between suspended and bottom sediments this dynamic size range was plotted for all bottom and suspended sediment samples along the central transect (Fig. 12). The bottom sediment in the channel and around the outer islands was coarser than the size range of suspended sediment at the same stations, which indicated no active exchange between suspension and the bottom. Values from stations in muddy patches of the river channel and the muddy area of Grand Dune Flats overlap with the dynamic size of the suspended sediment. The similarity in grain size of the material on the bottom and in suspension under the normal weather conditions during which the suspended sediment sampling occurred as well as the very fine size and low density are evidence that these mud deposits were relatively unstable and easily resuspended. The proximity of the seaward end of the turbidity maximum and the start of the Grand Dune Flats suggests a sink source relationship between the two.

6. DREDGING ACTIVITIES

6.1. Description of Channel Development Project

Dredging of the channel from the Gulf of St. Lawrence to Newcastle to a depth of 7.6 million m^3 was recommended after a four year study of relevant operational, engineering, environmental and economic factors (Philpott, 1978). The proposed plan called for the dredging of 4.3 million m^3 (place measure volume) of sediment largely from the existing navigation channel. The resulting dredge spoils were to be disposed of by dumping at three disposal sites (fig. 2). 0.575 million m^3 dredged from the river channel above Millbank at Dumpsite A between Newcastle and Chatham. 2.20 million m^3 originating from the outer part of the river channel and the Inner Bay at Dumpsite B and 1.74 million m^3 from the Outer Bay at Dumpsite C. Implementation of the plan commenced in 1981 and was completed in 1983. The actual volumes dredged (measured as scow measure) came to a total of 6.616 million m^3 , of which Dumpsites A, B and C received 1.439, 4.928 and 1.348 million m^3 respectively (MacLaren Plansearch, 1985). The difference in proposed and completed dredging volumes may be partly related to the difference between place measure and scow measure or hopper measure used to describe the volumes.

6.2. Dredging Practices

The Miramichi Channel was dredged principally using a trailing suction hopper dredge. This type of dredge has a draghead mounted on the end of a suction arm. The draghead scrapes loose the bottom material and mixes it with the surrounding water to form a slurry which is pumped up into the hopper in the hull of the dredge. When the slurry fills the hopper it is allowed to overflow into the surrounding water. The escaping material consists of water plus the sediment which did not settle out of the slurry during the retention time in the dredge. Eventually the dredge travels to the dumpsite and is emptied through doors in its hull.

6.3. Dredge Spoil Characteristics

It is not known exactly how much overflow was practiced during the Miramichi project. Some information on the relative amounts and grain size of the sediment retained and expelled may be obtained from analysis of samples collected on one occasion in and around the dredge while operating near station K in the channel portion of the Bay (Fig. 1). Three samples were collected from the dredge itself; one from the dredge inflow, one from the dredge outflow and one from the surface of the sediment in the hopper. The samples consisted of thick sediment slurries and were analyzed for total sediment concentration and grain size. A water sample was also collected about 20 metres away from the dredge in the surrounding turbid plume (Fig. 13) as well as five samples of normal water for comparison from selected stations within the Channel and Inner Bay.

6.3.1 Retention Volumes

The results showed that at the time of sampling the inflow contained 23008 mg/ℓ of sediment, the hopper 32321 mg/ℓ and the outflow 16711 mg/ℓ. This indicates that 72.6 percent of the sediment being dredged from the bottom at that time was being expelled back into the water column. The 9313 mg/ℓ higher concentration in the hopper than in the inflow represents a concentration factor of 13.1 percent due to settling within the hopper. The hopper sample was collected from the surface and higher concentrations as well as coarser sediment would be expected to occur deeper in the hopper.

6.3.2. Grain Size

The size spectra show that the dredged sediment (inflow, Fig. 14,a) consisted of a sandy silt with a modal size of 105 microns and 'tail' of floc settled sediment. From the difference in concentration in each size class between the inflow and outflow the size distribution of material retained by the dredge may be calculated. The resulting curve indicates that sand particles between about 60 and 300 microns with a modal size of about 120 microns were retained in the dredge along with 39 percent of finer material which had flocculated to this size (Fig 14,b). The calculated distribution has a narrower single grain curve than the hopper sample probably as a result of preferential settling of coarser particles.

6.3.3. Settling Rate of Overflow

The settling behaviour of the suspended sediment in the overflow contaminated water from near the dredge and the five samples of estuarine water collected at 0.5 m were observed in a series of settling experiments. The samples were suspended evenly in 180 cm high, 10 cm diameter settling cylinders. Samples were withdrawn 30 cm from the bottom after logarithmically increasing time intervals and analyzed for total concentration (Fig. 15) and grain size (fig. 16).

Results (Table 1) show that the initial concentration of dredge contaminated water was two orders of magnitude higher than the normal estuarine water. The median settling rate (time for the concentration in the settling cylinders to decrease to half the initial concentration) for the dredge contaminated water compared to the estuarine water was also two orders of magnitude greater . Despite the higher settling rate the concentration in the dredge sample after 24 hours of still water settling was still more than one order of magnitude higher than normal concentrations in the Bay. The grain size results show that particles were lost from all size classes showing that floc settling must have been the dominant mode of settling.

TABLE 1
Results of Settling Experiments Using Large Volume Water Samples from Miramichi Bay (sampled at 0.5 m).

Sample location	Half life	Settling rate (cm/sec)
M	18 hrs.	.00077
J	17 hrs	.00082
I	21 hrs.	.00066
H	44 hrs.	.00032
B	N.D.	N.D.
L (Dredge)	0.41 hrs.	.034

6.3.4 Discussion of Overflow

If the samples from the dredge are representative of the operation as a whole it is apparent that a considerable portion of the dredged material never reached the dumpsite via the dredge but was overflowed into the water column. In the more muddy areas in the Inner Bay the proportion of overflow may have been even higher. Some of this material may have been redredged after redepositing in the channel but the majority would have been dispersed away from the dredge by currents and waves greatly increasing the turbidity of the water in the vicinity (fig. 13).

Interpretation of the settling data must take into account a number of factors which are difficult to quantify. An order of magnitude decrease in grain size has been known to occur due to handling of samples during collection (Kranck, 1984) and the settling rates observed in these experiments represent minimum settling rates. On the other hand the natural turbulence due to tidal currents and waves will act to keep the sediment in suspension longer than indicated by the settling experiments. The difference between the 16711 mg/l concentration in the outflow and the 687.54 mg/l in the water some 20 metres away from the dredge may be due either to rapid settling of the slurry or to dilution with bay water. The exponential decrease in settling rates with time means that while some of the overflowed spoil material settled rapidly, much remained in suspension sufficiently long to be carried well away from the dredge site and to be redistributed throughout the Bay. The relatively high suspended concentrations remaining in the samples after many hours of settling helps to explain the turbid clouds observed around the working dredges (Fig. 13). Comparison of the size spectra of the outflow and the near dredge water shows that the particles above 80 microns had settled, probably as single grains prior to collection of the near dredge sample. The rest of the distribution had not changed shape indicating no settling or settling only as flocs had occurred. The grain size patterns of Miramichi Bay bottom sediments suggest the settling of most of this material will depend on flocculation and will result in very fluid, easily resuspended deposits.

6.4. Channel Topography

When the Miramichi Ship Channel was deepened, the dredging was carried out in virgin sediment never previously dredged. The bottom consisted of well consolidated material with a relatively rigid soil fabric. Attempts to obtain cores from the bottom of the channel using a light corer were unsuccessful as the light corer bounced off the bed despite the relatively fine grain size of the sediment. The compacted nature of the bottom was also evidenced by the longitudinal ridges created by the trailing arm of the dredge in the channel (Fig. 17). Slopes up to 30 degrees were stable in the mud bottom and did not fill in by plastic flow of the cohesive bottom sediment. Dislodgment of this bottom could be expected to produce sediment low in organic matter and without the bacterial component required for floc formation (Kranck and Milligan, 1980; Muschenheim et. al., in press). This helps to explain the relatively low settling rates of the fine component of the dredge spoils.

7. POST-DREDGING SURVEYS

7.1. Drogue Tracking

A surface float consisting of two flat rigid pieces of plywood inserted into each other and fixed rigidly in the form of a three dimensional cross was used to track currents and water masses in the Bay. It was weighted with lead so as to float below the surface with only a small pole and flag marking its position. This drogue was allowed to drift freely and its position recorded every half hour from a small boat positioned using Loran C. Water samples for suspended sediment and salinity determinations were collected along its path.

Five drogue deployments were carried out during which the drogues were tracked for 5 to 10 hours each (fig. 18). The salinity and suspended sediment as measured every half hour with a one metre depth interval are shown in figs 19 to 23. Also shown is the average speed of the drogues as calculated from the distance traveled between positioned stations.

The first drogue deployment (3 & 4.10.1982, Fig.18A) was started near dumpsite A in the River Channel and travelled seaward with the ebb tide probably reinforced by river runoff. SPM concentrations were around 3.5 ppm (Fig. 19), in the range normal for this time of the year (Fig 9). This drogue went aground at 1000 on the north shore of the channel. More turbid water near shore may account for the higher concentrations around 1100 to 1200 but it may also be a reflection of the turbidity maximum usually encountered in this area. The latter explanation is supported by the very high SPM values measured in the same vicinity the following day when the flood phase of the tide was followed by the drogue. During this deployment no resuspended dredge spoils could be identified. At the start SPM concentrations were low near dumpsite A, and there was no indication that the dumpsite was affecting the water down stream.

The second deployment (5.10.1982, Fig.18B) was started near the shoreward end of Inner Bay. Initially the SPM concentrations were relatively high due to the presence of river channel sediment (Fig.20). Drifting out into Inner Bay concentrations decreased due to settling and dilution with seawater until near the end of the ebb when normal Inner Bay values occurred throughout the water column. During slack water however concentrations rose again and concentrations up to 4.4 ppm, anomalously high for these waters, occurred near the bottom as well as higher up in the water column at one site. During this time the drogue was very close to the dumpsite (the last two stations were actually within its boundaries) and resuspension from the dumped dredge spoils is the most likely origin for the increased SPM concentrations.

The third drogue track (7.10.82, Fig.18C) was started at the northwestern corner of dumpsite B about one hour before high water slack. The upper half of the water column had the normal low Inner Bay suspended sediment concentrations but towards the bottom the concentrations increased to a maximum of 3.5 ppm (Fig.21). As the drogue drifted off the dumpsite simultaneously with the slackening of currents the water cleared near the bottom as well. With an increase in the northward flowing current, concentrations increased all through the water column to reach a high of 3.4 ppm before decreasing again. At the end of its track near the northern shore of the Bay salinities as low as 7 ppt were recorded. This low salinity may have been an undiluted parcel of river channel water exiting along this shore or outflow from Bartibog River on the north shore. No matching increase in suspended sediment concentrations was noted, indicating that the relatively high concentrations of suspended sediment usually associated with river water does not persist in the more sluggish flow of the Inner Bay.

The fourth drogue track (8.10.82, Fig.18B) was started inside dumpsite B, near the southwest border. Initially it drifted south past the boundary of the dumpsite. After slack tide the drogue turned and traversed across the whole of the dumpsite and continued northward across the channel. While SPM concentrations at most depths are generally low along this track (less than 1 ppm), a bottom layer of higher concentrations occurred during the first part of the track coinciding with the time the drogue spent inside the dumpsite (Fig.22). Concentrations decreased slightly during the time the drogue spent outside before turning north, but the turbid bottom layer persisted to the area between the edge of the dumpsite and the channel where clearer water was found right to the bottom. The association between the dumpsite and the occurrence of a more turbid layer points to resuspension of dredge spoils as the source of the suspended sediment.

A fifth drogue (11.10.88, Fig. 18C) was released near the north coast of the Inner Bay in the vicinity of the mouth of a small river. It was tracked for only 5.5 hours before tracking was abandoned due to bad weather. Suspended sediment concentrations were relatively high compared to earlier measurements from this area collected during drogue tracking, probably as a result of resuspension associated with the increased wave action (Fig. 23).

7.1.1 Discussion

Summary of Drogue Results: In the River Channel two SPM maxima were observed which extended from the bottom through most of the column. These features coincided with the period of strongest currents and indicate that active sediment resuspension occurs in the area although there is no indication that it is associated with the dredge spoils. In the Inner Bay suspended sediment concentrations in the surface and mid-column portion of the water along the drogue tracks were, generally, relatively constant with depth and in accord with the normal values for these waters. A near bottom turbid layer extending about 0.5 m above the bottom was found at all stations inside or within 500 m of dumpsite B but not outside this area. This feature shows that the dredge spoil bed was being actively resuspended and was unstable compared to the surrounding bottom.

7.2. Sediment Cores

A series of sediment cores from different years have been collected in the general vicinity of dumpsites A and B and have been examined for possible dredging related changes in structure and gross lithology. Cores collected in 1982 were also examined for changes in grain size.

7.2.1 1976

Schafer (1983) studied foraminiferal stratigraphy in cores from the Miramichi Inner Bay collected in 1976. Two of these cores came from stations within the dumpsite (Fig. 24) and provide information on the normal predredging configuration of the sediment bed. The cores consisted of well bioturbated silty mud with some faint banding and wavy laminae (Fig 25). They are relatively featureless with no pronounced variation in visible structure.

7.2.2. 1982

In 1982 Geomarine Associates, Halifax, under contract with Dept. of Fisheries and Oceans, Canada, collected 19 cores clustered around Dumpsite B (Fig.24) and 6 cores about Dumpsite A. The cores from the Inner Bay were characterized by two types of material (Fig.25). Sediment termed mottled mud was either relatively homogeneous or had the uneven speckled or slightly wavy structure often characteristic of sediment deposited sufficiently slowly that bioturbation has completely obliterated all primary banding. The more irregular portions of this sediment were similar in appearance to the pre-dredging material sampled by Schafer and Smith (1983). A second material referred to as layered mud consisted of banded or finely laminated sediment. The structures were usually parallel and horizontal. The boundary between the two types of material was sometimes gradational and sometimes sharp. The banded material formed the surficial sediment in most of the cores collected in the area of the dumpsite. It varied in thickness from less than a centimetre to 24 centimetres and occurred as a 3 km by 7 km deposit centered on the dumpsite (Fig.26). The total volume of sediment represented by the banded material constituted 1.5 million m^3. Normal mottled material underlay this deposit and formed the surface of the surrounding bottom.

7.2.3. 1984

Cores collected in 1984 by MacLaren Plansearch (1985) from the area of dumpsite B show the same two lithologies as sampled in 1982; banded material and mottled material. The surface portions of the banded material appeared to be lighter in colour than in 1982 indicating a less dense material due to higher water and/or clay content. Comparison between the occurrence of the banded sediment in 1982 and 1984 shows an increase in the thickness of the banded material as well as an apparent shift of the centre of the deposit inward toward the River Channel (Fig. 26). Many of the cores were composed entirely of banded sediment and core coverage did not extend beyond the eastern limit of the deposit. Consequently the total thickness could not be determined but the observed volume exceeded 3.42 million m^3.

7.2.4 Discussion

From the juxtaposition of the banded sediment distribution and dumpsite B it may be concluded that the deposit obviously originates from the dumped dredge spoils. The fine grained and parallel, horizontal structures indicate that this sediment has been deposited from relatively high turbidity, near bottom suspensions, similar to the stratified suspensions described from the Severn Estuary (Kirby and Parker, 1980 and pers. com.). The occurrence of this sediment outside the boundary of the dumpsite B indicates that it has flowed subsequent to its original disposal as observed for other spoil disposal operations (Biggs, 1968). The banded material is thicker in cores collected in 1984 than it was in 1982 and shows that this off-site transport is a continuing process. The lack of a well defined boundary between the layered sediment and the underlying material may indicate that both are dredge spoils and only the upper layer represents the mobile portion of the dumped material. The direction of transport is in accord with movement towards the region of the turbidity maximum at the end of the River Channel. It is not likely that this sediment settled directly from the hopper overflow during the dredging process since the extent of this deposit increased markedly after the fall of 1982 when 90 percent of the dredging had been completed. It is more likely that the banded deposit represents the dredge spoils initially discharged in the dredge overflow and dispersed widely within the Bay before settling. It is probably being remobilized by storm waves and currents to become concentrated in the area of the turbidity maximum where flocculation and deposition are promoted by the high suspended sediment concentrations.

