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Sources, Composition, and Transport of Suspended Particulate Matter in Lower Cook Inlet and Northwestern Shelikof Strait, Alaska

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NOTICE

CONTENTS

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ABSTRACT. The chemical composition and seasonal distribution of suspended particulate matter collected during 1977 and 1978 in lower Cook Inlet and northwestern Shelikof Strait are compared with published data on current patterns. With respect to suspended-matter dispersal patterns, Cook Inlet shows characteristics of both an estuary and an embayment. Estuarine characteristics are exemplified by the association of the inorganic terrestrial material from upper Cook Inlet with the outward-flowing estuarine water. Plots of total suspended-matter concentrations versus salinity for surface and near-bottom waters are roughly linear for the central region of lower Cook Inlet, indicating that dilution of the estuarine water by relatively nonturbid oceanic water is the major factor controlling suspended-matter concentrations in the inlet. Embayment characteristics are indicated by the cross-channel suspended-matter gradients and by the elemental ratios of the particulate matter, which show evidence for movement of Copper River-derived aluminosilicate material across the mouth of the inlet and into Shelikof Strait. These features, which are unique to lower Cook Inlet, are a direct result of the unusual nature of the current patterns existing within the inlet.

1. INTRODUCTION

The rapid expansion of petroleum and related industries in Cook Inlet has aroused considerable concern for the welfare of the local marine environment and its renewable resources, especially the rich fisheries. With few exceptions, the region has not been subjected to massive oil spills, and the effects of chronic, low-level inputs of petroleum products are only beginning to be addressed (Cline et al., 1979). Although various options for allocation and transportation of Alaskan crude oil to west coast ports are still under consideration, it is clear that increasing amounts of petroleum will be transported through the region to meet the demand.

Since crude oil is only slightly water-soluble, it tends to form an emulsion when introduced into seawater, especially under intense wave action. The emulsion has a high affinity for mineral particles and is adsorbed rapidly. Recent studies of oil spills in coastal waters containing heavy loads of suspended matter have indicated rapid removal of oil by sorption onto particles along the leading edge of frontal zones (Forrester, 1971; Kolpack, 1971; Klemas and Polis, 1977). These zones are regions where turbid estuarine water contacts seawater. At the interfaces downwelling usually occurs, causing the inorganic material and any associated contaminants to be carried down into the seawater column. Similarly, laboratory studies involving the interaction between crude oils and mineral

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particles show that significant amounts of oil may be accommodated by the particles (Huang and Elliott, 1977; Feely et al., 1978). The accommodation process is a function of the isoelectric points of oil and mineral particles, particle size and composition, temperature, and the ambient concentrations of oil and mineral particles. Thus, the association of oil and suspended particles can play an important role in the dispersal and deposition of petroleum hydrocarbons, especially in an area like Cook Inlet, which has exceptionally high concentrations of suspended materials. This study characterizes spatial variations of the distribution and composition of suspended particulate matter in lower Cook Inlet and northwestern Shelikof Strait in order to identify likely dispersal routes of suspended matter and any associated petroleum hydrocarbons.

2. BACKGROUND

Previous studies of suspended material in lower Cook Inlet have been limited to observations of LANDSAT satellite and aircraft photographs, augmented with sea-truth measurements in some places. These studies have provided useful information about dispersal patterns of near-surface suspended matter, particularly in the Kalgin Island region where extremely high concentration gradients have been observed. Sharma et al. (1974) used these sources of data to study suspended-matter distributions in Cook Inlet during late summer of 1972 and early spring of 1973. Concentrations of suspended matter ranged from 100 mg/L near the Forelands to 1-2 mg/L near the entrance of the inlet. Large temporal variations were related to tidal variations in water circulation.

Gatto (1976) studied the dispersal of sediment plumes from coastal rivers as affected by tidal currents in the inlet. Turbid plumes from the Tuxedni, Drift, Big, and McArthur rivers (fig. 1) on the west side formed distinct surface layers, riding over and mixing with the saline water from the south. During flood tide, the plumes flowed northward along the coast. On ebb tide, the plumes migrated back to the south and west. Occasionally, the relict plumes were observed far offshore, which indicated that at least some plumes of sediment-laden water were capable of maintaining their identity for several tidal cycles.

Burbank (1977) used LANDSAT imagery to study dispersal patterns of suspended matter in Kachemak Bay, where the suspended material is derived from inflow of inorganic and biogenic materials together with the saline Gulf of Alaska water, in situ production, and suspended material discharged from the Fox River and other local rivers. Sediment plumes were observed along the northwest shore of inner Kachemak Bay. These plumes were diverted around Homer Spit and into outer Kachemak Bay by a counterclockwise rotating gyre. In the outer bay, the plumes moved to the west and north under the influence of a second counterclockwise gyre.

3. THE STUDY REGION

Physiographically, Cook Inlet is divided into three sections: the head region, which is further divided into Knik and Turnagain arms; upper Cook Inlet; and lower Cook Inlet (fig. 1). Upper Cook Inlet is separated from

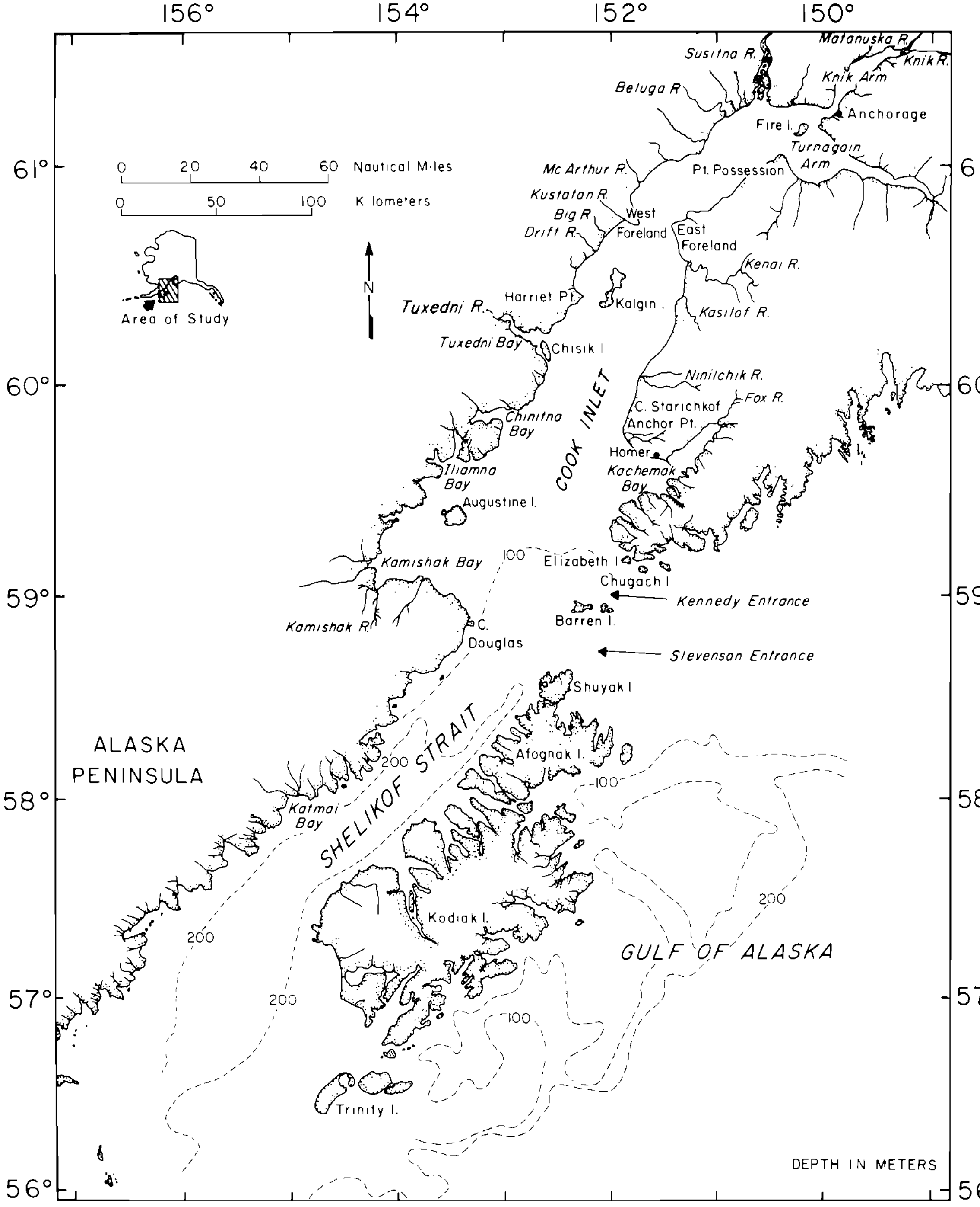

Figure 1.--Physiographic setting of Cook Inlet and Shelikof Strait, Alaska.

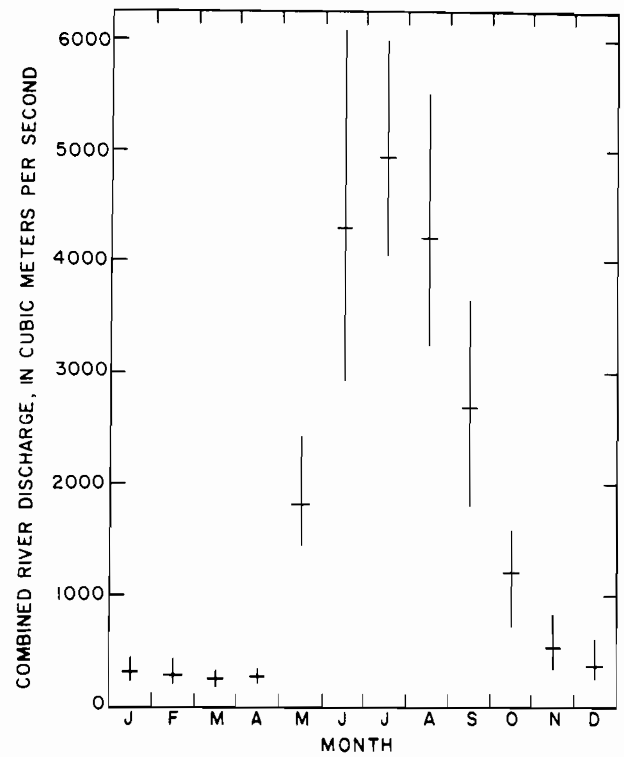

Figure 2.--Combined monthly means and ranges for gaged major rivers discharging into Cook Inlet. The data were compiled from USGS streamflow records for the following rivers and periods: Susitna River at Susitna, 1975-1978, mean annual discharge 1318 m^3/s; Knik River near Palmer, 1961-1978, mean annual discharge 185 m^3/s; Kenai River at Soldotna, 1965-1978, mean annual discharge 158 m^3/s; and Matanuska River at Palmer, 1961-1973, mean annual discharge 104 m^3/s.

lower Cook Inlet by two geographic constrictions: the East and the West Forelands. Below the Forelands, the coastline of lower Cook Inlet is characterized by several small embayments--Tuxedni Bay, Chinitna Bay, and Iliamna Bay, and two large embayments--Kamishak Bay and Kachemak Bay. At its mouth, the inlet opens into the Gulf of Alaska to the southeast, and Shelikof Strait to the southwest. Shelikof Strait is separated from the Gulf of Alaska by Shuyak, Afognak, Kodiak, and Trinity islands.

