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SEDIMENTOLOGY AND GEOCHEMISTRY OF MARINE SEDIMENTS NEAR COMOX, BRITISH COLUMBIA

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SEDIMENTOLOGY AND GEOCHEMISTRY OF MARINE SEDIMENTS NEAR COMOX, BRITISH COLUMBIA

Abstract

The estuary of Courtenay River includes an elongate sedimentary basin separated from the main part of the Strait of Georgia by a shallow, flat-topped sill (Comox Bar). Holocene sediments in this basin and in a similar basin east of Comox Bar consist mainly of clayey silt and sandy silt introduced into the area by streams and rivers and by wave erosion of coastal bluffs.

In contrast to the sediments in the basins, those on Comox Bar and nearshore to Vancouver Island are mainly well sorted sand and gravel. Comox Bar is thought to be the eroded remnant of a once continuous subaerial ridge of Pleistocene sediments which connected the north tip of Denman Island to Vancouver Island.

Goose Spit southeast of Comox is maintained by longshore drift of coarse grained sediment eroded from nearby coastal bluffs.

Trace metal contents are highest in the basins and lowest on Comox Bar. Differences are largely related to sediment texture, the finest sediments having the highest metal contents. Concentrations of most analyzed elements are comparable to or less than concentrations from other estuarine sediments in southwest British Columbia. However, anomalously high concentrations of lead occur in some sediment samples south of Goose Spit and east of Comox Bar.

Résumé

L'estuaire de la rivière Courtenay comprend un bassin sédimentaire allongé, séparé de la partie principale du détroit de Géorgie par un seuil peu profond et aplani (la flèche littorale de Comox). Les sédiments holocènes de ce bassin et d'un bassin semblable, situés à l'est de la flèche de Comox, consistent principalement en silt argileux et en silt sablonneux qui ont été déposés dans la région par des cours d'eau, et par l'action érosive des vagues sur les falaises.

Contrairement aux sédiments des bassins, ceux que l'on rencontre sur la flèche de Comox et à proximité de la rive de l'île Vancouver se composent principalement de sables et de graviers bien classés. On croit que la flèche de Comox est le vestige érodé d'une crête subaérienne de sédiments pléistocènes, autrefois continue, qui aurait jadis relié l'extrémité septentrionale de l'île Denman à l'île Vancouver.

La flèche littorale de Goose, située au sud-est de Comox, est entretenue par un courant littoral constitué de sédiments à grains grossiers, qui proviennent de l'érosion des falaises situées à proximité.

Les teneurs en métaux à l'état de traces sont les plus fortes dans les bassins, tandis qu'elles sont les plus faibles sur la flèche de Comox. Les différences observées dépendent largement de la texture des sédiments, les sédiments les plus fins possédant les plus fortes teneurs en métaux. Les concentrations de la plupart des éléments analysés sont égales ou inférieures aux concentrations observées chez les autres sédiments d'estuaires, trouvés dans le sud-ouest de la Colombie-Britannique. Toutefois, des concentrations en plomb, anormalement fortes, existent dans certains échantillons de sédiments recueillis au sud de la flèche de Goose et à l'est de la flèche de Comox.

INTRODUCTION

The estuarine environment is important both scientifically and economically, the former because of complex physiochemical and biological interactions resulting from the introduction of fresh water into a semi-enclosed body of sea water, the latter because estuaries are directly or indirectly utilized in furtherance of man's activities.

The environment of an estuary is controlled by many factors, some of the more important of which are the morphology, physical oceanography, and biota of the estuarine basin; sediment and water discharge characteristics of inflowing rivers; composition and texture of rocks and subaerial sediments adjacent to the estuary; and the amount and character of chemical and organic wastes introduced as a result of industrial and urban activities.

Because they are comparatively small in relation to adjacent bodies of sea water and because they comprise complex and delicate ecosystems, estuaries are particularly susceptible to change. For example, a decrease in the volume of sediment input into an estuary as a result of river channel dredging may alter the stability of a delta front or may affect benthic organisms off the river mouth. Likewise, the introduction of industrial wastes may alter biologic systems and increase the concentrations of certain trace elements in the bottom sediments.

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This report describes one estuary on the east coast of Vancouver Island. Granulometric and geochemical data are presented and interpreted. The purposes of the study are to document patterns of sediment dispersal within and adjacent to the estuary and to provide baseline geochemical and granulometric data by which the effects of future changes in the estuarine environment may be assessed.

Acknowledgments

Grain-size analyses were done by the Geological Survey of Canada and Beak Consultants Ltd., trace metal determinations by Bondar-Clegg and Company Ltd., and carbon analyses by Can Test Ltd. Preliminary versions of the manuscript were reviewed by Drs. B.D. Bornhold, C.F.M. Lewis, and J.L. Luternauer. This work is part of a larger study of the Quaternary geology of the northern Strait of Georgia undertaken by the Geological Survey of Canada.

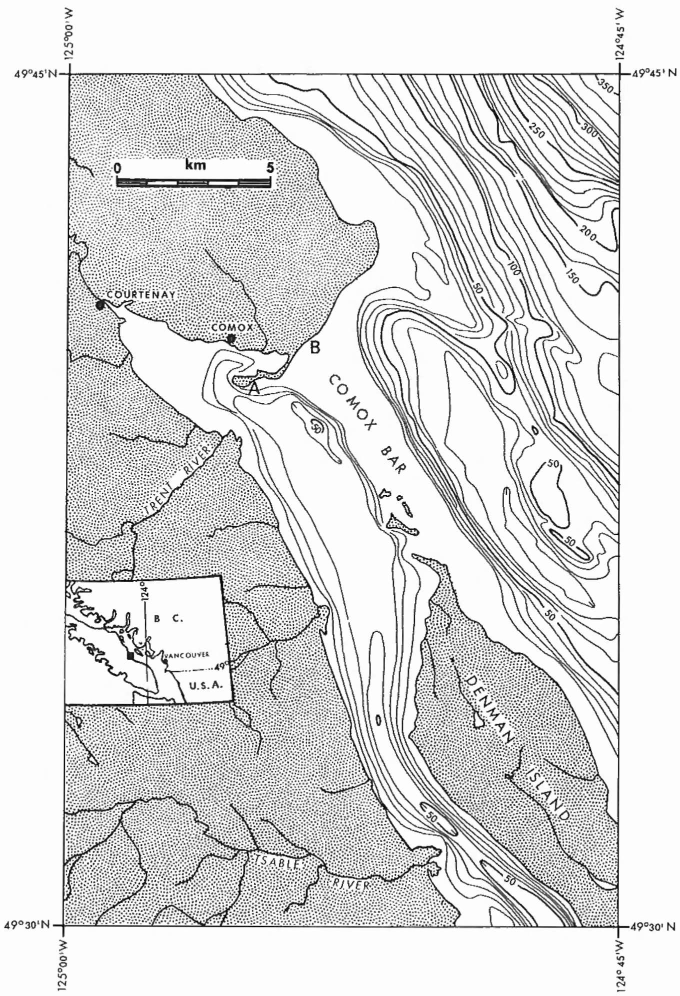

Figure 1. Index map showing bathymetry of study area (depths in metres). Goose Spit is located at A, Willemar Bluff at B.

STUDY AREA

The area of investigation is located south and east of Comox, British Columbia (Fig. 1). Detailed sampling was limited to the area between 49°36' and 49°42'N and between 124°46' and 124°56'W. This region is divisible into three major bathymetric elements: a shallow, flat-topped sill (Comox Bar) trending northwest-southeast between Vancouver Island and Denman Island, a trough (hereafter the inner trough) to the west of the sill with a maximum depth of 50 m, and a trough (the outer trough) immediately east of the sill with a maximum depth of 100 m. Southeast of Comox is Goose Spit (A in Fig. 1) which extends southwest from a headland near Willemar Bluff (B in Fig. 1) into the inner trough.

The inner trough includes the estuary of Courtenay River, the active delta of which extends from Courtenay to about 1 km west of Goose Spit. Tidal flats of the delta are separated from the floor of the inner trough by a depositional front sloping up to 6 degrees. Puntledge and Tsolum rivers, which join to form Courtenay River, have mean annual discharges of 43 and 11 m^3/s, respectively (Water Resources Branch, 1974, p. 492, 628). Courtenay River is thus the major source of fresh water, and probably sediment, to the trough. Tsable River (mean annual discharge 8 m^3/s; Water Resources Branch, 1974 p. 628) empties into the inner trough about 10 km south of the study area. Other streams and rivers, such as Trent River, are likely of secondary importance as suppliers of sediment.

Comox Bar, separating the inner and outer troughs, is submerged only a few metres at low tide. The bar is probably the eroded remnant of a former subaerial ridge of Pleistocene sediments connecting the headland near Comox with Denman Island (Mathews *et al.*, 1970, p. 696). Steep submarine slopes (locally exceeding 20 degrees) separate Comox Bar from the adjacent troughs.

The outer trough is bounded on the west by Comox Bar and on the east by a bank, the crest of which is 30 to 60 m below sea level (Fig. 1). The outer trough slopes from a depth of about 70 m at its margins to 100 m at its centre; the floor is not as flat as that of the inner trough.

North and east of the outer trough, the sea floor slopes towards the centre of the Strait of Georgia which has a maximum depth of about 430 m. The sediments and morphology of the northern Strait of Georgia are discussed by Clague (1975a, b) and are the subjects of continuing study. Sediments in the central and southern strait are described by Tiffin (1969) and Pharo (1972).

ANALYTICAL METHODS

Field and Laboratory Procedures

Sediment samples were collected from the inner and outer troughs with a Shipek sampler and from Comox Bar with an Ekman sampler. A single core was taken from the inner trough with an Alpine piston corer. Samples were collected over a regular grid, the sample spacing in the inner trough being 0.5 km and in the outer trough 1 km (Appendix A). Positioning was achieved by radar.

After collection each sediment sample was split into two equivalent parts, one for grain-size analysis and the second for geochemical analysis. The former were stored in polyethylene bags and plastic tubs, the latter in high strength kraft bags. All samples were frozen until processe in the laboratory.

Sediments were analyzed for their particle-size distributions by standard sieve and pipette procedures. Analyses at one-phi intervals from -5 to 9ϕ (32 to 0.002 mm) were performed on 124 grab samples and on 8 subsamples from the core. Percentages of sand-, silt-, and clay-size detritus were determined for the remainder (55) of the grab samples.

Trace metal concentrations in 161 grab samples and in the 8 subsamples from the core were determined by atomic absorption spectroscopy. Each sample was first wet-sieved through a 4ϕ (0.0625 mm) stainless steel screen.[1] The silt- and clay-size material was then air dried, weighed, and digested in hot LeFort aqua regia; concentrations of Ag, Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, and Zn were determined with Techtron AA-4 and AA-5 instruments. Background corrections were made for Ag, Cd, and Pb with a hydrogen lamp as a continuum source. Replicate analyses were performed on about 5 per cent of the samples, and both synthetic and matrix standards were used constantly during analysis.

Organic carbon contents of 5 samples from the study area and of about 100 samples from elsewhere in the northern Strait of Georgia were analyzed in a high-frequency induction furnace. The subgravel (< 2 mm) size fraction of each sample was ground to pass through a 2.75ϕ (0.149 mm) screen. A weighed split was then digested in acid and analyzed in a Leco furnace. Replicate analyses were performed on all samples, and certified cast iron standards were used for calibration.

Data Processing

Granulometric and geochemical data were processed with an IBM 360, model 67 computer at the University of British Columbia. A computer program package developed by the Department of Geological Sciences at the University of British Columbia and modified by Terrain Sciences Division of the Geological Survey of Canada was used to construct particle-size histograms and cumulative curves and to determine various statistical measures relating to the granulometry of the samples. Geochemical and particle-size data were subjected to correlation and regression analysis using UBC TRIP (Bjerring and Seagraves, 1974), a library program of the Computer Sciences Centre at the University of British Columbia.

[1] Samples containing insufficient mud for analytical determination of trace element concentrations were sieved through a 2.75ϕ (0.149 mm) screen. These are indicated in Appendix B.

RESULTS

Complete data for all analyzed samples are listed in Appendices A and B.

