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CURRENT WATER QUALITY IN COOK INLET, ALASKA, STUDY

A Report by
ENVIRONMENT AND NATURAL RESOURCES INSTITUTE
UNIVERSITY OF ALASKA ANCHORAGE
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EXECUTIVE SUMMARY

The University of Alaska Anchorage's Environment and Natural Resources Institute conducted a 1993 field investigation to establish a baseline of information on the occurrence of petroleum hydrocarbons, naturally occurring radioactive materials, and trace metals in Cook Inlet, Alaska. The sampling and analysis program included collection of seawater, sediments, and biota for detailed chemical analyses and bioassays. Analyses included trace metals and hydrocarbons in water, biota, and sediments; sediment grain size; carbon-hydrogen-nitrogen in sediments; naturally occurring radioactive materials in mollusc shells; total suspended solids and suspended sediment trace metals in water; hydrography; and water and sediment bioassays.

Sampling sites were chosen in a variety of Cook Inlet environments. Some were located in bays where fine-grained sediments indicated a depositional environment, some were in the vicinity of inlet petroleum production platforms, and others were near petroleum and natural gas processing and transportation facilities in northern lower Cook Inlet. Many of the sediment sites had been sampled during the Outer Continental Shelf Environmental Assessment Program between 1976 and 1979. These sites were generally chosen to determine whether or not hydrocarbons and trace metals have been accumulating in the sediments. Water sampling sites were selected to investigate possible near-field contamination in current oil and gas development areas and possible far-field effects near Kachemak and Kamishak bays.

Two research cruises were conducted in 1993. The first took place 20 June through 28 June, and the second 16 August through 4 September. The principal goal of these cruises was to occupy six to eight water chemistry stations and take multiple samples at depths of 1 meter at both high and low tides. Suspended sediments were collected at these stations via filtration of seawater as well. Sediment samples were taken by bottom grab at these stations and at several other stations throughout the inlet. Hydrographic casts were made for each station and, when possible, for points in between. Water samples were taken for bioassay at the eight water chemistry stations. Sediment samples were taken for bioassay at these sites plus six others throughout the inlet. Biota samples were collected from six sites in the middle to lower inlet.

Less than method detection limits of volatile organic analytes and polycyclic aromatic hydrocarbons were found in all water chemistry samples from the eight Cook Inlet stations, but minute traces of several alkanes were detected. Total saturated hydrocarbons in water ranged from less than method detection limits to 4.14 micrograms per liter. Iron was by far the metal with the highest concentration in water; the highest concentrations were found in the northern sampling stations. Overall, the metal concentrations found were similar to those reported in global marine waters, but mercury appeared to be somewhat higher.

The suspended sediment input from the head of Cook Inlet is very high; it is principally comprised of very fine-grained glacial till. Samples from the eight water sampling stations were analyzed for total suspended solids; measured concentrations ranged from 3 to 440 milligrams per liter. As expected due to dynamic mixing in the northern inlet and the predominance of river inputs of suspended sediments into the upper inlet, stations in the upper inlet had the highest total suspended solids concentrations. Those in the middle to lower inlet had the lowest.

Metals within the water column are strongly partitioned onto the suspended sediment. In Cook Inlet this latter material is overwhelmingly inorganic (glacially ground rock flour). A comparison between data on metal content of suspended sediment extracts taken in lower Cook Inlet during the Outer Continental Shelf Environmental Assessment Program showed concentrations for cadmium, copper, nickel, zinc, and iron to be lower than those found during this study. Lower values are not surprising

for the environmental assessment program samples, because a weak acid leach was used for the metals extraction.

Of the 46 sediment samples analyzed for grain size from 16 stations, most were primarily sand. The preponderance of sand in the samples is in agreement with past studies. The total organic carbon content of sediments from this study ranged from 0.05% to 4.09%. With the exception of the value of 4.09% observed at station Alt 30, the range was 0.05% to 1.59%, which is almost identical to that previously described for Cook Inlet.

Hydrographic data for both Cruise 1 and Cruise 2 are in reasonable agreement at depths of 10 meters. Cruise 1 temperatures north of the forelands were 11°C to 12°C and decreased to 9°C to 10°C near Ninilchik. Cruise 2 temperatures were 2°C to 3°C warmer than Cruise 1 temperatures north of the forelands, and they were about 1°C warmer south of the forelands. Cruise 2 temperatures ranged from 14°C near Tyonek in the north to 9°C near Port Graham in the south. Cruise 1 salinities increased from 17 near Tyonek, to 25 near the forelands, to 31 near Ninilchik. North of the forelands, Cruise 2 salinities were lower than those from Cruise 1. South of the forelands, salinities from the two cruises were similar, and they increased to 31 near Port Graham. Cruise 1 and Cruise 2 transmissivities were also similar; they increased from 0% near Tyonek, to 90% near Ninilchik, to 98% near Port Graham.

Hydrocarbon analyses performed on sediment yielded concentrations of individual saturated and aromatic hydrocarbons. Total alkanes with chain lengths of 12 through 33 carbon atoms ranged from 62 nanograms per gram to 5388 nanograms per gram for sediment replicates throughout the area. Low molecular weight alkanes with chain lengths of 12 through 20 carbon atoms ranged from less than method detection limits to 674 nanograms per gram. The saturated hydrocarbons were dominated by n-alkanes with a strong odd-even preference. N-alkanes ranging in length from 21 to 29 carbon atoms dominated, especially those with 27 and 29. This is consistent with a prevalent biogenic input of hydrocarbons from terrigenous plant material, likely resulting from transport of riverine-suspended particulate matter. In general, the highest saturated hydrocarbon concentrations were associated with sediments taken from nearshore stations in the middle inlet.

Mean polycyclic aromatic hydrocarbons concentrations in sediments were very low and followed trends similar to those of saturated hydrocarbons. Highest polycyclic aromatic hydrocarbons concentrations were found in sediments in the lower inlet and nearshore in the middle inlet. Total polycyclic aromatic hydrocarbons concentrations from the ten stations where detectable concentrations were found ranged from 2 to 958 nanograms per gram. Polycyclic aromatic hydrocarbons detected were found in very low concentrations that probably represent baseline conditions and background hydrocarbon inputs. Concentrations of individual polycyclic aromatic hydrocarbons rarely exceeded 10 nanograms per gram, and values were often near method detection limits. Dominance of the phenanthrene series indicates most polycyclic aromatic hydrocarbons detected were of petrogenic origin.

Universally high levels of both aluminum and iron were found in sediments throughout the inlet. This would be expected, as the majority of suspended material in Cook Inlet is aluminosilicate minerals. The concentration of metals in Cook Inlet sediment is similar to that found elsewhere in Alaska and throughout the world. No geographic area contained significantly lower or higher metal concentrations than other areas.

Detectable but very low concentrations of polycyclic aromatic hydrocarbons were found in four of the six mussel tissue samples. These contained few individual target polycyclic aromatic hydrocarbons at concentrations ranging from near method detection limits (less than 10 to 230 nanograms per gram). Unlike the polycyclic aromatic hydrocarbons, mussels showed higher concentrations and a more diverse array of saturated hydrocarbons in the tissues. Samples were generally dominated by higher molecular weight alkanes, which are indicative of sediment-associated hydrocarbons.

Metal concentrations found in mussel tissues from six Cook Inlet locations are comparable with those obtained in past Cook Inlet, Gulf of Alaska, and Beaufort Sea studies; no anomalous trends are evident. Concentrations of heavy metals cadmium, copper, and zinc found in mussel tissues at Kasitsna and

Kachemak bays in 1977 and those found in this study are almost identical. Concentrations of barium, cadmium, copper, and zinc found in Beaufort Sea bivalve tissues and those from this study are also very similar. Concentrations of naturally occurring radioactive material were extremely low in all shells analyzed. Radium-226, radium-228, and bismuth-214 were not detectable; and lead-214 was extremely low.

For the solid-phase Microtox® bioassay, median effective concentration values below 2% can be considered to indicate possibly contaminated sediment in Cook Inlet. Results showed six stations with no toxicity and five with possible toxicity using the 2% median effective concentration level. With the exception of station 227 in Kachemak Bay, all locations that exhibited possible sediment toxicity through the Microtox® bioassay were located on the west side of the middle inlet.