The cores related to Dumpsite A do not form a sufficient data base to allow definitive conclusions regarding the fate of material dumped at that site. A few of the cores show layered sediment which could be dredge spoils. The rapidly changing nature of the river channel environment however, could produce similar structures and no conclusions can be drawn from the cores regarding spoil ground stability in this area.

7.3. Changes in Bottom Sediment Distribution

Most of the stations where bottom sediment was collected in 1975 were resampled in 1982. Results of bottom sediment analysis were compared with the earlier analysis and the results show an increase of maximum particle size (and K values) in the centre of the Inner Bay (Fig. 27). All stations from inside Dumpsite B and stations north toward the dredged channel contain significant amounts of medium and coarse sand which had not been present in the predredging samples. The dredge site samples were poorly sorted and coarser and more irregular than the normal sediment from this area. It is noteworthy that the particle spectra did not conform to the pattern of decrease in the floc tail with increase in modal size characterizing estuarine sediments. The difference in the character of dredge site bottom and normal bottom is well demonstrated by the size spectra of bottom sediment collected along the path of the drogue of 8.10.1982 which passed right across the dump site (Fig 28). A change to generally finer sediment was also detected at a number of stations near the edges of Inner Bay (Fig.27). Here the typical well sorted sand and low tail of fines had changed to a finer more poorly sorted sediment.

The cause of the coarsening of sediment around the dumpsite must be the dumping of dredge spoils which were coarser than the equilibrium maximum size for the normal sedimentation regime of this location. Poor sorting is normal for the fine grained end of estuarine sediment size distributions, but the lack of sorting up into coarse sand sizes indicates that flocculation as well as hindered settling played a role in settling of this fluid mass, as would be expected in dumping a hopper load.

7.4. Dumpsite Sounding Survey Information

During the course of the dredging project the dumpsites were surveyed using modern echo sounders and electronic positioning. The records from these surveys have been examined by F. Jordan, Coastal Oceanography, D.F.O. with a view to determining the apparent rate of sediment accretion on the dumpsites (F. Jordan, unpublished). Only for Dumpsite A was sufficiently reliable information available to allow some conclusions on changes in volume measures. These values are subject to errors due to survey base levels and navigational corrections, but nevertheless they provide some information on temporal changes for this dumpsite.

No survey was carried out immediately before the start of dredging. Comparison between the most recent pre-dredging survey (1971) and a survey completed after the initial season of dumping (October, 1981) indicates that a net accumulation of 0.103 million m^3 had occurred. The reported dumped volume during this time was 0.195 million m^3. The latter volume is scow measure and the exact relationship between the two types of data is not known, but the most likely cause of the discrepancy is post dumping compaction. Between October, 1981 and July, 1982 an increase of 0.298 million m^3 occurred in the volume of the dumpsite. No volume is available for the actual amount dumped during this time. The next survey, in November 1982, unfortunately was carried out using a different grid pattern and possibly a different datum reference. The unreliable nature of these data is indicated by the comparison with the July survey which indicates scouring of more than one half metre of sediment even though 0.130 million m^3 was dumped during this time. A survey in May 1983 before the renewal of dredging, and using the same survey system as in November 1982 showed no significant difference in the bottom during the winter period, indicating that after the end of dumping the bottom remained relatively stable.

It may be tentatively concluded that, initially after dumping, a 50 percent decrease in volume occurred due to compaction but that subsequently the dumpsite remained stable. It is unfortunate that more data did not result from this potentially important source of information.

8. SUMMARY AND CONCLUSIONS

Studies of the sedimentation regime in Miramichi Bay prior to the 1982 to 1983 channel development showed a close relationship between sediment distribution and current speeds. Areas of low tidal current energies in the centre of the Inner Bay were dominated by fine muds, with muddy sand and sand occurring shoreward and seaward as average currents increased towards the constriction formed by the Miramichi River Channel and the openings through the barrier islands. The Bay has a typical estuarine circulation and the highest suspended sediment concentrations occur in a turbidity maximum near the channel entrance to the Inner Bay believed to be the point of shift from net seaward to net shoreward sediment transport. The high turbidity and high turbulence promote flocculation and the adjacent mud flats of the western Inner Bay are the focus of deposition for the Miramichi sedimentation regime.

In 1982 and 1983 during a major dredging program 6.558 million m^3 of sediment were removed from the ship channel through the Bay and dumped on one of three designated dumpsites. Most of the material (75 %) was destined for dumpsite B in the Inner Bay 10 to 15 kilometres seaward of the turbidity maximum.

A cutter suction dredge was used in the dredging project. From samples collected on one occasion it is estimated that more than 70 percent of the sediment pumped into the barge was overflowed back into the surrounding water. The maximum particle size in the outflow material was only slightly finer than that of the inflow. Only sand and finer grains which had flocculated to particles with the same settling rate of sand were retained in the hopper of the barge. Sampling and settling experiments performed on water samples from the Bay, including the turbid water around the barge, indicated that while the coarse material from the outflow settled rapidly, the fine fraction below about 40 microns remained in suspension from hours to days until it flocculated prior to settling.

Dredge spoils retained by the dredge were dumped on the dumpsites. On and around the dumpsite they form a deposit distinguished from the natural bottom by the coarser grain size and fine parallel banding. The spoil deposit extends beyond the borders of the dumpsite, some of which may have originated from dredge overflow. The dumpsite sediment was easily resuspended and was detected in near bottom water samples collected over the dumpsite.

Some of the 3 million m^3 of sediment lost from the dredging was probably deposited over most areas of the Inner Bay and Channel. It was probably not noticeable as a change in grain size over the much of the Inner Bay because the impact of a corer or grab would have dispersed the soft low density material. (A layer a few cm thick would have resulted if all the material had been spread evenly everywhere). The presence of dredged sediment near the dredging activity is indicated by an increase in bottom sediment grain size at many stations. A change to finer sediment at stations near the outer margins of the Inner Bay is evidence that this is where some of the slower settling fractions eventually deposited.

Massive change in the configuration of the sediment deposit associated with dumpsite B is documented by the difference in the volume and location of banded sediment in cores collected in 1982 and in 1984. Although the 1984 core coverage was inadequate to map the whole deposit, it is apparent that its areal extent had increased and its centre had moved to the east of the original dumpsite. The volume of sediment had more than doubled from 1.5 million m^3 to 3.4 million m^3 and since virtually no dumping occurred between the 1982 and

1984 coring programs, this massive sedimentation cannot all be attributed to transport from the dumpsite. No grain size determinations were carried out on the 1984 cores but the low density, banded nature of the material indicates that it consisted of relatively fine sediment with high water content. It is noteworthy that the 1984 deposit coincides with the location of the turbidity maximum near which sediment transported within the whole bay eventually tends to end up. Over 70 percent of the material dredged from the channel bottom is known to have ended up in the water column and a 3.4 million m^3 discrepancy exists between the material dumped on site B and the volumes seen in the cores. It is therefore likely that this deposit represents sediment lost from the dredging operation either through overflow or through erosion from the dumpsite shortly after dumping. This sediment was probably initially dispersed widely throughout the Bay but with time and winter storms became concentrated in the turbidity maximum. Some of it may never have settled and caused the increase in suspended sediment levels recorded during post dredging monitoring. Much of it probably occurs as a wide spread low density, bottom deposit which becomes resuspended every storm. Flocculated sediment is known to be transported as a near bottom, bed-load like, moving layer (Sternberg et. al., 1986) and confirmation of massive movement of sediment in the western end of the Inner Bay and in the Channel area comes from claims from fishermen for compensation for damages to fishing gear and nets coated and torn by sediment during heavy storms (Scarratt, 1985).

The present study does not allow prediction of the rate at which the massive amounts dispersed from the dredge will stabilize and consolidate. Heavily dredged harbours in other parts of the world are characterized by moving fluid mud deposits called "fluff" layers (Allersma et.al. 1966; Parker and Kirby, 1982; Einstein and Krone, 1962) and a similar feature may have formed in Miramichi Bay. The rate of dewatering and consolidation will depend on how often the sediment is disturbed by tides and storms. Even without additional dredging the soft, dredge disturbed, bottom is probably too frequently resuspended to allow a stable deposit to form. Further maintenance dredging and dumping will delay the consolidation process and prevent the formation of a stable bottom. The progressive westward movement indicated by Fig. 26A may be expected to continue causing gradual channel infilling.

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LIST OF FIGURES

Fig. 10. Salinity, light attenuance and current speed variation and inferred direction (arrows) with depth over 24 hours at station K (Fig. 1). Direction of ebb currents and river flow is towards the right.

Fig. 11. Salinity, light attenuance and current speed variation and inferred direction (arrows) with depth over 24 hours at station A (Fig. 1). Direction of ebb currents and river flow is towards the right.

Fig. 12. Sediment properties along central channel showing ranges of suspended sediment concentrations recorded and modal to maximum grain size of suspended and bottom sediment. Note overlap of suspended and bottom sediment size range in muddy central area near seaward end of turbidity maximum.

Fig. 13, A. Photograph of dredge working in Miramichi Bay showing turbid water formed by overflow. B. Turbid plume left behind by dredge. (Courtesy of A. McIver, E.P.S., Environment Canada).

Fig. 14, A. Grain size distributions of slurry samples collected from the dredge while operating in the Channel portion of the estuary. B. Grain size distribution of sample retained by the dredge as inferred from the difference between inflow and outflow. Floc and grain settled portions determined according to Kranck and Milligan, 1985.

Fig. 15. Decrease in total suspended sediment concentration with time in experimental settling of water samples from Miramichi Bay. Sample from near station L was collected in plume from dredge overflow.

Fig. 16. Grain size analysis from settling experiments showing size distributions of sediment remaining in suspension after logarithmically increasing periods of settling. Sampling times correspond to data points in fig. 15. A. Sample collected adjacent to dredge working near station L. B. Sample collected near station I.

Fig. 17. Echogram of navigation channel after first month of dredging showing cross section of longitudinal ridges formed by trailing hopper arm.

Fig. 18 a-c. Drift paths of drogues.

Fig. 19. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 3&4.10.1988.

Fig. 20. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 5.10.1988.

Fig. 21. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 7.10.1988.

Fig. 22. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 8.10.1988.

Fig. 23. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 11.10.1988.

Fig. 24. Location of cores from vicinity of the dumpsite.

Fig. 25. X-radiographs of cores. A: Core 12A (courtesy of C.T. Schafer A.G.C., Geological Survey of Canada). B: Core 32, C: Core 49. Arrow shows start of dredge related material.

Fig. 26. Distribution of dredge related sediment around the dumpsite B. Contours show thicknesses of banded sediment in centimetres.

Fig. 27. Changes in grain size of bottom samples collected in 1975 and 1982.

Fig. 28. Grain size spectra of bottom sediments collected along the path of drogue of 8.10.1988 showing coarser sediment on the dumpsite.

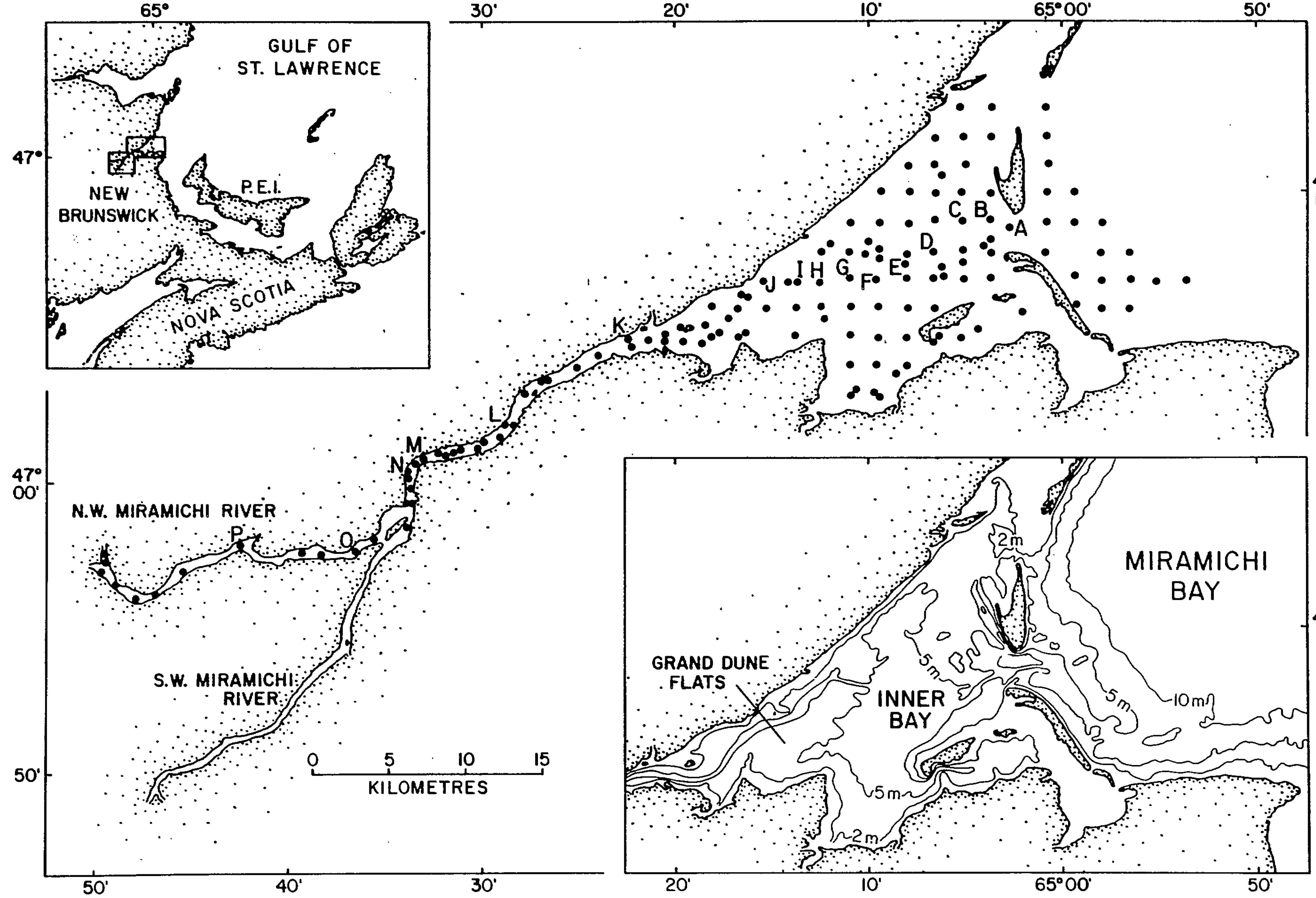


Fig. 1. Location of Miramichi Bay, bottom sediment (dots), and suspended sediment (letters) stations and bathymetry.