Sedimentology

Bottom sediments in the study area are mainly of the following types, as defined by Shepard (1954): Clayey silt, sandy silt, silty sand, sand, gravelly sand,

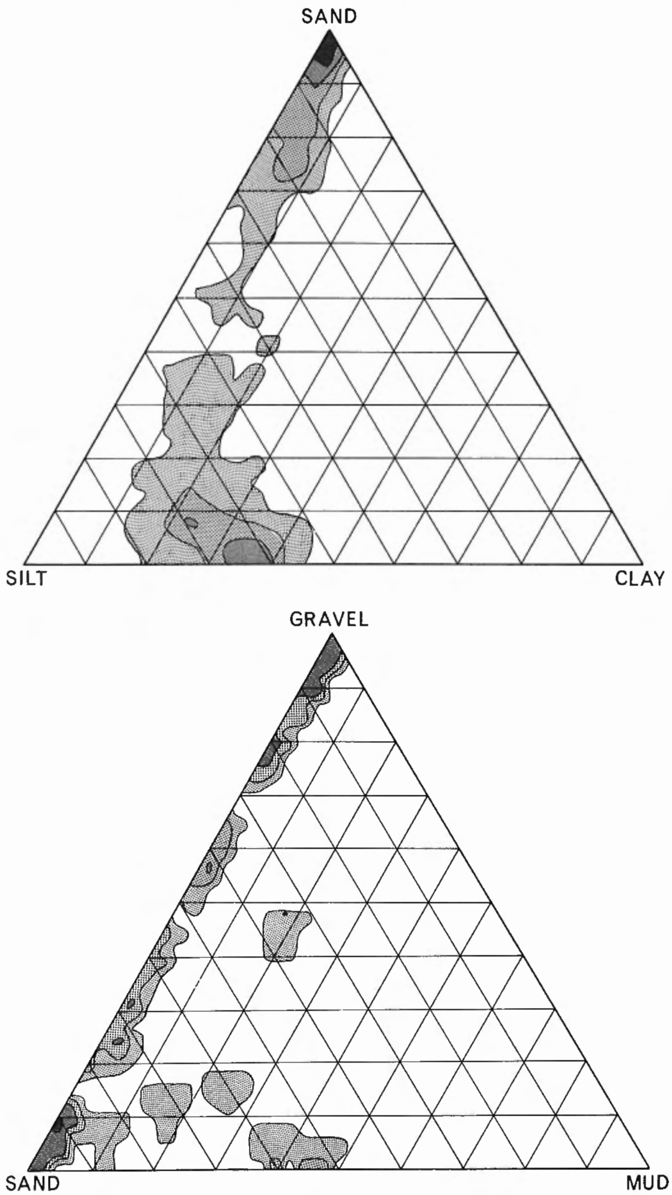

Figure 2. Contoured triangular diagrams showing sand-silt-clay ratios of nongravelly samples (top), and gravel-sand-mud ratios of samples containing more than 1 per cent gravel (bottom). Contours are 1, 5, 10, and 20 per cent per 1 per cent area, where the number of samples forming the top diagram is 148 and the bottom diagram 31.

Table 1

Grain-size parameters and water depths of sediment groups

Sediment group	Number of samples	Grain size		Water depth (m)
		Mean	Standard deviation	
Clayey silt	26	6.8 (0.7)	2.5 (0.2)	42 (21)
Sandy silt	7	5.4 (0.5)	2.6 (0.3)	50 (26)
Silty sand	16	3.5 (0.5)	2.0 (0.6)	35 (18)
Sand	44	2.5 (0.4)	1.0 (0.4)	29 (20)
Gravel > 1%	31	-0.5 (2.4)	2.0 (0.9)	14 (15)

Note: values in table are mean and standard deviation (latter in parentheses) for sample groups shown in Figure 5.

sandy gravel, and gravel (Figs. 2 and 3). Fine grained sediment, mainly clayey silt, is confined to the two troughs. Sandy silt and silty sand occur on slopes bounding the troughs. The surface sediments on Comox Bar and on the bank east of the outer trough are sand and gravel. Coarse grained sediment also occurs in shallow water along the coast of Vancouver Island and extends across the inner trough south of Goose Spit. A small elevated area of the sea floor west of Denman Island is covered by gravelly sand (Fig. 3).

The transition between coarse sediment on Comox Bar and clayey silt in the inner trough is remarkably sharp (Figs. 3 and 4). In contrast, the transition from coarse to fine grained sediment in the outer trough is more gradual. Despite the fact that the outer trough is about twice as deep as the inner trough, sediments in the former are somewhat coarser than in the latter. For example, no sample from the outer trough contains less than 7 per cent sand-size material, whereas several from the inner trough contain about 1 per cent sand.

Most sediment groups shown in Figure 3 (for example, sand, silty sand, sandy silt, and clayey silt) have characteristic mean grain-size and sorting characteristics (Fig. 5, Table 1). Gravelly sediments, on the other hand, have a wide range of particle-size distributions. Some contain only gravel-size material, others are mixtures of sand and gravel, and others are very poorly sorted mixtures of gravel, sand, and mud.

Geochemistry

Trace metal concentrations, in general, are highest in trough sediments and lowest in sediments on Comox Bar (Fig. 6, Table 2). The geochemical patterns shown in Figure 6 are similar to the grain-size patterns shown in Figure 4, indicating a close relationship of metal concentrations to the grain-size characteristics of the sediments. For example, all analyzed elements except Mn and Pb correlate moderately to strongly with mean grain size and per cent sand, silt, and clay (Table 3). Coarse sediments (e.g. those on Comox Bar) have relatively low concentrations of metals, whereas the clay-rich sediments in the troughs have the highest metal contents.

The distribution patterns of most trace elements are similar. Moderate to high positive correlation coefficients are obtained when the metals are regress against one another. Mn and Pb, however, do not correlate strongly with other metals (Table 3).

Table 2

Mean and range of trace metal concentrations

	Mean	Range
Ag	0.3	<0.2-0.8
Cd	1.1	<0.5-3.7
Co	10	<2-17
Cu	48	4-74
Fe	2.0	0.5-2.8
Hg	98	10-180
Mn	240	50-1630
Ni	26	<2-38
Pb	26	3-340
Zn	93	6-145

Note: all concentrations are expressed in ppm, except iron (%) and mercury (ppb).

A short core from the inner trough provides some data on vertical variations in trace element content (Fig. 7). For many metals (e.g. Ag, Co, Fe, Mn, and Ni) concentrations do not differ significantly through the core. In contrast, concentrations of Cu, Hg, Pb, and Zn appear to be higher, and Cd lower, at the top of the core. Differences in grain size within the core are comparatively minor.

Three clayey silt samples from the inner trough contain by weight 4.70, 6.85, and 7.70 per cent organic carbon. In contrast, sediments of similar texture from the northern Strait of Georgia excluding the inner trough average less than 2 per cent organic carbon (Clague, 1975b). One sample of clayey silt from the outer trough yielded 2.08 per cent organic carbon.

DISCUSSION

Sediment Distribution and Dispersal Patterns

The distribution of sediments within the study area is closely related to bathymetry. Muds and sandy muds are restricted to the troughs, whereas coarser, better sorted sediments occur on banks and in shallow water adjacent to Vancouver Island. This suggests that at shallow depths, wave and current energy is sufficiently high to prevent deposition of silt and clay. For example, sand and gravel occurring at shallow depths off Vancouver Island have been concentrated by wave and current energy from unconsolidated sediments exposed in nearby coastal bluffs. Likewise, tidal

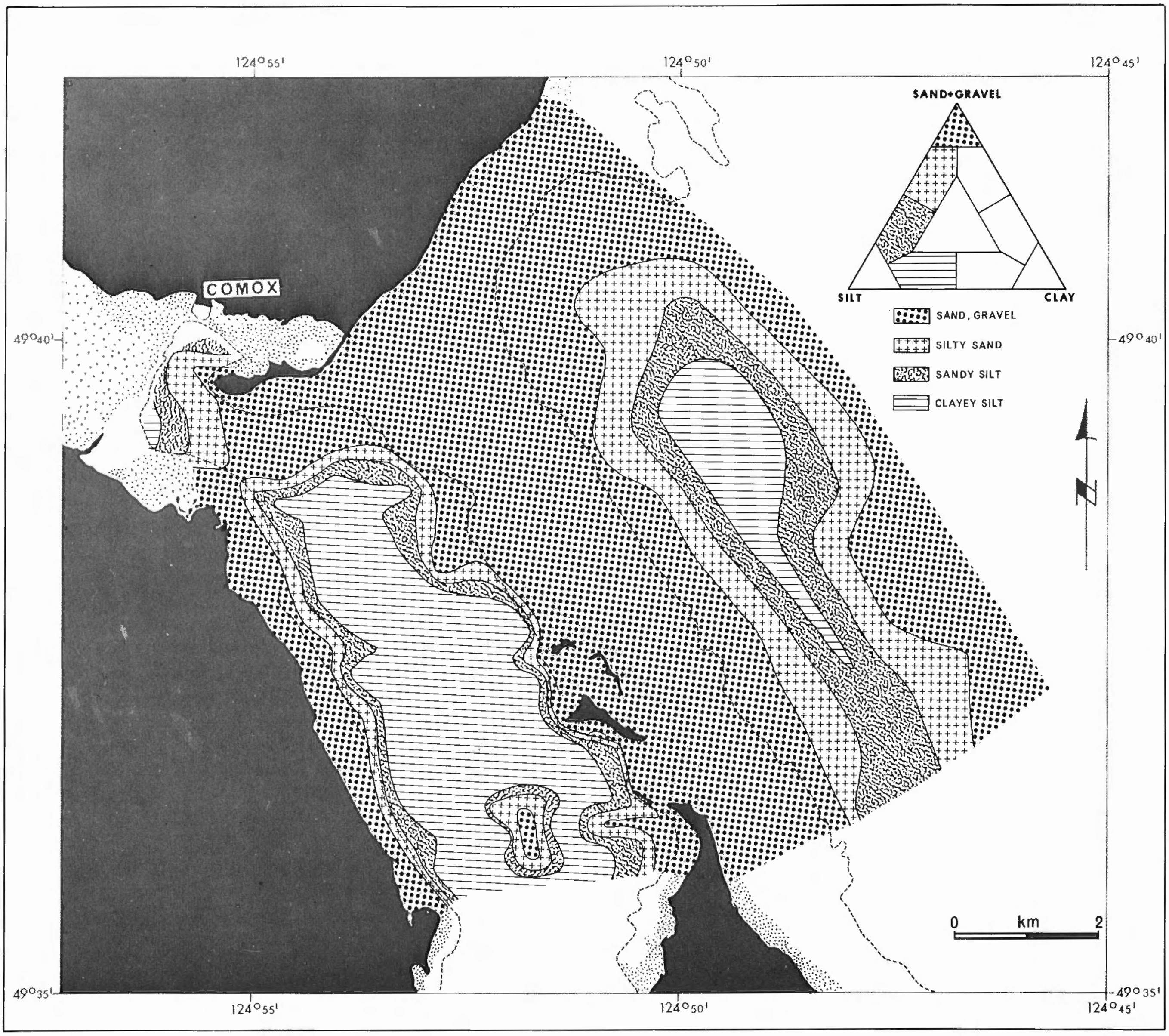

Figure 3. Distribution of sediment types; nomenclature after Shepard (1954). Dashed line is 10 m isobath.