Upper Cook Inlet receives freshwater and suspended sediment from the Matanuska and Knik rivers at the head of Knik Arm and the Susitna and Beluga rivers to the northwest. The combined flow of these rivers supplies about 70% to 80% of the freshwater input and 75% to 90% of the suspended-sediment input to upper Cook Inlet (Rosenberg and Hood, 1967; Feulner et al., 1971). The rivers originate in glaciers and show large seasonal fluctuations in discharge (fig. 2). Peak discharge occurs in July and minimum discharge in March. Suspended sediment in these rivers is derived from glacial erosion at higher altitudes. In addition to the rivers discharging into upper Cook Inlet, the lower inlet receives suspended sediment from several smaller rivers that carry glacial flour into the inlet from both sides. Included in this category are the Kenai, Kasilof, Ninilchik, Anchor, and Fox rivers on the east side and the McArthur, Big, Drift, and Tuxedni rivers which discharge into the inlet from the west.

The physical oceanography of lower Cook Inlet has been described by several authors (Kinney et al., 1970; Wright et al., 1973; Gatto, 1976; Burbank, 1977; and Muench et al., 1978). The last reference provides the most complete description of water circulation. Water mass movement in the inlet is characterized by a net inward movement of oceanic water up the eastern shore and a net outward movement of a mixture of oceanic water and estuarine water along the western shore. In the vicinity of the Forelands, the water masses are vertically mixed because of the turbulent action of tidal currents. However, lateral separation of the water masses is apparent and results in a shear zone between the incoming saline water on the east side and the outflowing estuarine water on the west. Coastal upwelling occurs along the eastern shore from the region west of Kennedy Entrance to Cape Starichkof.

The distribution and composition of bottom sediments in lower Cook Inlet have been studied (Sharma and Burrell, 1970; Bouma and Hampton, 1976; Hein et al., 1979). The sediments are composed primarily of medium- to fine-grained sands; however, occasionally silt- and clay-sized sediments have been observed. The deposits in the northern part of the inlet are winnowed Pleistocene--early Holocene--gravels, and many of the particles sand-sized and smaller have been removed and redeposited to the south. In addition to relict sands and gravels, bottom deposits also contain some modern fine-grained silts and clays. Hein et al. (1979) show that the clay mineral suites in lower Cook Inlet are from two distinct sources. A chlorite-rich suite dominates the clay mineral fraction in deposits from Kennedy Entrance to Kachemak Bay. The Copper River appears to be the major source of this material as it discharges chlorite-rich, fine-grained sediments into the northeast Gulf of Alaska which are then diverted to the west and southwest by the coastal along-shelf currents (Hein et al., 1979; Feely et al., 1979). Apparently, some of this material reaches Kennedy Entrance and is transported into lower Cook Inlet along with inflowing Gulf of Alaska water. The region to the west and north of Kachemak Bay is dominated by an illite-rich suite which has the Susitna-Knik-Matanuska River system in upper Cook Inlet as its major source. Hein et al. (1979) suggest that the distribution of clay minerals in bottom sediments of lower Cook Inlet reflects the dispersal routes of suspended matter in the overlying water. Thus, fine-grained particles from these two sources appear to follow the general pattern of water circulation in the inlet and also form the bulk of the mud deposits in the quiescent embayments along the shore.

4. EXPERIMENTAL PROCEDURES

4.1 Sampling Methods

In order to obtain information about seasonal variations of the distribution and composition of suspended matter, samples were collected during five cruises in lower Cook Inlet. (4-16 April 1977, 28 June-12 July 1977, 5-12 October 1977, 4-17 May 1978, and 22 August-6 September 1978). Figure 3 shows the locations of the 1977 sampling stations, and figure 4 shows the locations of the 1978 sampling stations. Water samples were collected in General Oceanics Model 1070 10-L PVC Top Drop Niskin bottles from the surface and 5 m above bottom at all stations, and from several intermediate depths along vertical sections between Kachemak Bay and Kamishak Bay

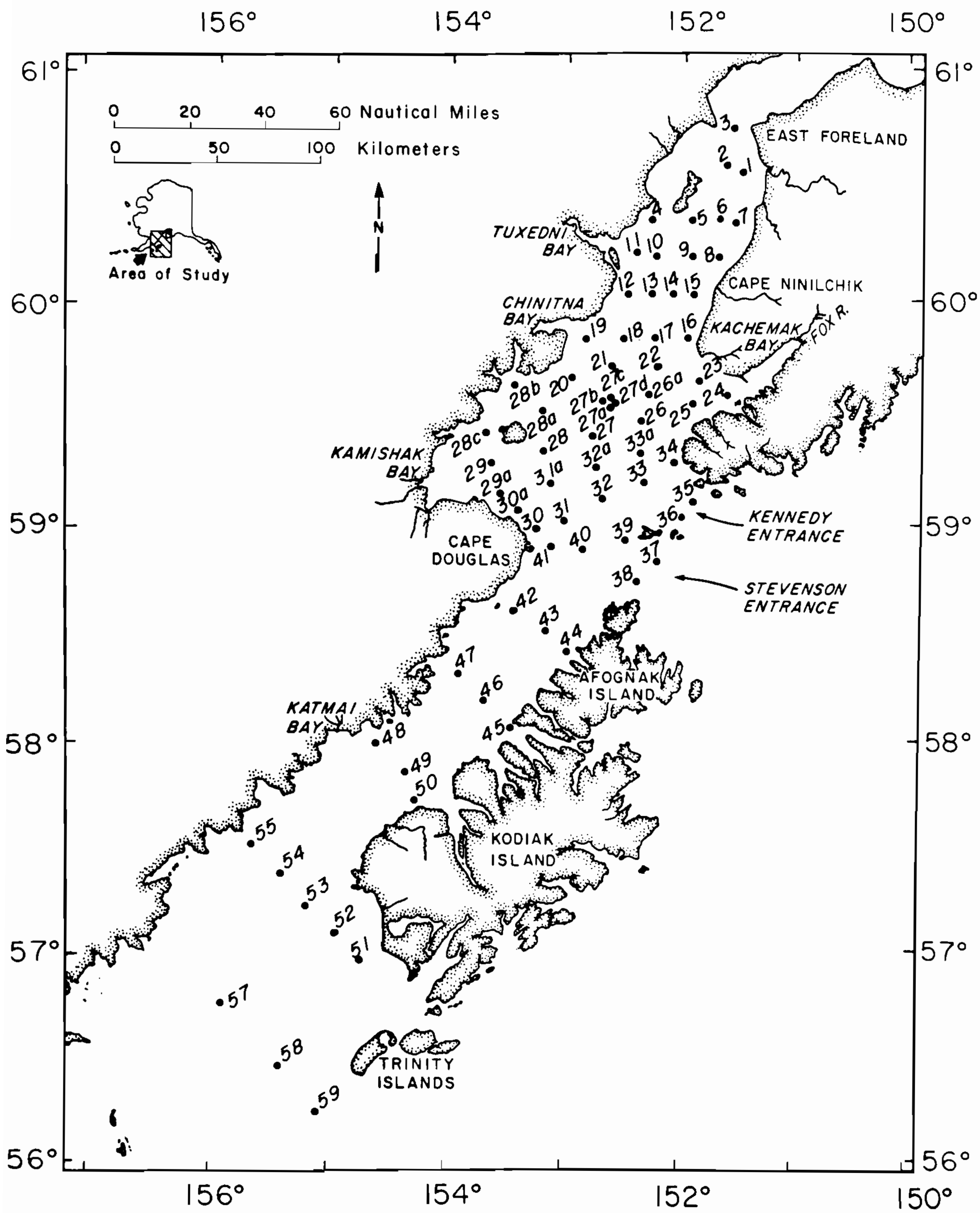

Figure 3.--Locations of 1977 sampling stations in lower Cook Inlet and Shelikof Strait. During October, only stations 24-29 were occupied.

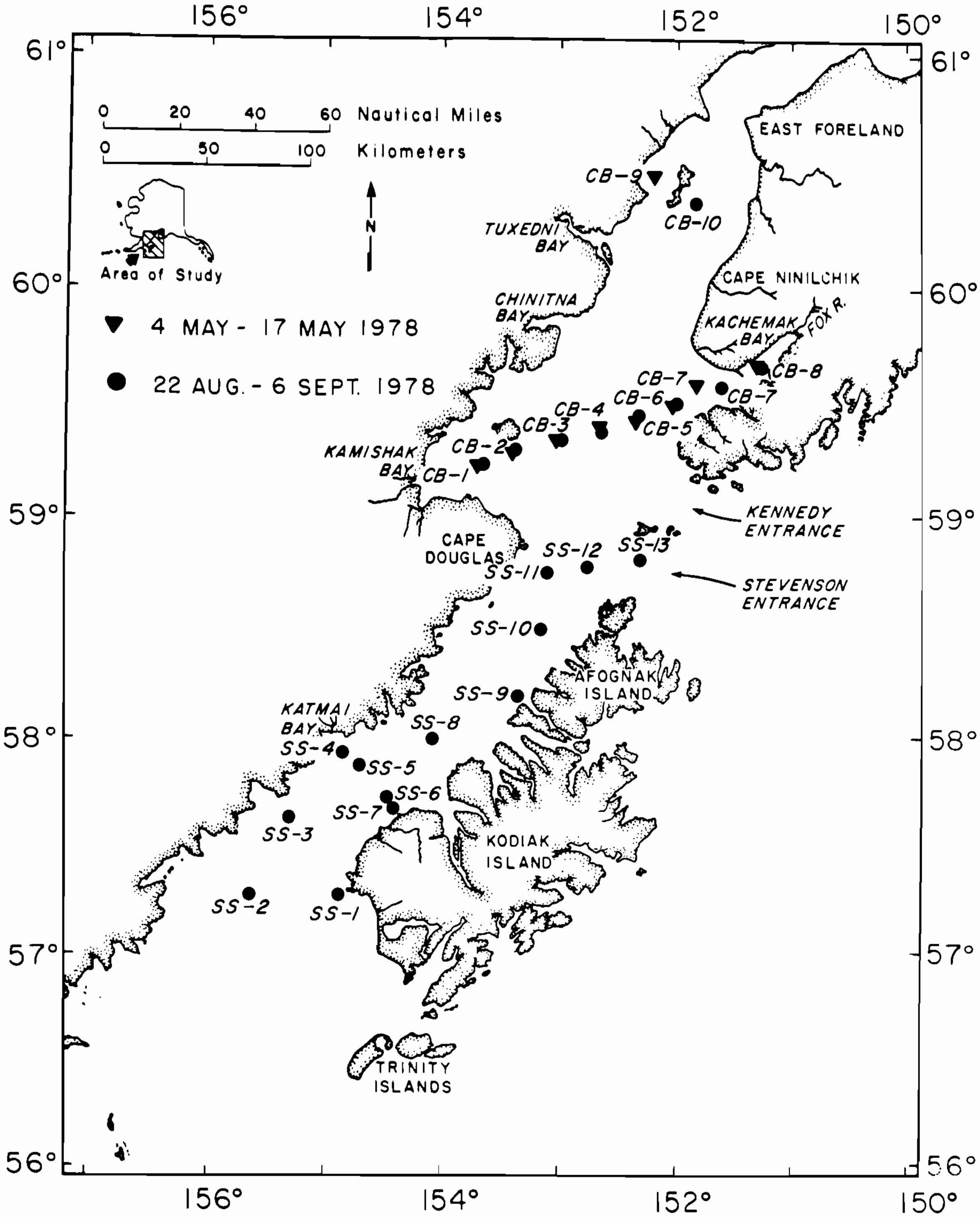

Figure 4.--Locations of 1978 sampling stations in lower Cook Inlet and Shelikof Strait.