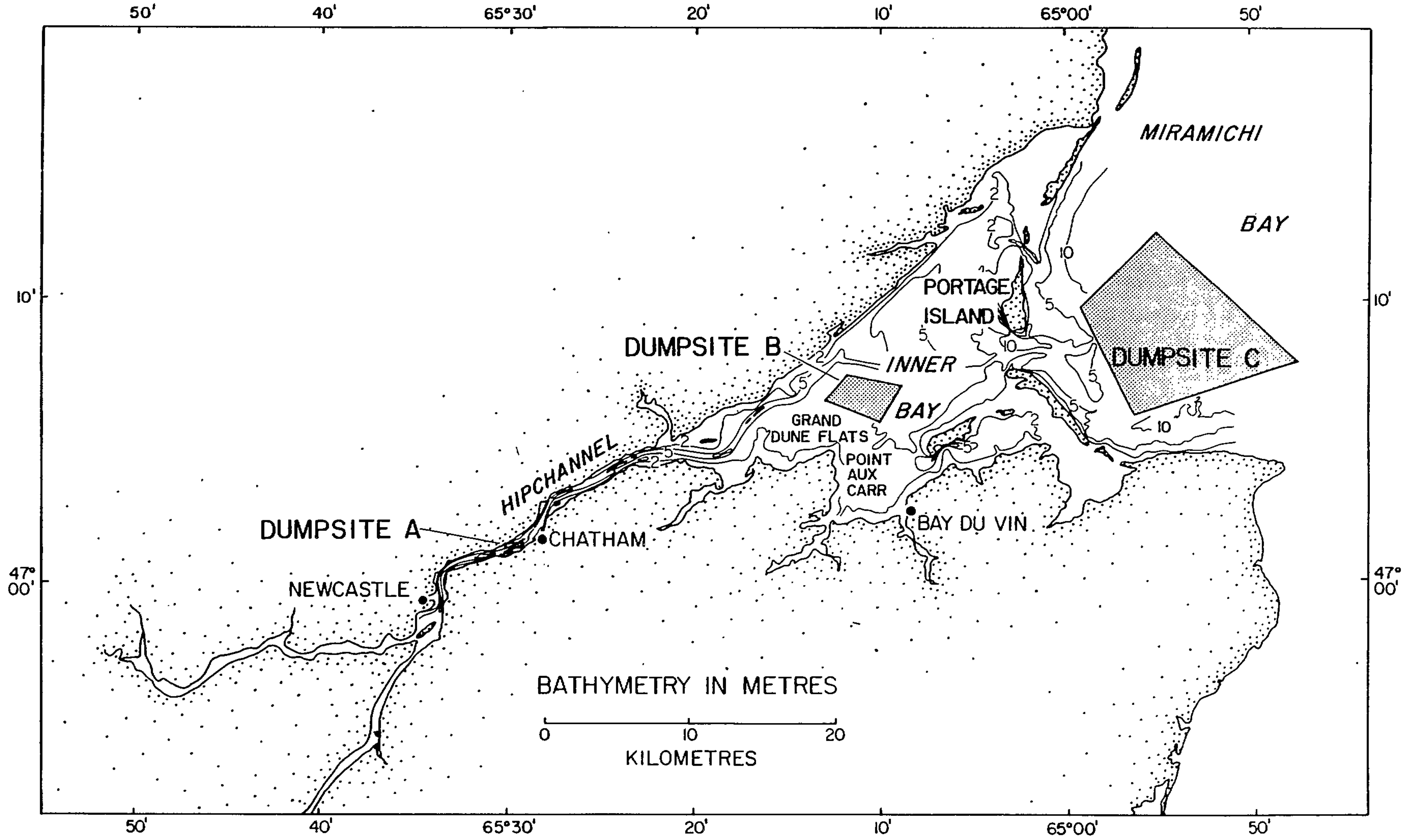


Fig. 2. Geographical names and location of dump site.

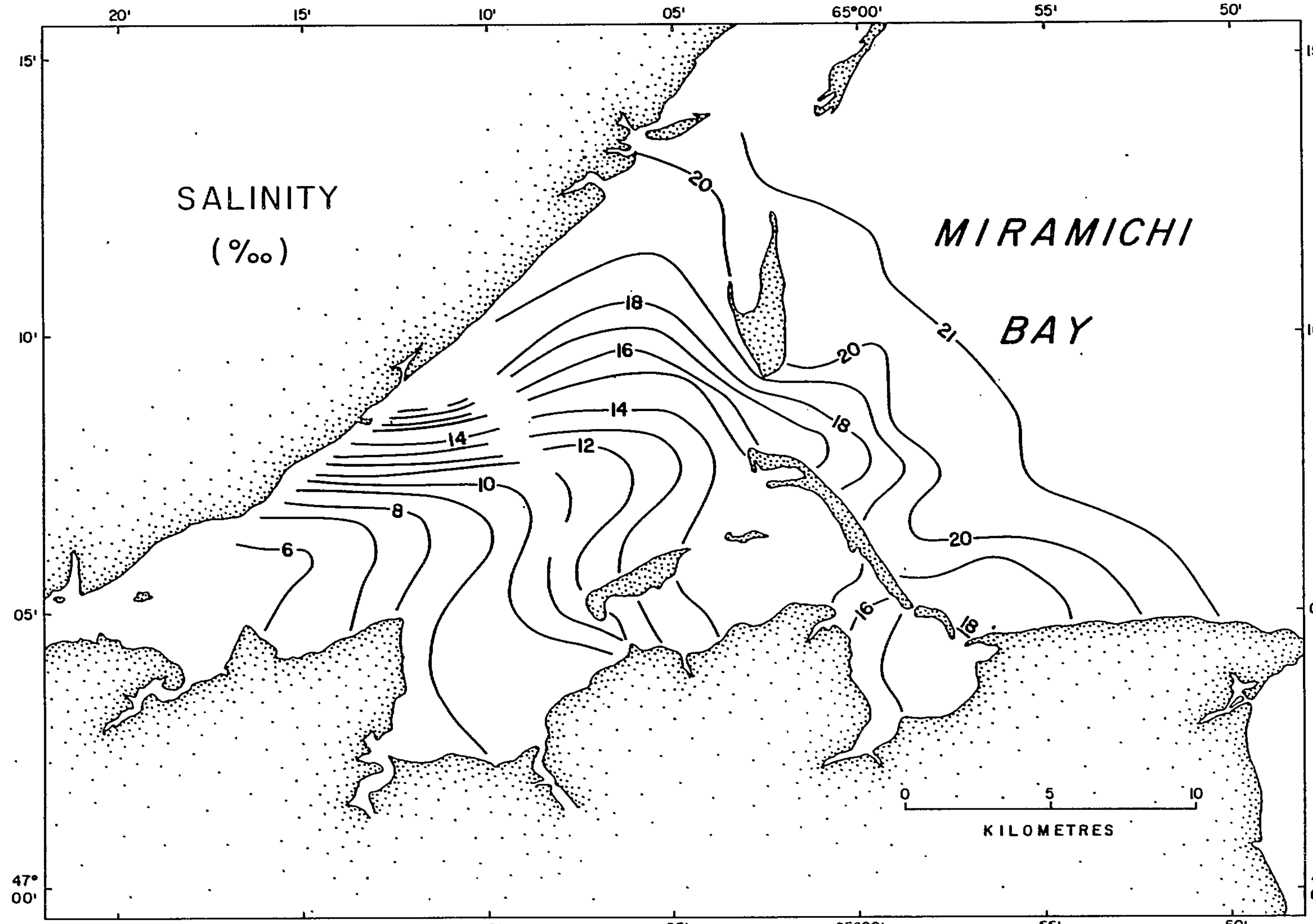


Fig. 3. Surface salinity distribution within the Inner Bay at low water showing more saline water on the north shore, drawn from Bousfield, (1955).

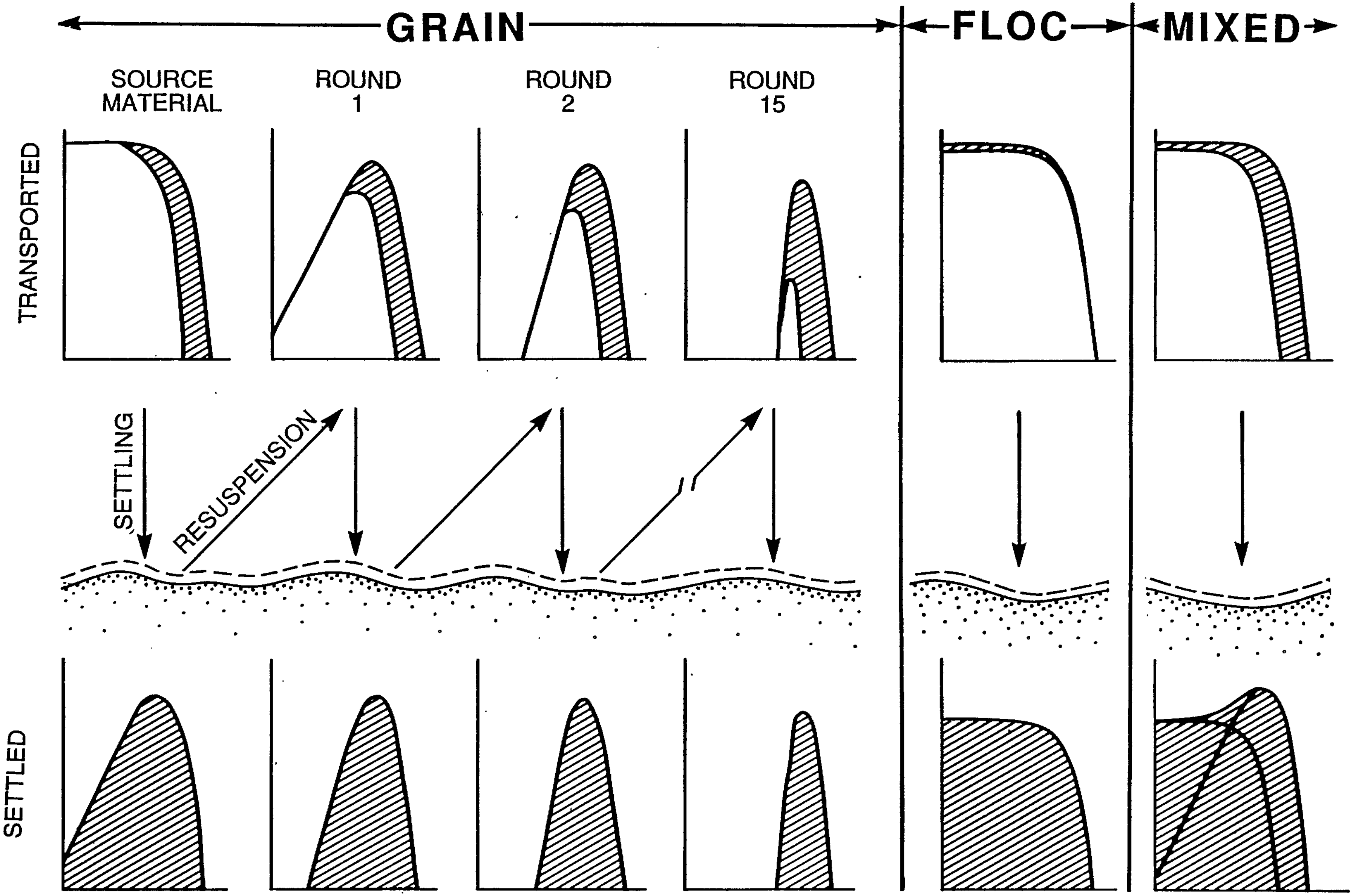


Fig. 4. Sketch illustrating sediment grain size model. Size distributions are shown as log-log plots of volume of sediment in each size class the mid-class grain volume of which doubles in successive classes.

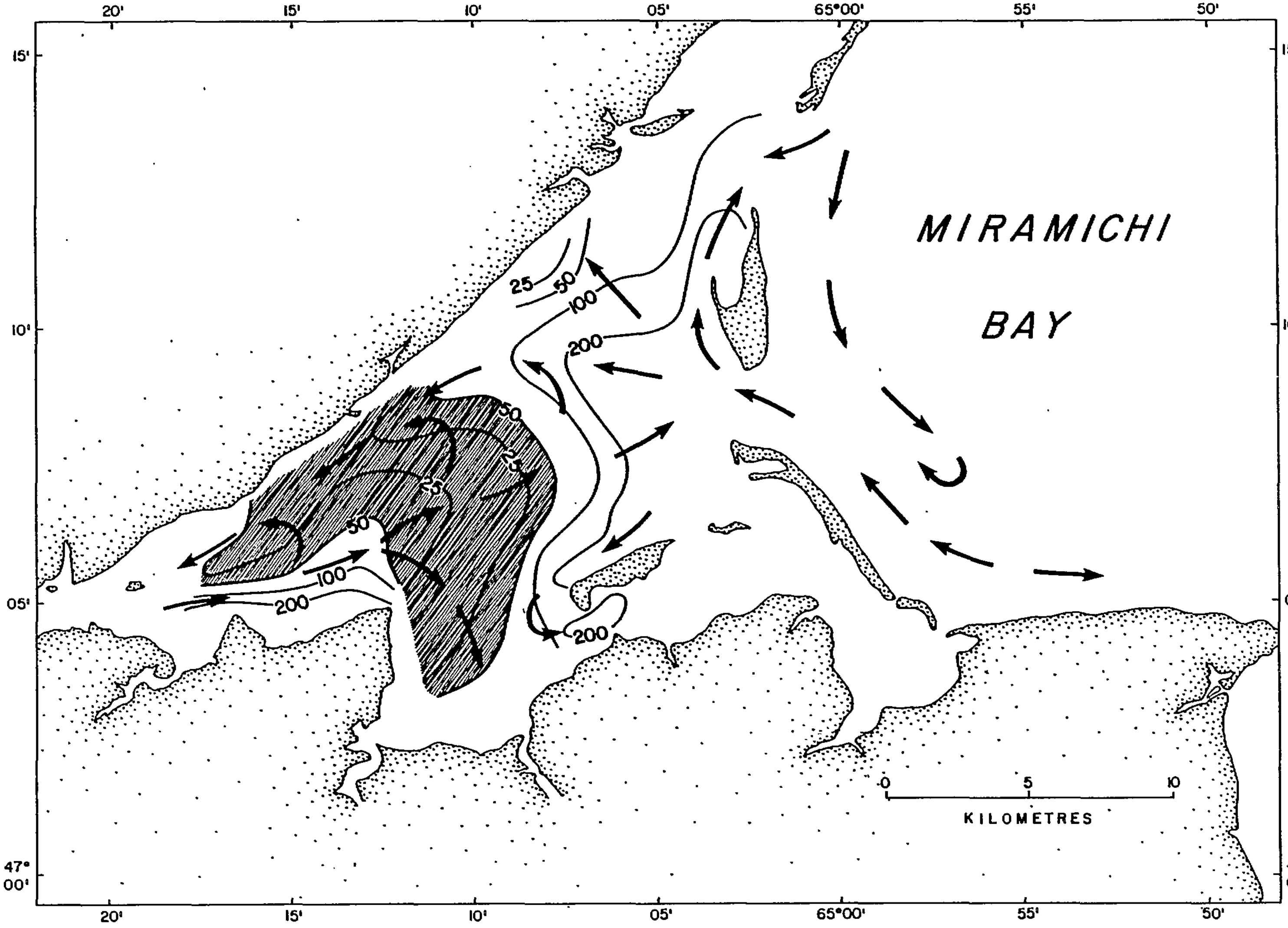


Fig. 5. Distribution of pre-dredging modal grain sizes in the Inner bay. Area of fine mud shaded. Arrows indicate inferred directions of dominant sediment transport.

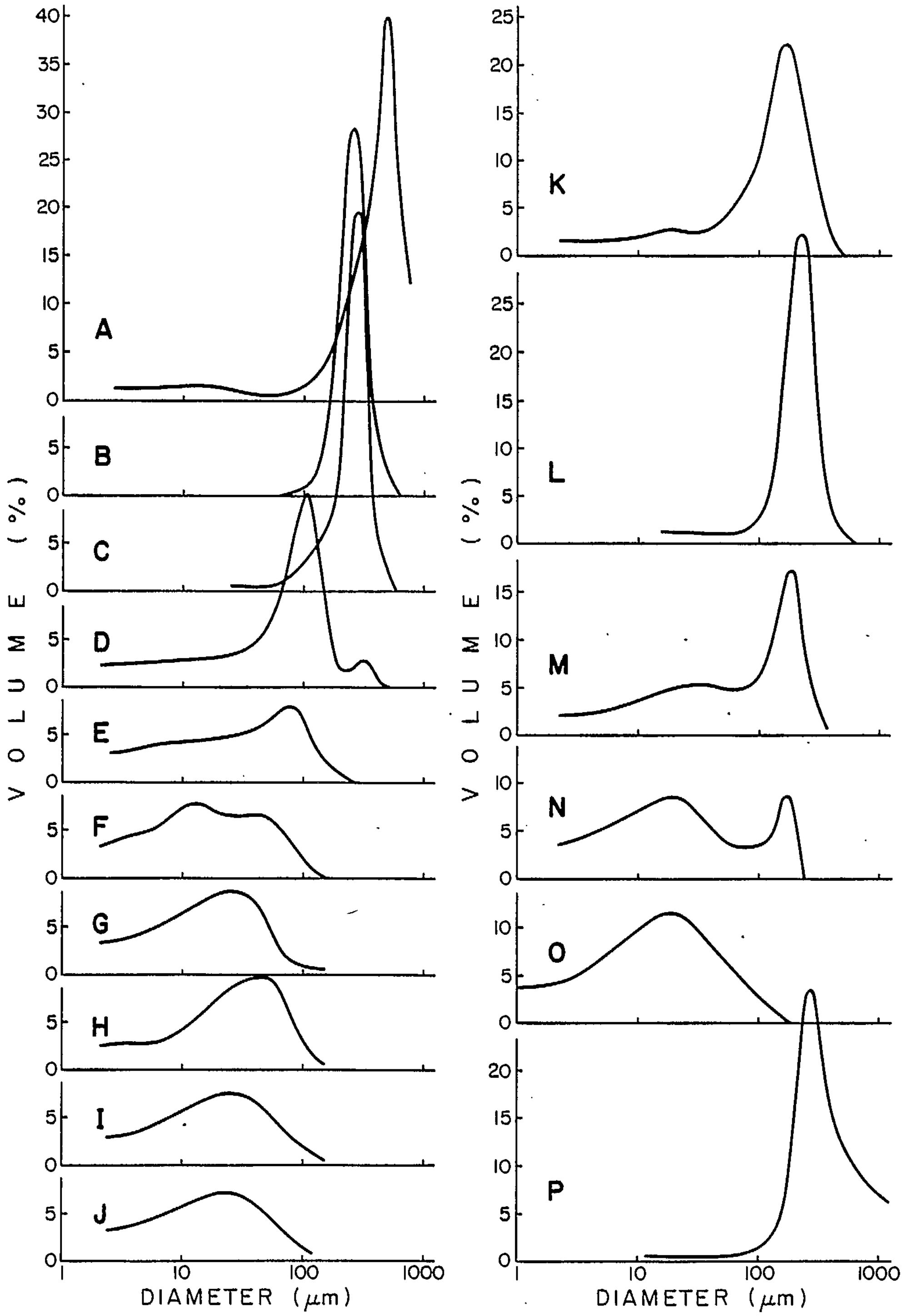


Fig. 6. Semi-log plotted grain size spectra of pre-dredging bottom sediment samples from the central line of stations. For location of samples see Fig.1.