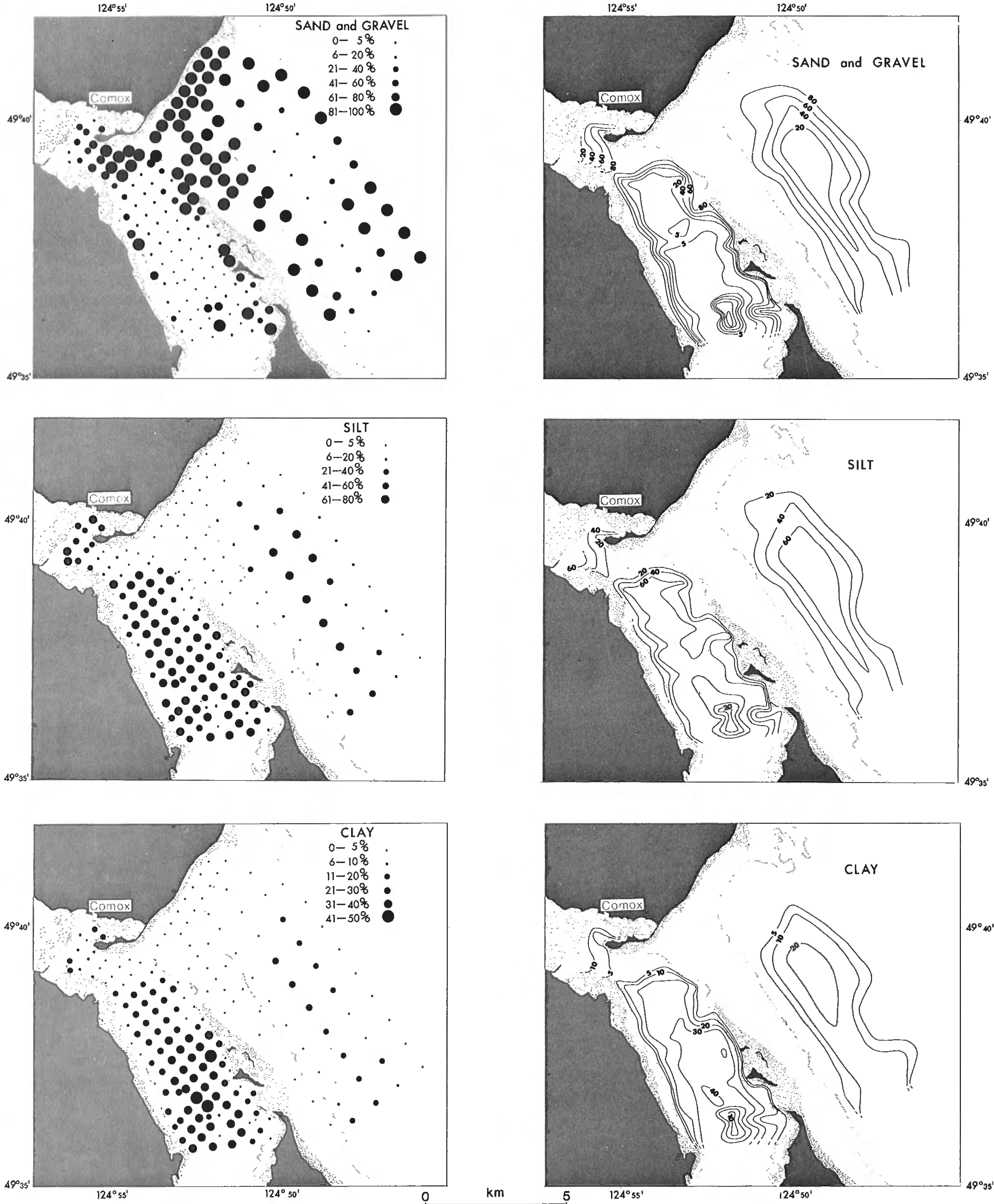

Figure 4. Distribution of sand and gravel (>0.0625 mm), silt (0.004 - 0.0625 mm), and clay (<0.004 mm). Numbers and isopleths indicate per cent of the sediment by weight.

currents over Comox Bar are probably of sufficient strength to transport mud and some sand. The coarse sediments occurring on the bar are perhaps lag concentrates from Pleistocene sediments which once formed a continuous subaerial ridge between Denman and Vancouver Islands. Remnants of this ridge at the north end of Denman Island and near Comox comprise a variety of sediment types, including diamictons of glacial and glaciomarine origin, clay, silt, sand, and gravel (Fyles, 1960). Presumably, similar materials form the core of Comox Bar.

Sedimentation in the troughs probably has been continuous throughout postglacial time. Continuous seismic profiles across the outer trough indicate that Holocene sediments are up to 50 m thick there (Fig. 8), and it is probable that sediments in the inner trough

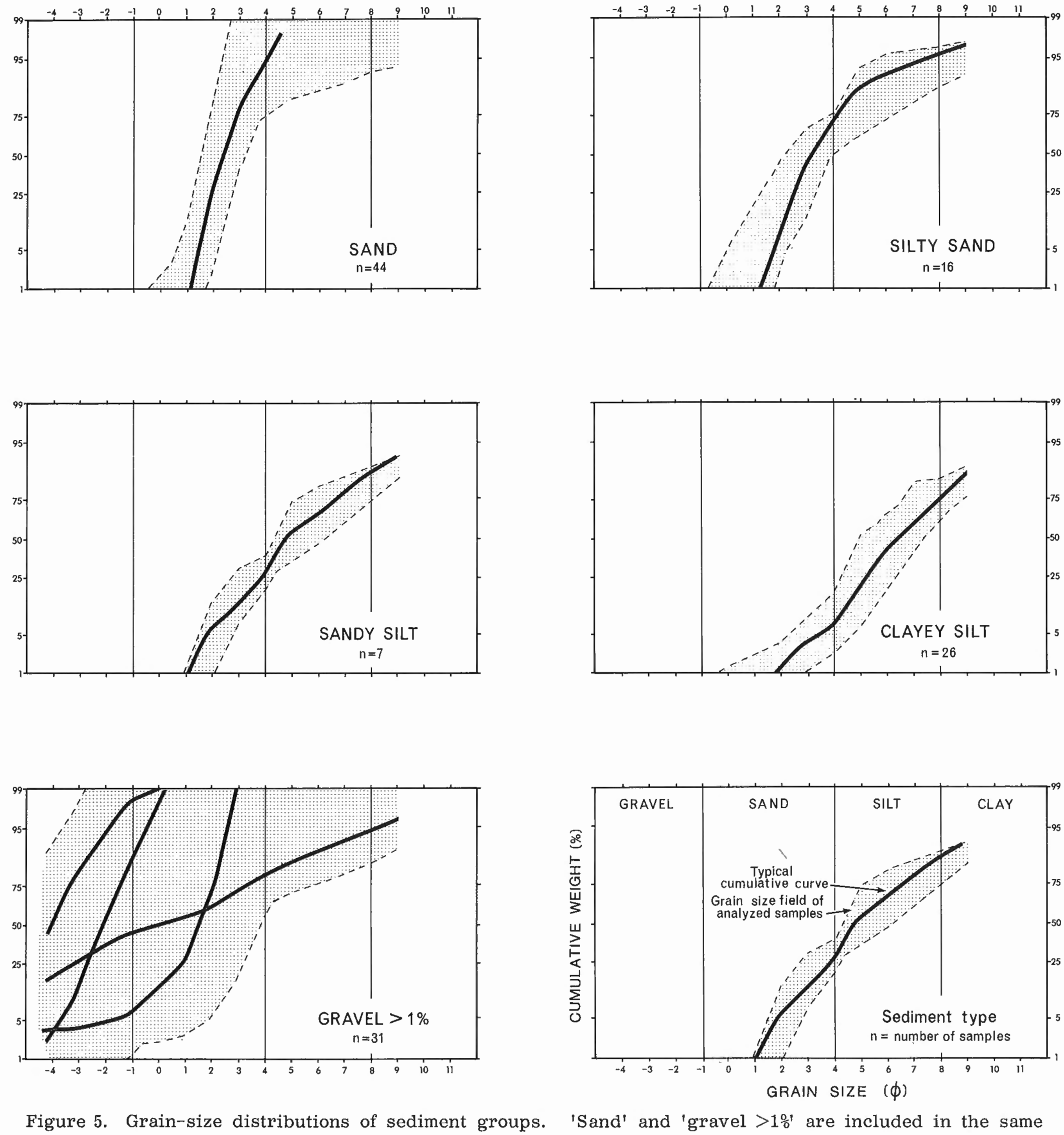

Figure 5. Grain-size distributions of sediment groups. 'Sand' and 'gravel >1%' are included in the same map-unit in Figure 3 because the two are spatially inseparable.

Table 3

Correlation matrix

		Grain-size parameters						Trace elements								
	Depth	$\overline{X}$	S	Gravel	Sand	Silt	Clay	Ag	Cd	Co	Cu	Fe	Ng	Mn	Ni	Pb
$\overline{X}$*	0.51†															
S**	0.26†	0.36†														
Gravel	-0.42†	-0.77†	0.05													
Sand	-0.16§	-0.30†	-0.66†	-0.17§												
Silt	0.39†	0.83†	0.61†	-0.40†	-0.82†											
Clay	0.31†	0.81†	0.62†	-0.34†	-0.80†	0.85†										
Ag	0.12	0.45†	0.41†	-0.12	-0.51†	0.45†	0.59†									
Cd	-0.04	0.71†	0.51†	-0.20§	-0.70†	0.63†	0.80†	0.59†								
Co	0.31†	0.60†	0.64†	-0.17§	-0.67†	0.66†	0.62†	0.46†	0.52†							
Cu	0.30†	0.67†	0.68†	-0.19§	-0.73†	0.70†	0.75†	0.59†	0.66†	0.90†						
Fe	-0.01	0.54†	0.53†	-0.17§	-0.64†	0.60†	0.67†	0.50†	0.67†	0.73†	0.80†					
Hg	0.44†	0.52†	0.45†	-0.23†	-0.54†	0.50†	0.60†	0.49†	0.51†	0.78†	0.88†	0.66†				
Mn	0.27†	0.14	0.42†	0.03	-0.16§	0.14	0.17§	0.15	0.08	0.55†	0.49†	0.28†	0.47†			
Ni	0.36†	0.58†	0.60†	-0.23†	-0.63†	0.63†	0.64†	0.54†	0.63†	0.92†	0.93†	0.76†	0.84†	0.48†		
Pb	0.03	-0.14	-0.16	0.02	0.22†	-0.22†	-0.17§	0.03	-0.13	0.08	0.11	0.08	0.23†	0.17§	0.18§	
Zn	0.32†	0.57†	0.56†	-0.20†	-0.64†	0.60†	0.69†	0.58†	0.64†	0.86†	0.94†	0.80†	0.89†	0.53†	0.92†	0.23†

*$\overline{X}$ = mean grain size.
**S = standard deviation.
† Correlation coefficient significant at 1% level.
§ Correlation coefficient significant at 5% level.

are of comparable or greater maximum thickness. In comparison, Holocene mud in deep basins of the northern Strait of Georgia east of the study area is locally thicker than 175 m (Clague, 1975a).

The boundary between coarse sediments on Comox Bar and fine sediments in the inner trough is sharp and coincides with the slope break between the two regions (Figs. 3 and 4). The slope is characterized by intermediate sediment types, mainly silty sand and sandy silt. A similar relationship exists on the west side of the inner trough where muds are in contact with coarser sediments bordering Vancouver Island. The sharpness of these boundaries is thought to be due to limited exchange of detritus between the two sedimentologic zones. Coarse sediment on Comox Bar, for example, is not transported far beyond the edge of the inner trough, and silt and clay remain in suspension where the bottom is shallower than about 10 m.

There are a few areas, however, where coarse sediment is deposited in the inner trough. One such area is south of Goose Spit where sediment consisting largely of sand extends across the full width of the trough (Figs. 3 and 4). This sand probably has been eroded from coastal bluffs to the northeast and transported by currents west and southwest into the trough. Current measurements south of Goose Spit (Waldichuck *et al.*, 1968) indicate the complexity of energy exchange within the water column in this area (Fig. 9). The data presented in Figure 9 were collected over a two-day period and show that surface currents in this area differ both in magnitude and direction from subsurface currents. Specifically, surface currents are dominantly towards the southeast and east and are stronger than subsurface currents directed mainly towards the southwest and west. The former are controlled, in part, by the outflow of fresh water from Courtenay River. The current patterns also are affected by the prevailing winds and tidal fluctuations.

Salinity and temperature determinations (Waldichuk *et al.*, 1968) in the inner trough indicate that the water column is strongly stratified (Fig. 10). A surface layer with relatively low salinities (1 to 27 ‰) exists over the trough and is due to the influx of Courtenay River water. As suggested by the current measurements in Figure 9, movement of this surface layer differs from water movement across the sea floor. Thus, although sediment has moved west and southwest across the sea floor south of Goose Spit, in agreement with bottom currents in this area (i.e. data at 27 m in Fig. 9), suspended silt and clay may be transported in the upper layer to the southeast or east.