Of the 12 stations assayed by the solid-phase static amphipod sublethal bioassay, only two (Alt C and 227) had statistically significant lower survivals than the controls. Survival rates differing by more than 20% from controls are often considered to be of concern. Amphipod survival in sediment from station 227 in Kachemak Bay was 21% lower than observed from the control. Sediments from this area could be considered toxic based on this difference. Sediment pore water from four stations showed statistical differences for percent fertilization when compared to the control. One of these stations (233) was actually higher than the control, while the other three (F, 16B, and Alt 22) were lower. Station Alt 22, which is near Kalgin Island, had the lowest fertilization rate of only 18%. Station F had a fertilization rate of 38.4% and 16B had a fertilization rate of 47.2%; both are located in the middle inlet. These three stations could be considered to have pore waters exhibiting toxicity.

Five stations showed statistically significant reduction of fertilization rates for receiving water samples. However, three of these (A, C, and F) have mean percent fertilization values over 90% with a control of 96%. This difference of less than 6% should not be considered an indication that the water samples were toxic. Stations E and B exhibited fertilization rates of 55%. This is 15% lower than their control and could be considered an indication that the water exhibits toxicity. Stations E and B were the two most northern stations in the inlet; they have extremely high suspended particulate loads that may contribute to toxicity. Percent survival and percent normal development for urchin larvae in receiving water from the eight stations sampled were high. With the exception of survival at station 211, there were no statistically significant differences between sample and control survivals or normal development numbers. Although there was a statistically significant difference in survival between the sample and controls, larvae exposed to water from station 211 showed a survival rate of 87%, which is only 9% below the control.

The physical, chemical, and bioassay results of this study show that Cook Inlet has very low environmental concentrations of hydrocarbons and that sediments and water are generally free from toxicity. Results also show no immediate evidence of heavy metal pollution in Cook Inlet.

INTRODUCTION 1

The University of Alaska Anchorage's Environment and Natural Resources Institute (ENRI) conducted a field study in 1993 for the U.S. Minerals Management Service (MMS) to establish a baseline of information on the occurrence of petroleum hydrocarbons, trace metals, and naturally occurring radioactive materials (NORM) in Cook Inlet, Alaska. This work was done under Cooperative Agreement No. 14-35-0001-30704. ENRI collected seawater, sediments, and biota for detailed chemical analyses and bioassays including trace metals and hydrocarbons in water, biota, and sediments; sediment grain size; carbon-hydrogen-nitrogen (CHN) in sediments; NORM in mollusc shells; total suspended solids (TSS) and suspended sediment trace metals in water; hydrography; and water and sediment bioassays. Samples were analyzed by the project team that included ENRI, the Alaska Department of Environmental Conservation's Juneau Environmental Analysis Laboratory (JEAL), Battelle Memorial Institute's Pacific Northwest Division's Marine Sciences Laboratory (MSL), and Huffman Laboratories. ENRI was responsible for sediment grain size, hydrography, and some bioassays; JEAL for water and sediment chemistry; MSL for NORM and some bioassays; and Huffman Laboratories for CHN.

Sampling stations for this study were chosen in a variety of Cook Inlet environments. Some were contiguous to known point discharge sources and others were not. A number were located in bays where fine-grained sediments indicated a depositional environment. Others were near production platforms in upper Cook Inlet and processing and transportation facilities in the northern part of lower Cook Inlet. Many of the proposed sediment sampling stations were previously sampled for the Alaska Outer Continental Shelf (OCS) Environmental Assessment Program (OCSEAP) between 1976 and 1979. Sediment sampling stations were generally chosen to determine whether or not hydrocarbons and trace metals were accumulating in the sediments. Water sampling locations were selected to investigate the possibility of near-field contamination in the area of current oil and gas development and far-field effects near Kachemak and Kamishak bays.

MMS proposed that samples be collected at or in the vicinity of 27 stations in lower and upper Cook Inlet (Figure 1). To achieve this goal, ENRI conducted two research cruises in 1993. The first took place 20 June through 28 June, and the second 16 August through 4 September. The principal goal of Cruise 1 was to occupy six middle to upper inlet water chemistry stations and take multiple samples at depths of 1 meter (m) at both high and low tides. Sediment samples were to be collected at all six stations by a stainless steel, Teflon-coated bottom grab. Suspended sediments were to be taken via filtration of seawater at two stations. Hydrographic casts were planned for each station and, when possible, for points in between.

The principal goal of Cruise 2 was to occupy eight water chemistry stations and take multiple samples at depths of 1 m at both high and low tides. Suspended sediments were to be collected at these stations via filtration of seawater. Sediment samples were to be taken at these eight stations by bottom grab, as well as at 20 other stations throughout the inlet (provided they had not been sampled during Cruise 1). Hydrographic casts were planned for each station and, when possible, for points in between. Water samples were to be collected for bioassay at the eight water chemistry stations. Sediment samples were to be taken for bioassay at these stations plus six others throughout the inlet. Biota samples were to be collected from five stations in the middle to lower inlet.

This document adopts as a convention the practice of reporting analyte concentrations in solution as mass per volume in micrograms per liter (μg/L). Analyte concentrations in sediments are reported as mass per mass in either nanograms per gram (ng/g) or micrograms per gram (μg/g). Concentration values in μg/L and ng/g can be read directly as parts per billion (ppb), while those in μg/g can be read directly as parts per million (ppm). A list of these and the other abbreviations used in this document is provided on page 119.

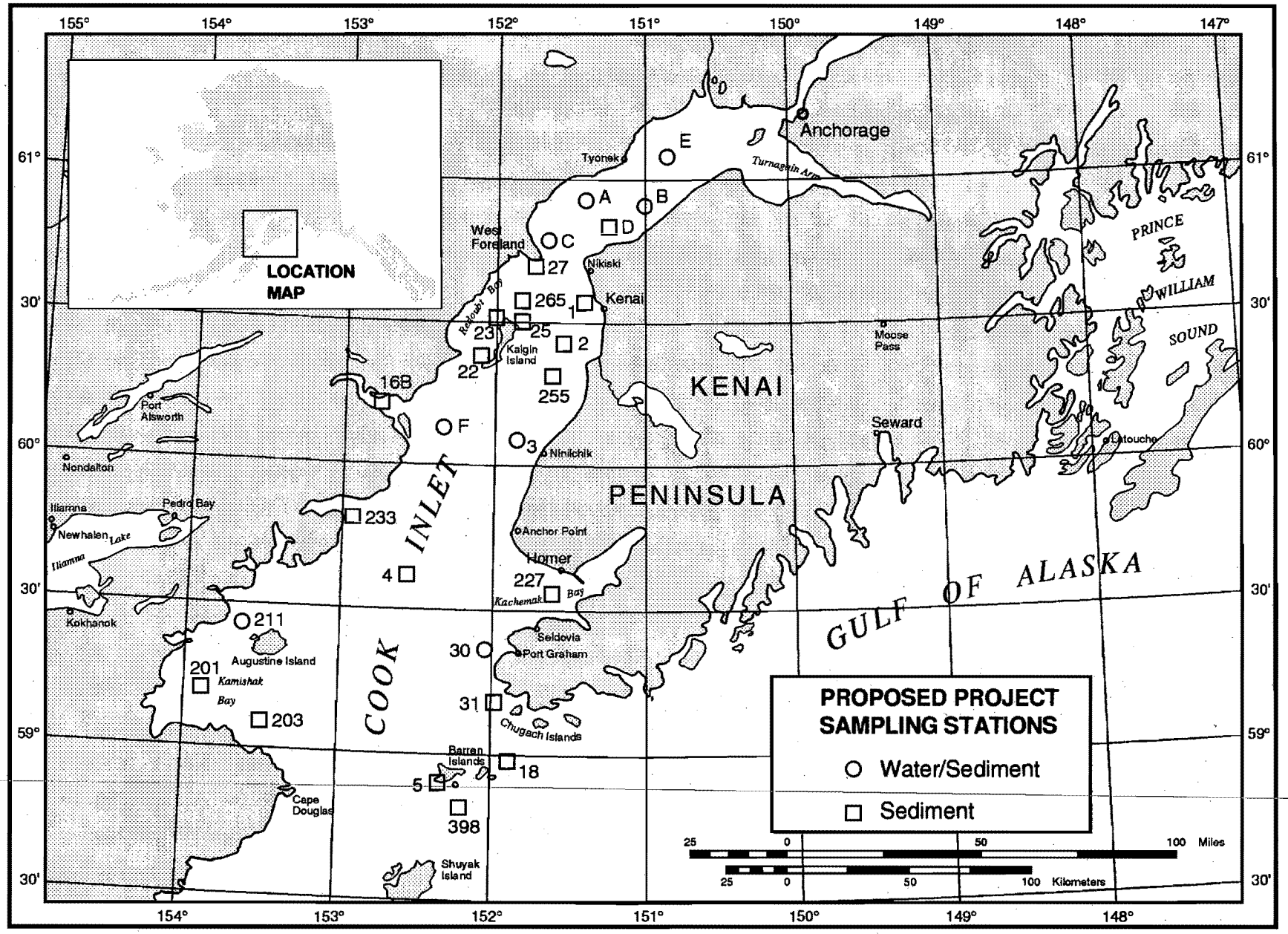


Figure 1. Proposed project sampling stations.