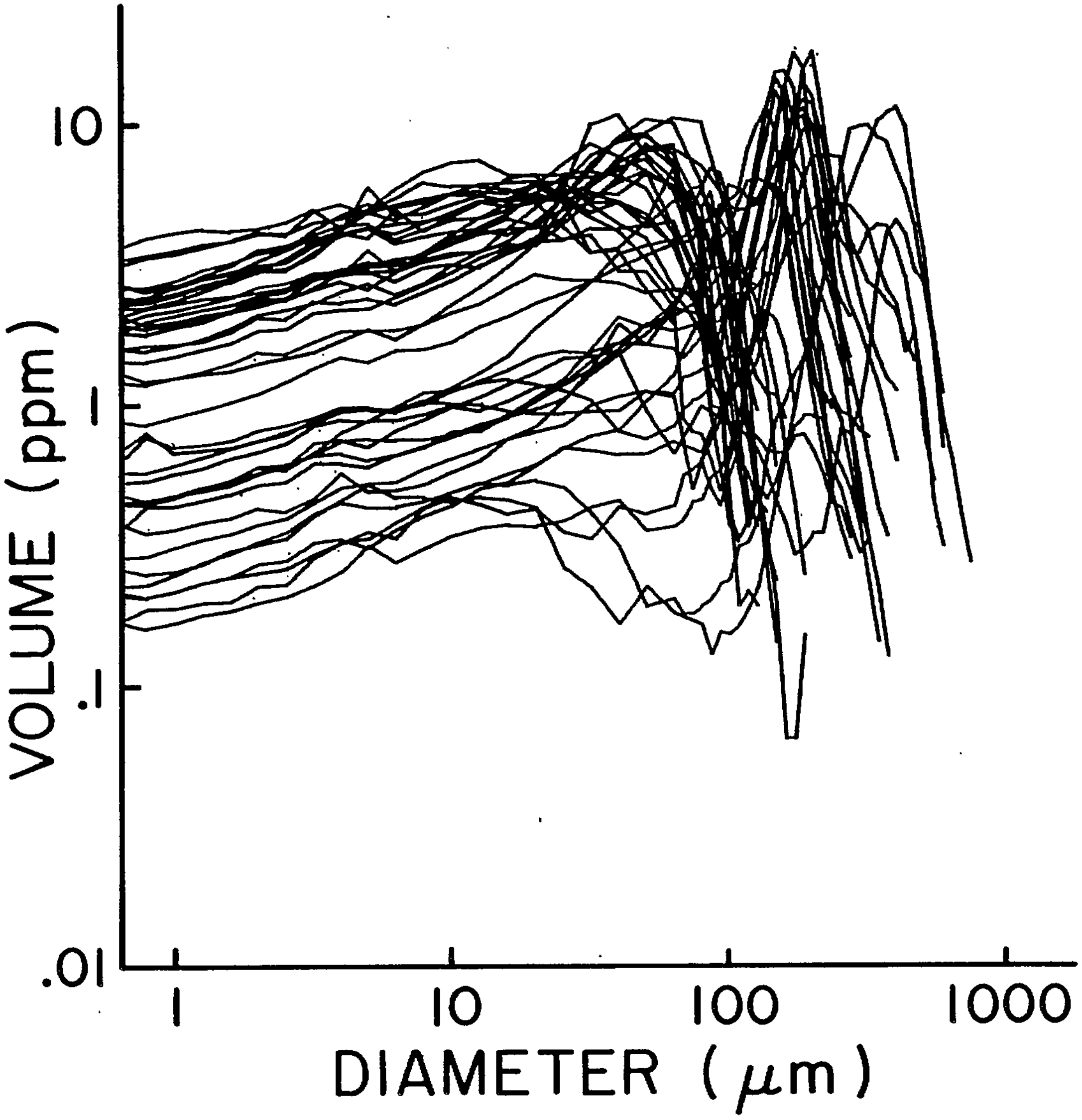


Fig. 7. Log-log plotted grain size spectra of Inner Bay bottom sediments.

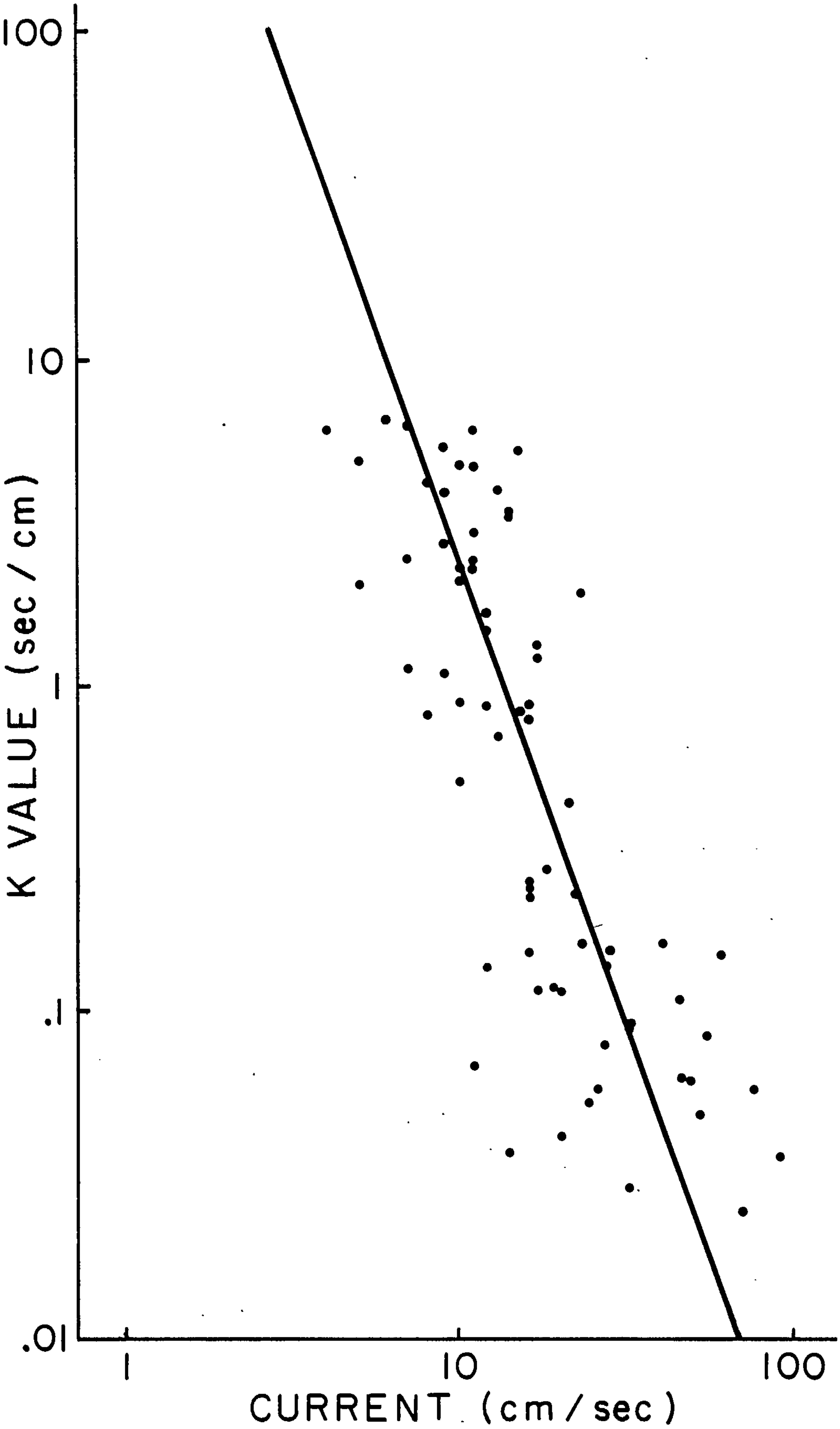


Fig. 8. Relationship between K-values and average current speed (V) based on samples from the Inner Bay. Regression calculation indicates $\log K = 0.78 - 2.84 \log V$.

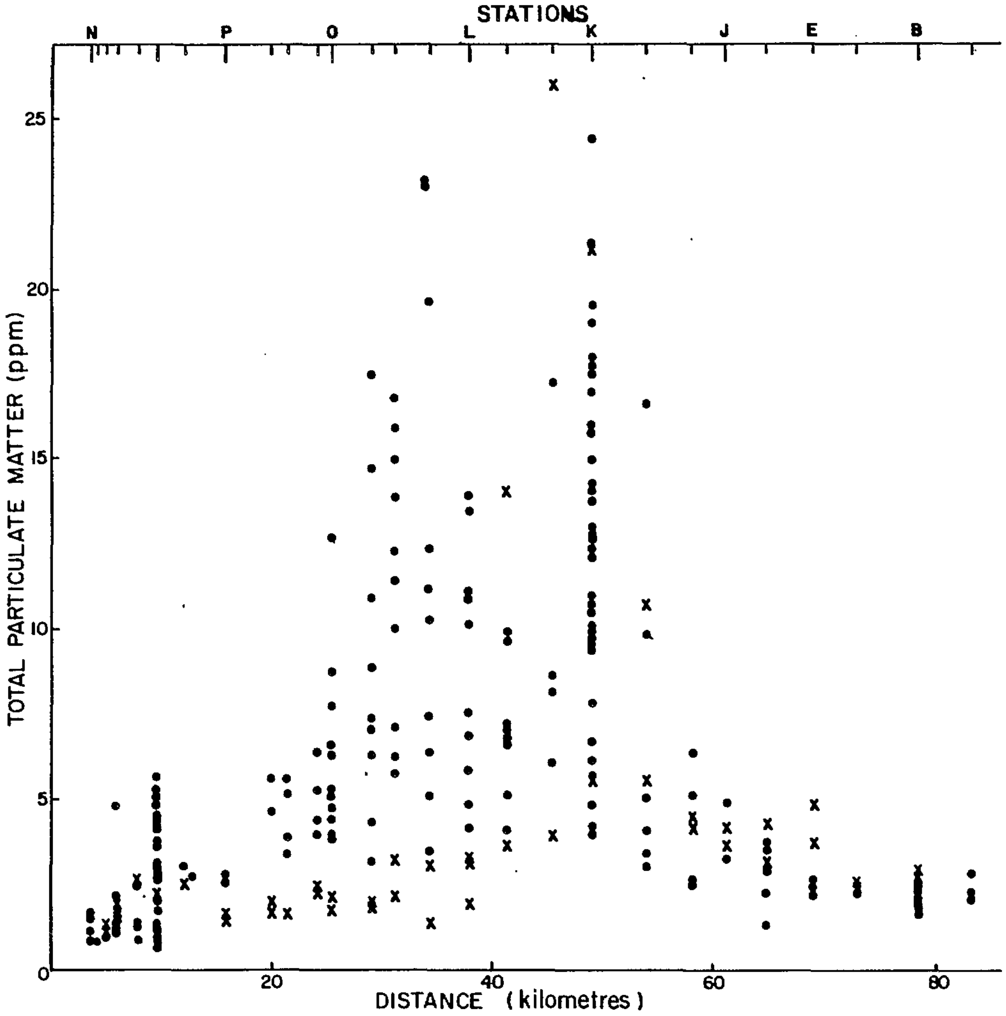


Fig. 9. Suspended particulate matter concentrations measured in 1973 along central channel of Miramichi Estuary. Letters refer to stations in Fig. 1. Dots; September to October; X's, May.

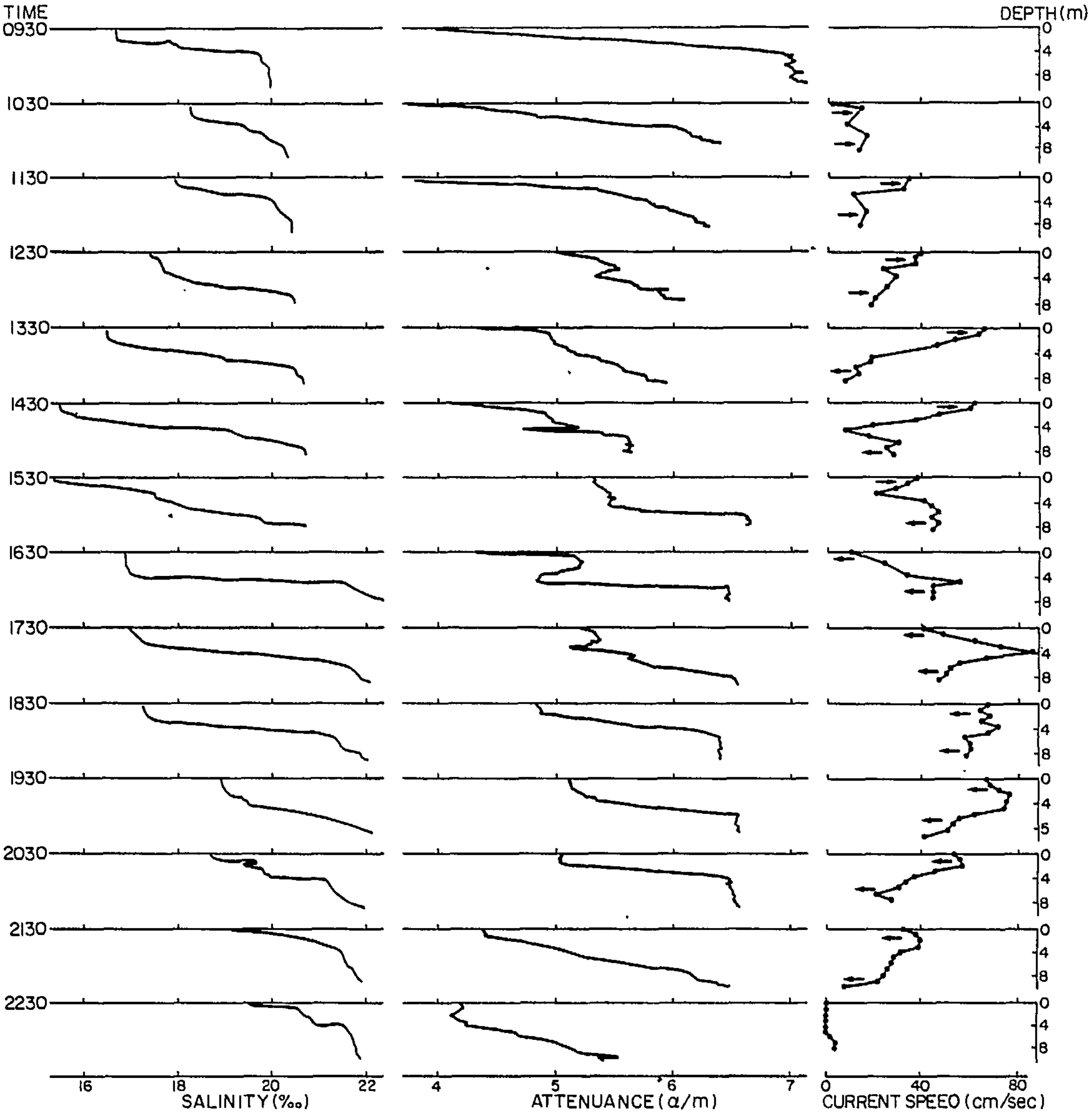


Fig. 10. Salinity, light attenuance and current speed variation and inferred direction (arrows) with depth over 24 hours at station K (Fig. 1). Direction of ebb currents and river flow is towards the right.