In the outer trough, sediments transitional from well sorted sand to poorly sorted clayey silt occur over a larger area and depth range than in the inner trough (Fig. 3). Contacts between sediment groups are relatively sharp in the inner trough but are diffuse in the outer trough. Despite its greater depth, the outer trough lacks sediments as fine as some on the floor of the inner trough. The reasons for these differences are not known although they undoubtedly relate to different current regimes and sediment supply patterns in the two areas. In this regard, the outer trough is more

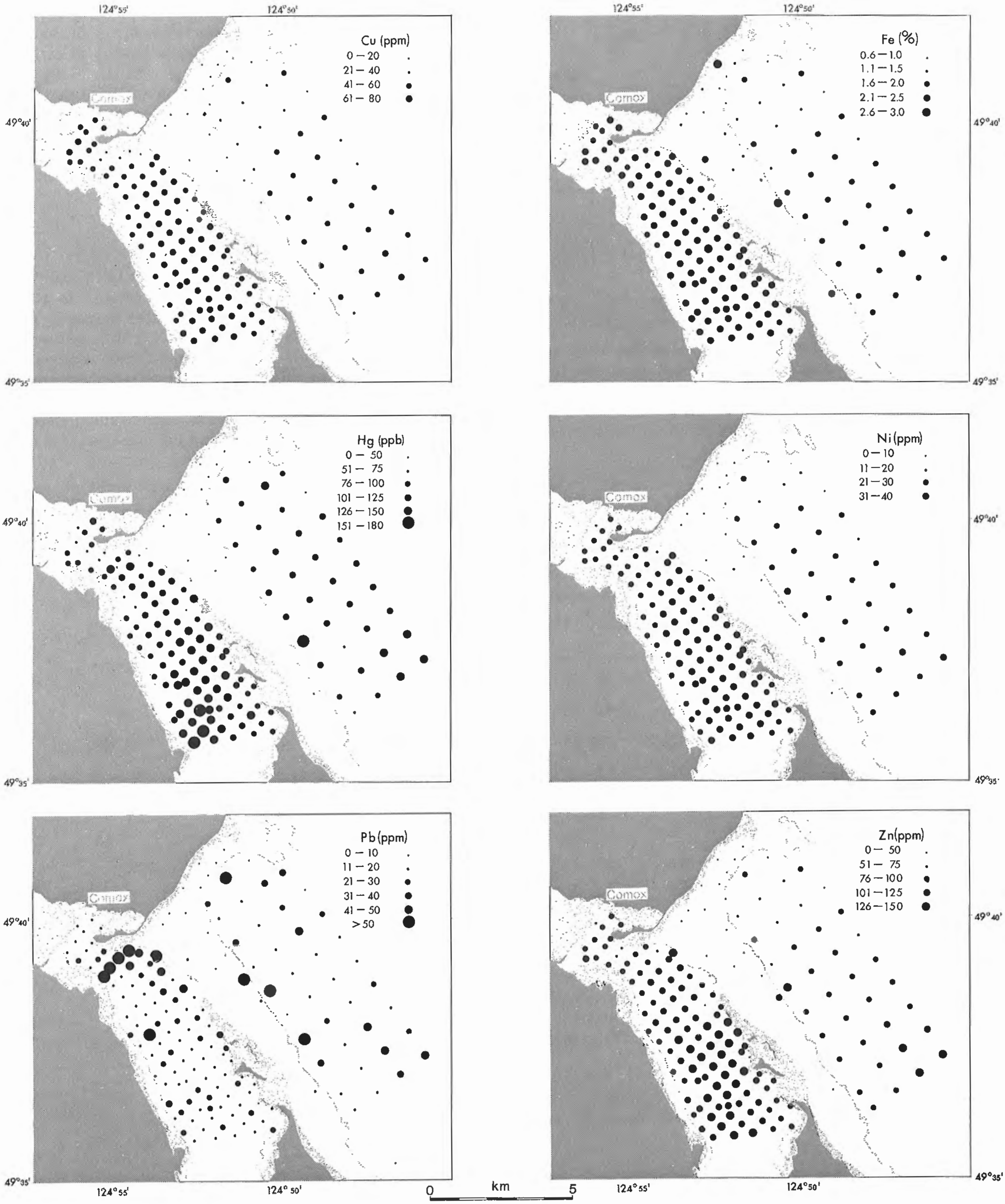

Figure 6. Distribution of selected metals in the subsand-size fraction (< 0.0625 mm) of bottom sediments. For samples with insufficient silt and clay, that part of the sample finer than 0.149 mm was analyzed (*see* Appendix B).

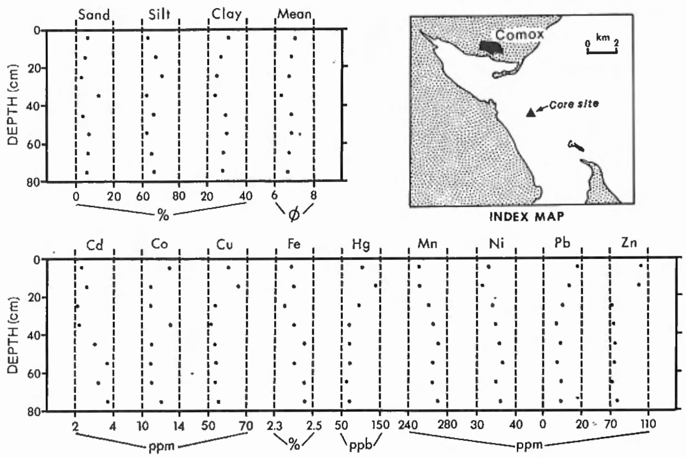

Figure 7. Analytical results from an undisturbed 80 cm core of clayey silt collected from the inner trough. Grain-size and geochemical analyses were performed on 10 cm increments of the core. The vertical scale indicates depth below the sea floor.

affected than the inner by energy exchanges occurring within the main part of the northern Strait of Georgia. Perhaps most of the tidal and wave energy is dissipated on the eastern edge of Comox Bar with the result that coarse sediment is carried into the adjacent depression.

In conclusion, sediment dispersal patterns in the study area (Fig. 11) are controlled by sea-floor morphology, waves and tidal currents, rivers emptying into the inner trough, and the texture of the transported sediment.

Geochemistry

The distribution of trace elements in the study area is closely related to that of sediment types. In general, the highest metal concentrations occur in clayey silt and the lowest in sand and gravel. It thus appears that most of the elements are associated either with exchange positions on clay minerals and secondary hydrous iron oxides, or with organic matter (Krauskopf, 1956; Goldberg and Arrhenius, 1958; Jenne, 1968; Cooper and Harris, 1974). Only Mn and Pb correlate poorly with

Table 4

Comparison of trace metal concentrations in estuarine sediments of southwest British Columbia, crustal rocks, and deep-sea clay

	Southwest British Columbia*								Deep-sea
	A	B	C	D	E	F	G	Crust**	clay†
n††	162	63	70	218	263	94	5		
Mean % sand	45	34	40	46	82	51	5		
Size fraction§	<4ϕ	<2.5ϕ	<2.5ϕ	<2.5ϕ	<2.5ϕ	<2.5ϕ	-	-	-
Co§§	10	11	7	13	13	6	-	25	74
Cu	48	131	66	30	18	100	63	55	250
Fe	2.0	2.8	1.5	2.3	2.0	1.6	4.2	5.0	6.5
Mn	240	251	163	327	348	148	566	950	6700
Ni	26	72	20	48	46	28	26	75	225
Pb	26	234	90	11	5	207	5	13	80
Zn	93	805	153	77	55	176	94	70	165

*A, Comox (this study); B, False Creek (Whiticar, 1974); C, Port Moody (Bourne, 1974); D, Fraser Delta foreslope (Grieve and Fletcher, 1975; pers. comm. 1975), E. Fraser Delta tidal flats (Grieve and Fletcher, 1975; pers. comm., 1975); F. Victoria Harbour (Carne, 1974); G. Knight Inlet (Popp, 1975)

**Mason, 1966, Table 3

†Turekian and Wedephol, 1961, Table 2

††n = number of samples

§Size fraction analyzed; dash indicates that total sample was used

§§Trace metal concentrations are arithmetic means and are expressed in ppm except iron (%); dash indicates that element was not determined.

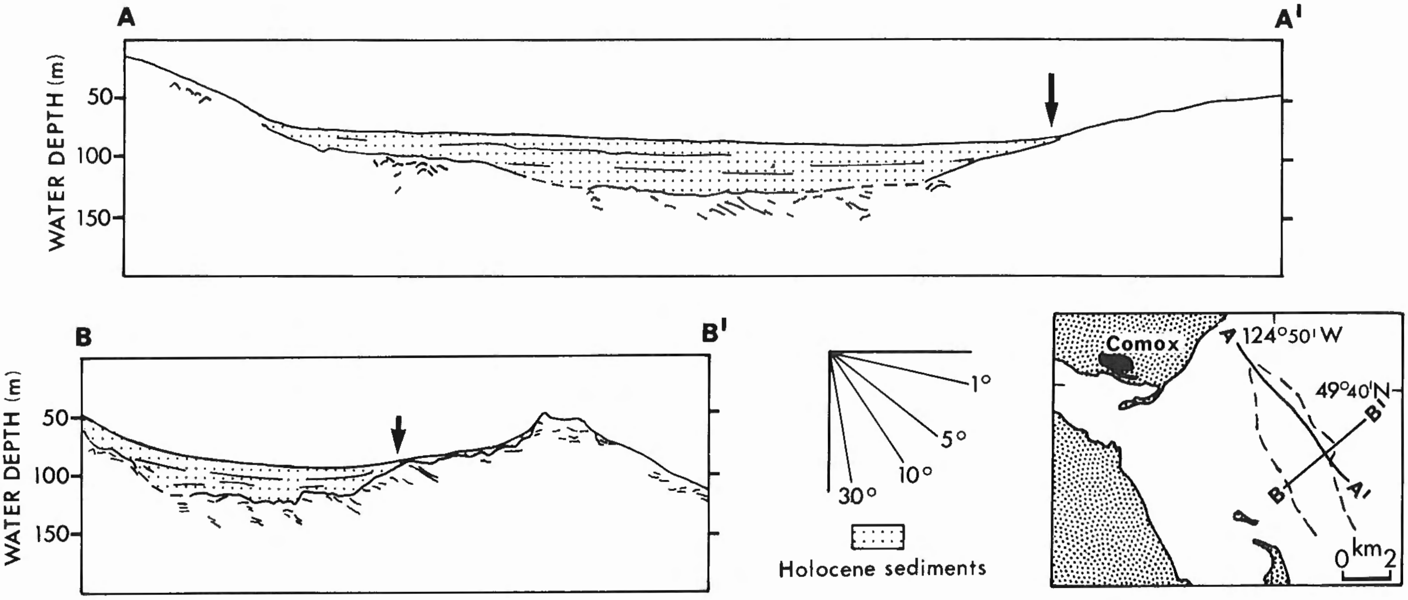

Figure 8. Interpreted, continuous seismic profiles of the outer trough. Dashed line on index map is 70 m isobath which approximately delineates trough floor. Arrows indicate intersection of the two tracklines. An air gun source of 16 cm^3 (1 cu. in.) was used to obtain the profiles. Holocene sediments underlying the trough floor have a maximum thickness of about 50 m, assuming a sound velocity through these sediments of 1585 m/s (Tiffin, 1969, p. 272-276).

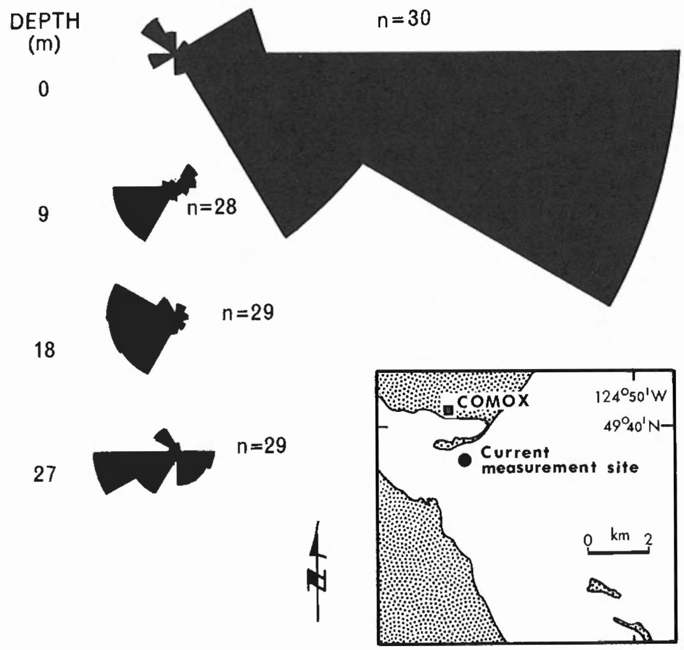

Figure 9. The direction and magnitude of currents at various water depths south of Goose Spit during the period January 30-31, 1958 (Waldichuck *et al.*, 1968, p. 63-67). The depth of the sea floor at this site is 29 m. The length of each current-rose ray is proportional to the sum of current velocities within that 30 degree interval, in other words, the higher the velocities, the longer the ray (n = the number of current measurements at the indicated depth).

the various grain-size parameters. High concentrations of Pb south of Goose Spit and at scattered sites in the outer trough (Fig. 6) are not easily explained. Although there is a relationship between Mn and grain size in the inner trough and on Comox Bar, no such relationship exists in the outer trough where very high Mn concentrations occur at a few sites (Appendix B).