(stations 25 through 29 on the 1977 cruises and stations CB1 through CB8 on the 1978 cruises) and in Shelikof Strait (stations SS2, SS3, SS6, SS8, SS9, SS10, and SS12 in the 1978 cruises). To avoid the loss of rapidly settling particles (Gardner, 1977) and the resultant bias in elemental compositon caused by fractionation (Calvert and McCartney, 1979), aliquots from each sample were withdrawn promptly (within 10 to 15 minutes of collection), and vacuum filtered through 47-mm diameter, 0.4-μm pore size Nuclepore filters for total suspended-matter loading determinations and through 25-mm diameter, 0.4-μm pore size Nuclepore filters for elemental analyses. All samples were rinsed with three 10-mL aliquots of deionized membrane-filtered water, placed in individual polycarbonate petri dishes with lids slightly ajar for a 24-hour dessication period over sodium hydroxide, and then sealed and stored for subsequent laboratory analysis.

Temperature and salinity data were obtained with a Plessey Model 9040 CTD system equipped with a Model 8400 data logger. This system samples twice per second for simultaneous values of conductivity, temperature, and depth. The data were averaged to provide 1-m temperature and salinity values from which σ_t was computed. The σ_t values are accurate to ±0.02.

4.2 Analytical Methods

Total suspended-matter concentrations were determined gravimetrically. Samples of total suspended matter, collected on Nuclepore filters, were weighed on a Cahn Model 4700 Electrobalance before and after filtration. The weighing precision (2σ = ±0.011 mg) and volume reading error (±10 mL) yield a combined relative standard deviation in suspended-matter concentration of approximately 1%. However, investigations of sampling precision (relative standard deviations ranging from 5% to 17%) suggest that the actual variability in particulate matter concentrations of these waters is much greater than the above analytical precision.

The major inorganic elements (Mg, Al, Si, K, Ca, Ti, and Fe) in the suspended matter were determined by X-ray secondary emission (fluorescence) spectrometry using a Kevex Model 0810A-5100 X-ray energy spectrometer and the thin-film technique (Baker and Piper, 1976). The inherent broadband radiation from a silver X-ray tube was used to obtain a series of characteristic emission lines from a single-element secondary target which more efficiently excited the thin-film sample. A sequence of Fe and Se targets was used to fluoresce the aforementioned elements to provide maximum sensitivity and linearity. Standards were prepared from suspensions of finely ground* USGS Standard Rocks (W-1, BCR-1, AGV-1, and GSP-1) collected on Nuclepore membrane filters identical to those used for sample acquisition. The relative standard deviations for 10 replicate analyses of a largely inorganic sample of approximately mean mass were less than 2% for major constituents. However, when sampling precision was considered, the relative standard deviations increased to as much as 10%.

*By volume, 90% of the rock particles were less than 15 μm in diameter as determined by scanning electron microscopy.

5. RESULTS AND INTERPRETATION

Figures 5 through 8 show the distributions of salinity, temperature, σ_t, and total suspended matter at the surface and at 5 m above the bottom for the April and July 1977 cruises in lower Cook Inlet and Shelikof Strait. As shown in figures 5 and 7, the surface particulate matter distributions are characterized by unusually high horizontal gradients. On the eastern side, particulate concentrations were relatively low, ranging from 0.5 mg/L near Elizabeth Island to about 5.0 mg/L just north of Cape Ninilchik. In July, the nonturbid water remained close to the eastern shore and extended at least as far north as the East Forelands. On the western side, suspended loads increased sharply from concentrations averaging about 5.0 mg/L in the vicinity of Kamishak Bay to concentrations greater than 100 mg/L north of Tuxedni Bay. The salinity and temperature data in figures 5 and 7 show similar horizontal distribution patterns, reflecting the predominance of the inflowing, relatively clear, saline Gulf of Alaska water on the eastern side and the outflowing turbid, low-salinity water from upper Cook Inlet on the western side. The outflowing estuarine water is transported to the southwest past Augustine Island and Cape Douglas into Shelikof Strait.

The near-bottom suspended-matter distributions (figs. 6 and 8) are very similar to the surface distributions, which suggests that cross-channel gradients in suspended-matter concentrations exist throughout the water column. In agreement with this, vertical cross sections of the distribution of suspended matter and water properties from Kamishak to Kachemak Bay (figs. 9 through 13) show large cross-channel variations, which can be used to identify three distinct water masses. On the west side (stations 28 and 29 for the 1977 data, and stations CB1 through CB3 for the 1978 data) the water properties are characterized by low salinity ($29.8°/_{oo}$-$31.6°/_{oo}$) and high suspended-matter concentrations (0.9-8.2 mg/L). The water is virtually unstratified. These properties are characteristic of the outward-flowing estuarine water that originates in upper Cook Inlet and flows south along the western coast. This water mass contains much of the terrigenous sediment from the major rivers draining into upper Cook Inlet and lower Cook Inlet along the western shore. The central lower Cook Inlet region (stations 25 and 26 for the 1977 data, and stations CB5 and CB6 for the 1978 data) contains water that is more saline ($31.4°/_{oo}$-$31.8°/_{oo}$) and less turbid (0.4-1.4 mg/L) than the estuarine water to the west. This water is characteristic of inflowing Gulf of Alaska water which flows north along the east side of the inlet. In Kachemak Bay (station 24 from the 1977 data and stations CB7 and CB8 from the 1978 data), the waters are relatively warmer, less saline ($27.3°/_{oo}$-$31.4°/_{oo}$), and more turbid (0.9-2.8 mg/L) than the water in the central region of the inlet. These waters generally display the most intense stratification, with maximum $\Delta\sigma_t$ values occurring during the July and August-September sampling periods.

The May and August-September 1978 data show some patterns that are consistent with data from the previous year. First, the outward-flowing estuarine water on the western side is colder in May and warmer in August-September than the inward-flowing Gulf of Alaska water. This feature is consistent with data obtained in April and June-July 1977 (figs. 5 and 7) and appears to be regulated by heat exchange between upper basin water and the overlying continental air masses that exhibit relatively large seasonal fluctuations in temperature. Additionally, this feature is augmented by the

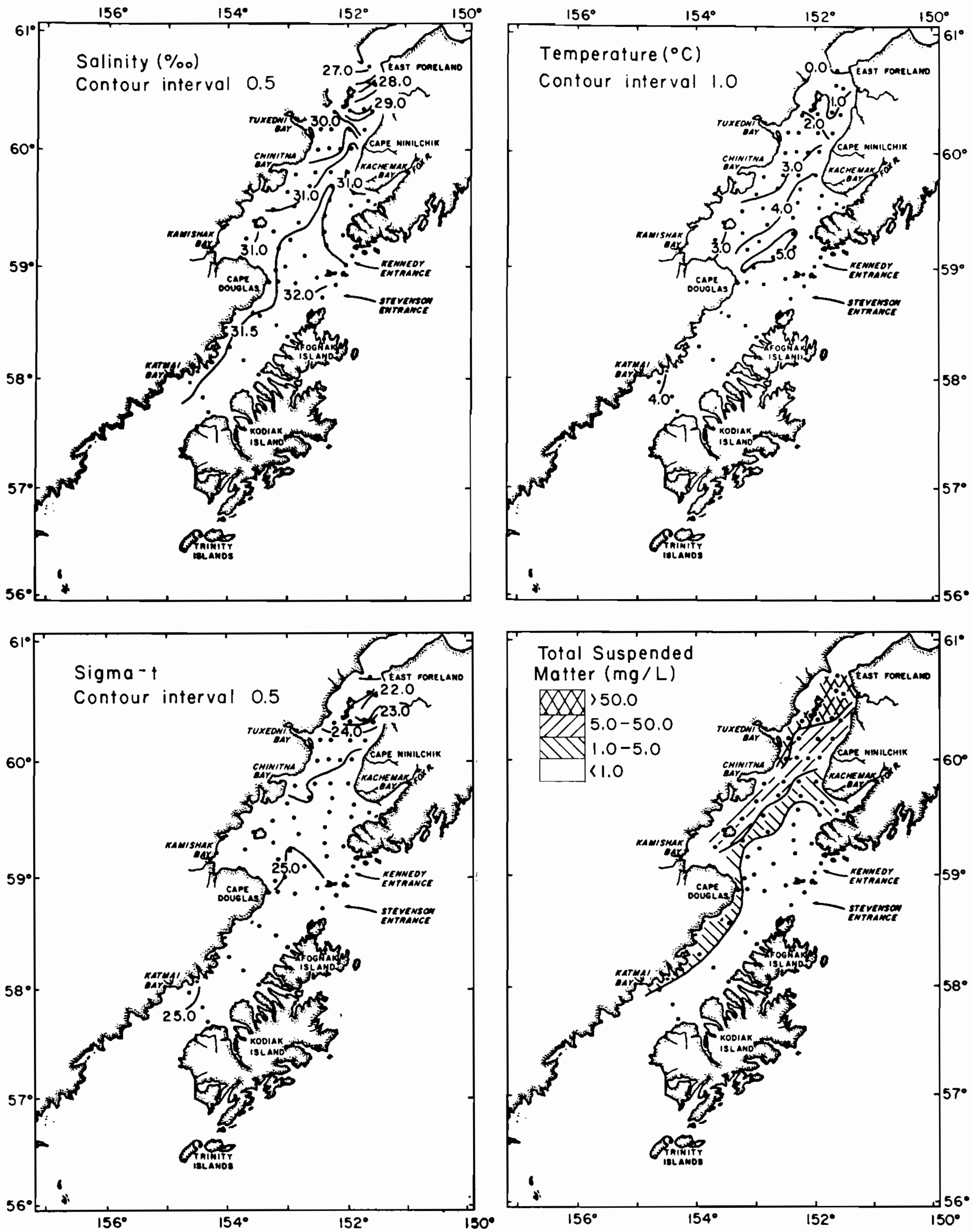

Figure 5.--Distributions of salinity, temperature, σ_t, and total suspended matter at the surface (4-16 April 1977).