BACKGROUND 2

The history of the petroleum industry in Cook Inlet can be traced to 1892, when a wildcat well was sunk at Oil Bay in the Iniskin area of lower Cook Inlet (MBC Applied Environmental Sciences 1992). However, it was not until 1957 that commercial quantities of recoverable oil were discovered in the Cook Inlet area, when a successful well was sunk on the Kenai Peninsula. Three production wells were operating in the area by 1959, and there were five fields producing oil and nine producing natural gas by the late 1960s. The first offshore exploration took place in 1959, and some offshore fields were producing by 1968. Twelve oil and gas production platforms are presently operating in upper Cook Inlet.

Under terms of their original permits, oil and gas production platforms were allowed to discharge drilling muds, cuttings, and produced water directly into the inlet. Discharged materials such as these can contain significant quantities of hydrocarbons and trace metals. Discharge of bilge, ballast, and cleaning waters from vessels, as well as discharges of industrial and municipal effluents, river flow from inland sources, and natural oil seeps also contribute hydrocarbons and trace metals to Cook Inlet waters.

MMS and the U.S. Bureau of Land Management (BLM) funded numerous investigations in Alaska during OCSEAP to characterize heavy metal and hydrocarbon inventories of water, sediment, and biota. Areas investigated included the Beaufort Sea, Bering Sea, Chukchi Sea, northwest Gulf of Alaska, and Cook Inlet. Most of the existing water and sediment chemistry data for Cook Inlet were gathered during these studies in the mid-1970s to early 1980s.

Cook Inlet is a large tidal estuary in southcentral Alaska (see Figure 1). It lies on a northeast-southeast axis and is about 150 nautical miles (nmi) long and 50 nmi wide at its mouth. The inlet is divided into three physiographic sections. At its head it splits into Knik Arm (which is 45 nmi long) and Turnagain Arm (which is 43 nmi long). Near its middle, upper Cook Inlet is constricted by two geographic features known as the East Foreland and West Foreland (Feely and Massoth 1982).

The inlet receives fresh water from four major rivers. These include the Matanuska and Knik rivers at the head of Knik Arm and the Susitna and Beluga rivers to the northwest. They supply about 70% to 80% of the freshwater input (Feely et al. 1980). In addition, numerous streams containing large concentrations of glacial flour drain into the lower inlet from both sides. Included in this category are the Kenai, Kasilof, Ninilchik, and Anchor rivers on the east and the McArthur, Big, Drift, and Tuxedni rivers on the west (Feely et al. 1980).

Cook Inlet is an almost textbook example of a well-mixed estuary with mixing dominated by an intense tidal regime. The tidal range is second only to that of the Bay of Fundy and very strong currents are generated, especially between the forelands. Consequently, the central portion of Cook Inlet tends to be swept clear of fine-grained sediment, and benthic biota show patchy distribution patterns (Burrell 1979).

Muench, Mofjeld, and Charnell (1978) provide a complete description of water circulation in lower Cook Inlet. It is characterized by a net inward movement of oceanic water along the eastern shore and a net outward movement of a mixture of oceanic water and runoff water along the western shore. In much of the inlet, the water masses are vertically mixed due to the turbulent action of tidal currents. However, lateral separation of the water masses is apparent, resulting in a shear zone between the incoming saline water on the east and the outgoing less saline water on the west. Coastal upwelling occurs in the vicinity of the Chugach Islands from the region west of Elizabeth Island to Cape Starichkof.

Bottom sediments in lower Cook Inlet are primarily composed of medium- to fine-grained sands; silt and clay-sized sediments have been observed occasionally. Deposits in the northern part of the inlet are winnowed Pleistocene to early Holocene gravels, with many of the sand-sized and smaller particles being removed and redeposited to the south. In addition to relict sands and gravels, sediments also contain a very thin cover of modern fine-grained silts and clays (Sharma and Burrell 1970, Bouma and Hampton 1976, Hein et al. 1979). Hein et al. (1979) state the clay-mineral deposits in lower Cook Inlet are dominated by clay-mineral suites from two distinct sources. A chlorite-rich material dominates the clay-mineral fraction in deposits from the region around the Barren Islands to Kachemak Bay. The Copper River, which drains into the Gulf of Alaska about 250 miles (mi) to the east of Cook Inlet, appears to be the major source of this material. It discharges chlorite-rich, fine-grained material into the northeast gulf, which is diverted to the west and southwest by the coastal longshore currents (Feely et al. 1980). Apparently, some of this material reaches Kennedy Entrance and is transported into lower Cook Inlet 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 River in upper Cook Inlet as its major source. Feely and Massoth (1982) state the distribution of clay minerals in the bottom sediments in lower Cook Inlet reflects the dispersal routes for suspended material in the overlying water. Thus, fine-grained particles from these two sources follow the general pattern of water circulation in the inlet and form the bulk of mud deposits in quiet embayments along the coast and throughout Shelikof Strait.

Suspended matter distributions appear to follow the general pattern of circulation in lower Cook Inlet and Shelikof Strait. The inflowing, relatively clear Gulf of Alaska water, which contains significant amounts of biogenic particles as well as aluminosilicate material from the Copper River, flows northward along the eastern coast until it reaches Cape Ninilchik, where it mixes with the outflowing turbid, brackish water. The outflowing turbid water moves along the western side of the inlet past Augustine Island and Cape Douglas into Shelikof Strait, where it mixes with the oceanic water and is dispersed. Comparison of suspended matter and sediment characteristics, as well as regional sedimentation rates, indicates that net sedimentation of suspended matter in the central basin of lower Cook Inlet is minimal. However, net sedimentation does occur in embayments along the coast (Feely and Massoth 1982). According to Atlas et al. (1983), most fine-grained sediment entering Cook Inlet is transported out of the inlet into Shelikof Strait, although sediment accumulation does occur within Kamishak and Kachemak bays.

Chemical analyses of suspended material from lower Cook Inlet reveal aluminosilicate minerals from the coastal rivers comprise about 80% to 95% of suspended matter, with biogenic matter making up the rest. Analysis of seasonal and regional variations of carbon to nitrogen ratios indicates organic matter of marine origin predominates in the eastern part of lower Cook Inlet throughout the year, whereas organic matter of terrestrial origin predominates in the western part of the inlet during winter and early spring, when primary production is at a minimum (Feely and Massoth 1982).

Due to turbidity associated with high suspended matter concentrations, biological activity near Kalgin Island is low, resulting in organic matter comprising only 2% of the total weight of suspended material. Organic matter has a carbon to nitrogen ratio of 11:3, which is indicative of terrestrial origin. Unlike upper Cook Inlet, the suspended matter concentration in Kachemak Bay shows smaller fluctuations and little difference with depth. Surface suspended material consists of 35% organic matter and has a carbon to nitrogen ratio of 7:6, which is characteristic of marine origin (Feely et al. 1980).

According to Kaplan and Venkatesan (1985), total organic carbon contents of Cook Inlet sediments vary from 0.06% to 1.57% and are characteristic of unpolluted, relatively coarse marine sediments. The Kachemak Bay and Shelikof Strait regions contain relatively fine-grained sediments and higher organic carbon content (>1%) than the sandy gravel or gravel found in the northern and central regions of Cook Inlet and Kamishak Bay. This might indicate enhanced hydrocarbon accumulation in the two former regions. The higher values observed in Kachemak Bay are also due to the very high primary productivity that persists over several months in this area.

Part of the organic matter produced in the Kachemak Bay region probably settles to the sea floor and gets buried within the sediments. However, the remaining fraction of organic matter produced in Kachemak Bay may eventually be deposited in Shelikof Strait via the net water circulation to the north along the eastern shore and to the southwest along the western shore (Muench, Mofjeld, and Charnell 1978; Hein et al. 1979). This would contribute to the higher organic carbon content in the Shelikof Strait area. The organic carbon content in Alaska sediment is related to its distance from the terrigenous source of detrital minerals, and it is higher with increasing distance from shore (Kaplan and Venkatesan 1985).