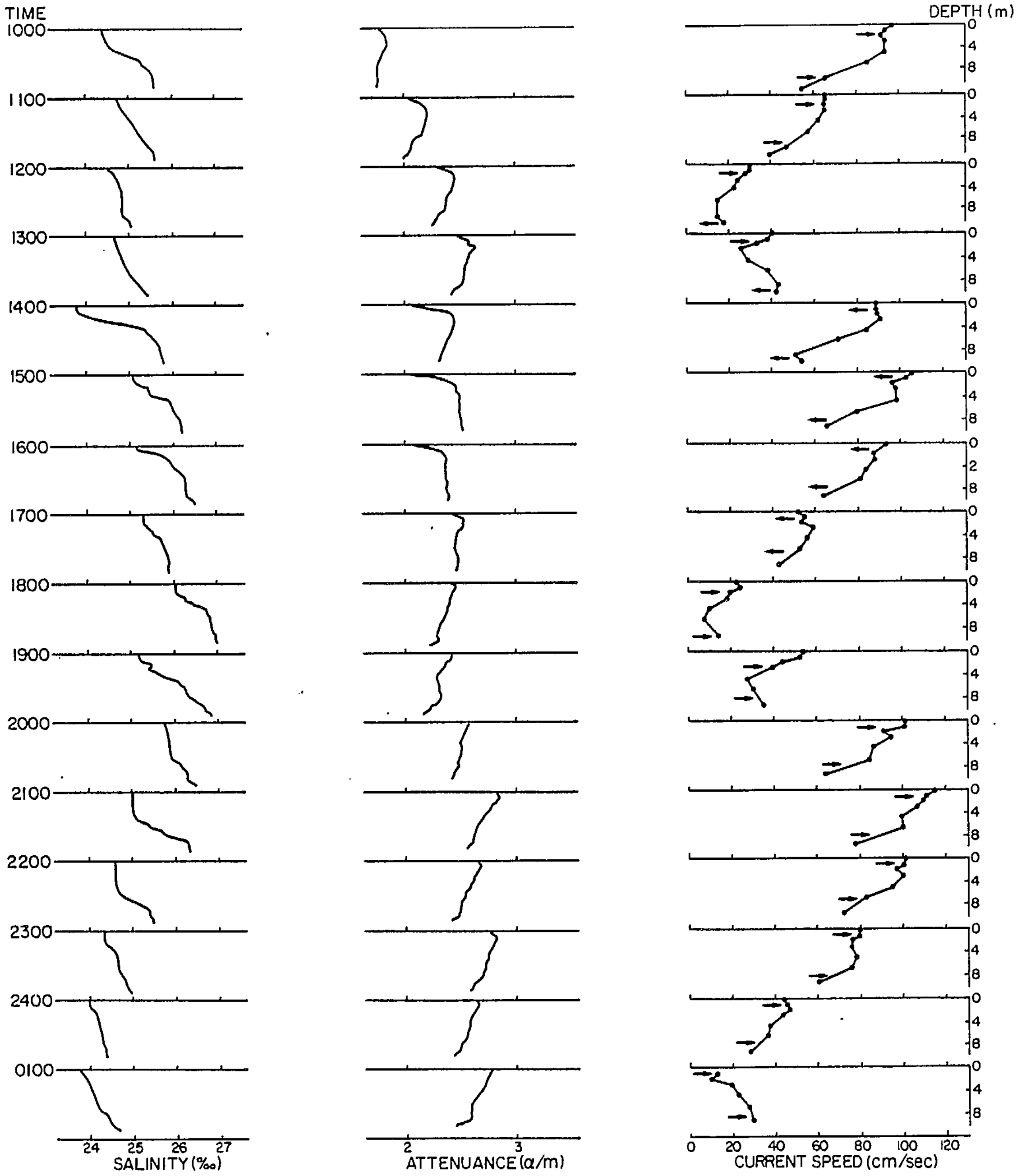


Fig. 11. Salinity, light attenuance and current speed variation and inferred direction (arrows) with depth over 24 hours at station A (Fig. 1). Direction of ebb currents and river flow is towards the right.

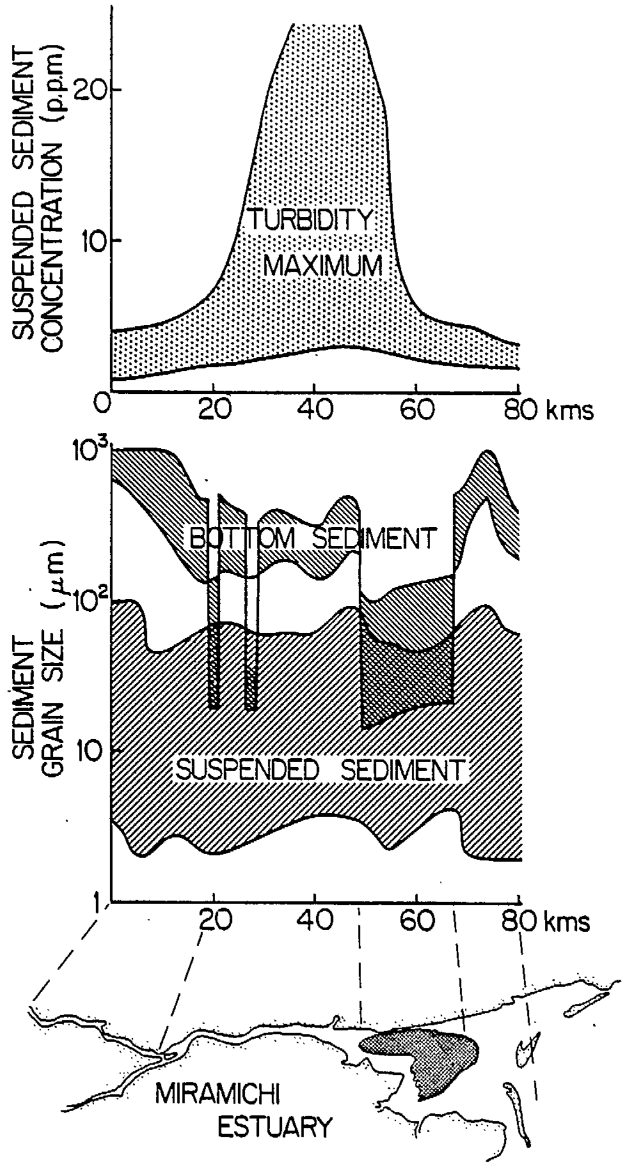


Fig. 12. Sediment properties along central channel showing ranges of suspended sediment concentrations recorded and modal to maximum grain size of suspended and bottom sediment. Note overlap of suspended and bottom sediment size range in muddy central area near seaward end of turbidity maximum.

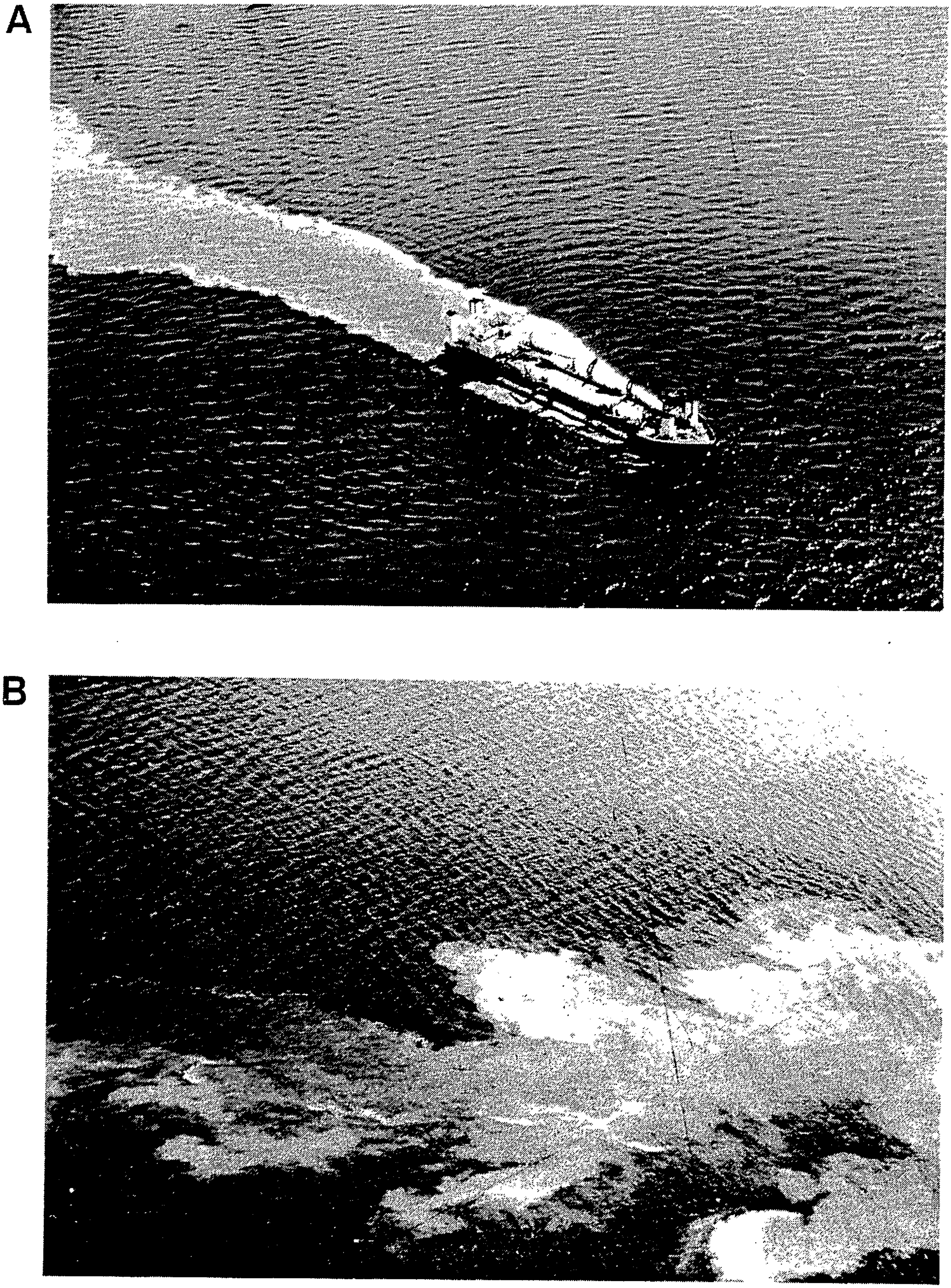


Fig. 13, A. Photograph of dredge working in Miramichi Bay showing turbid water formed by overflow. B. Turbid plume left behind by dredge. (Courtesy of A. McIver, E.P.S., Environment Canada).

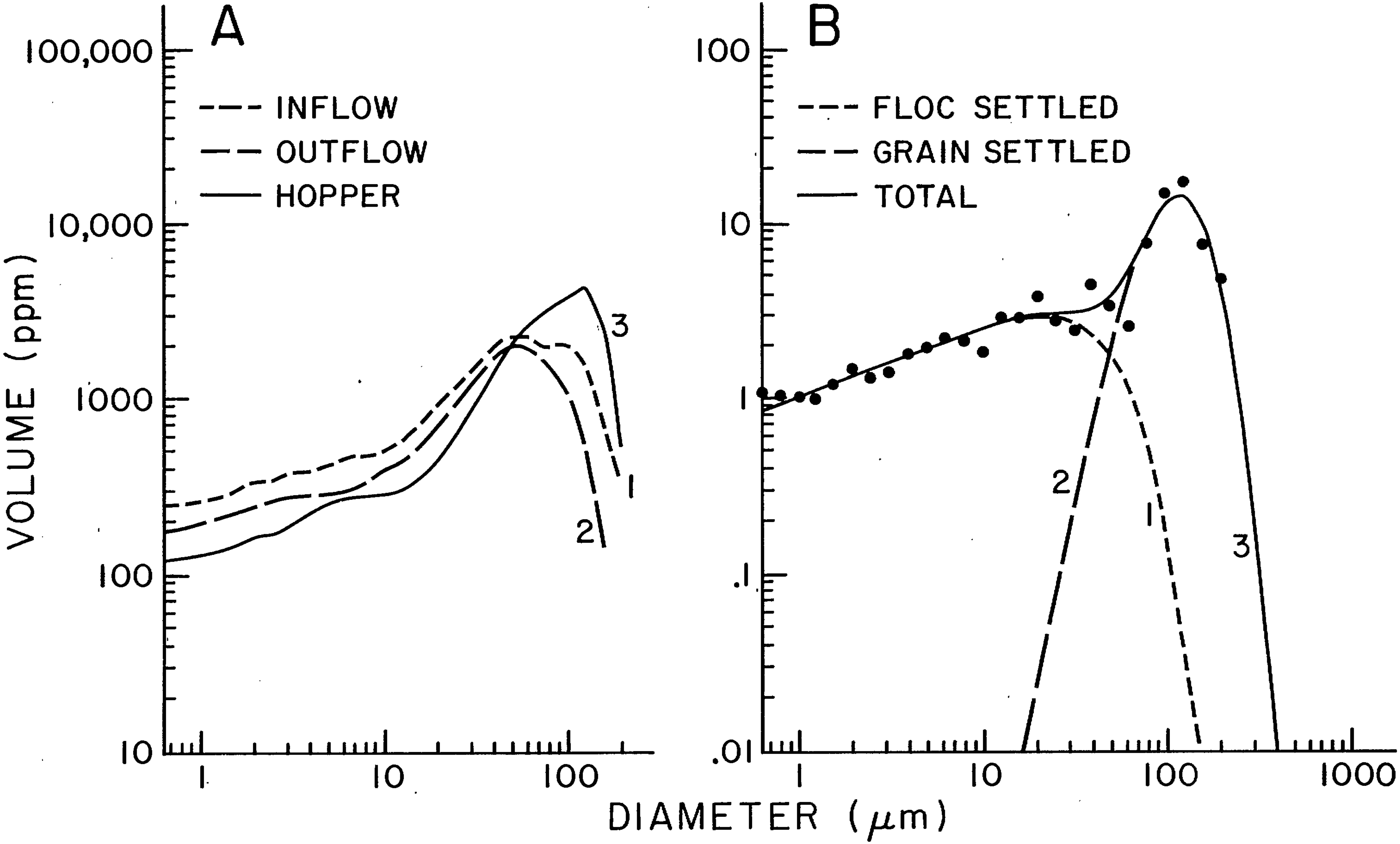


Fig. 14, A. Grain size distributions of slurry samples collected from the dredge while operating in the Channel portion of the estuary. B. Grain size distribution of sample retained by the dredge as inferred from the difference between inflow and outflow. Floc and grain settled portions determined according to Kranck and Milligan, 1985.