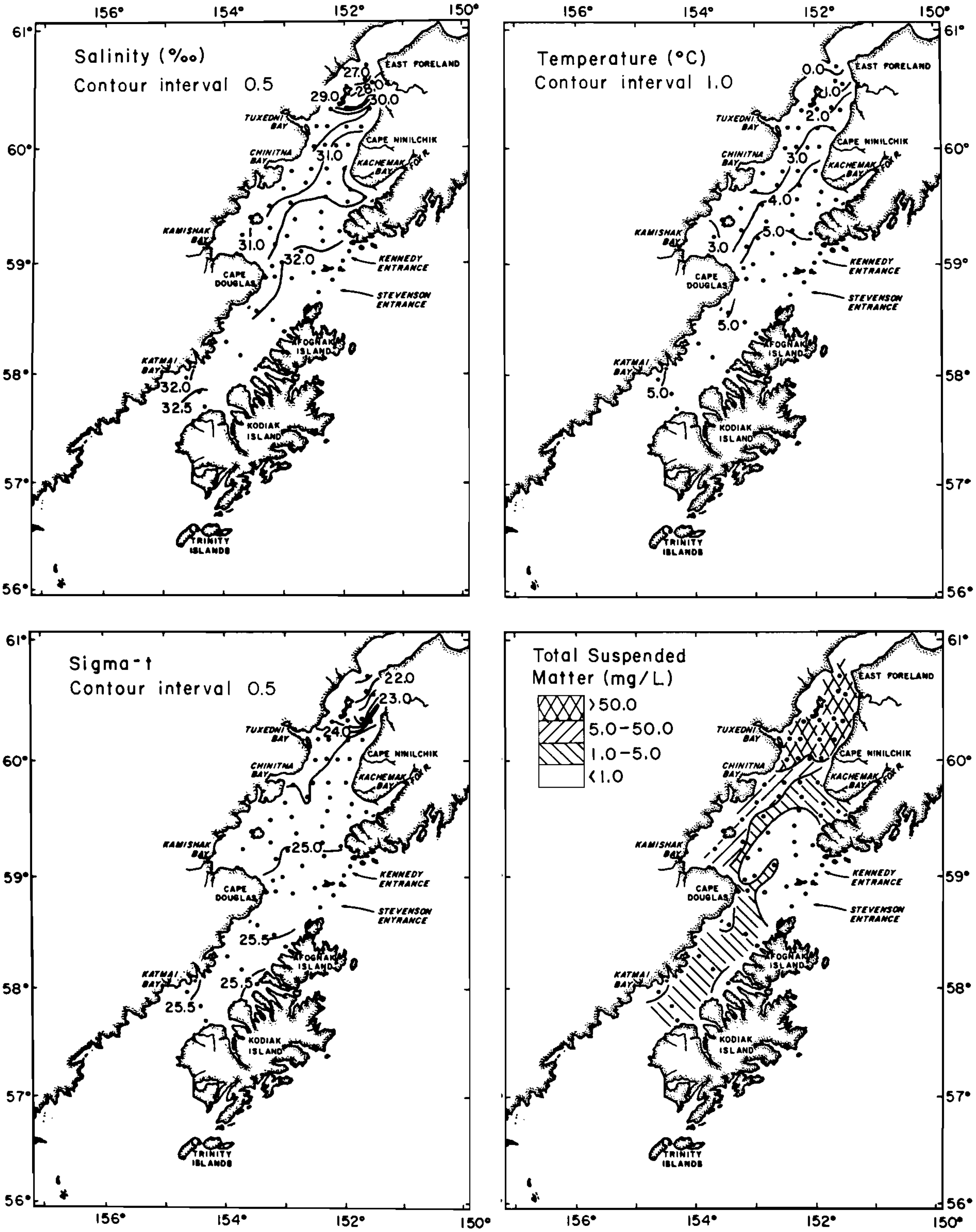

Figure 6.--Distributions of salinity, temperature, σ_t, and total suspended matter 5 m above the bottom (4-16 April 1977).

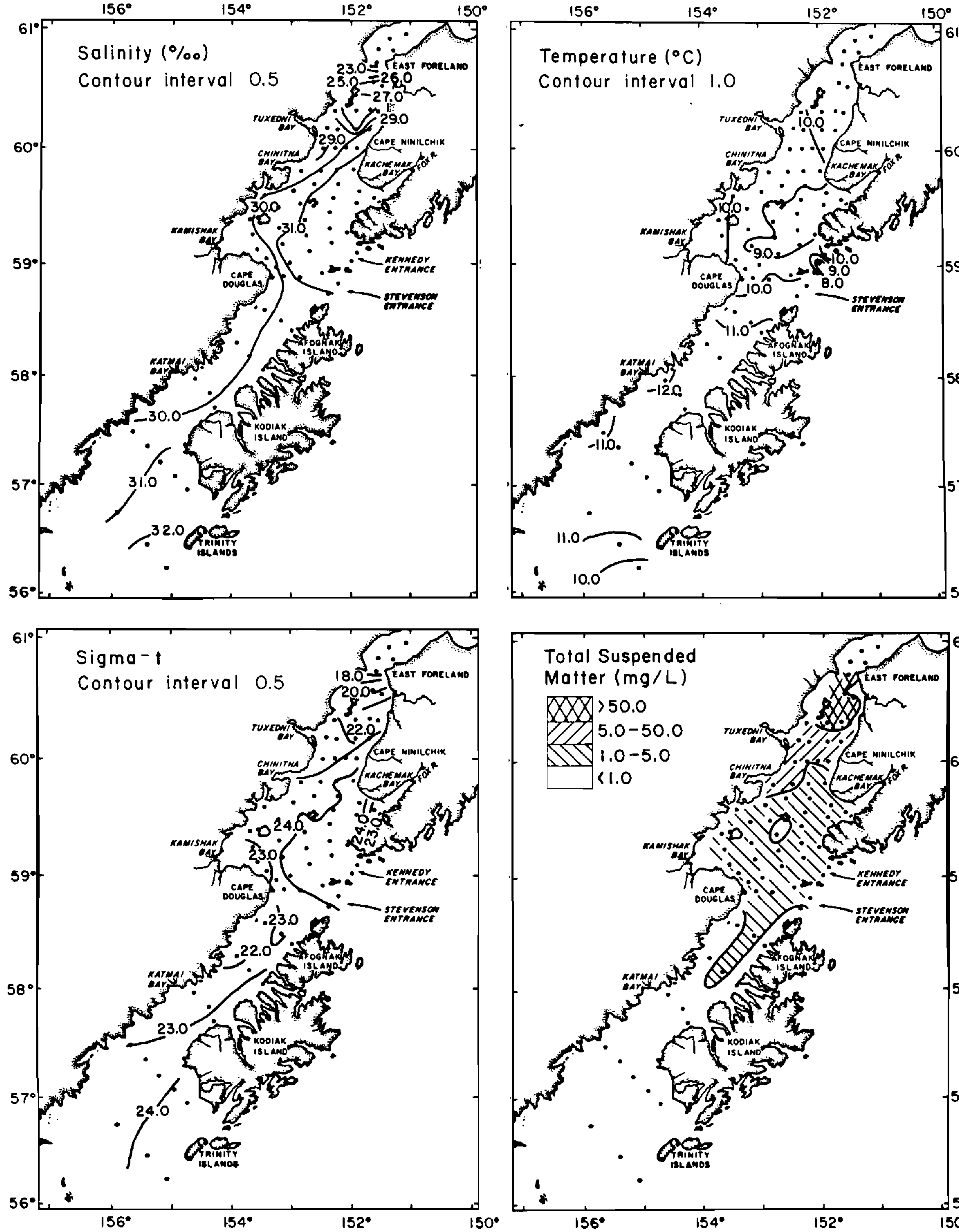

Figure 7.--Distributions of salinity, temperature, σ_t, and total suspended matter at the surface (28 June-12 July 1977).

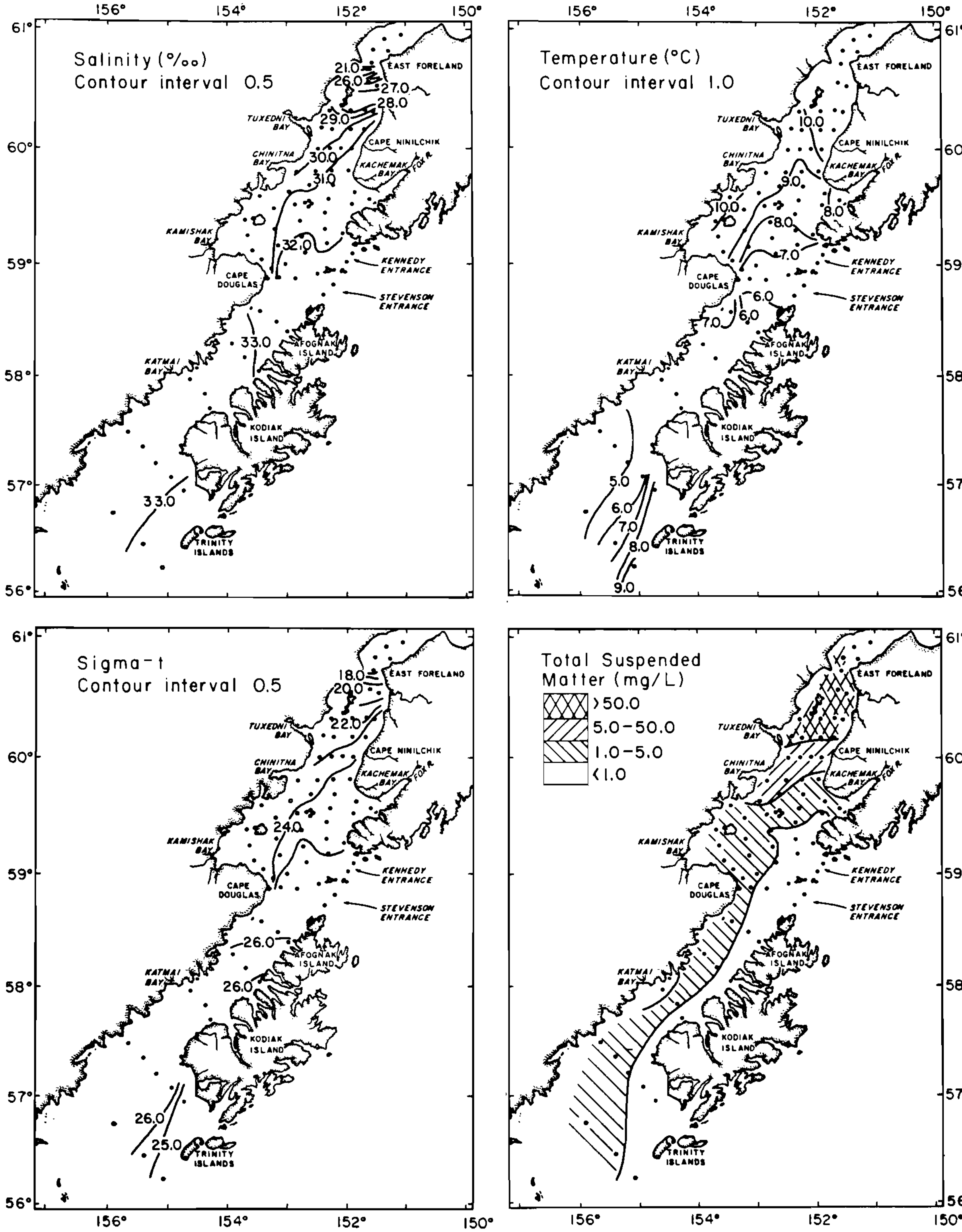

Figure 8.--Distributions of salinity, temperature, σ_t, and total suspended matter 5 m above the bottom (28 June-12 July 1977).