HISTORICAL HYDROCARBON DATA

High molecular weight hydrocarbon data gathered during OCSEAP for surface sediments from different regions of the Alaska OCS indicate the entire area is uniformly free of petroleum contaminants except in a few isolated cases (Kaplan and Venkatesan 1985). The organic carbon content in these sediments is $\leq 1.5\%$, which is characteristic of pristine environments. Unresolved complex mixture is present in very few samples, and the total hydrocarbon content in the sediments varies from 0.9 μg/g to 50 μg/g. These values are low; petroleum hydrocarbon concentrations in uncontaminated coastal sediments elsewhere are usually below 70 μg/g (Kaplan and Venkatesan 1985). However, there are differences in the sediment hydrocarbon concentrations in various areas of the Alaska OCS. Beaufort Sea sediments have the highest hydrocarbon content, while Kodiak area sediments have the lowest.

Resolved n-alkanes follow the same trend, but polycyclic aromatic hydrocarbon (PAH) compounds do not exhibit the same pattern, and the Gulf of Alaska and Kodiak area sediments are rich in PAH that is biologically produced as well as in those produced by pyrolytic combustion. Even though the PAH content in the above two areas is as high as that observed in Beaufort Sea sediments, the pyrolytic and biogenic imprint predominates in the former areas, while a mixed pyrolytic and fossil PAH profile is reflected in the latter (Kaplan and Venkatesan 1985).

Terrigenous influx is indicated by the maxima observed at chain lengths of 27 or 29 carbon atoms in sediments. The odd-even ratios demonstrate that terrestrial input varies from region to region of the Alaska OCS. Of the areas investigated, Norton Sound and Cook Inlet receive the maximum plant wax contribution, whereas the Gulf of Alaska and Kodiak area receive the least. The Beaufort Sea, Navarin Basin, and southeastern Bering Sea are second in order of Alaska OCS areas of plant wax content. According to Kaplan and Venkatesan (1985), allochthonous hydrocarbons are to be expected in the Beaufort Sea, Cook Inlet, Norton Sound, and Bering Sea.

The lipid, hydrocarbon, and organic carbon contents in lower Cook Inlet are generally high in and around Kachemak Bay. Stations in Shelikof Strait are next in order of abundance of organic matter. The middle and upper parts of the inlet have the lowest concentrations (Kaplan and Venkatesan 1985). It appears organic matter produced in Kachemak and Kamishak bays may be deposited in Shelikof Strait, a hypothesis that is consistent with the postulated net circulation pattern of the water and suspended matter (Muench, Mofjeld, and Charnell 1978; Feely et al. 1980).

The lipid, total hydrocarbon, alkane, and resolved n-alkane contents in Cook Inlet sediment follow the same trend as organic carbon. They are generally high in and around Kachemak Bay and low in the middle and upper parts of lower Cook Inlet. Stations near Shelikof Strait are next to Kachemak Bay in order of abundance of lipids and alkanes, whereas Kamishak Bay is moderately enriched with lipids (Kaplan et al. 1980).

The n-alkanes in Cook Inlet sediments generally show a bimodal distribution of biogenic origin, which is typical of mixed marine and terrestrial hydrocarbons. An odd-carbon predominance of n-alkanes characteristic of terrigenous plants is evident in most areas, suggesting the influence of major rivers in the area. The n-fatty acids (unbound) present in these samples are also typical of a mixed marine and terrestrial input (Kaplan and Venkatesan 1985).

Molecular markers such as diterpenoids, 17β(H), 21β(H), olefinic triterpenoids, and extended 17β(H), 21β(H)-hopanes also reflect biogenic origin of the lipids in most of the Cook Inlet sediment samples

(Kaplan et al. 1980). Stations north of Kalgin Island are the exception. They show a typical weathered petroleum distribution of n-alkanes and triterpenoids that can be characteristic of oil pollution (Kaplan and Venkatesan 1985). The triterpenoidal residue consists predominantly of 17α-hopanes and *R* and *S* diastereomers at position 22 in nearly 1:1 abundance, which is characteristic of petroleum contamination. Oil production activities in upper Cook Inlet may be the contaminating source in stations near Kalgin Island. However, the possibility of a local seep around the island with similar triterpenoidal distribution cannot be ruled out (Kaplan and Venkatesan 1985).

A complex mixture of PAH compounds was identified by gas chromatograph (GC)/mass spectrometer (MS) in all Cook Inlet sediments (Kaplan and Venkatesan (1985). The relative distribution of parent homologs and their alkylated derivatives is characteristic of pyrolytic (natural and/or anthropogenic) sources (Kaplan and Venkatesan 1985). Trace amounts to 50 ng/g of perylene were found in samples. Like any other aliphatic or aromatic compound, perylene is also found at higher concentrations in Kachemak Bay and Shelikof Strait than it is in Kamishak Bay or in the central part of Cook Inlet. Origin of perylene in these sediments is probably terrestrial (Kaplan and Venkatesan 1985).

Extensive OCSEAP investigations indicate sediment in the study area is generally unpolluted with very few exceptions. Characteristics of the aliphatic hydrocarbons are typical of a mixture of marine autochthonous and terrestrial allochthonous components. Norton Sound and Cook Inlet sediments contain the highest levels of terrigenous input and Kodiak area the lowest, while other areas show intermediate concentrations. Distribution of PAHs is complex and shows a pyrolytic source in all study areas. Bioaccumulation of PAHs is probably prevalent in the Gulf of Alaska and Kodiak area (Kaplan and Venkatesan 1985).

Few studies have been conducted on the distributions and concentrations of hydrocarbons in the water column of Alaska's coastal waters. Most have examined sediment or tissues, and they have been limited in scope. More than 3000 water samples were collected throughout Prince William Sound following the wreck of the *Exxon Valdez*. These samples revealed consistently low concentrations of total petroleum hydrocarbons (TPH). More than 89% of the samples analyzed contained nondetectable concentrations of <50 μg/L (Neff 1991).

Due to extremely low concentrations of hydrocarbons existing in Prince William Sound and the Gulf of Alaska, the TPH method is not sensitive enough for monitoring (Neff 1991). Concentrations of PAH are the best indicator of the distribution of spilled crude oil in the water column. A total of 1683 water samples were analyzed for PAH in Prince William Sound. Only 27 of these (1.6%) contained more than 1 μg/L PAH, and most (16) were collected nearshore (Neff 1991). Samples of subsurface seawater within Prince William Sound collected 1 to 5 weeks following the spill showed summed PAH concentrations ranged from 1.92 μg/L to 5.23 μg/L at sampling stations near heavily oiled beaches and from 0.4 μg/L to 1.5 μg/L at stations distant from the path of the spilled oil (Short and Rounds 1993).

In an upper Cook Inlet study done for Marathon Oil Company, only 1 of 26 water samples in the mixing zone contained a volatile organic analyte (VOA) compound at a concentration greater than method detection limits (MDL) (2.9 μg/L toluene), and this was taken 50 m south of the Trading Bay treated water outfall (Neff and Douglas 1994).

In June 1976, Shaw (1977) collected 20 unfiltered water samples in lower Cook Inlet from Kennedy Entrance to Cape Ninilchik, including both Kachemak and Kamishak bays. Observed concentrations of total hydrocarbons ranged from 0.2 micrograms per kilogram (μg/kg) to 1.5 μg/kg (or about 0.2 μg/L to 1.5 μg/L); this is indicative of biogenic rather than petroleum origin (Shaw 1985). Twenty-nine filtered water samples were taken in May and August 1978 (Shaw et al. 1979). Twenty showed no detectable hydrocarbons (<0.01 μg/L). Hydrocarbon concentrations in the other nine were low enough to suggest they were probably bacterial in origin. Results indicate intensive tidal mixing of upper and middle Cook Inlet rapidly disperses any petrogenic hydrocarbons (Shaw 1985).

Shaw (1980) determined hydrocarbon composition over a three-year period (1978 to 1980) for 41 specimens of attached plants and 51 specimens of benthic animals from lower Cook Inlet. Specimens of *Macoma* (clam) and *Mytilus* (mussel) from northern Kachemak Bay showed an array of hydrocarbons

associated with detrital coal. Whether or not these hydrocarbons were assimilated or were part of gut contents was unknown. All mussel specimens contained pristane, suggesting planktonic material in food. They also contained small concentrations (0.02 μg/g to 0.05 μg/g) of other alkanes (chain lengths from 14 to 21 carbon atoms) naturally common in tissues (Shaw 1980).

HISTORICAL TRACE METAL DATA

Studies of trace metal associations with particulate matter reveal that manganese, copper, and zinc are enriched in the organic phase of suspended matter in surface waters of Kachemak Bay; and the weak-acid soluble phase contains about 46% to 99% of the total copper, nickel, and zinc in samples from the Kalgin Island region. These differences are attributed to differences in the sources for the particles, with primary production of biogenic particles predominant in Kachemak Bay and river discharge of terrestrial rock debris predominant in the Kalgin Island region (Feely and Massoth 1982).