Thus, it is likely that factors in addition to texture affect sediment geochemistry in the study area. Some of the most important of these may be chemical and organic wastes, organisms, sediment mineralogy, and the chemistry of interstitial and sea-floor waters. For example, high concentrations of Cu, Hg, Pb, and Zn at the top of a core from the inner trough (Fig. 7) may be due to the discharge of industrial and urban wastes into the estuary. However, many metals, including Ag, Co, Fe, Mn, and Ni, are not concentrated at the top of this core indicating perhaps that other factors are also significant.

The effects of man's activities on sediments of the study area may be assessed further by comparing the Comox geochemical data with data from other estuaries in southwest British Columbia (Table 4). Some of the geochemical differences in Table 4, however, reflect textural differences among the sediment groups. For example, sediment suites with high sand content likely would have lower metal concentrations than those with low sand content. In addition Comox geochemical data (A in Table 4) were determined by analyzing the fraction finer than 4ϕ (0.0625 mm), whereas Vancouver and Victoria area geochemical data (B, C, D, E, and F in Table 4) were obtained on the fraction finer than 2.5ϕ (0.177 mm). Thus because the Comox data are based on a finer size fraction, higher metal concentrations

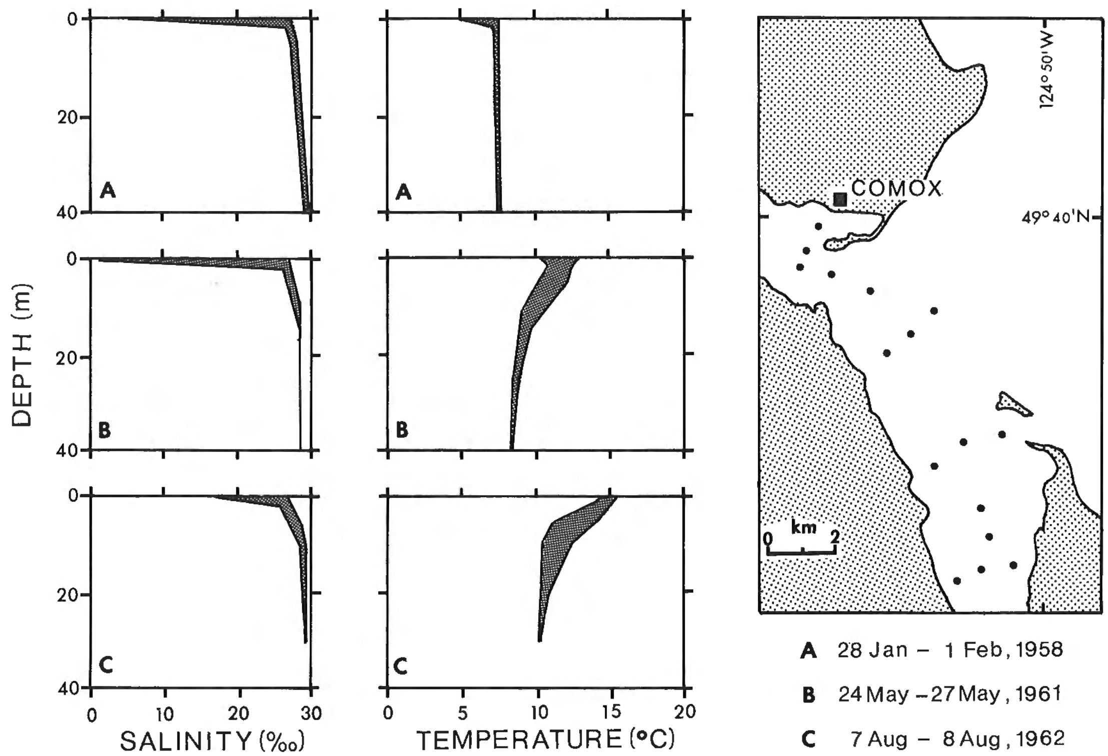

Figure 10. Integrated salinity-depth and temperature-depth profiles for the inner trough (Waldichuck *et al.*, 1968). Data stations are indicated on the index map by dots. Salinity profiles differ little seasonally and spatially. The upper layer of low salinity water is generated as Courtenay River empties into the inner trough. This layer is warmer than the underlying water mass in the summer but is colder in the winter.

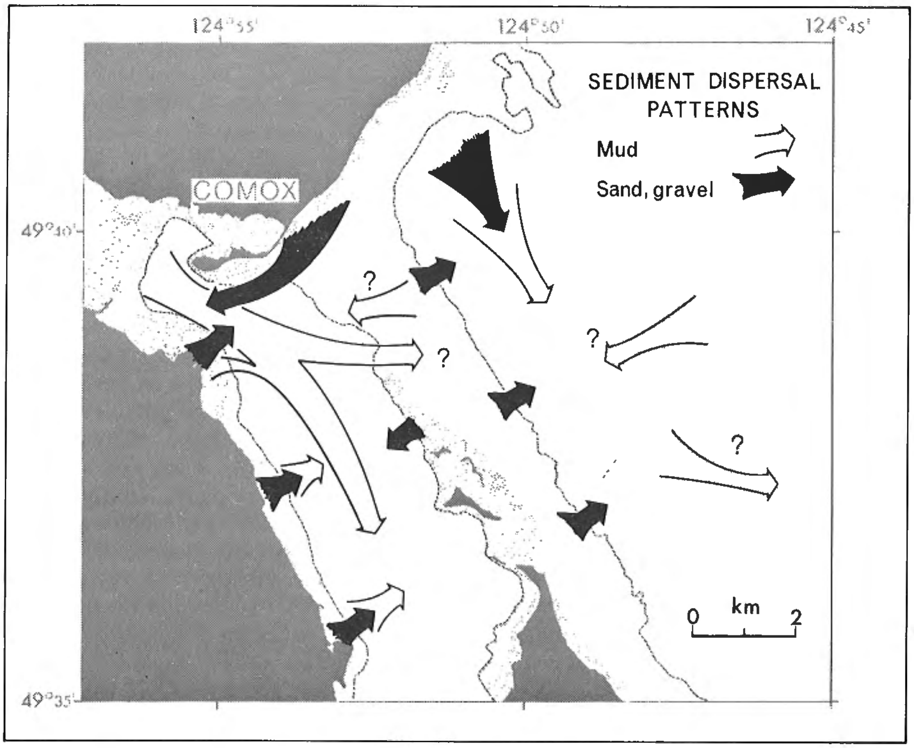

Figure 11.

Generalized pattern of sediment dispersal. Sediment is transported into the troughs by rivers, currents and waves. Source materials include unconsolidated Pleistocene sediments exposed in sea cliffs, sediments and rocks underlying the coastal lowland of Vancouver Island, and sediments forming Comox Bar. Suspended detritus may be transferred across Comox Bar and the bank separating the outer trough from the main part of northern Strait of Georgia.

might be expected, all other factors being equal. Notwithstanding the importance of texture as a control on the metal content of sediments, the Comox geochemical data can be compared with other data sets in Table 4 as a first attempt to measure the impact of man on the Courtenay River estuary.

Knight Inlet is located in an area free of industrial and urban activity, thus the metal content of sediments in the inlet is probably "normal". An inspection of the data in Table 4 shows that the Comox sample suite has mean concentrations of Cu, Fe, Mn, Ni, and Zn which are comparable to or lower than concentrations in Knight Inlet sediments; only Pb concentration is higher in the Comox suite. It is important to note, however, that the Knight Inlet suite is finer grained than the Comox suite (sand content averages 5 per cent for the former, 45 per cent for the latter) and, therefore, solely on the basis of texture, might be expected to have higher metal concentrations.

False Creek, Port Moody, and Victoria Harbour (B, C, and F, respectively, in Table 4) are areas where chemical and other wastes have affected the bottom materials (Bourne, 1974; Carne, 1974; Whiticar, 1974). Concentrations of Cu, Pb, and Zn are much higher in the sediments of these areas than in Comox sediments, even though a finer size fraction was used for the Comox analyses.

In comparison to deep-sea clays (Turekian and Wedepohl, 1961), the Comox suite has lower concentrations of all analyzed elements. This is, in part, attributed to textural differences between the two sample groups, the Comox suite being coarser grained and, therefore, more likely to have lower metal contents. The average crustal rock (Mason, 1966) contains more Co, Cu, Fe, Mn, and Ni, and less Pb and Zn than Comox sediments.

In conclusion, trace metal concentrations in bottom sediments of the study area, for the most part, are comparable to or less than those in other estuarine sediments of southwest British Columbia. The data obtained from a core in the inner trough (Fig. 7), however, indicate that concentrations of some metals are higher at the top of the sediment column than at depth, possibly due to recent contamination. Also, Pb concentrations are anomalously high in some Comox samples. The source of the Pb contamination is not known; nothing was observed in the mineralogy of the samples which might account for the high values, and industrial and urban sources have not been identified.

Limited data suggest that organic carbon is anomalously high in the bottom sediments of the inner trough. The inner trough muds contain up to about 8 per cent organic carbon, largely in the form of very fine grained, black organic matter. Possible sources of the carbon include sewage from Courtenay and Comox, coal mined until 1967 from the coastal lowland of Vancouver Island west of the inner trough (Muller and Atchison, 1971), terrestrial vegetation, and marine organisms. Substantially more carbonaceous material is being introduced into the inner trough and deposited with the sediment there than is the case outside the trough.

CONCLUSIONS

A study of the estuary of Courtenay River and adjacent parts of the Strait of Georgia has resulted in the following conclusions:

1) The area includes two troughs separated by a shallow, flat-topped sill, Comox Bar. This sill, to a large extent, isolates the inner trough from many of the oceanographic influences of the Strait of Georgia. A bank separating the outer trough from the main part of the strait shoals in deeper water and is narrower than Comox Bar, and thus is less effective as a barrier to sediment and water exchange.

2) The distribution of sediments is closely related to the bathymetry of the area. Fine grained sediment occurs on the floors of the troughs, whereas sand and gravel are found on Comox Bar and nearshore areas along Vancouver Island. Comox Bar likely is cored by Pleistocene sediments of similar lithologies to those forming adjacent ridges on Denman and Vancouver Islands. Sand and gravel on this sill are probably lag concentrates eroded from a subaerial ridge which once joined the two islands. The thickest Holocene sediments occur in the troughs; seismic profiles over the outer trough indicate postglacial sediments are up to 50 m thick there.

3) The marine sediments include detritus transported into the area by streams and rivers, the most important being Courtenay River, and material eroded from coastal bluffs and Comox Bar.

4) Goose Spit is maintained by sediment eroded from sea cliffs to the northeast. Sand extends across the inner trough at Goose Spit and separates mud at the front of Courtenay Delta from mud flooring the main part of the trough.

5) The content of most metals in marine sediments of the study area is closely related to sediment texture. Metal concentrations are highest in clayey silt and lowest in sand and gravel. Thus, areal trends of most metals are due largely to differences in sediment texture. Trace metal concentrations in bottom sediments of the study area, for the most part, are comparable to or less than those in other estuarine sediments of southwest British Columbia. However, anomalously high lead concentrations, which are not related to texture, occur south of Goose Spit and at scattered sites in the outer trough. Another possible indication of contamination is the occurrence of higher concentrations of some metals (e.g. Cu, Hg, Pb, and Zn) near the top of a core taken from the inner trough.

6) The organic carbon content of the inner trough sediments is higher than that of similar sediments elsewhere in the Strait of Georgia.