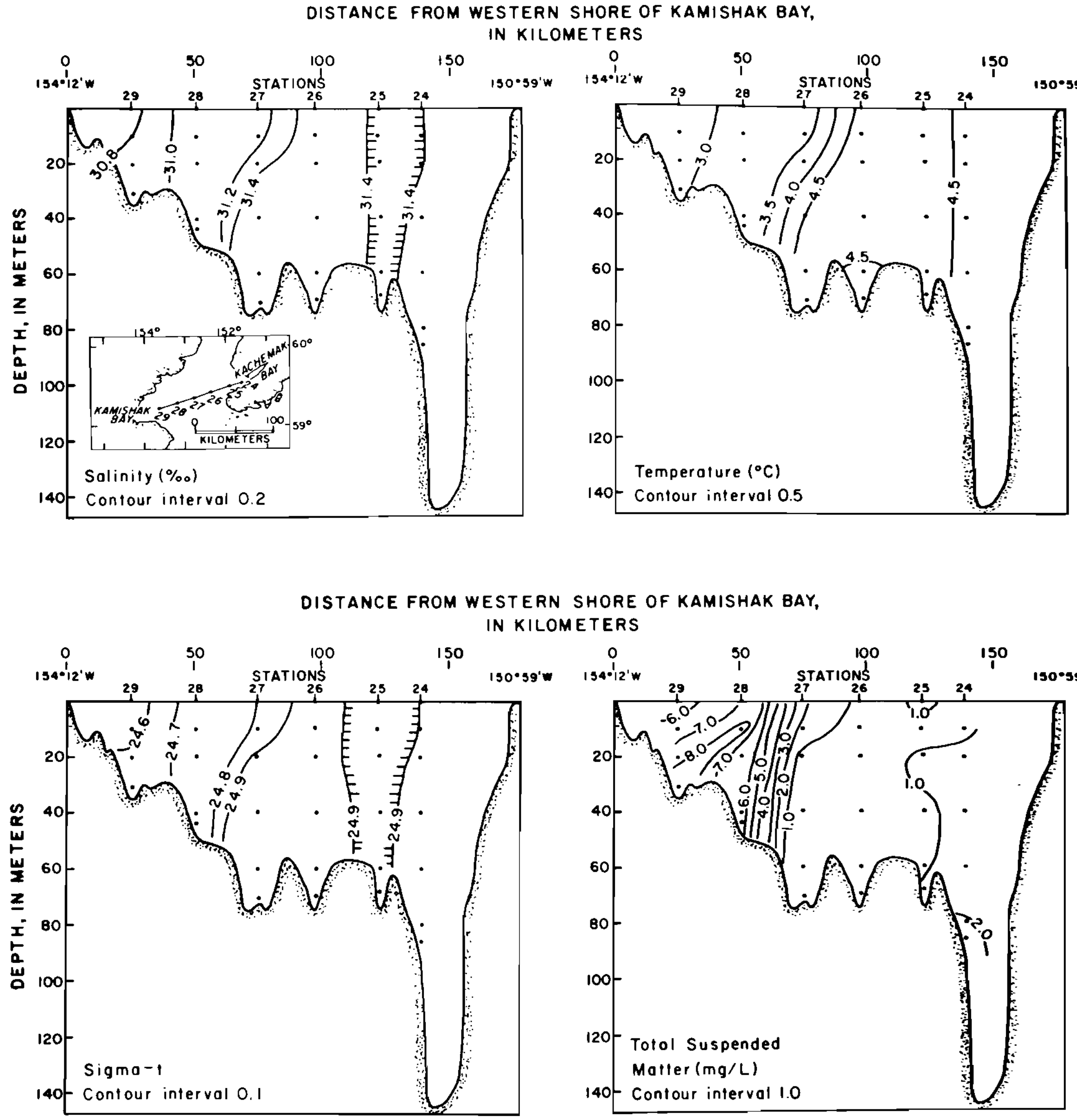

Figure 9.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations 24-29 in lower Cook Inlet (4-16 April 1977).

relatively longer period of advective replacement of water in upper Cook Inlet (Muench et al., 1978). Second, suspended-matter concentrations in the Kamishak Bay region are higher in early spring than in late summer even though there is more freshwater input into lower Cook Inlet during late summer (fig. 2). A possible explanation for this phenomenon is that in early spring, when most of the ice breakup occurs in upper Cook Inlet, resuspension and transport of previously deposited sediments may result from the ice movement. Another possibility is that in spring, turbulent mixing is sufficiently intense throughout the inlet to cause resuspended sediment to be mixed vertically throughout the water column and, in particular, in the Kamishak Bay region. Although the temperature, salinity, σ_t, and total suspended-matter data in figures 9 and 12 support the second possibility,

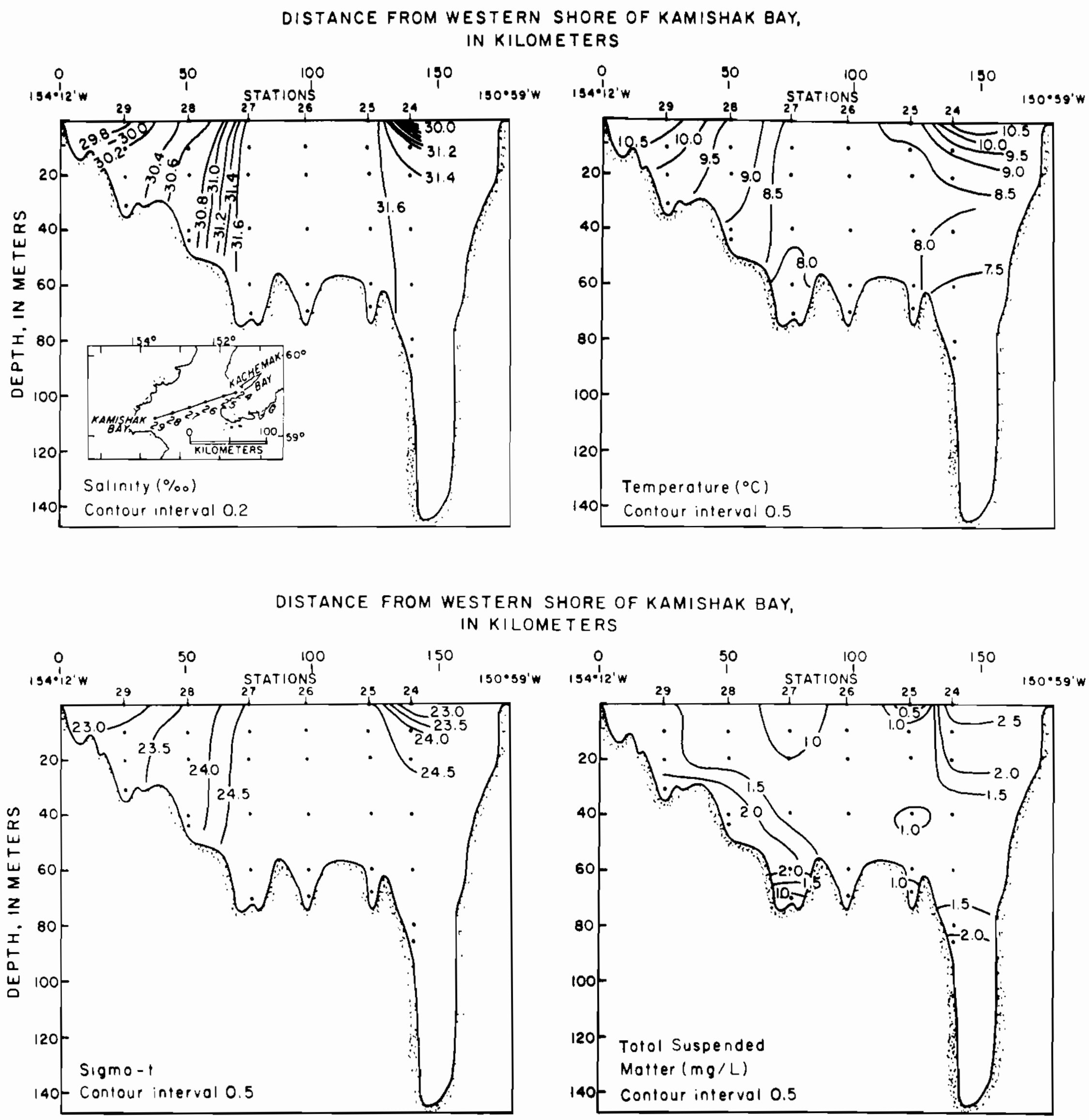

Figure 10.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations 24-29 in lower Cook Inlet (23 June-12 July 1977).

the first explanation cannot be rejected entirely because higher concentrations of surface suspended matter are observed throughout the inlet in early spring relative to early summer (figs. 5 through 8). Indeed, both processes may be contributing to this effect.

Figure 14 shows vertical cross sections of temperature, salinity, σ_t, and total suspended matter for stations located in Shelikof Strait. The data were obtained on the August-September 1978 cruise. Stations SS2, SS3, SS6, SS8, SS9, SS10, and SS12 represent a longitudinal cross section along the main axis of the strait. Stations SS4 through SS7 and SS11 through SS13 represent transverse cross sections at midstrait and upperstrait, respectively. Cross-channel gradients of temperature, salinity, and suspended

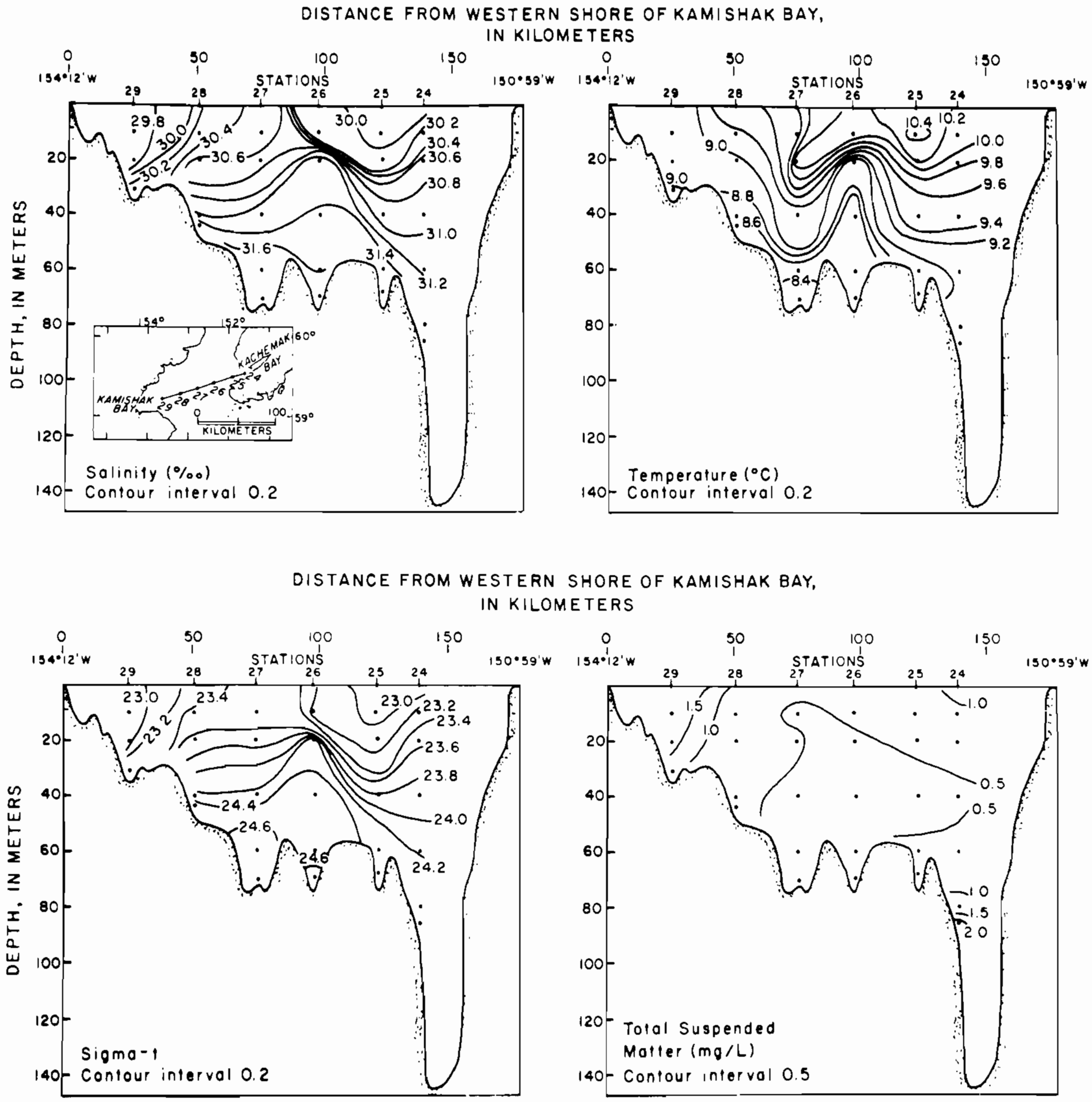

Figure 11.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations 24-29 in lower Cook Inlet (3-12 October 1977).