Studies of sediment accumulation rates in lower Cook Inlet have indicated most of the suspended material discharged from local rivers is deposited in Shelikof Strait, *not* in Cook Inlet. This finding is important for understanding and predicting the long-term fates of contaminants associated with suspended matter (Feely and Massoth 1982).

Analyses of samples from lower Cook Inlet by Burrell (1978, 1979) and Robertson and Abel (1979) indicate sediments, water, and biota of the Alaska OCS and coastal waters have heavy metal contents that are as low as or lower than those recorded elsewhere for similar unpolluted oceanographic environments in more temperate regions.

Because of the dynamic nature of the hydrographic regime in Cook Inlet, the average surficial sediment in the area is relatively coarse, and concentrations of extractable ("available") heavy metals released (per unit of dry weight) (Burrell et al. 1977) are generally lower than in other Alaska coastal areas that have been studied.

METHODS 3

FIELD SAMPLING

Sampling was conducted from the MMS-supplied RV *1273*, a 37-foot (ft) all-aluminum vessel with a Global Positioning System (GPS), radar, fathometer, radios, power winches, and a crane. Three scientists plus a vessel captain were aboard ship during all sampling periods, and an onshore logistics person was stationed either in Homer or Kenai to ensure timely sample delivery. While on the boat, samples were either stored in a small refrigerator or in coolers with dry ice or frozen (blue) ice packs.

WATER

The sampling plan called for eight water and suspended sediment sampling stations in Cook Inlet, six of which were to be sampled during Cruise 1. Table 1 lists the Cruise 1 water chemistry sampling stations and locations. Table 2 provides the number and type of samples to be taken. During Cruise 1, triplicate samples were to be collected for VOAs, single samples for PAHs, and duplicate samples for metals on the ebb and flow at five of the stations. (Six VOA, two PAH, and four metals samples were collected at each of the five stations.) The same sampling routine was to be followed at the sixth station, but all samples were to be collected in triplicate (18 for VOA, 6 for PAH, and 12 for metals). This sampling plan was adhered to during Cruise 1.

Table 1. Cruise 1 water chemistry sampling stations.

Sample No.	Date	Time	Tide[1]	Station	Lat (N)	Long (W)
001	6/21/93	14:30	R	3	60° 5.30′	151° 50.40′
002	6/21/93	19:00	F	3	60° 5.20′	151° 50.40′
003	6/22/93	16:30	R	B	60° 54.76′	150° 58.42′
004	6/22/93	22:25	F	B	60° 54.65′	150° 59.60′
005	6/23/93	3:25	F	E	61° 5.02′	150° 51.34′
006	6/23/93	8:45	R	E	61° 4.99′	150° 48.88′
007	6/24/93	8:30	R	C	60° 47.20′	151° 39.52′
008	6/24/93	8:35	R	C	60° 47.20′	151° 39.52′
009	6/24/93	8:42	R	C	60° 47.20′	151° 39.52′
010	6/24/93	14:24	F	C	60° 47.23′	151° 39.16′
011	6/24/93	14:30	F	C	60° 47.23′	151° 39.16′
012	6/24/93	15:00	F	C	60° 47.23′	151° 39.16′
013	6/24/93	23:17	R	A	60° 55.50′	151° 23.50′
014	6/25/93	5:56	F	A	60° 55.50′	151° 23.57′
015	6/26/93	17:16	F	F	60° 8.09′	152° 19.93′
016	6/26/93	0:20	R	F	60° 7.79′	152° 19.90′

[1] R = rising, F = falling.

Table 2. Cruise 1 water chemistry samples by station.

Sample No.	Station	VOA	PAH	Metals
1001	3	3	1	2
1002	3	3	1	2
1003	B	3	1	2
1004	B	3	1	2
1005	E	3	1	2
1006	E	3	1	2
1007	C	3	1	2
1008	C	3	1	2
1009	C	3	1	2
1010	C	3	1	2
1011	C	3	1	2
1012	C	3	1	2
1013	A	3	1	2
1014	A	3	1	2
1015	F	3	1	2
1016	F	3	1	2

During Cruise 2, triplicate samples were to be collected for VOAs, single samples for PAHs, and duplicate samples for metals on the ebb and flow at seven of the stations. (Six VOA, two PAH, and four metals samples were collected at each of the seven stations.) The same sampling routine was to be followed at the eighth station, but all samples were to be collected in triplicate (18 for VOA, 6 for PAH, and 12 for metals). With the exception of station 211, where samples were only collected on the ebb tide, the sampling plan was adhered to during Cruise 2. Table 3 lists the water chemistry sampling stations and locations. Table 4 provides the number and type of samples to be taken. Figure 2 shows the locations of water sampling stations for both cruises.

All water chemistry samples were collected with a 5-liter (L) Go-Flo bottle from 1 m below the surface. Samples for VOA analysis were decanted directly into glass vials spiked with 0.1 milliliter (mL) of nitric acid and then refrigerated. Four liters of water were drawn from the same sample bottle for PAH analysis into a 4.5 L amber-glass bottle to which 100 mL of methylene chloride were added. The sample was spiked with 1 mL of an internal standard, and the bottle was then shaken vigorously and placed aside. As soon as time and safety allowed, the bottle was agitated on a shaker for 10 minutes (min). The water layer was decanted into a second 4.5 L bottle, while the methylene chloride layer was collected in a 1 L amber-glass sample bottle; 100 mL of methylene chloride were again added and the bottle agitated on a shaker table for 10 min. The water and methylene chloride were separated as before, and the process was repeated one more time. All sequential methylene chloride extracts for a sample were combined.

A second Go-Flo sample was taken for the metals analysis. Collected water was decanted into 1 L high-density polyethylene plastic bottles spiked with 2 mL of hydrochloric acid and stored in a cooler. Upon returning to port in either Homer or Kenai, all water chemistry samples were shipped via Alaska Airlines' Goldstreak (first flight delivery) to JEAL in Juneau, AK.

Table 3. Cruise 2 water chemistry sampling stations.

Sample No.	Date	Time	Tide[1]	Station	Lat (N)	Long (W)
2001	8/19/93	19:17	F	30	59° 21.80′	152° 2.87′
2002	8/19/93	3:00	R	30	59° 29.80′	152° 2.87′
2003	8/20/93	19:55	R	3	60° 5.35′	151° 50.37′
2004	8/20/93	20:20	F	3	60° 5.56′	151° 50.37′
2005	8/20/93	20:30	R	3	60° 5.25′	151° 50.36′
2006	8/21/93	2:10	F	3	60° 5.23′	151° 50.69′
2007B	8/21/93	3:00	F	3	60° 5.40′	151° 50.81′
2008B	8/21/93	3:30	F	3	60° 5.80′	151° 50.95′
2007	8/21/93	20:40	R	E	61° 4.15′	150° 50.79′
2008	8/22/93	2:00	R	E	61° 4.15′	150° 50.79′
2009	8/22/93	12:36	F	B	60° 54.19′	150° 59.85′
2010	8/22/93	17:00	F	B	60° 54.19′	150° 59.85′
2011	8/22/93	21:05	R	A	60° 55.50′	151° 23.50′
2012	8/22/93	23:59		C	60° 47.19′	151° 39.20′
2013	8/23/93	5:00	R	A	60° 55.38′	151° 23.84′
2014	8/23/93	7:00	R	C	60° 47.16′	151° 39.23′
2015	8/24/93	4:53	F	F	60° 7.81′	152° 19.94′
2016	8/24/93	13:00		F	60° 7.81′	152° 19.94′
2017	8/25/93	0:01		211	59° 26.10′	153° 37.50′

[1] R = rising, F = falling.

Table 4. Cruise 2 water chemistry samples by station.