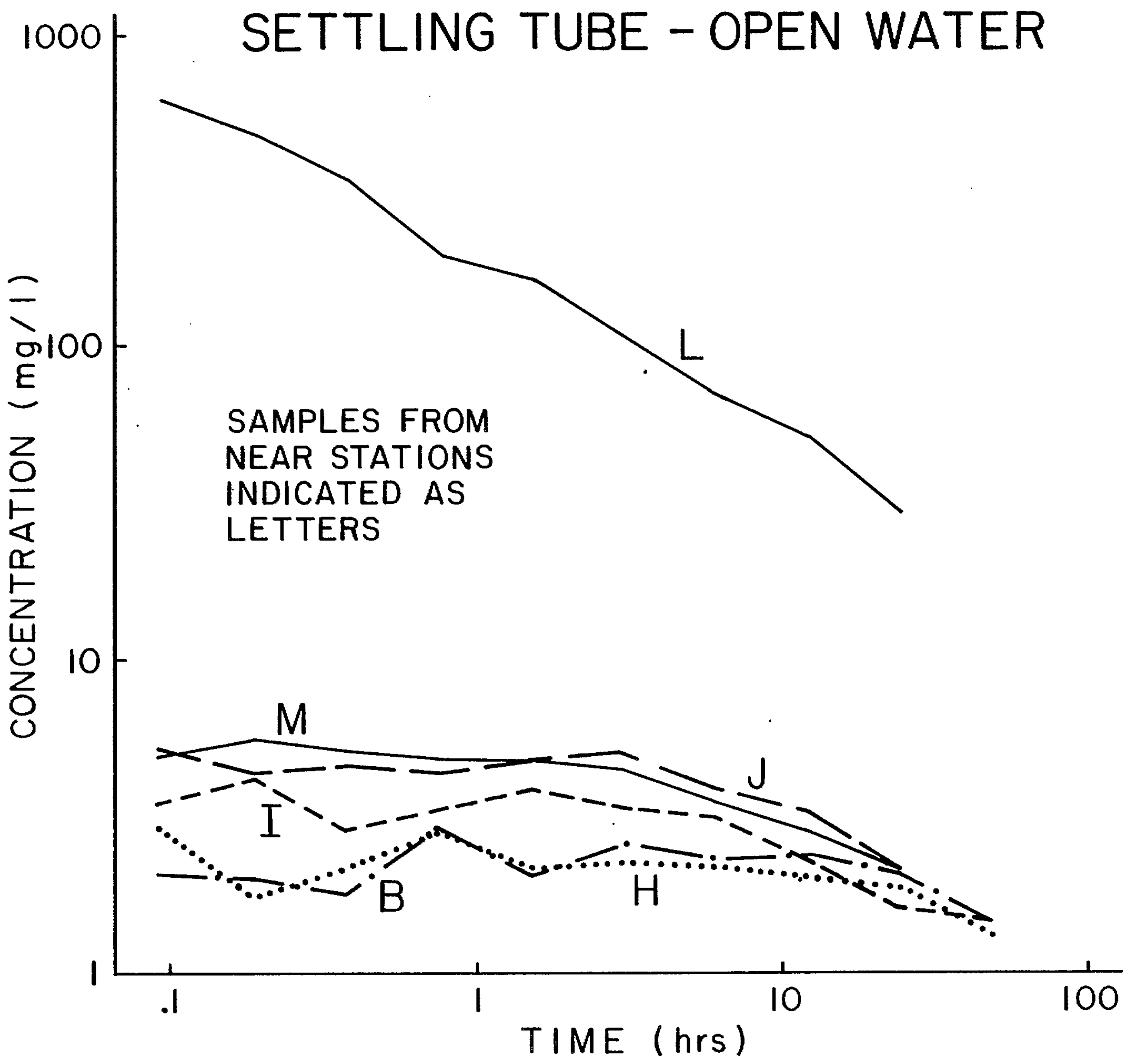


Fig. 15. Decrease in total suspended sediment concentration with time in experimental settling of water samples from Miramichi Bay. Sample from near station L was collected in plume from dredge overflow.

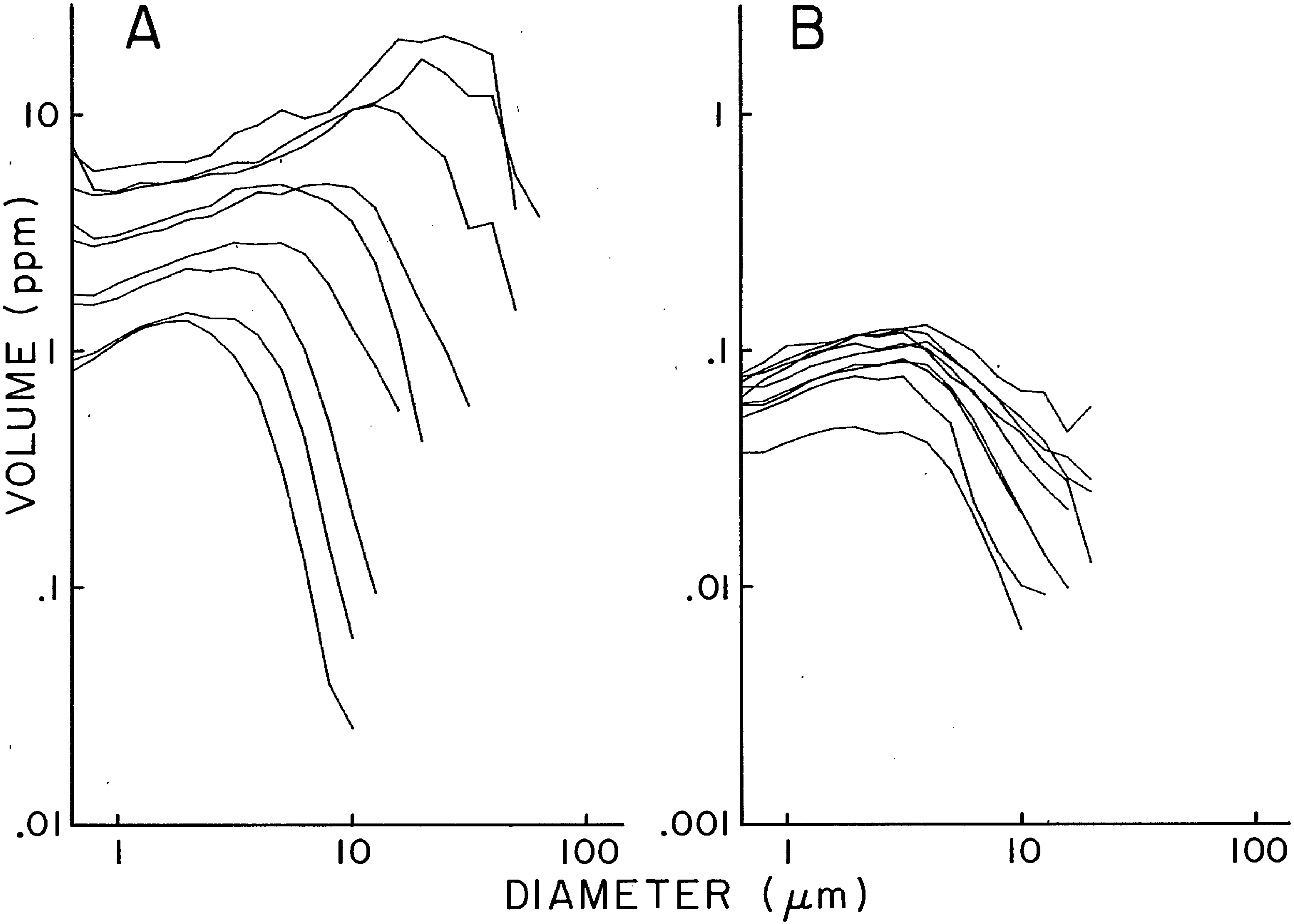


Fig. 16. Grain size analysis from settling experiments show size distributions of sediment remaining in suspension after logarithmically increasing periods of settling. Sampling times correspond to data points in Fig. 15. A. Sample collected adjacent to dredge working near station L. B. Sample collected near station I.

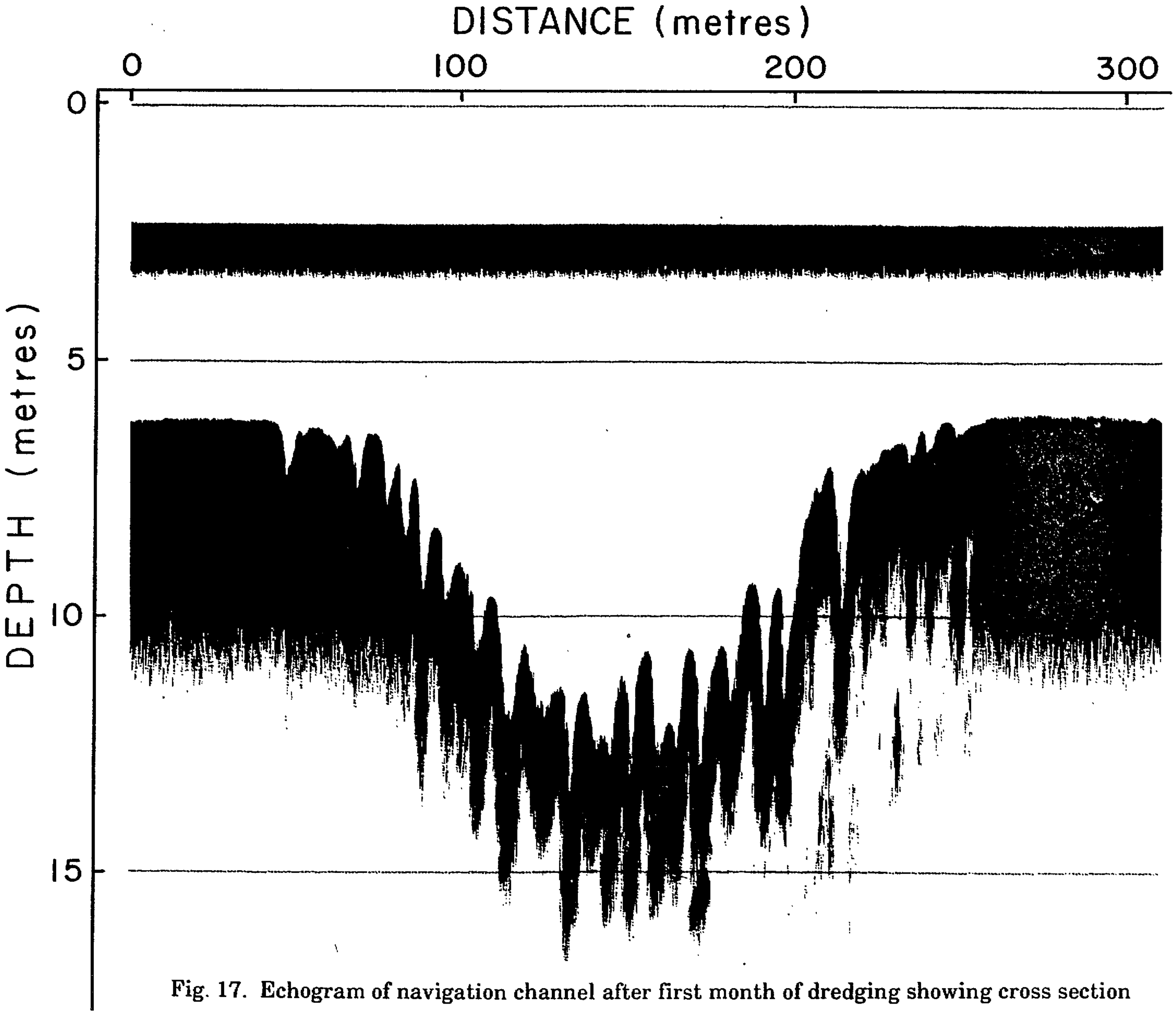


Fig. 17. Echogram of navigation channel after first month of dredging showing cross section of longitudinal ridges formed by trailing hopper arm.

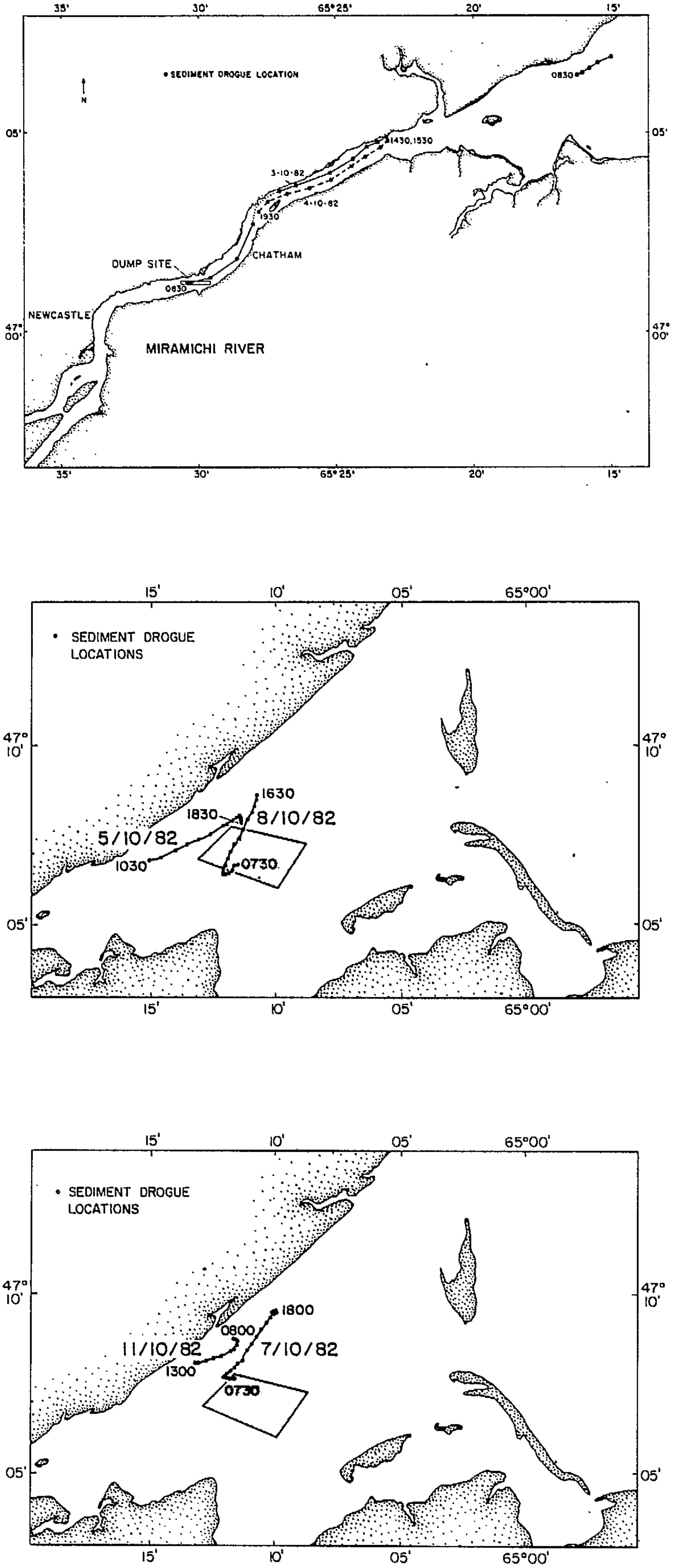


Fig. 18 a-c. Drift paths of drogues.

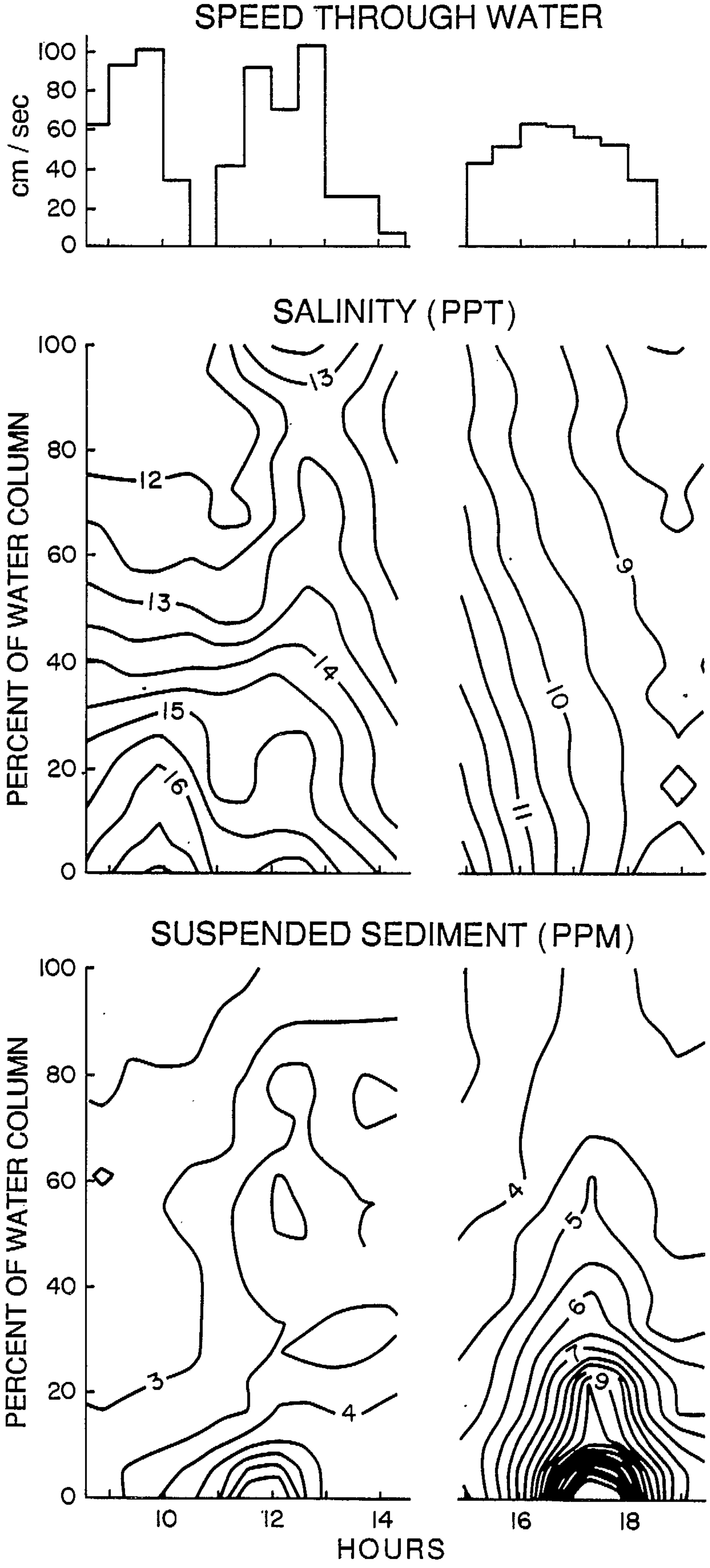


Fig. 19. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 3&4.10.1988.