matter are consistent with cross-channel gradients observed in lower Cook Inlet. In particular, the surface temperature, salinity, and suspended-matter values at SS11 in Shelikof Strait are nearly the same as corresponding parameters at CB3 and CB4 in lower Cook Inlet for the same sampling period (fig. 13). This evidence strongly supports the view that water and suspended material from western lower Cook Inlet are transported into Shelikof Strait. There is also evidence for a near-bottom nepheloid layer in the strait, in the lower 50-60 m of the water column. Since there are no corresponding large gradients in σ_t that would tend to buoy up suspended material, the bottom nepheloid layer in this region is probably a result of resuspension of bottom sediment.

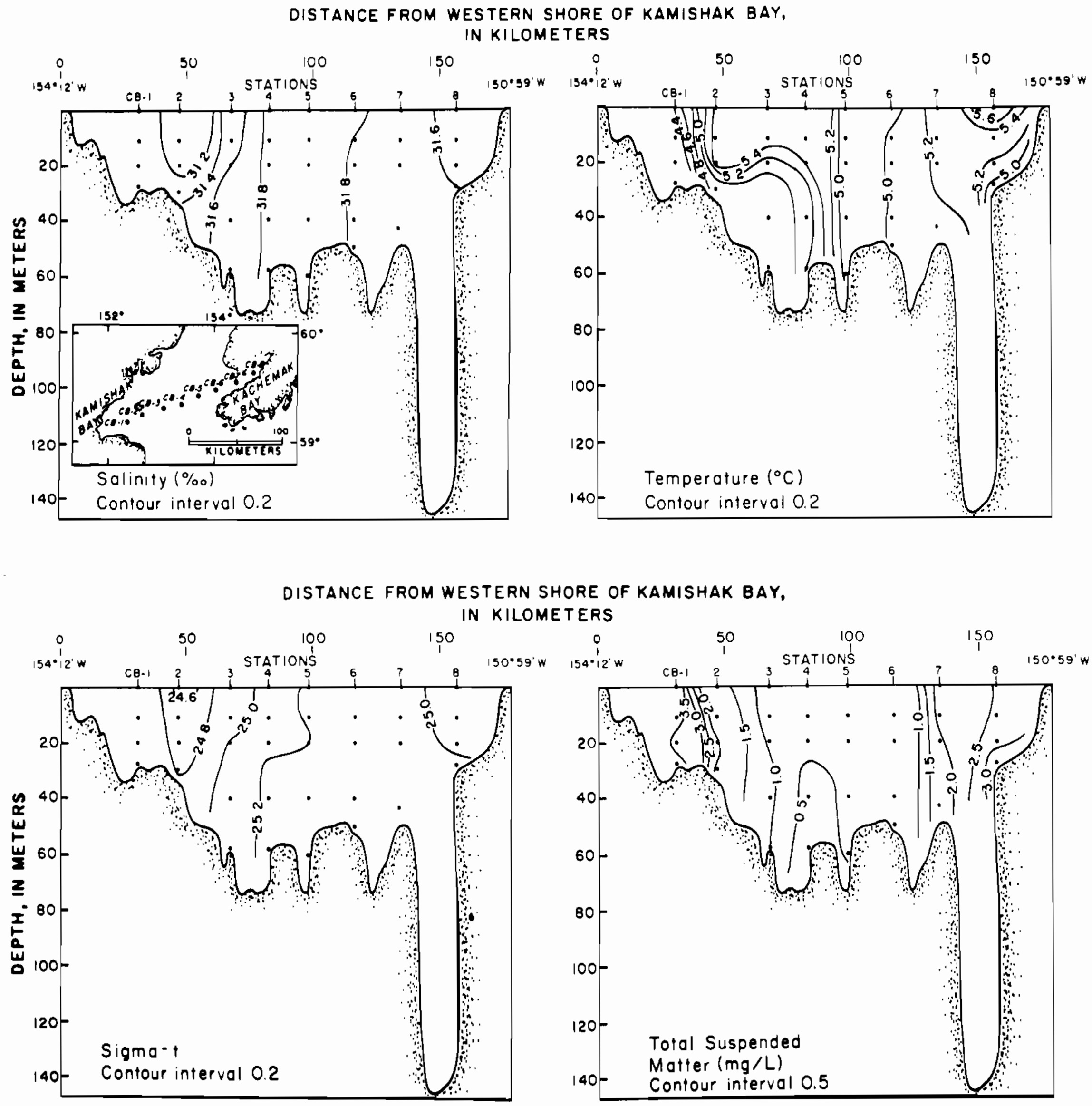

Figure 12.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations CB-1 through CB-8 in lower Cook Inlet (4-17 May 1978).

5.1 Temporal Variability of Suspended Matter

In order to obtain information about short-term variations of suspended-matter concentrations in the inlet, time-series experiments were conducted at station CB7 in Kachemak Bay and stations CB9 and CB10 on either side of Kalgin Island. Water samples from the surface and 5 m above the bottom were collected and filtered every two hours. The results of these experiments are shown in figure 15. High and low tides are represented in the figures by arrows. Reference points for the tidal data are in the caption. On either side of Kalgin Island, suspended-matter concentrations are highly variable both at the surface

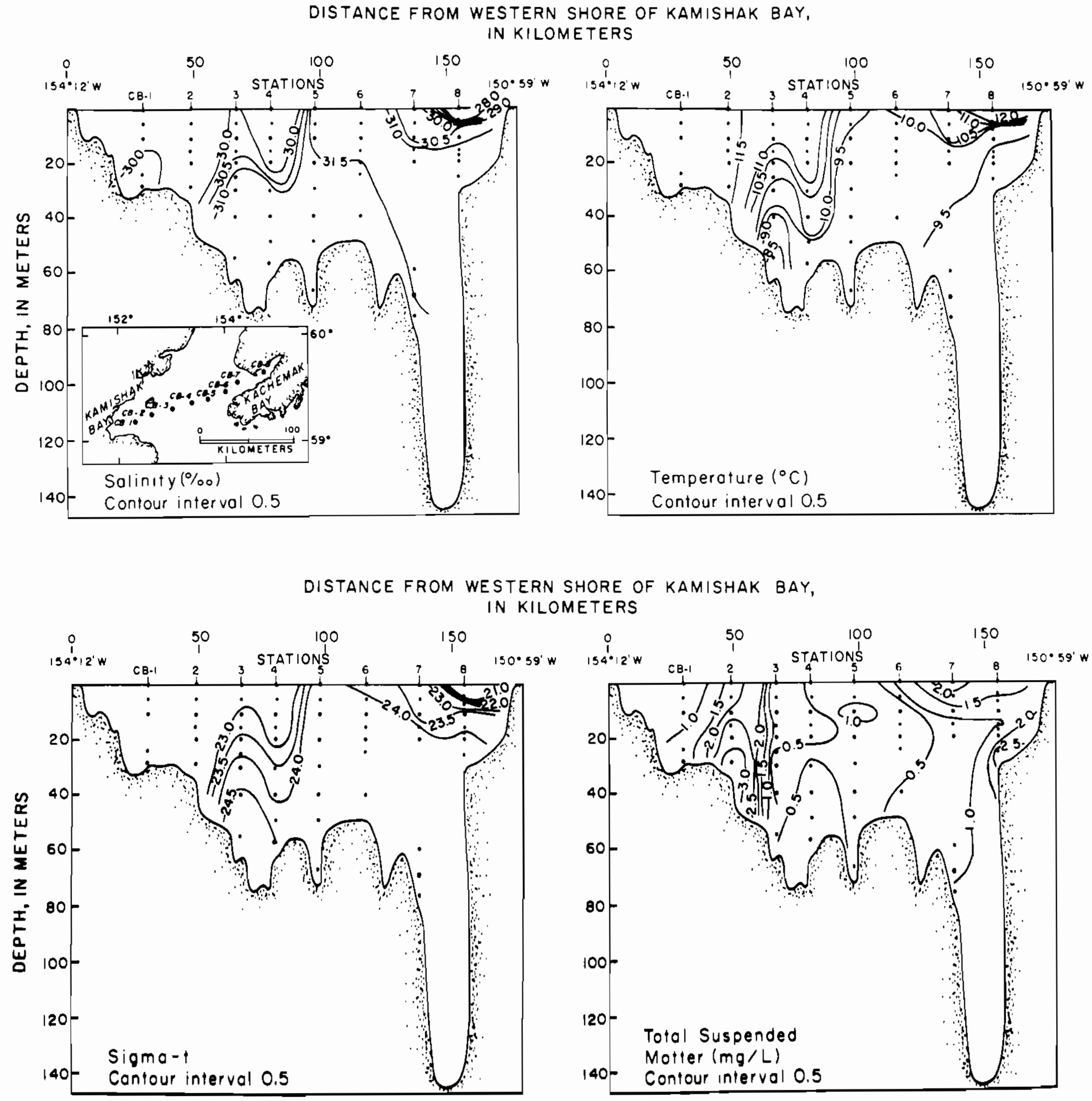

Figure 13.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations CB-1 through CB-8 in lower Cook Inlet (22 August-6 September 1978).

(10-180 mg/L) and near the bottom (28-254 mg/L). Highest concentrations were obtained at station CB10 on the east side of Kalgin Island. Surface maxima occurred shortly before low tide and exhibited a diurnal character. Tidal currents converge here, current velocities are high, and the water column is vertically mixed, causing complex circulation patterns (Gatto, 1976). On the west side of the island, flow patterns were dominated by tidal currents, with maximum suspended-matter concentrations in surface waters usually occurring during flood tide. This was probably the result of lateral movement of relict suspended-matter plumes from the coastal rivers along the western shore (Gatto, 1976).