Sample No.	Station	VOA	PAH	Metals
2001	30	3	1	2
2002	30	3	1	2
2003	3	3	1	2
2004	3	3	1	2
2005	3	3	1	2
2006	3	3	1	2
2007B	3	3	1	2
2008B	3	3	1	2
2007	E	3	1	2
2008	E	3	1	2
2009	B	3	1	2
2010	B	3	1	2
2011	A	3	1	2
2012	C	3	1	2
2013	A	3	1	2
2014	C	3	1	2
2015	F	3	1	2
2016	F	3	1	2
2017	211	3	1	2

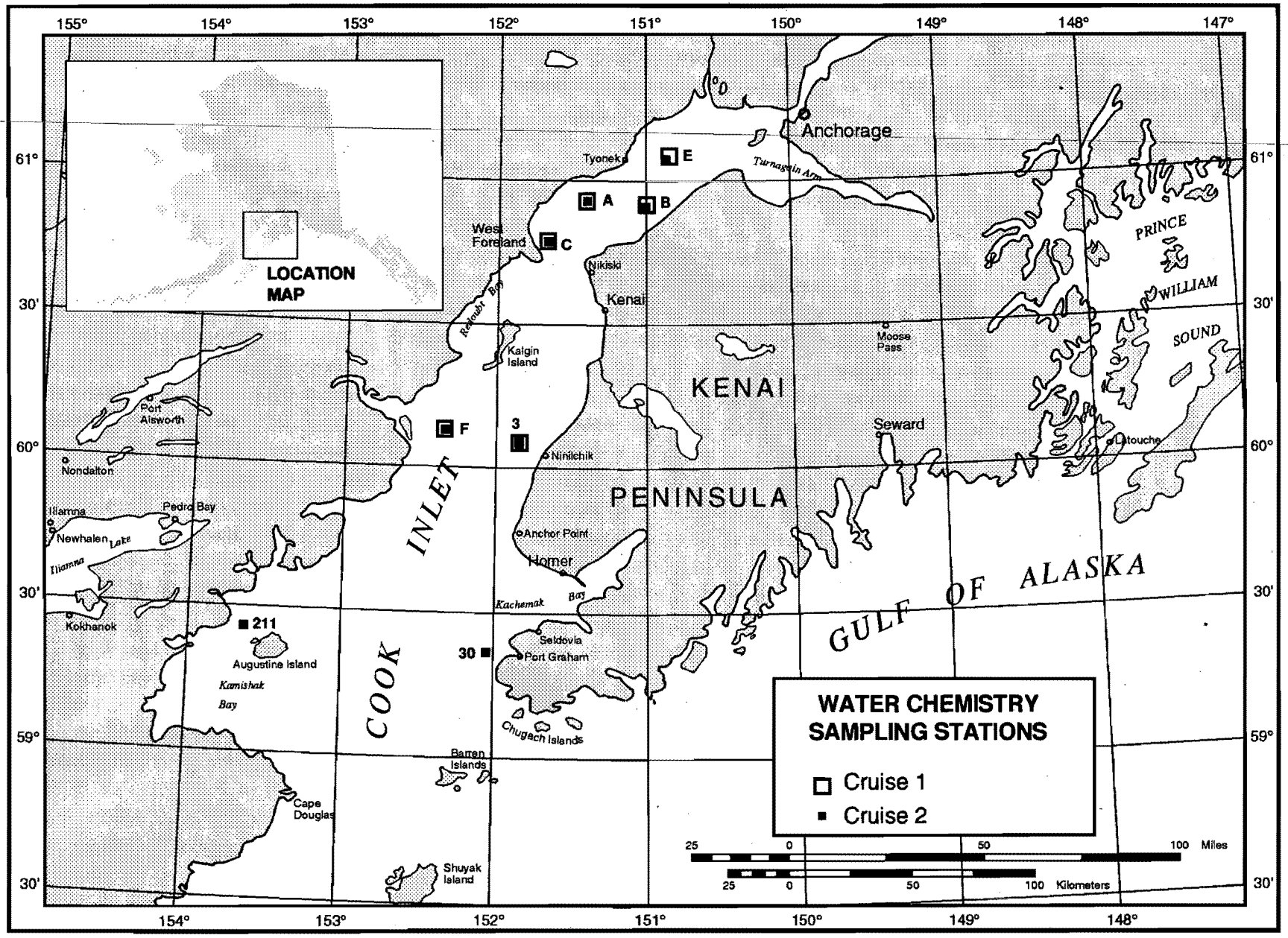


Figure 2. Water chemistry sampling stations.

Suspended sediment samples were collected during Cruise 2 by filtration of seawater at seven of the eight water chemistry stations. Table 5 lists the suspended sediment sampling stations and locations. Table 6 provides the number of samples taken for each type of analysis. Figure 3 shows the location of sediment sampling stations.

Table 5. Cruise 2 suspended sediment sampling stations.

Sample No.	Date	Time	Tide[1]	Station	Lat (N)	Long (W)
2001	8/19/93	19:17	F	30	59° 21.80′	152° 2.87′
2002	8/20/93	3:00	R	30	59° 29.80′	152° 2.87′
2003	8/20/93	19:55	R	3	60° 5.35′	151° 50.37′
2004	8/21/93	3:30	F	3	60° 5.80′	151° 50.95′
2005	8/21/93	20:40	R	E	61° 4.15′	150° 50.79′
2006	8/22/93	2:00	F	E	61° 4.15′	150° 50.79′
2007	8/22/93	12:36	F	B	60° 54.19′	150° 59.85′
2008	8/22/93	17:00	R	B	60° 54.19′	150° 59.85′
2009	8/22/93	21:05	R	A	60° 55.50′	151° 23.50′
2010	8/22/93	23:59	F	C	60° 47.19′	151° 39.20′
2011	8/23/93	5:00	F	A	60° 55.38′	151° 23.84′
2012	8/23/93	7:00	R	C	60° 47.16′	151° 39.23′
2013	8/24/93	4:53	R	F	60° 7.81′	152° 19.94′
2014	8/24/93	13:00	F	F	60° 7.81′	152° 19.94′

[1] R = rising, F = falling.

Table 6. Cruise 2 suspended sediment samples by station.

Sample No.	Station	Filter TSS/Metals	Filter Hg
2001	30	1	1
2002	30	1	1
2003	3	1	1
2004	3	1	1
2005	E	3	1
2006	E	3	1
2007	B	1	3
2008	B	1	3
2009	A	3	1
2010	C	1	3
2011	A	3	1
2012	C	1	3
2013	F	1	1
2014	F	1	1

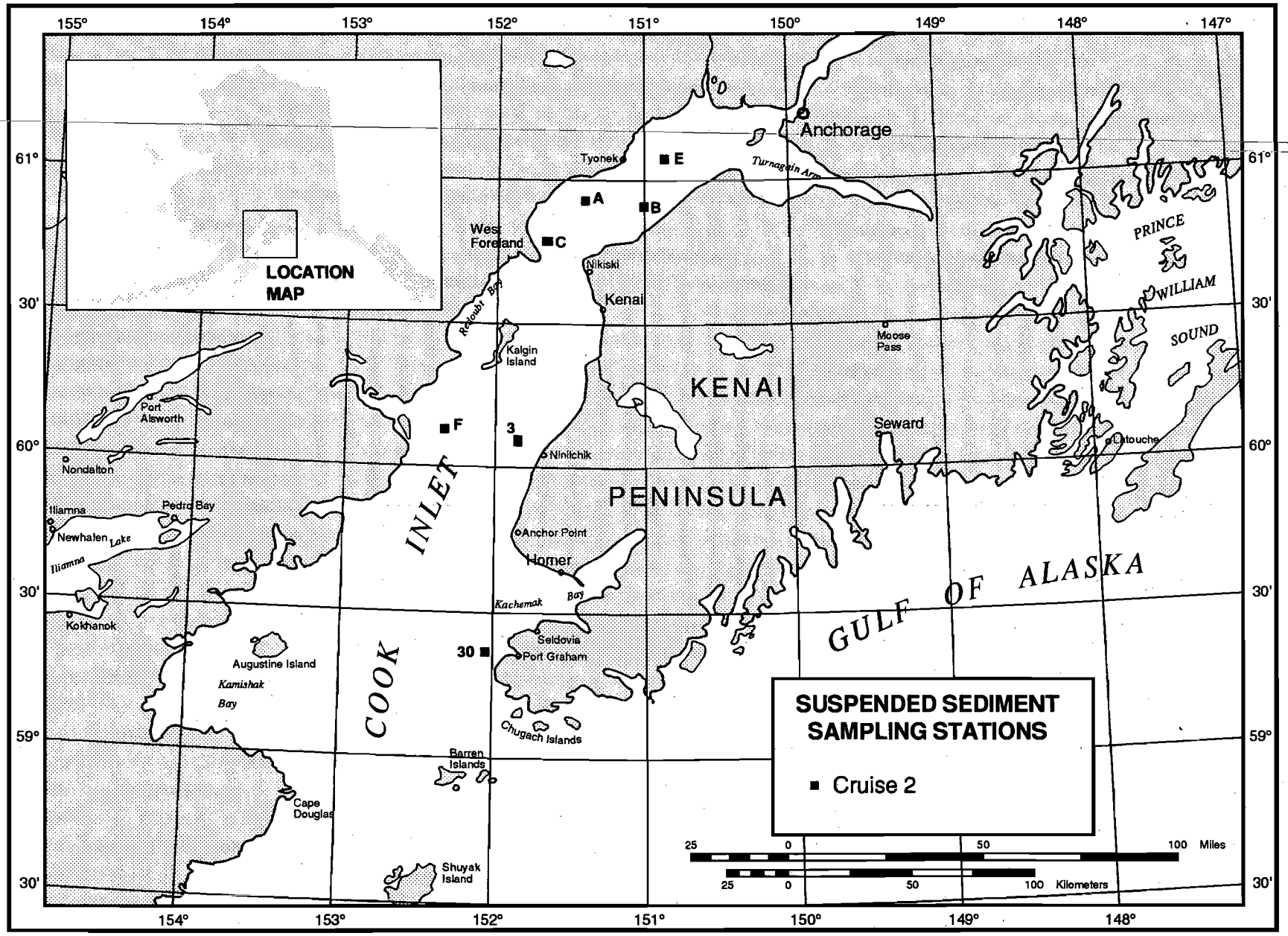


Figure 3. Suspended sediment sampling stations.