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APPENDIX A

Grain-size data

Sample no.	Location Lat.N	Location Long.W	Depth (m)	Mean (ϕ)*	Standard deviation (ϕ)**	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
				Inner Trough					
1	49°35.8'	124°51.9'	40			0.0	1.6	63.0	35.4
2	49°35.8'	124°52.5'	31			0.0	5.1	60.0	34.9
3	49°35.9'	124°51.4'	41	7.3	2.6	0.0	6.0	61.5	32.5
4	49°36.0'	124°50.2'	15	2.5	1.1	0.0	91.9	6.4	1.7
5	49°36.0'	124°50.8'	30			0.0	15.8	69.1	15.1
6	49°36.0'	124°51.7'	39	1.7	2.0	5.3	84.8	5.3	4.6
7	49°36.0'	124°52.3'	38	8.0	2.5	0.0	3.0	60.0	37.0
8	49°36.0'	124°52.8'	24	6.4	2.4	0.0	9.8	68.9	21.3
9	49°36.1'	124°51.1'	38			0.0	2.3	64.7	33.0
10	49°36.2'	124°50.5'	29			0.0	32.6	55.6	11.8
11	49°36.2'	124°52.0'	41			0.0	1.4	66.2	32.4
12	49°36.2'	124°52.6'	31			0.0	3.0	61.1	35.9
13	49°36.2'	124°53.1'	19			0.0	36.7	51.3	12.0
14	49°36.3'	124°50.9'	33	2.7	1.8	0.0	83.2	11.8	5.0
15	49°36.3'	124°51.4'	41	7.4	2.6	0.0	5.0	62.4	32.6
16	49°36.3'	124°52.9'	25			0.0	5.4	70.2	24.4
17	49°36.4'	124°50.3'	22	2.8	2.3	0.4	71.1	22.6	5.9
18	49°36.4'	124°51.8'	38	3.2	2.7	0.3	75.0	16.0	8.7
19	49°36.4'	124°52.1'	45	3.6	3.1	0.0	71.6	16.7	11.7
20	49°36.4'	124°52.3'	38	8.0	2.5	0.0	2.4	60.6	37.0
21	49°36.5'	124°50.7'	30			0.0	22.9	61.7	15.4
22	49°36.5'	124°51.2'	39			0.0	3.1	63.1	33.8
23	49°36.5'	124°52.7'	31			0.0	2.0	63.7	34.3
24	49°36.5'	124°53.3'	20	6.2	2.4	0.0	9.5	69.8	20.7
25	49°36.6'	124°51.5'	41			0.0	7.3	55.3	37.4
26	49°36.6'	124°52.1'	40			0.0	1.2	57.7	41.1
27	49°36.7'	124°50.9'	32			0.0	15.7	71.4	12.9
28	49°36.8'	124°50.8'	25	5.2	2.5	0.0	28.3	59.5	12.2
29	49°36.8'	124°51.8'	41	7.7	2.6	0.0	4.9	61.6	33.5
30	49°36.8'	124°52.4'	37			0.0	3.8	53.7	42.5
31	49°36.9'	124°51.2'	38			0.0	9.2	75.1	15.7
32	49°36.9'	124°52.8'	33	7.7	2.4	0.0	4.1	56.9	39.0
33	49°36.9'	124°53.0'	31			0.0	1.5	69.5	29.0
34	49°36.9'	124°53.4'	24			0.0	6.0	70.3	23.7
35	49°37.0'	124°51.1'	31	3.1	1.9	0.0	74.0	21.5	4.5
36	49°37.0'	124°51.6'	42			0.0	17.1	57.1	25.7
37	49°37.0'	124°52.2'	39			0.0	3.7	64.1	32.2
38	49°37.0'	124°53.7'	16	3.0	1.7	0.1	74.5	21.2	4.2
39	49°37.1'	124°52.5'	35			0.0	2.0	62.4	35.6
40	49°37.1'	124°53.1'	31			0.0	1.6	67.5	30.9
41	49°37.2'	124°51.9'	39			0.0	4.4	60.7	34.9
42	49°37.3'	124°51.4'	29			0.0	91.1	5.7	3.2
43	49°37.3'	124°52.8'	33			0.0	1.1	61.1	37.8
44	49°37.3'	124°53.4'	31	7.2	2.4	0.0	3.6	66.9	29.5
45	49°37.4'	124°51.7'	37			0.0	16.2	55.5	28.3
46	49°37.4'	124°52.3'	37	7.0	2.0	0.0	2.8	78.7	18.5
47	49°37.4'	124°53.8'	29			0.0	6.2	74.1	19.7
48	49°37.5'	124°51.6'	29	2.5	0.9	0.0	94.5	5.5	0.0
49	49°37.5'	124°52.6'	35			0.0	1.1	60.0	38.9
50	49°37.5'	124°53.2'	33			0.0	1.7	64.9	33.4
51	49°37.6'	124°52.0'	40			0.0	6.6	52.4	41.0
52	49°37.6'	124°53.5'	32			0.0	13.8	63.9	22.3
53	49°37.6'	124°54.1'	17	2.7	1.6	0.0	82.5	13.8	3.7
54	49°37.7'	124°52.9'	34			0.0	5.8	56.4	37.8
55	49°37.8'	124°51.9'	37	6.5	2.6	0.0	13.2	64.4	22.4
56	49°37.8'	124°52.3'	39			0.0	4.3	60.8	34.9
57	49°37.8'	124°53.8'	30	6.6	2.3	0.0	6.4	68.0	25.6
58	49°37.8'	124°54.4'	20			0.0	71.9	24.0	4.1

Sample no.	Location Lat.N	Long.W	Depth (m)	Mean (ϕ)*	Standard deviation (ϕ)**	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
				Inner Trough					
59	49°37.9'	124°52.7'	37			0.0	8.8	58.4	32.8
60	49°37.9'	124°53.3'	33			0.0	1.8	61.1	37.1
61	49°38.0'	124°52.1'	40	6.8	2.6	0.0	11.2	58.0	30.8
62	49°38.0'	124°53.6'	32			0.0	8.9	63.8	27.3
63	49°38.0'	124°54.2'	29			0.0	6.4	66.4	27.2
64	49°38.1'	124°52.4'	40			0.0	32.6	49.0	18.4
65	49°38.1'	124°53.0'	35	7.5	2.6	0.0	4.0	67.0	29.0
66†	49°38.2'	124°53.3'	34	6.9	2.8	0.0	9.9	60.1	30.0
66A	48°38.2'	124°53.3'	34	7.0	2.5	0.0	6.1	63.4	30.5
66B	48°38.2'	124°53.3'	34	6.9	2.4	0.0	5.4	67.6	27.0
66C	48°38.2'	124°53.3'	34	6.8	2.2	0.0	3.9	71.2	24.9
66D	48°38.2'	124°53.3'	34	6.3	2.5	0.0	12.6	62.9	24.5
66E	48°38.2'	124°53.3'	34	6.9	2.4	0.0	4.9	66.1	29.0
66F	48°38.2'	124°53.3'	34	6.9	2.6	0.0	7.3	62.7	30.0
66G	48°38.2'	124°53.3'	34	6.7	2.4	0.0	6.9	65.0	28.1
66H	48°38.2'	124°53.3'	34	6.7	2.4	0.0	5.9	66.1	28.0
67	49°38.2'	124°53.9'	30	7.0	2.6	0.0	6.0	65.6	28.4
68	49°38.2'	124°54.5'	27	4.0	1.8	0.0	57.0	36.0	7.0
69	49°38.3'	124°52.3'	21	3.1	1.8	0.0	74.7	19.5	5.8
70	49°38.3'	124°52.8'	40	2.1	0.8	0.0	99.0	1.0	0.0
71	49°38.4'	124°53.6'	32			0.0	8.1	66.2	25.7
72	49°38.4'	124°54.2'	30			0.0	6.9	69.5	23.6
73	49°38.5'	124°52.5'	26	3.0	1.3	0.0	83.6	12.9	3.5
74	49°38.5'	124°53.1'	42			0.0	44.7	36.9	18.4
75	49°38.5'	124°54.6'	27	5.3	2.5	0.0	27.5	58.4	14.1
76	49°38.6'	124°54.0'	34	6.4	2.5	0.5	9.4	65.1	25.0
77	49°38.7'	124°52.8'	42	2.9	1.4	0.0	87.0	8.4	4.6
78	49°38.7'	124°53.4'	41	6.2	2.9	0.0	23.2	50.2	26.6
79	49°38.8'	124°53.7'	38			0.0	10.7	65.1	24.2
80	49°38.8'	124°54.3'	34			0.0	7.5	69.0	23.5
81	49°38.8'	124°54.8'	26			0.0	22.2	62.1	15.7
82	49°38.9'	124°52.6'	22	0.2	2.7	21.0	77.8	1.2	0.0
83	49°38.9'	124°53.2'	44	6.9	2.8	0.0	12.6	62.1	25.3
84	49°39.0'	124°53.0'	10	-3.7	1.4	95.0	4.2	0.4	0.4
85	49°39.0'	124°53.5'	49	5.3	3.1	0.0	37.9	42.8	19.3
86	49°39.0'	124°54.1'	39	5.9	2.5	0.0	18.6	61.8	19.6
87	49°39.0'	124°54.6'	40	3.0	1.6	0.0	81.3	14.1	4.6
88	49°39.0'	124°55.1'	23	0.2	4.1	44.4	36.1	14.5	5.0
89	49°39.1'	124°54.4'	31	2.7	0.7	0.0	94.0	3.8	2.2
90	49°39.1'	124°55.0'	34	2.7	1.2	0.0	86.9	10.6	2.5
91	49°39.1'	124°55.5'	28	3.9	2.0	0.0	60.9	31.4	7.7
92	49°39.2'	124°53.8'	42	3.3	2.1	0.0	75.3	17.1	7.6
93	49°39.2'	124°55.9'	21			0.0	32.2	57.9	9.9
94	49°39.2'	124°56.2'	12	6.0	2.6	0.0	13.9	68.5	17.6
95	49°39.3'	124°53.6'	34	2.2	0.8	0.0	95.7	4.3	0.0
96	49°39.3'	124°54.7'	24	2.9	0.8	0.0	90.3	7.0	2.7
97	49°39.3'	124°55.3'	33	3.3	1.2	0.0	78.7	17.5	3.8
98	49°39.4'	124°54.1'	28	2.7	0.8	0.0	94.9	3.5	1.6
99	49°39.4'	124°54.4'	17	2.6	0.8	0.0	97.4	2.6	0.0
100	49°39.4'	124°55.1'	15	2.8	0.8	0.0	94.6	5.4	0.0
101	49°39.4'	124°55.7'	23	4.1	1.9	1.9	52.4	38.2	7.5
102	49°39.4'	124°56.2'	13	5.9	2.1	0.0	7.4	76.8	15.8
103	49°39.6'	124°55.5'	27	3.6	2.1	0.5	64.4	28.6	6.5
104	49°39.6'	124°56.0'	21	4.2	1.9	0.0	50.2	42.2	7.6
105	49°39.8'	124°55.2'	18	4.4	3.2	0.0	46.5	40.8	12.7
106	49°39.8'	124°55.7'	25	2.7	2.8	14.9	60.1	21.5	3.5
107	49°39.9'	124°55.9'	22	4.1	1.7	0.0	49.2	44.4	6.4
108	49°40.0'	124°55.5'	23	5.7	2.4	0.0	16.5	68.1	15.4