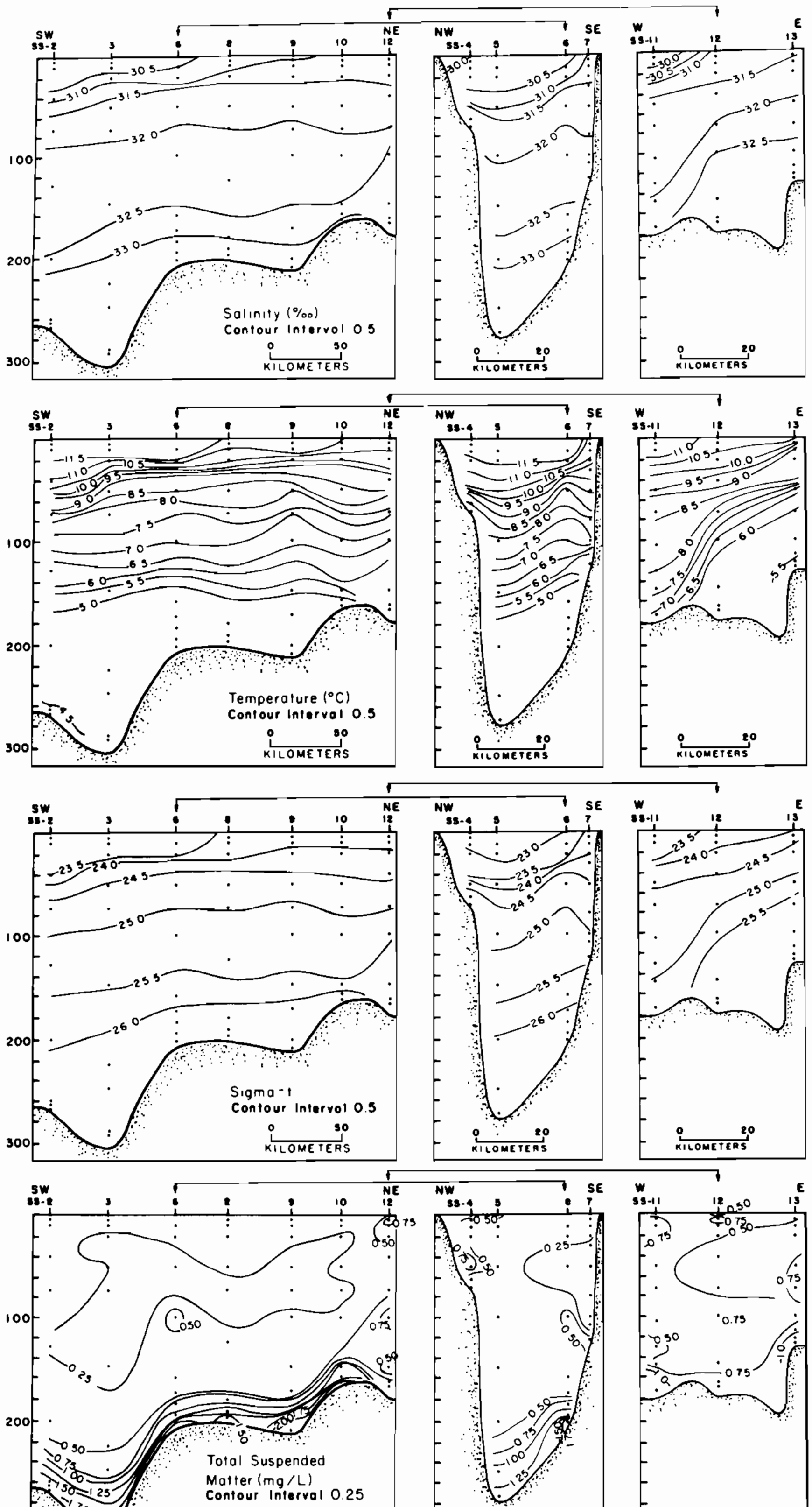

Figure 14.--Vertical cross sections of the distributions of salinity, temperature, σ_t, and total suspended matter for stations SS-2, SS-3, SS-6, SS-8, SS-9, SS-10, SS-12, and SS-13 in Shelikof Strait (22 August-6 September 1978).

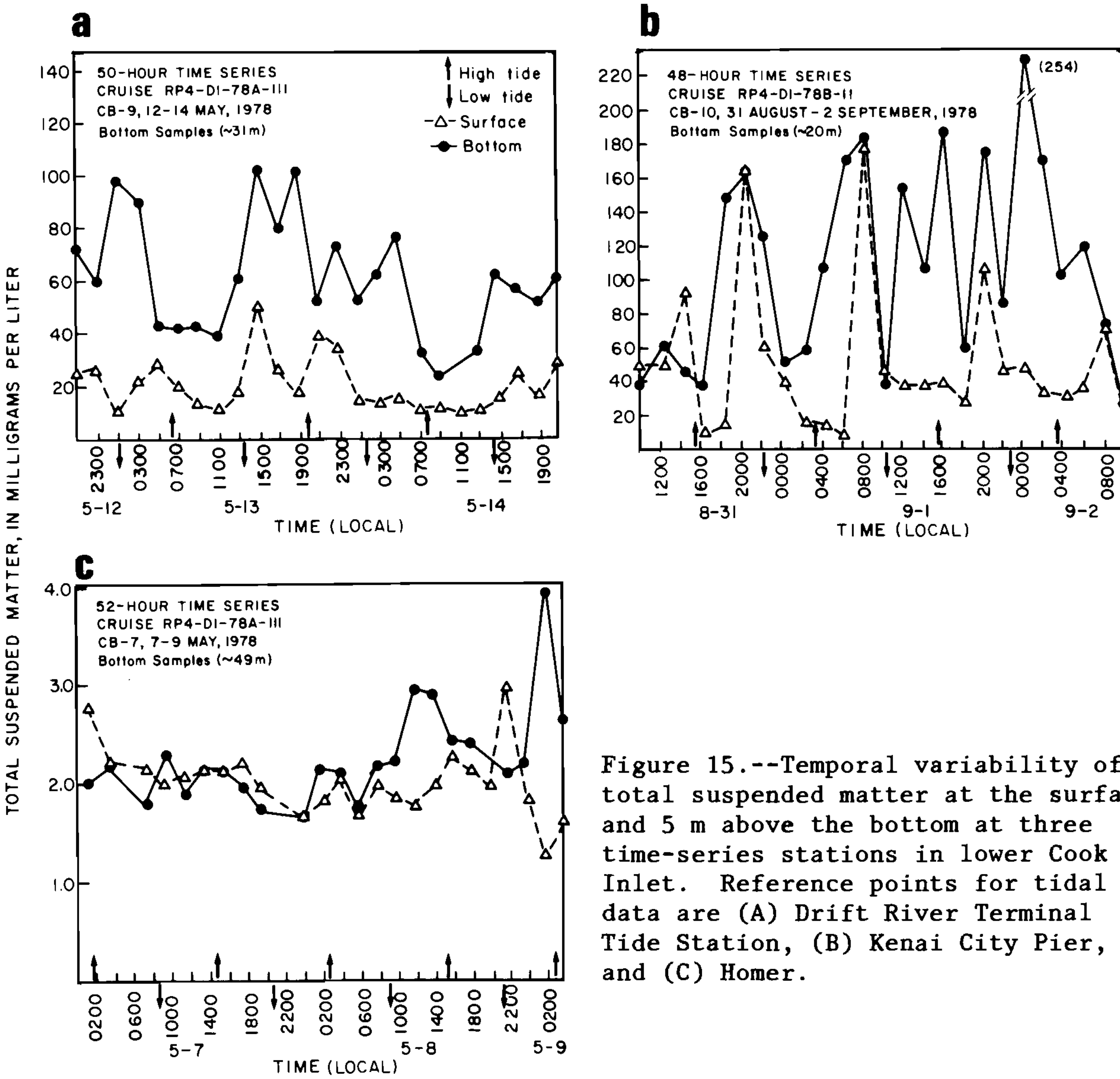

Figure 15.--Temporal variability of total suspended matter at the surface and 5 m above the bottom at three time-series stations in lower Cook Inlet. Reference points for tidal data are (A) Drift River Terminal Tide Station, (B) Kenai City Pier, and (C) Homer.

Near-bottom particulate maxima did not show a consistent periodicity, but peaks associated with both ebb and flood currents were evident. Furthermore, near-bottom suspended-matter concentrations were generally higher than at the surface. These data indicate that when the near-bottom tidal currents reached maximum velocity, resuspension of bottom sediment increased significantly.

The surface data at the Kachemak Bay station (CB7) show greatly reduced concentration fluctuations. With the exception of the last 16 hours of data, all of the surface variability is within the sampling error. Only one peak associated with ebb current exceeds the estimated sampling precision by more than a factor of two. This may be caused by southward movement of sediment plumes from the Anchor and Ninilchik Rivers during ebb tide (Burbank, 1977). This result is consistent with the general conclusion of Gatto (1976) based on observations of LANDSAT images of lower Cook Inlet, that turbid plumes were more prominent in the southern and central part of the lower inlet just after ebb current.

5.2 Major Element Composition of the Suspended Matter

In order to further characterize the primary sources of suspended material in lower Cook Inlet, samples of particulate matter were analyzed for their major inorganic elements. The resulting data have been segregated into five regions: Kalgin Island and upper Cook Inlet, Kamishak Bay, Kachemak Bay, Kennedy and Stevenson entrances, and northwestern Shelikof Strait. The averaged chemical data, along with those from the combined Susitna-Knik-Matanuska River system and the Copper River, are given in table 1. The Cook Inlet data represent regional and seasonal composites; therefore, they exhibit rather large ranges of values and standard deviations, primarily because of relative (in time and space) biogenic dilution. The last two columns in table 1, biogenic silicon percentages and estimated percentages of aluminosilicates, give a measure of this dilution for the various regions. The river data represent a single-point-in-time sampling, that of maximum discharge. The Copper River data give an estimate of the precision of the analytical technique, whereas the combined upper Cook Inlet river data reflect the error of averaging values from several locations. In general, suspended material from upper and western Cook Inlet has nearly the same elemental composition as the river samples. This is especially true for the major rock-forming elements (Al, K, Ti, and Fe), which are almost exclusively associated with aluminosilicate minerals of terrestrial origin (Price and Calvert, 1973; Feely et al., 1981). The high concentrations of these elements in the suspended matter from lower Cook Inlet indicate that aluminosilicate minerals are a predominant phase in the particulate matter, ranging from 49% in the Kachemak Bay samples to 98% in the samples from Kamishak Bay. The remaining material consists of organic matter and biogenic tests.

To identify the sources of the aluminosilicate materials in suspension, several authors have examined interelement ratios (Spencer and Sachs, 1970; Price and Calvert, 1973; Feely, 1975; Baker and Feely, 1978; Feely et al., 1981). Table 2 uses the averaged chemical data in table 1 to generate ratios of the major elements to aluminum. This procedure minimizes the effects of dilution by terrestrial and marine biogenic matter. The data show that aluminosilicate material from the Copper River has higher Mg/Al, Ca/Al, and Fe/Al ratios and a lower K/Al ratio than suspended matter from the Susitna-Knik-Matanuska River system. This is as expected, since chlorite minerals are characteristically enriched in Mg, Ca, and Fe and depleted in K relative to illites (Deer et al., 1962). Similarly, the elemental ratios of the particulate samples from the various regions in lower Cook Inlet are indicative of the sources for these materials. The elemental ratios of samples from Kennedy Entrance and Kachemak Bay are similar to elemental ratios for Copper River suspended matter, whereas samples from the Kalgin Island and Kamishak Bay regions more closely resemble the elemental ratios of suspended matter from the upper Cook Inlet rivers.