SEDIMENTS

A 0.1 m^2 Teflon-coated Van Veen grab was used to collect bottom sediments. During Cruise 1, sediments were collected at two of the planned stations, at an alternate station proximate to a planned station, and at two alternate stations located some distance from the MMS-designated locations. At times, the collection of bottom sediments was hindered by swift bottom currents, rough seas, inclement weather, and large cobble or boulder bottoms. As a contingency, ENRI sampled a range of new or alternate sediment stations. Triplicate grabs were made at each station where sediments were found. The hydrocarbon analysis samples were placed on dry ice immediately after collection and stored in coolers. Table 7 lists the Cruise 1 bottom sediment sampling stations and locations. Table 8 provides the number of samples taken for each type of analysis.

Table 7. Cruise 1 sediment sampling stations.

Sample No.	Date	Time	Depth (m)	Station	Lat (N)	Long (W)
013	6/24/93	17:20	9.8	Alt A	60° 52.39′	151° 40.47′
014	6/24/93			Alt C	60° 54.13′	151° 37.72′
019	6/25/93		6.1	27	60° 42.32′	151° 45.95′
022	6/26/93	17:40	54.0	F	60° 8.28′	152° 19.82′
023	6/26/93	21:30	7.9	16B	60° 13.01′	152° 44.33′

Table 8. Cruise 1 sediment samples by station.

Sample No.	Station	Hydrocarbons	Metals	Grain Size	CHN
1013	Alt C	3	3	3	3
1014	Alt A	3	3	3	3
1019	Alt 27	3	3	3	3
1022	F	3	3	3	3
1023	16B	3	3	3	3

During Cruise 2, sediments were collected at six of the planned stations, at six alternate stations proximate to a planned station, and at four new stations located some distance from the MMS-designated locations. Triplicate grabs were made at each station where sediments were found. All samples for analysis were collected from approximately the top 1 centimeter (cm) of the grabs. Samples for metals analysis were taken with a plastic spoon, and all others were collected with a stainless steel scoop. Hydrocarbon analysis samples were placed in U.S. Environmental Protection Agency (EPA)-level-2 cleaned glass bottles, placed on dry ice immediately after collection, and stored in coolers. Samples were placed in EPA-level-2 cleaned high-density polyethylene jars for metal analyses, in double-bagged whirl packs for grain-size analyses, and in 25-gram (g) disposable vials for CHN analyses; they were then stored in coolers. Table 9 lists the Cruise 2 bottom sediment sampling stations and locations. Table 10 provides the number of samples taken for each type of analysis. Figure 4 shows the location of sediment sampling stations for both cruises.

Upon returning to port in Homer or Kenai, all sediment samples for hydrocarbon and metal analyses were shipped via Goldstreak to JEAL in Juneau. Grain-size and CHN samples were transported to ENRI in Anchorage. Grain-size samples were stored for later analyses, and CHN samples were shipped to Huffman Laboratories, Inc., in Golden, CO, for analyses.

Table 9. Cruise 2 sediment sampling stations.

Sample No.	Date	Time	Station	Depth (m)	Lat (N)	Long (W)
2003	8/21/93	0:00	Alt-E		61 6.44′	151° 5.46′
2005	8/23/93	7:00	C	25.6	60° 47.16′	151° 39.23′
2006	8/23/93		Alt-A	8.2	60° 57.49′	151° 31.87′
2007	8/23/93	13:10	27	4.6	60° 42.39′	151° 45.92′
2009	8/24/93	4:53	F	54.0	60° 7.81′	152° 19.94′
2010	8/24/93	9:00	16B	5.5	60° 13.00′	152° 45.00′
2012	8/24/93	14:45	New E5		59° 58.08′	152° 38.72′
2013	8/24/93	17:05	233	18.3	59° 48.50′	152° 55.73′
2014	8/24/93	21:00	New E6	16.2	59° 37.06′	153° 15.38′
2015	8/29/93	13:30	Alt 30	40.2	59° 21.93′	151° 57.84′
2016	8/29/93	17:00	227	95.1	59° 33.05′	151° 35.94′
2017	8/30/93	10:08	New E7	28.4	59° 49.42′	151° 56.46′
2018	8/30/93	12:25	New E8	33.5	60° 2.24′	151° 53.58′
2019	8/31/93	10:00	Alt 265	19.2	60° 34.67′	151° 49.58′
2020	8/31/93	15:00	Alt 22	24.1	60° 23.31′	152° 5.46′
2021	8/31/93	17:00	Alt 23	45.1	60° 30.72′	152° 1.15′

Table 10. Cruise 2 sediment samples by station.

Sample No.	Site	Hydrocarbons	Metals	Grain Size	CHN
2003	Alt E	1	1	1	1
2005	C	1	1	1	1
2006	Alt A	3	3	3	3
2007	27	3	3	3	3
2009	F	3	3	3	3
2010	16B	3	3	3	3
2012	New E5	3	3	3	3
2013	233	3	3	3	3
2014	New E6	3	3	3	3
2015	Alt 30	3	3	3	3
2016	227	3	3	3	3
2017	New E7	3	3	3	3
2018	New E8	3	3	3	3
2019	Alt 265	3	3	3	3
2020	Alt 22	3	3	3	3
2021	Alt 23	3	3	3	3