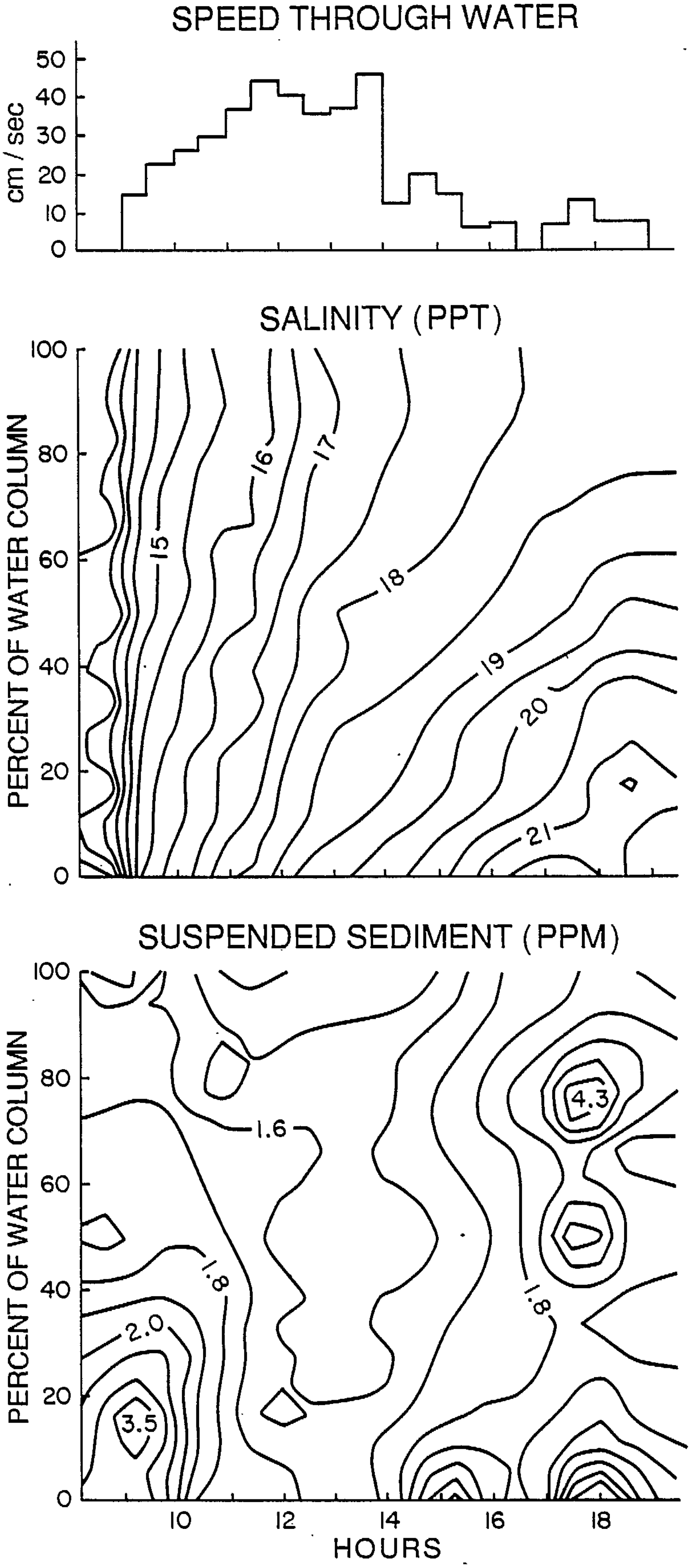


Fig. 20. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 5.10.1988.

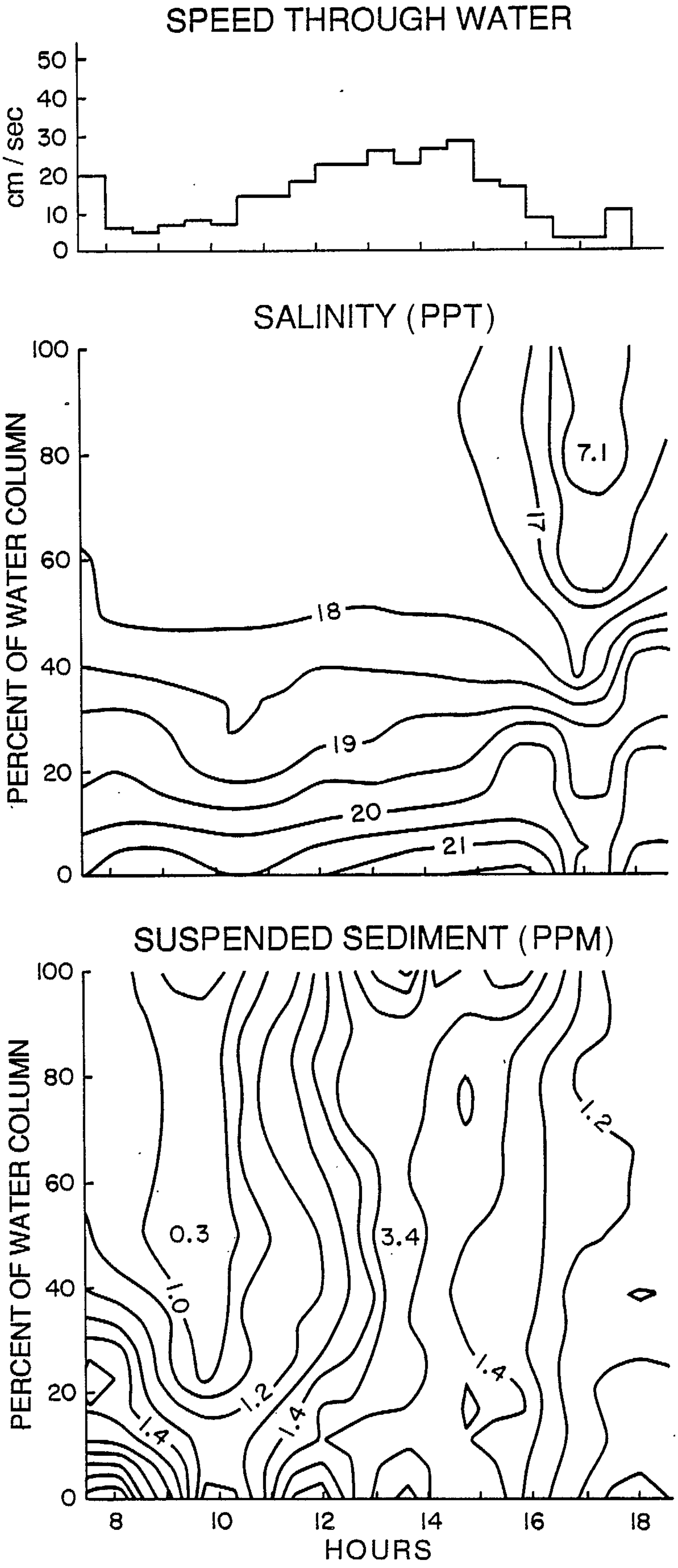


Fig. 21. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 7.10.1988.

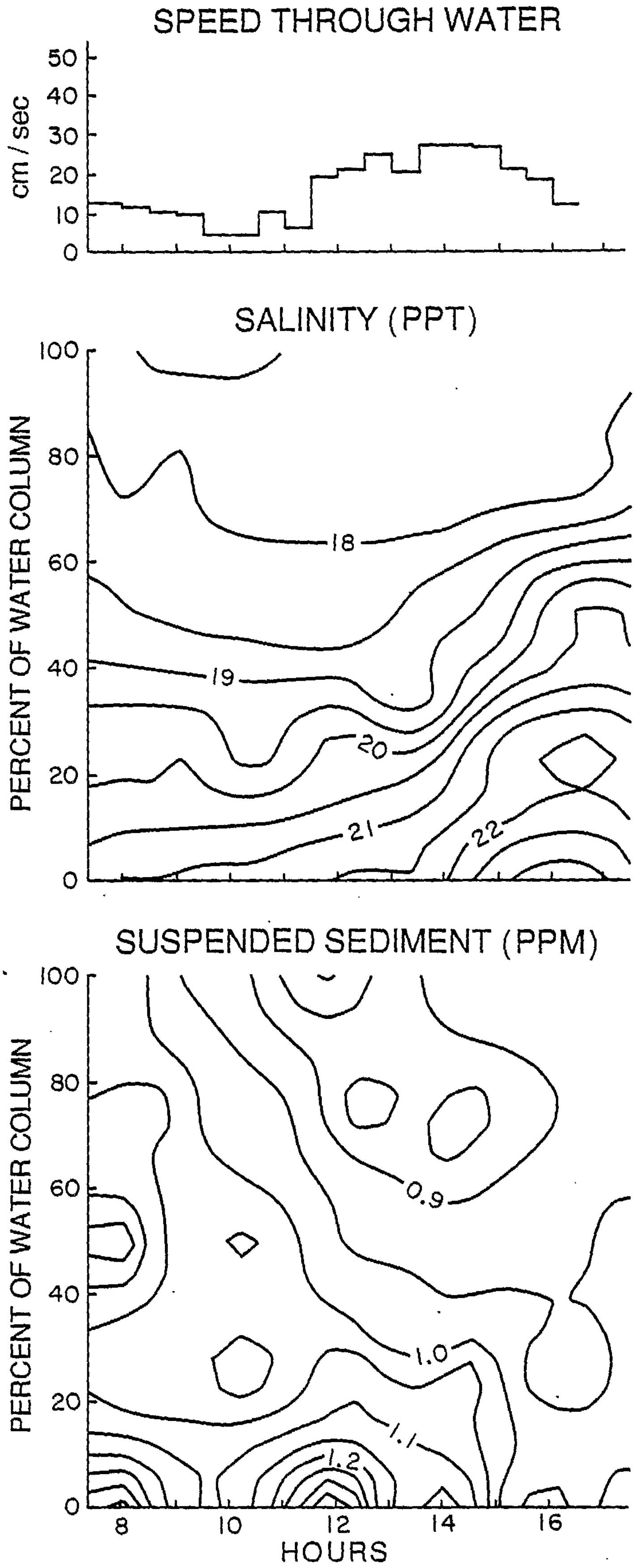


Fig. 22. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 8.10.1988.

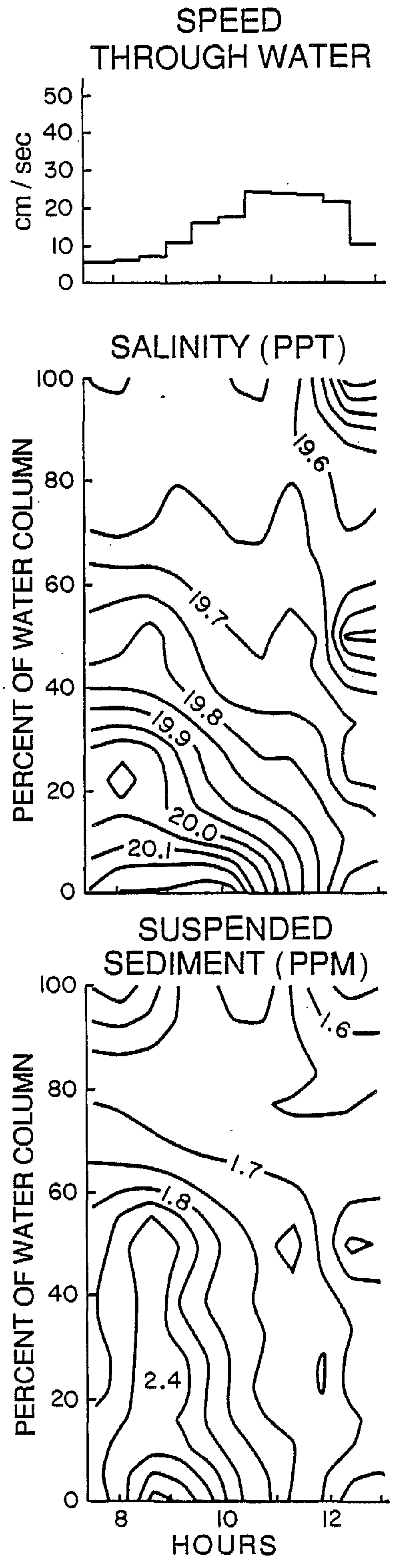
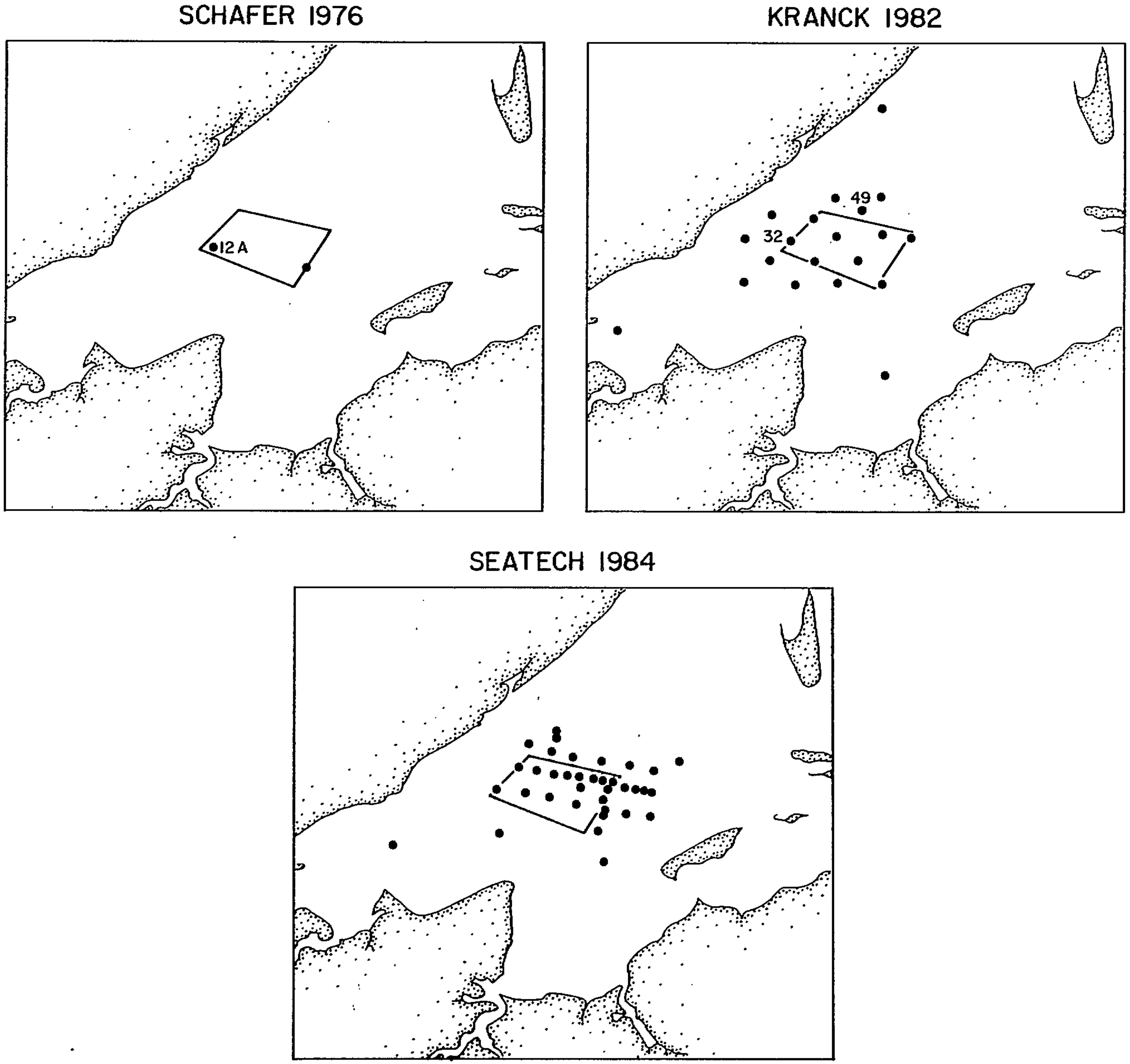


Fig. 23. Drift speed, salinity and total suspended sediment concentration along path of the drogue of 11.10.1988.