This similarity is best illustrated by comparing K/Ca ratios. The K/Ca ratio of Copper River suspended matter is 0.40, signifying the enrichment of Ca and depletion of K in a chlorite-rich mineral suite relative to an illite-dominated suite. In contrast, suspended material from the Susitna-Knik-Matanuska River system has a K/Ca ratio of 1.14. K/Ca ratios in the Kennedy and Stevenson entrances and Kachemak Bay samples are 0.48 and 0.47 respectively, indicating that the Copper River is the primary source for the

Table 1.--Averaged 1977-1978 chemical composition data for surface suspended-matter samples from selected regions described in the text

Region	n	Mg wt.% ±1σ	Al wt.% ±1σ	Si wt.% ±1σ	K wt.% ±1σ	Ca wt.% ±1σ	Ti wt.% ±1σ	Fe wt.% ±1σ	Biogenic Si wt.%	Estimated aluminosilicate wt. %
Susitna-Knik-Matanuska River system	13	3.73 ±0.61	10.39 ±2.03	33.41 ±3.42	2.26 ±0.63	1.98 ±0.58	0.607 ±0.059	6.39 ±0.40	0.00	104
Kalgin Island-upper Cook Inlet	9	3.05 ±0.67	8.59 ±1.91	28.57 ±6.05	1.95 ±0.38	1.73 ±0.38	0.505 ±0.085	5.33 ±0.90	0.94	86
Kamishak Bay	5	3.69 ±0.59	9.84 ±1.66	34.82 ±3.76	2.09 ±0.36	1.77 ±0.25	0.483 ±0.084	5.31 ±0.79	3.15	98
Kachemak Bay	6	2.15 ±1.02	4.85 ±2.78	30.38 ±8.72	0.81 ±0.53	1.74 ±0.95	0.287 ±0.159	2.95 ±1.68	14.75	49
Kennedy-Stevenson entrances	9	1.68 ±1.11	3.91 ±2.55	27.82 ±5.48	0.65 ±0.48	1.36 ±0.55	0.205 ±0.126	2.03 ±1.58	15.24	39
NW Shelikof Strait	6	2.98 ±0.73	7.02 ±2.14	33.46 ±4.01	1.32 ±0.47	1.71 ±0.55	0.353 ±0.118	3.64 ±1.32	10.87	70
Copper River	5	4.65 ±0.17	9.25 ±0.19	27.91 ±0.54	1.78 ±0.03	4.42 ±0.09	0.638 ±0.013	6.70 ±0.16	0.00	93

NOTE: Excess (biogenic) Si % was determined relative to Susitna-Knik-Matanuska River system Si/Al value of 3.22. Estimated aluminosilicate % values were obtained by multiplication of respective regional Al % by 10 (Sackett and Arrhenius, 1962).

Table 2.--Element/Al and K/Ca ratios for data presented in Table 1

Region	Mg/Al	Si/Al	K/Al	Ca/Al	Ti/Al	Fe/Al	K/Ca
Susitna-Matanuska-Knik River system	0.359	3.22	0.218	0.191	0.058	0.615	1.14
Kalgin Island-upper Cook Inlet	0.355	3.33	0.228	0.201	0.059	0.621	1.13
Kamishak Bay	0.375	3.54	0.212	0.182	0.049	0.540	1.17
Kachemak Bay	0.443	6.26	0.167	0.359	0.059	0.608	0.47
Kennedy-Stevenson entrances	0.430	7.12	0.166	0.348	0.052	0.519	0.48
NW Shelikof Strait	0.424	4.77	0.188	0.244	0.050	0.519	0.77
Copper River	0.503	3.01	0.192	0.478	0.069	0.724	0.40

aluminosilicate fraction of the suspended matter in these regions. Suspended material from Kalgin Island and Kamishak Bay have K/Ca ratios of 1.13 and 1.17, respectively. These data indicate that the Susitna-Knik-Matanuska River system is the major source for the suspended matter in these regions. In northwestern Shelikof Strait, the K/Ca ratio in the suspended matter is approximately 0.77. This ratio is indicative of an admixture of aluminosilicate material from both sources. This indication is supported by the Mg/Al and Ca/Al ratios, which are also elevated in comparison with respective values for the combined Susitna-Knik-Matanuska River system. These findings indicate that the aluminosilicate material in northwestern Shelikof Strait is largely a composite of illite-rich material discharged into upper Cook Inlet from the Susitna-Knik-Matanuska River system and chlorite-rich Copper River material.

6. DISCUSSION

In a discussion of circulation patterns in lower Cook Inlet, Muench et al. (1978) described the inlet as having characteristics of both an estuary and an embayment. The estuarine characteristics are illustrated by the outflowing low-salinity water from upper Cook Inlet which laterally entrains water from the eastern side of the inlet, whereas cross-channel flow at the mouth of the inlet is described as being more characteristic of flow in a large embayment. The same kind of analogy can be used to describe the general features of suspended-matter distributions and dispersal patterns in the inlet. Estuarine characteristics are exemplified by the association of the inorganic, terrestrial material from upper Cook Inlet with the outward-flowing estuarine water. Figure 16 shows plots of total suspended-matter concentrations versus salinity for surface and near-bottom waters from the central part of the lower inlet. The plots are roughly linear, indicating that dilution of the estuarine water by relatively nonturbid oceanic water is the major factor controlling suspended-matter concentrations in the lower inlet. Embayment characteristics are indicated by the cross-channel suspended-matter gradients and by the evidence for movement of Copper River-derived aluminosilicate material across the mouth of the inlet and into Shelikof Strait.

Figure 17 shows a generalized scheme of suspended-matter dispersal in lower Cook Inlet. It represents a composite of this study and suspended-matter studies by Gatto (1976) and Burbank (1977). The major features of the dispersal patterns are (1) bifurcation of the inflowing oceanic water, with a portion of the aluminosilicate material from the Copper River flowing up the eastern side of the inlet and with some entrainment by the outflowing estuarine water, and the remaining material flowing across the mouth of the inlet and down into Shelikof Strait; and (2) movement of the turbid estuarine water, enriched in aluminosilicate material from the Susitna and other rivers along the western shore, around Cape Douglas and into Shelikof Strait. These results provide further support for the general conclusion of Hein et al. (1979) that the major controlling force affecting suspended-sediment distributions is the strong, semidiurnal tidal currents augmented by the estuarine and embayment types of circulation patterns present in the inlet.

The significance of these results is apparent when dispersal routes for environmental contaminants, particularly crude oils, are considered. As

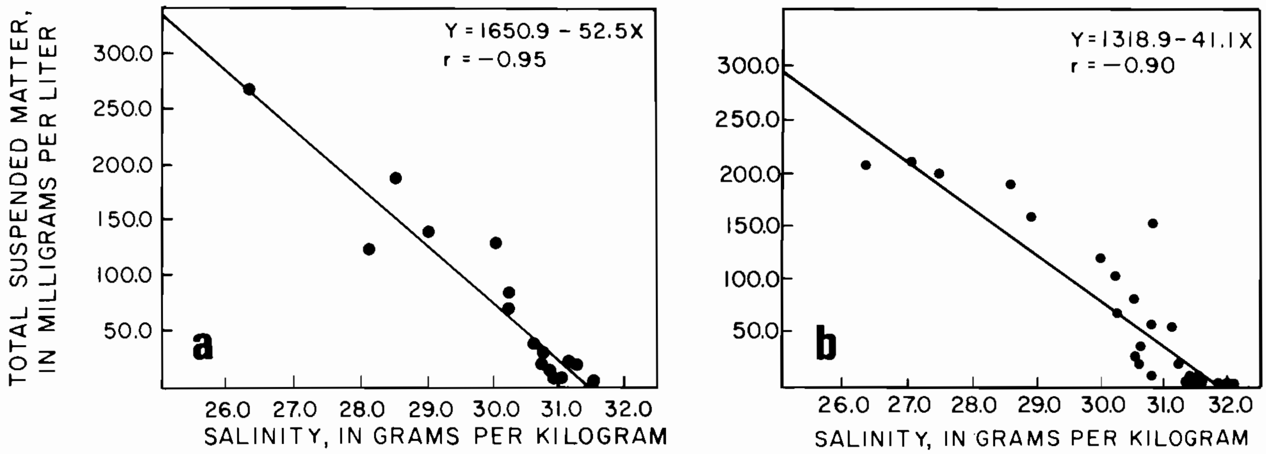

Figure 16.--Scatter plots of the relationships between total suspended matter and salinity for (A) surface and (B) 5 m above the bottom in the central region of lower Cook Inlet (4-16 April 1977).

stated earlier, experiments conducted in our laboratory have shown that suspended materials from lower Cook Inlet are capable of accomodating up to 11% of their weight in Cook Inlet crude oil (Feely et al., 1978). The particles with adsorbed oil formed spherical aggregates that ranged in diameter from 5 to 45 μm. Using Stoke's settling model, these authors estimated that settling velocities for the aggregates ranged between 0.6 and 30 m/day. This suggests that in the absence of vertical turbulence and dissolution processes, it would take from ~2 to ~117 days for the aggregates to fall through a water column of 70 m, the average depth near the mouth of the inlet. Thus, the aggregates of oil and suspended matter could be

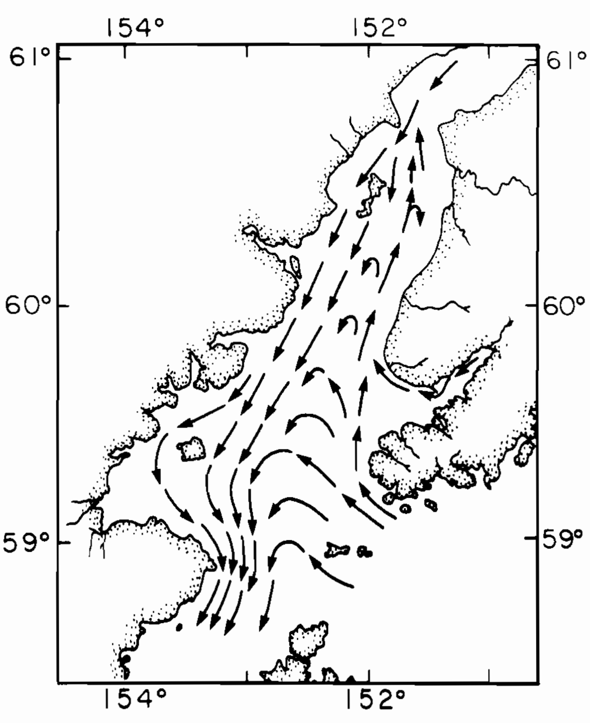

Figure 17.--Generalized scheme of suspended-matter dispersal routes in lower Cook Inlet and northern Shelikof Strait.

distributed throughout the inlet before they were (eventually) deposited in quiescent embayments along the shore or carried into Shelikof Strait.

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