Sample no.	Location Lat.N	Location Long.W	Depth (m)	Mean (ϕ)*	Standard deviation (ϕ)**	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
			Outer Trough						
109	49°36.3'	124°47.8'	79			0.0	24.7	59.3	16.0
110	49°36.7'	124°47.1'	92	5.4	2.7	0.0	31.0	52.7	16.3
111	49°36.7'	124°48.2'	73	3.2	1.8	0.0	74.0	19.9	6.1
112	49°37.0'	124°46.5'	51	2.1	2.8	11.2	72.3	9.4	7.1
113	49°37.2'	124°47.6'	88			0.0	25.9	59.6	14.5
114	49°37.3'	124°48.8'	75			0.0	78.1	17.6	4.3
115	49°37.4'	124°45.8'	56	2.4	1.2	0.0	93.7	4.7	1.6
116	49°37.5'	124°47.0'	43	4.0	3.5	4.6	57.5	22.8	15.1
117	49°37.6'	124°48.1'	88	5.8	2.5	0.0	16.6	63.7	19.7
118	49°37.7'	124°49.3'	55	2.2	0.8	0.0	98.0	2.0	0.0
119	49°37.8'	124°46.3'	52	2.3	1.2	0.2	92.9	4.5	2.4
120	49°37.9'	124°47.4'	58	0.4	2.9	21.7	73.4	3.1	1.8
121	49°38.1'	124°48.6'	83	6.0	2.4	0.0	11.6	69.4	19.0
122	49°38.2'	124°49.8'	66	2.8	1.6	0.0	81.5	14.8	3.7
123	49°38.3'	124°46.8'	52	3.0	0.9	0.0	88.1	8.9	3.0
124	49°38.4'	124°47.9'	80	3.1	1.2	0.0	83.3	13.5	3.2
125	49°38.5'	124°49.1'	80			0.0	9.1	65.7	25.2
126	49°38.6'	124°50.3'	42	2.2	1.0	0.0	93.6	4.9	1.5
127	49°38.7'	124°47.3'	54	2.3	1.0	0.0	94.7	3.4	1.9
128	49°38.9'	124°48.4'	85			0.0	26.2	57.8	16.0
129	49°39.0'	124°49.6'	74	6.7	2.8	0.0	7.6	71.1	21.3
130	49°39.1'	124°50.8'	55	3.4	1.6	0.0	68.3	27.6	4.1
131	49°39.2'	124°47.8'	56			0.0	78.9	15.9	5.2
132	49°39.3'	124°48.9'	81	6.0	2.5	0.0	11.6	68.2	20.2
133	49°39.4'	124°50.1'	70			0.0	6.6	72.0	21.4
134	49°39.6'	124°48.3'	58			0.0	78.1	16.9	5.0
135	49°39.6'	124°51.3'	37	2.9	0.7	0.0	92.9	5.7	1.4
136	49°39.8'	124°49.4'	80	5.7	2.5	0.0	17.1	65.3	17.6
137	49°39.9'	124°50.6'	63	3.5	1.2	0.0	68.9	27.6	3.5
138	49°40.0'	124°51.8'	44	2.7	1.1	0.0	85.0	13.3	1.7
139	49°40.1'	124°48.7'	49	2.8	1.1	0.6	92.2	5.9	1.3
140	49°40.2'	124°49.9'	78	4.7	2.2	0.0	35.5	53.7	10.8
141	49°40.3'	124°52.1'	17	2.1	0.7	0.7	99.1	0.2	0.0
142	49°40.4'	124°51.1'	59	3.4	1.2	0.0	72.4	24.2	3.4
143	49°40.6'	124°49.2'	27	2.4	1.0	0.1	97.4	1.9	0.6
144	49°40.7'	124°50.4'	61	3.2	0.9	0.0	82.5	15.4	2.1
145	49°40.8'	124°51.6'	31	2.9	0.6	0.0	96.0	4.0	0.0
146	49°40.9'	124°49.9'	18	1.7	1.3	7.2	92.0	0.8	0.0
147	49°41.1'	124°50.9'	14	1.7	0.9	1.2	98.7	0.1	0.0
			Comox Bar						
148	49°36.3'	124°48.5'	7	-0.6	2.4	35.7	64.1	0.2	0.0
149	49°36.7'	124°49.0'	9	1.4	1.3	6.1	93.8	0.1	0.0
150	49°37.1'	124°49.5'	7	-3.1	2.9	75.1	24.9	0.0	0.0
151	49°38.0'	124°50.6'	3	-3.8	0.9	98.4	1.6	0.0	0.0
152	49°38.4'	124°50.6'	15	1.6	0.6	0.0	99.9	0.1	0.0
153	49°38.4'	124°51.6'	3	-3.4	1.4	89.4	10.6	0.0	0.0
154	49°38.6'	124°51.4'	5	-3.5	1.3	91.8	8.2	0.0	0.0
155	49°38.8'	124°52.1'	3	-2.0	1.0	86.3	13.7	0.0	0.0
156	49°38.9'	124°51.1'	8	1.8	0.7	0.0	99.9	0.1	0.0
157	49°38.9'	124°51.6'	4	-3.7	1.2	92.6	7.4	0.0	0.0
158	49°39.1'	124°51.9'	4	0.9	1.2	8.6	91.3	0.1	0.0
159	49°39.2'	124°52.7'	5	1.2	1.3	9.6	90.3	0.1	0.0
160	49°39.3'	124°51.6'	6	2.1	0.6	0.0	99.9	0.1	0.0
161	49°39.3'	124°52.2'	4	-2.5	2.4	59.3	40.7	0.0	0.0
162	49°39.5'	124°52.4'	4	-2.5	2.4	80.1	19.9	0.0	0.0
163	49°39.7'	124°52.7'	4	0.0	2.6	40.7	59.2	0.1	0.0
164	49°39.7'	124°53.6'	3	-2.9	3.0	60.3	39.7	0.0	0.0
165	49°39.8'	124°52.1'	5	2.2	0.6	0.0	99.8	0.2	0.0

Sample no.	Location Lat.N	Long.W	Depth (m)	Mean (ϕ)*	Standard deviation (ϕ)**	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
				Comox Bar					
166	49°39.9'	124°52.9'	4	-1.8	2.8	76.6	23.3	0.1	0.0
167	49°39.9'	124°53.4'	3	2.2	0.6	0.0	99.8	0.2	0.0
168	49°40.1'	124°52.7'	4	2.5	0.6	0.0	99.8	0.2	0.0
169	49°40.1'	124°53.2'	4	2.2	0.6	0.0	99.6	0.4	0.0
170	49°40.4'	124°52.5'	5	0.5	1.9	28.3	71.6	0.1	0.0
171	49°40.4'	124°53.0'	3	-3.6	0.5	99.9	0.1	0.0	0.0
172	49°40.6'	124°52.3'	7	2.4	0.6	0.0	99.9	0.1	0.0
173	49°40.6'	124°52.8'	2	2.3	0.6	0.0	99.6	0.4	0.0
174	49°40.8'	124°52.1'	10	2.1	0.7	0.0	99.9	0.1	0.0
175	49°40.8'	124°52.6'	3	2.1	0.7	0.3	99.4	0.3	0.0
176	49°41.1'	124°51.9'	8	1.4	1.3	9.1	90.8	0.1	0.0
177	49°41.1'	124°52.3'	2	1.8	0.7	0.1	99.8	0.1	0.0
178	49°41.3'	124°51.6'	9	-1.2	2.4	53.5	46.4	0.1	0.0
179	49°41.3'	124°52.1'	2	-0.5	1.5	29.3	70.6	0.1	0.0

*Graphic mean
**Arithmetic standard deviation
†Sample no. 66 is a grab sample. A core collected at the same site was subdivided into subsamples 66A through 66H. Each subsample includes 10 cm of the core, A being the highest 10 cm and H being the lowest 10 cm.

APPENDIX B

Geochemical data

Sample no.	Location Lat.N	Long.W	Depth (m)	Ag	Cd	Co	Cu	Fe	Hg	Mn	Ni	Pb	Zn
				Inner Trough									
1	49°35.8'	124°51.9'	40	0.5	2.1	11	70	2.45	140	260	34	20	130
2	49°35.8'	124°52.5'	31	0.4	2.0	13	68	2.50	180	260	32	18	120
3	49°35.9'	124°51.4'	41	0.4	2.5	12	63	2.41	120	260	36	15	128
4	49°36.0'	124°50.2'	15	0.2	0.5	10	39	1.72	85	240	28	26	78
5	49°36.0'	124°50.8'	30	<0.2	2.2	12	44	2.10	95	240	30	13	97
6	49°36.0'	124°51.7'	39	0.5	1.0	11	63	2.42	150	270	35	27	120
7	49°36.0'	124°52.3'	38	0.4	2.5	12	70	2.55	155	260	33	18	128
8	49°36.0'	124°52.8'	24	0.6	1.4	11	61	2.35	140	255	30	28	118
9	49°36.1'	124°51.1'	38	0.5	2.3	12	57	2.30	105	260	34	13	115
10	49°36.2'	124°50.5'	29	0.2	2.0	11	42	2.02	80	235	30	12	95
11	49°36.2'	124°52.0'	41	0.5	1.9	14	70	2.50	140	260	34	18	130
12	49°36.2'	124°52.6'	31	0.4	2.1	14	70	2.50	150	260	32	16	126
13	49°36.2'	124°53.1'	19	0.2	1.8	11	50	2.28	110	240	29	13	98
14	49°36.3'	124°50.9'	33	0.4	1.2	12	52	2.30	140	260	32	24	100
15	49°36.3'	124°51.4'	41	0.5	2.4	14	64	2.38	115	265	37	20	124
16	49°36.3'	124°52.9'	25	<0.2	1.6	14	60	2.35	130	250	30	22	110
17	49°36.4'	124°50.3'	22	0.3	1.5	10	44	2.00	85	235	29	13	90
18	49°36.4'	124°51.8'	38	0.4	1.4	11	61	2.30	120	265	33	20	112
19	49°36.4'	124°52.1'	45	0.4	1.0	12	66	2.42	130	265	34	22	115
20	49°36.4'	124°52.3'	38	0.6	2.6	11	68	2.55	155	270	32	18	120
21	49°36.5'	124°50.7'	30	0.4	2.0	11	51	2.20	90	240	32	8	100
22	49°36.5'	124°51.2'	39	0.5	2.3	13	56	2.25	95	245	34	13	115
23	49°36.5'	124°52.7'	31	0.4	1.9	12	72	2.50	130	270	34	29	132
24	49°36.5'	124°53.3'	20	0.4	1.4	13	54	2.30	110	250	29	31	105
25	49°36.6'	124°51.5'	41	0.4	2.2	12	64	2.40	145	260	34	19	122
26	49°36.6'	124°52.1'	40	0.6	2.0	14	71	2.50	130	260	34	22	135
27	49°36.7'	124°50.9'	32	0.4	1.5	12	52	2.17	90	240	30	12	96
28	49°36.8'	124°50.8'	25	0.5	1.3	12	51	2.17	90	240	30	12	100
29	49°36.8'	124°51.8'	41	0.6	2.4	12	70	2.50	135	260	36	18	130
30	49°36.8'	124°52.4'	37	0.6	2.6	12	74	2.50	140	270	35	29	135
31	49°36.9'	124°51.2'	38	0.5	1.9	14	60	2.20	110	240	33	21	120
32	49°36.9'	124°52.8'	33	0.4	2.0	12	70	2.45	140	260	31	16	125
33	49°36.9'	124°53.0'	31	0.6	1.6	12	66	2.50	135	260	31	18	125
34	49°36.9'	124°53.4'	24	0.3	1.1	14	54	2.35	110	250	29	11	96
35	49°37.0'	124°51.1'	31	0.6	1.4	11	46	2.05	85	230	30	17	92
36	49°37.0'	124°51.6'	42	0.6	3.1	13	66	2.45	130	260	37	17	128
37	49°37.0'	124°52.2'	39	0.3	2.0	11	70	2.40	145	255	33	20	135
38	49°37.0'	124°53.7'	16	0.3	1.2	12	46	2.10	85	245	28	14	92
39	49°37.1'	124°52.5'	35	0.5	2.4	12	70	2.50	140	255	32	18	128
40	49°37.1'	124°53.1'	31	0.4	1.6	12	67	2.50	130	250	31	16	128
41	49°37.2'	124°51.9'	39	0.5	2.3	14	69	2.50	120	260	34	16	135
42	49°37.3'	124°51.4'	29	<0.2	<0.5	7	16	1.65	15	155	24	13	49
43	49°37.3'	124°52.8'	33	0.5	1.5	11	69	2.50	125	250	32	19	130
44	49°37.3'	124°53.4'	31	0.4	1.7	13	66	2.50	120	260	32	25	120
45	49°37.4'	124°51.7'	37	0.5	2.1	12	60	2.40	125	250	34	16	115
46	49°37.4'	124°52.3'	37	0.5	2.4	12	71	2.40	135	250	33	15	145
47	49°37.4'	124°53.8'	29	0.4	1.0	10	55	2.30	100	255	30	12	98
48	49°37.5'	124°51.6'	29	<0.2	0.9	12	52	2.15	115	250	33	23	102
49	49°37.5'	124°52.6'	35	0.8	2.2	12	73	2.58	140	260	33	19	131
50	49°37.5'	124°53.2'	33	0.6	1.4	14	71	2.42	120	250	32	22	130
51	49°37.6'	124°52.0'	40	0.7	2.6	11	69	2.45	140	250	34	18	142
52	49°37.6'	124°53.5'	32	0.5	1.4	13	67	2.40	120	250	32	20	126
53	49°37.6'	124°54.1'	17	0.5	<0.5	11	48	2.05	80	250	28	19	90
54	49°37.7'	124°52.9'	34	0.4	1.4	15	70	2.35	140	245	31	20	120
55	49°37.8'	124°51.9'	37	0.4	1.9	12	66	2.45	125	255	36	39	127
56	49°37.8'	124°52.3'	39	0.7	2.4	11	68	2.50	135	250	34	21	136
57	49°37.8'	124°53.8'	30	0.4	1.2	12	65	2.45	110	260	31	52	115
58	49°37.8'	124°54.4'	20	0.4	0.8	12	47	2.05	80	245	27	21	84
59	49°37.9'	124°52.7'	37	0.5	2.3	14	70	2.50	130	250	33	20	130