SCHAFER 1976

KRANCK 1982

SEATECH 1984

Fig. 24. Location of cores from vicinity of the dumpsite.

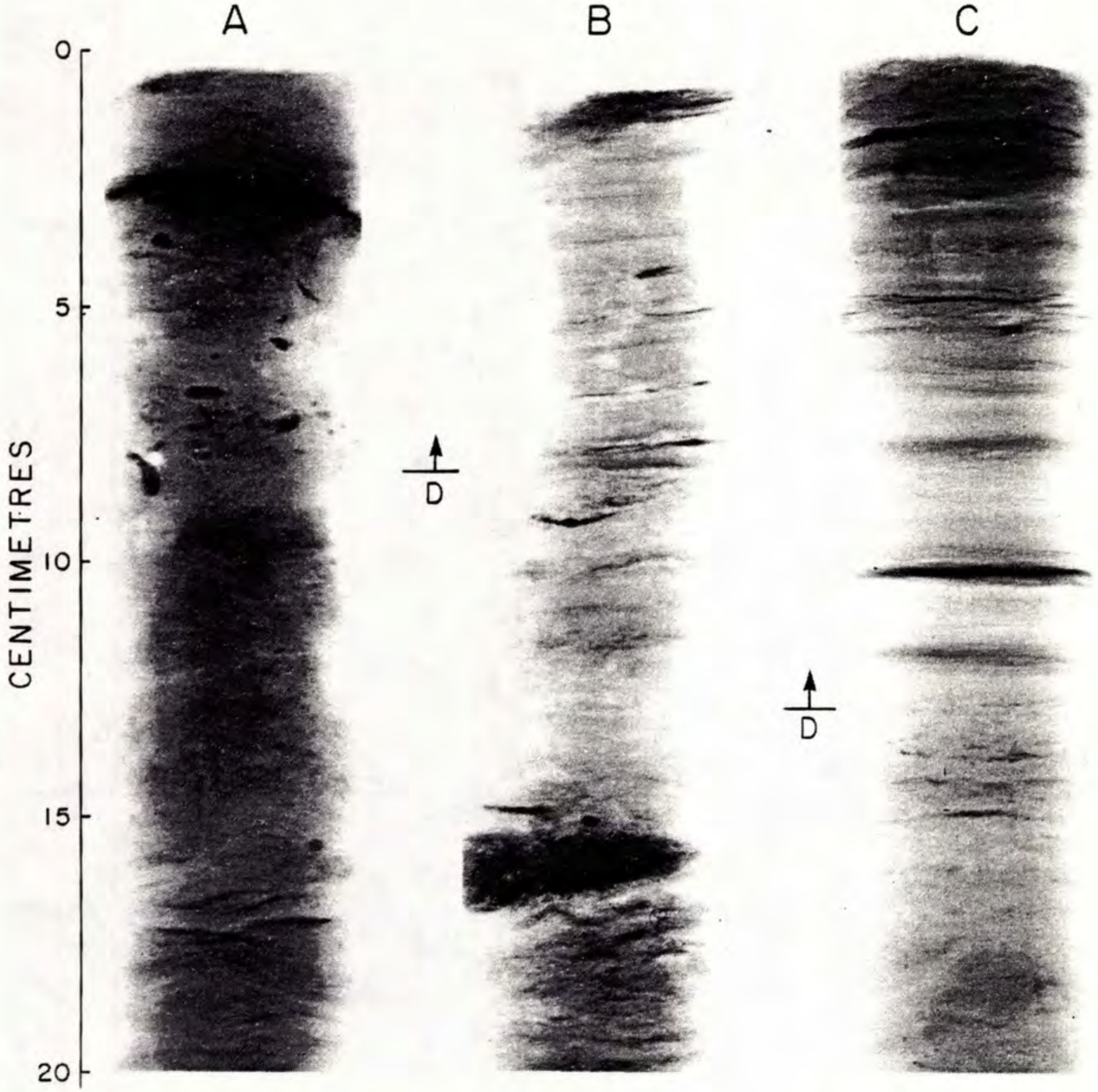


Fig. 25. X-radiographs of cores. A: Core 12A (courtesy of C.T. Schafer, AGC, Geological Survey of Canada). B: Core 32, C: Core 49. Arrow shows start of dredge related material.

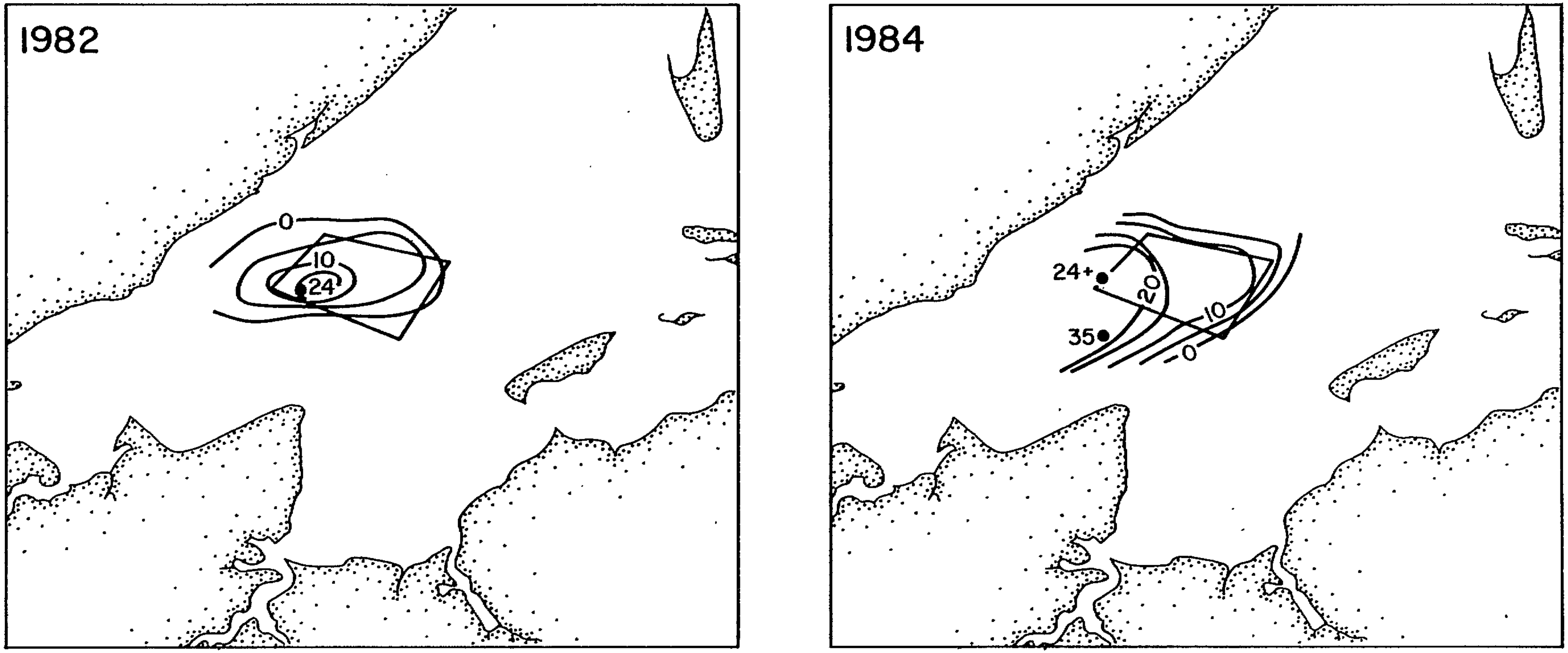


Fig. 26. Distribution of dredge related sediment around the dumpsite B. Contours show thickness of banded sediment in centimetres.

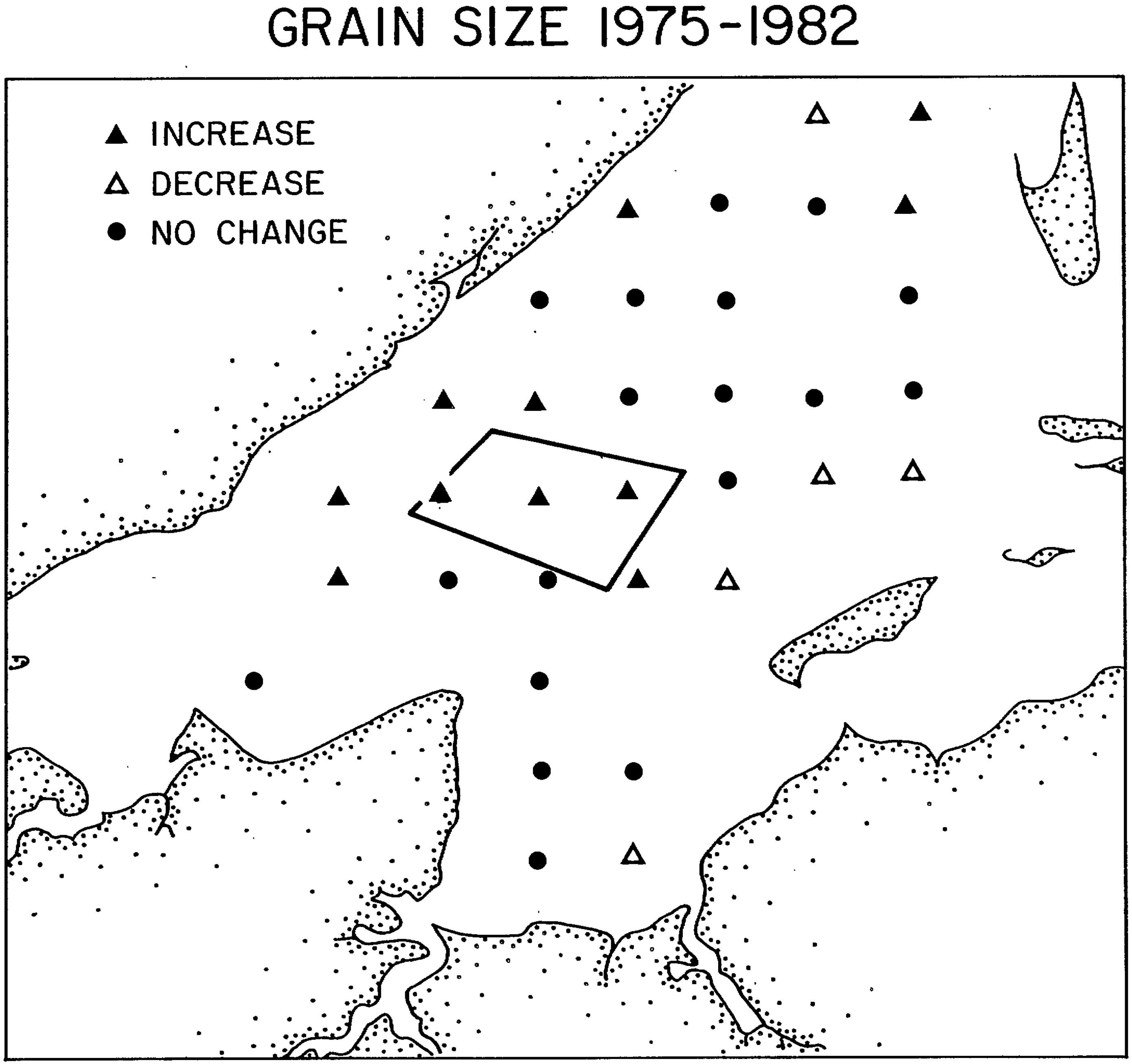


Fig. 27. Changes in grain size of bottom samples collected in 1975 and 1982.

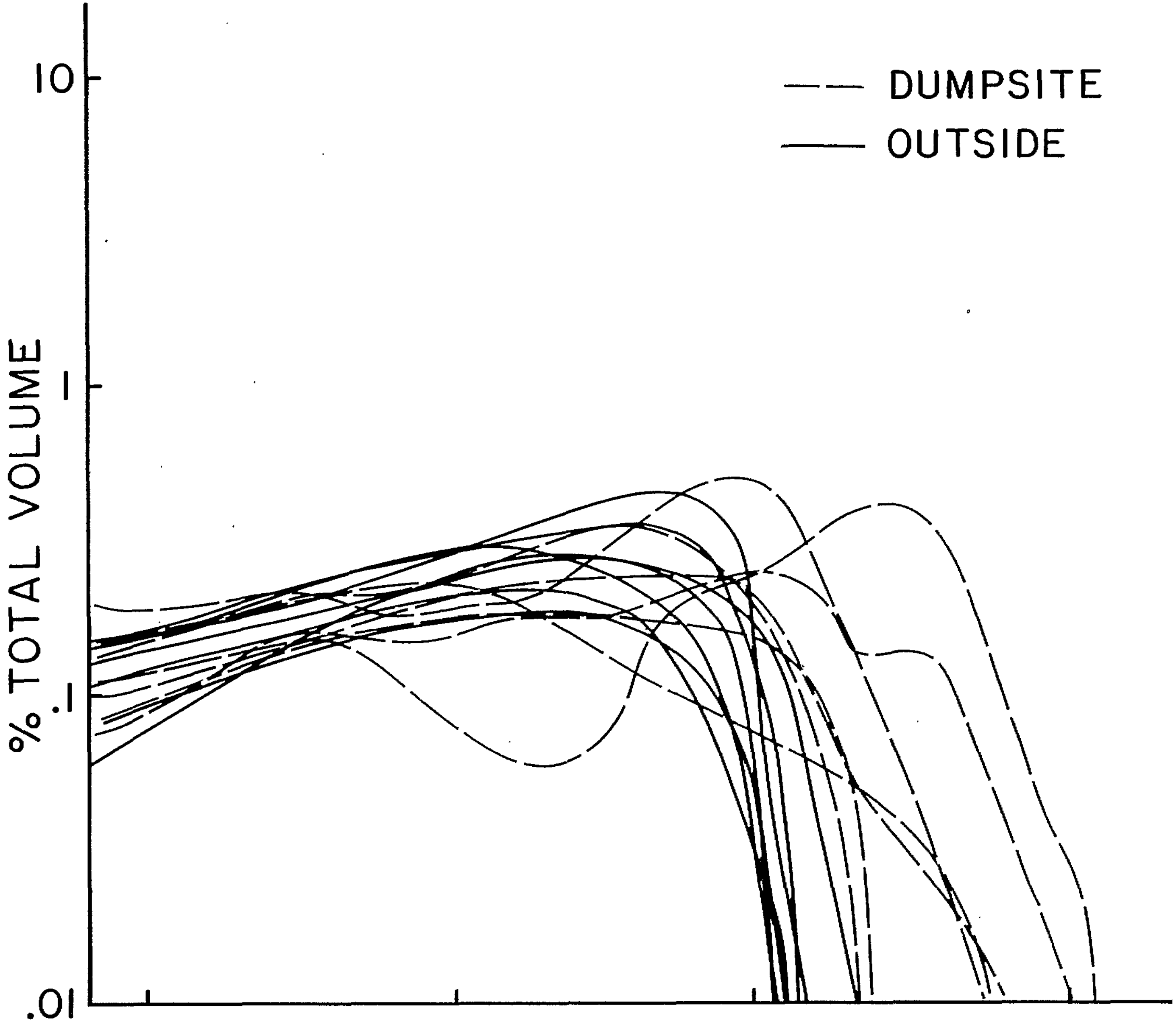


Fig. 28. Grain size spectra of bottom sediments collected along the path of drogue of 8.10.1988 showing coarser sediment on the dumpsite.