Sample no.	Location Lat.N	Long.W	Depth (m)	Ag	Cd	Co	Cu	Fe	Hg	Mn	Ni	Pb	Zn
				Inner Trough									
60	49°37.9'	124°53.3'	33	0.4	1.7	12	67	2.45	120	255	32	13	123
61	49°38.0'	124°52.1'	40	0.6	1.8	10	65	2.48	130	250	33	18	126
62	49°38.0'	124°53.6'	32	0.3	1.1	14	67	2.35	110	250	31	27	120
63	49°38.0'	124°54.2'	29	0.6	1.4	12	57	2.35	95	250	30	14	102
64	49°38.1'	124°52.4'	40	0.2	1.7	12	60	2.28	100	245	35	21	115
65	49°38.1'	124°53.0'	35	0.5	1.4	14	67	2.35	120	245	36	21	125
66A*	49°38.2'	124°53.3'	34	0.4	2.3	13	61	2.38	105	250	33	18	102
66B	49°38.2'	124°53.3'	34	0.4	2.6	11	66	2.40	140	250	32	14	100
66C	49°38.2'	124°53.3'	34	0.3	2.1	11	54	2.35	90	260	34	10	72
66D	49°38.2'	124°53.3'	34	0.3	2.2	13	52	2.40	70	265	35	7	74
66E	49°38.2'	124°53.3'	34	0.4	3.0	11	54	2.45	70	270	36	9	76
66F	49°38.2'	124°53.3'	34	0.4	3.7	11	54	2.40	70	265	37	7	75
66G	49°38.2'	124°53.3'	34	<0.2	3.2	11	54	2.45	60	265	35	9	72
66H	49°38.2'	124°53.3'	34	0.3	3.7	12	56	2.45	70	270	36	9	78
67	49°38.2'	124°53.9'	30	0.5	1.4	12	64	2.38	110	250	31	20	120
68	49°38.2'	124°54.5'	27	0.3	1.1	12	49	2.15	85	250	28	17	88
69	49°38.3'	124°52.3'	21	<0.2	1.4	13	46	2.00	65	235	33	17	100
70**	49°38.3'	124°52.8'	40	0.5	0.6	6	14	0.98	20	110	12	10	30
71	49°38.4'	124°53.6'	32	0.4	1.8	11	65	2.32	110	240	32	18	116
72	49°38.4'	124°54.2'	30	0.2	1.5	12	54	2.30	70	245	29	19	92
73	49°38.5'	124°52.5'	26	0.2	0.9	13	47	2.06	145	240	35	17	92
74	49°38.5'	124°53.1'	42	0.2	1.9	10	64	2.38	110	250	33	29	118
75	49°38.5'	124°54.6'	27	0.2	1.2	12	50	2.30	70	250	28	13	88
76	49°38.6'	124°54.0'	34	<0.2	1.4	12	64	2.40	115	240	30	19	110
77	49°38.7'	124°52.8'	42	0.4	0.9	11	53	2.25	100	245	33	41	95
78	49°38.7'	124°53.4'	41	<0.2	1.9	12	68	2.45	120	255	34	31	117
79	49°38.8'	124°53.7'	38	0.4	1.6	11	61	2.30	120	240	31	21	115
80	49°38.8'	124°54.3'	34	0.4	1.2	11	59	2.30	110	245	30	15	104
81	49°38.8'	124°54.8'	26	0.5	1.3	11	59	2.45	100	260	30	18	98
82**	49°38.9'	124°52.6'	22	<0.2	<0.5	5	10	1.30	15	105	8	6	21
83	49°38.9'	124°53.2'	44	0.4	2.1	10	65	2.45	120	245	32	18	98
85	49°39.0'	124°53.5'	49	0.4	1.8	10	61	2.40	120	245	34	50	120
86	49°39.0'	124°54.1'	39	0.3	1.5	11	57	2.30	100	240	30	24	105
87	49°39.0'	124°54.6'	40	0.2	0.7	10	54	2.22	105	240	28	20	93
88	49°39.0'	124°55.1'	23	0.4	<0.5	14	56	2.30	90	325	30	56	100
89	49°39.1'	124°54.4'	31	0.2	<0.5	10	47	1.91	135	225	27	44	90
90	49°39.1'	124°55.0'	34	0.5	<0.5	10	42	1.83	140	255	25	61	80
91	49°39.1'	124°55.5'	28	0.3	0.6	12	49	2.20	90	270	27	16	86
92	49°39.2'	124°53.8'	42	0.4	1.4	10	56	2.29	100	230	32	23	104
93	49°39.2'	124°55.9'	21	<0.2	0.5	12	49	2.20	80	250	26	26	84
94	49°39.2'	124°56.2'	12	0.5	<0.5	13	60	2.30	85	295	29	16	104
95	49°39.3'	124°53.6'	34	0.4	0.8	11	65	2.42	—	270	38	340	143
96	49°39.3'	124°54.7'	24	0.3	<0.5	9	40	2.15	100	200	22	125	88
97	49°39.3'	124°55.3'	33	0.3	<0.5	8	40	1.82	65	210	21	30	72
98**	49°39.4'	124°54.1'	28	<0.2	0.8	10	10	1.65	15	150	18	48	52
99	49°39.4'	124°54.4'	17	0.2	<0.5	11	40	2.00	100	200	24	63	98
100	49°39.4'	124°55.1'	15	0.3	<0.5	7	31	1.75	60	180	15	30	55
101	49°39.4'	124°55.7'	23	0.2	<0.5	10	47	2.02	65	245	24	11	80
102	49°39.4'	124°56.2'	13	<0.2	<0.5	14	66	2.30	95	275	28	14	90
103	49°39.6'	124°55.5'	27	0.5	<0.5	10	47	1.95	95	230	25	19	82
104	49°39.6'	124°56.0'	21	0.5	0.8	10	48	1.92	65	225	23	17	76
105	49°39.8'	124°55.2'	18	0.3	1.0	10	57	2.20	100	235	26	17	98
106	49°39.8'	124°55.7'	25	0.3	<0.5	10	47	1.92	85	230	22	15	80
107	49°39.9'	124°55.9'	22	0.2	<0.5	10	43	1.78	70	200	20	11	67
108	49°40.0'	124°55.5'	23	0.3	0.7	12	53	2.15	115	240	25	19	94
				Outer Trough									
109	49°36.3'	124°47.8'	79	0.4	<0.5	10	40	1.60	70	215	22	13	77
110	49°36.7'	124°47.1'	92	0.4	<0.5	10	44	1.70	90	225	23	11	79
111	49°36.7'	124°48.2'	73	0.2	<0.5	10	42	1.65	100	260	24	16	88
112	49°37.0'	124°46.5'	51	0.4	<0.5	12	70	1.80	130	730	27	34	132

Sample no.	Location Lat.N	Long.W	Depth (m)	Ag	Cd	Co	Cu	Fe	Hg	Mn	Ni	Pb	Zn
				Outer Trough									
113	49°37.2'	124°47.6'	88	0.3	<0.5	10	44	1.65	105	245	24	11	86
114	49°37.3'	124°48.8'	75	0.4	<0.5	10	47	1.70	110	245	25	31	86
115	49°37.4'	124°45.8'	56	0.5	<0.5	10	56	1.86	130	390	32	41	126
116	49°37.5'	124°47.0'	43	0.2	<0.5	17	67	2.08	135	1630	34	43	144
117	49°37.6'	124°48.1'	88	<0.2	<0.5	10	41	1.90	70	245	27	15	76
118	49°37.7'	124°49.3'	55	0.2	<0.5	9	46	1.70	160	270	26	93	95
119	49°37.8'	124°46.3'	52	0.3	<0.5	10	54	1.85	130	500	28	30	120
120	49°37.9'	124°47.4'	58	0.3	<0.5	10	54	1.80	125	510	25	43	116
121	49°38.1'	124°48.6'	83	0.5	<0.5	11	48	1.80	110	240	27	21	90
122	49°38.2'	124°49.8'	66	<0.2	<0.5	9	42	1.62	120	230	25	10	83
123	49°38.3'	124°46.8'	52	0.2	<0.5	9	45	1.85	120	295	23	19	95
124	49°38.4'	124°47.9'	80	0.2	<0.5	9	42	1.62	110	245	22	13	84
125	49°38.5'	124°49.1'	80	0.3	<0.5	10	48	1.76	120	250	26	14	90
126	49°38.6'	124°50.3'	42	0.5	<0.5	10	49	1.90	120	390	35	250	140
127	49°38.7'	124°47.3'	54	0.3	<0.5	10	49	1.70	110	355	23	26	94
128	49°38.9'	124°48.4'	85	0.3	<0.5	10	42	1.80	110	230	26	14	78
129	49°39.0'	124°49.6'	74	0.3	<0.5	10	50	1.68	110	215	26	16	95
130	49°39.1'	124°50.8'	55	0.2	<0.5	9	34	1.40	85	185	23	13	70
131	49°39.2'	124°47.8'	56	0.5	<0.5	10	39	1.80	105	280	21	15	78
132	49°39.3'	124°48.9'	81	0.2	<0.5	10	49	1.80	105	240	26	16	90
133	49°39.4'	124°50.1'	70	0.4	<0.5	12	50	1.75	110	220	27	13	94
134	49°39.6'	124°48.3'	58	<0.2	0.7	8	29	1.55	100	205	19	18	67
135	49°39.6'	124°51.3'	37	0.4	<0.5	9	40	1.70	100	240	26	35	90
136	49°39.8'	124°49.4'	80	0.2	<0.5	10	50	1.70	105	230	26	42	93
137	49°39.9'	124°50.6'	63	0.3	<0.5	9	30	1.45	80	200	22	14	62
138	49°40.0'	124°51.8'	44	0.4	<0.5	8	31	1.50	95	195	23	18	66
139	49°40.1'	124°48.7'	49	0.3	<0.5	10	45	1.80	115	360	23	28	88
140	49°40.2'	124°49.9'	78	0.3	<0.5	10	36	1.55	80	205	22	22	75
141**	49°40.3'	124°52.1'	17	<0.2	<0.5	2	9	0.82	20	80	5	26	22
142	49°40.4'	124°51.1'	59	<0.2	<0.5	8	30	1.40	85	180	20	11	60
143**	49°40.6'	124°49.2'	27	0.2	<0.5	3	9	0.84	30	100	7	10	24
144	49°40.7'	124°50.4'	61	0.2	<0.5	8	28	1.40	130	180	18	32	60
145	49°40.8'	124°51.6'	31	<0.2	<0.5	9	42	2.00	110	250	23	75	90
146	49°40.9'	124°49.9'	18	<0.2	<0.5	8	41	1.75	100	275	20	138	92
147**	49°41.1'	124°50.9'	14	0.2	<0.5	2	6	0.70	20	60	2	5	12
					Comox Bar								
149**	49°36.7'	124°49.0'	9	<0.2	<0.5	3	8	2.25	15	70	7	13	22
152**	49°38.4'	124°50.6'	15	<0.2	<0.5	3	4	2.70	—	70	3	16	112
156**	49°38.9'	124°51.1'	8	<0.2	<0.5	3	16	1.20	—	85	8	58	50
158**	49°39.1'	124°51.9'	4	<0.2	<0.5	5	18	1.50	20	135	12	10	25
159**	49°39.2'	124°52.7'	5	<0.2	<0.5	4	11	2.18	10	98	7	16	19
160**	49°39.3'	124°51.6'	6	0.3	<0.5	2	7	1.45	15	80	4	9	15
165**	49°39.8'	124°52.1'	5	<0.2	<0.5	2	5	1.55	20	70	2	5	12
167**	49°39.9'	124°53.4'	3	<0.2	<0.5	2	5	1.28	15	57	2	3	6
168**	49°40.1'	124°52.7'	4	<0.2	<0.5	<2	4	0.85	15	50	2	4	6
169**	49°40.1'	124°53.2'	4	<0.2	<0.5	<2	5	0.55	10	52	<2	4	8
172**	49°40.6'	124°52.3'	7	<0.2	<0.5	<2	4	0.90	15	60	2	5	11
173**	49°40.6'	124°52.8'	2	<0.2	<0.5	2	9	1.33	10	67	2	6	30
174**	49°40.8'	124°52.1'	10	<0.2	<0.5	<2	5	0.80	15	55	2	5	11
176**	49°41.1'	124°51.9'	8	<0.2	<0.5	<2	4	1.20	10	53	2	4	11
177**	49°41.1'	124°52.3'	2	<0.2	<0.5	3	9	2.80	10	70	2	7	20
178**	49°41.3'	124°51.6'	9	<0.2	<0.5	<2	6	1.05	10	60	3	7	12

Note: Trace element concentrations are expressed in ppm, except iron (%) and mercury (ppb). Dash indicates that concentration was not determined.

*66A through 66H are subsamples of a core; each subsample includes 10 cm of the core, A being the highest 10 cm and H the lowest 10 cm.

**Analyses performed on sediment finer than 0.149 mm; for other samples, the fraction finer than 0.0625 mm was analyzed.