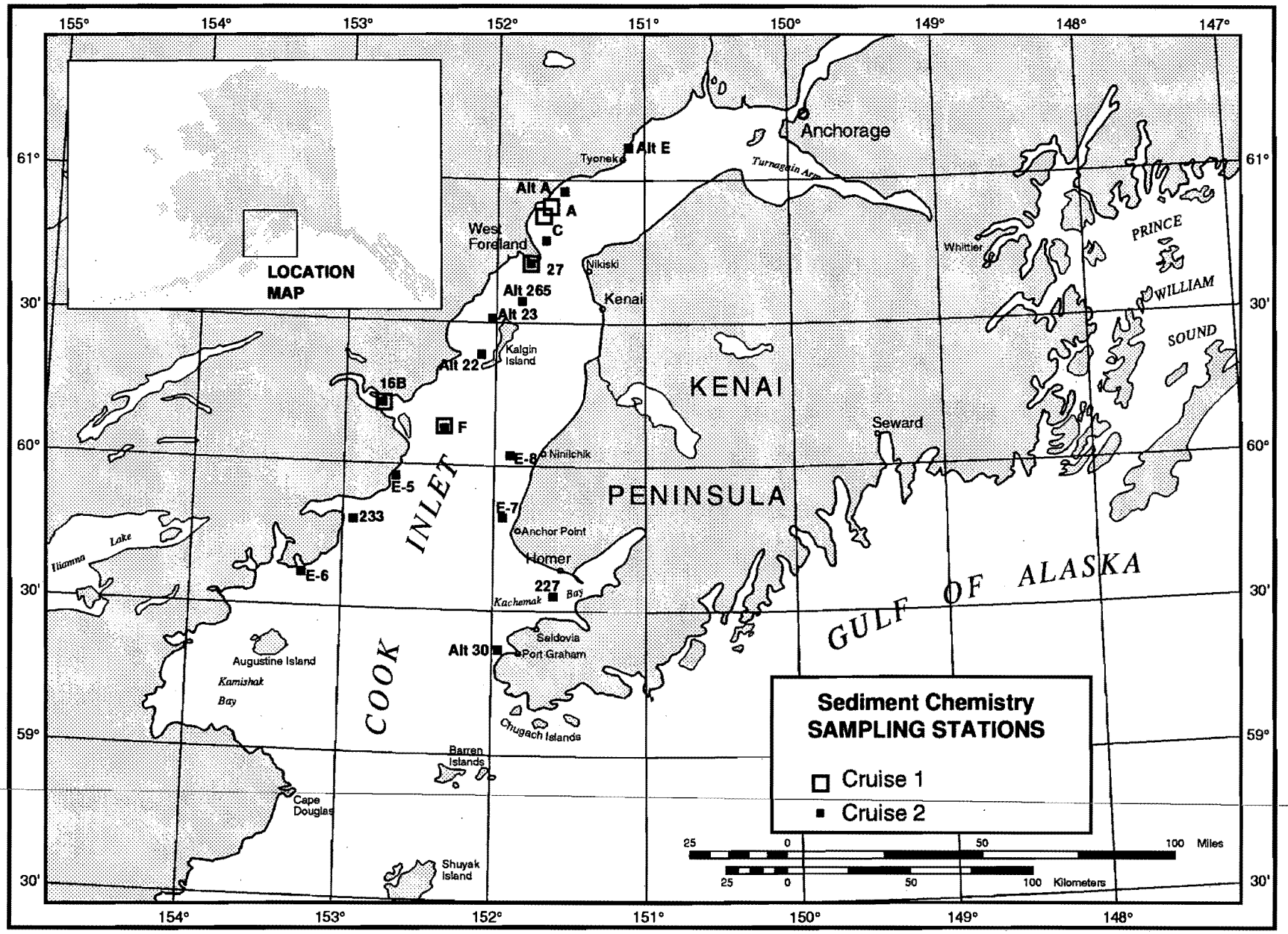


Figure 4. Bottom sediment sampling stations.

HYDROGRAPHY

Hydrographic and transmissivity data were obtained using an MMS-provided Applied Microsystems Ltd. internal recording Model STD-12 salinity, temperature, and depth profiler fitted with a SeaTech 10 cm transmissometer. Thirty-eight casts were made at 16 stations during Cruises 1 and 2 at all water chemistry stations and at a number of sediment stations. Cast numbers, station locations, and water depths at the time of cast are presented in Tables 11 and 12. Figure 5 presents the areal distribution of the hydrographic stations within Cook Inlet.

Standard hydrographic procedures were followed. After each cast, data were downloaded to the hard disk of one of ENRI's laptop computers. Backup copies of the data were made on floppy disks to preclude data loss. Parameters recorded in the STD-12 included probe number, time code, raw pressure, raw temperature, raw conductivity ratio, and raw transmissivity values.

BIOTA

Biota samples were only collected during Cruise 2. Composite samples of approximately 30 mussels (*Mytilus edulis*) were removed at low tide from rocks on both the eastern and western sides of lower Cook Inlet. Mussels were washed, and then the tissue samples taken. These samples were put in whirl-pak bags and stored in coolers. Shells were placed in separate packs and stored on deck in lockers. Table 13 lists the benthic sampling stations and purpose of each. Figure 6 shows the locations of biota sampling stations. Mussel tissue samples were shipped via Goldstreak from Homer to JEAL in Juneau, and shells were included in the final Goldstreak shipment of bioassay materials to MSL in Sequim, WA.

BIOASSAY

Bioassay samples were only collected during Cruise 2. Bioassay water samples were taken with a 5 L Go-Flo bottle from 1 m below the surface. They were decanted directly into 1-gallon (gal) amber-glass bottles and placed in coolers. Table 14 lists the water bioassay sampling stations and locations. Figure 7 shows their locations.

Bioassay sediment samples were collected with the 0.1 m^2 grab sampler. They were taken from the top 2 cm to 4 cm of sediment with a stainless steel scoop, placed in a 1 gal wide-mouthed glass container, and placed in coolers. Table 15 lists the sediment bioassay sampling stations and locations. Figure 8 shows their locations.

Sediment samples were collected at the same time for Microtox®. They were taken from the top 1 cm to 2 cm of sediment from the grab sample using the stainless steel scoop, placed in a 250 mL EPA-level-2 cleaned wide-mouthed jar, and placed in a cooler. Table 16 lists the Microtox® sampling stations and locations. Figure 9 shows their locations.

All water and sediment bioassay samples were returned to either Homer or Kenai within 12 hours (h) of being collected and were subsequently shipped via Goldstreak to MSL in Sequim. They were kept at temperatures below 4°C at all times before reaching the laboratory. In order to be considered for analyses, all samples had to reach MSL within 48 h of collection. With the exception of the first set of samples shipped, all were received within 24 h in good condition and processing began immediately. The first set was delayed in shipping and was subsequently discarded. All Microtox® samples were also kept at temperatures below 4°C; they were shipped via Goldstreak to ENRI facilities in Anchorage for processing.

FIELD DATA MANAGEMENT AND SAMPLE HANDLING

Field operations and sample collection, preservation, and transfer procedures were recorded on various forms. These included trip logs, survey forms (containing information on casts and on sediment, water, and biota samples), sample custody and identification forms, and sample transmittal forms. Each time the sampling equipment was lowered it was recorded by station, date, and time. Then, an

Table 11. Cruise 1 hydrography sampling stations.

Cast No.	Date	Time	Tide[1]	Station	Depth (m)	Lat (N)	Long (W)
001	6/21/93	16:59	R	3	43.3	60° 8.51′	151 44.13′
002	6/21/93	19:00	F	3	42.1	60° 5.30′	151° 50.40′
003	6/22/93	16:30	R	B	24.4	60° 54.76′	150° 58.42′
004	6/22/93	22:25	F	B	24.4	60° 54.65′	150° 59.60′
005	6/23/93	3:45	R	E	26.2	61° 5.02′	150° 51.34′
006	6/23/93	8:45	F	E	26.2	61° 4.99′	150° 48.88′
007	6/24/93	10:00	R	C	26.8	60° 45.65′	151° 39.24′
008	6/24/93	15:39	F	C	30.5	60° 47.65′	151° 39.15′
009	6/24/93	23:50	R	A	59.1	60° 55.60′	151° 22.51′
010	6/25/93	6:10	F	A	60.4	60° 55.35′	151° 23.29′
011	6/25/93			27	17.1	60° 42.00′	151° 46.84′
012	6/25/93	11:50		27	21.6	60° 38.82′	151° 48.92′
013	6/26/93	13:47	R	2	29.0	60° 24.58′	151° 32.37′
014	6/26/93	14:51		255	30.2	60° 17.23′	151° 37.82′
015	6/26/93	17:30	F	F	54.0	60° 8.09′	152° 19.93′
016	6/26/93	21:30		16B	7.9	60° 13.01′	152° 44.33′
017	6/27/93	0:35	R	F	56.7	60° 7.79′	152° 19.90′

[1] R = rising, F = falling.

Table 12. Cruise 2 hydrography sampling stations.

Cast No.	Date	Time	Tide[1]	Station	Depth (m)	Lat (N)	Long(W)
2001	8/19/93	19:17	F	30	63.7	59° 18.69′	152° 4.80′
2002	8/19/93	3:00	R	30	64.0	59° 29.80′	152° 2.87′
2003	8/20/93	19:55	R	3	41.5	60° 4.51′	151° 50.96′
2004	8/21/93	2:10	F	3	38.7	60° 6.07′	151° 52.53′
2005	8/21/93	20:40	R	E	27.1	61° 4.15′	150° 50.79′
2006	8/22/93	2:00	F	E	37.2	61° 4.15′	150° 50.79′
2007	8/22/93	3:54	F	B	19.8	60° 54.50′	150° 59.39′
2008	8/22/93	12:36	F	B	24.4	60° 54.19′	150° 59.85′
2009	8/22/93	17:00	R	B	24.4	60° 54.19′	150° 59.85′
2010	8/22/93	21:05	R	A	62.2	60° 55.50′	151° 23.50′
2011	8/22/93	23:59	F	C	29.3	60° 47.19′	151° 39.20′
2012	8/23/93	5:00	F	A	63.1	60° 55.38′	151° 23.84′
2013	8/23/93	7:00	R	C	25.6	60° 47.16′	151° 39.23′
2014	8/23/93	13:10		27	4.6	60° 42.39′	151° 45.92′
2015	8/24/93	4:53	R	F	54.0	60° 7.81′	152° 19.94′
2016	8/24/93	9:00	R	16B	5.5	60° 13.00′	152° 45.00′
2017	8/24/93	13:00	F	F	54.0	60° 7.81′	152° 19.94′
2018	8/24/93	14:45		New E5		59° 57.79′	152° 39.52′
2019	8/24/93	17:05		233	18.3	59° 48.50′	152° 55.73′
2020	8/24/93	21:00		New E6	16.2	59° 37.06′	153° 15.38′
2021	8/25/93	0:01		211		59° 26.10′	153° 37.50′

[1] R = rising, F = falling.

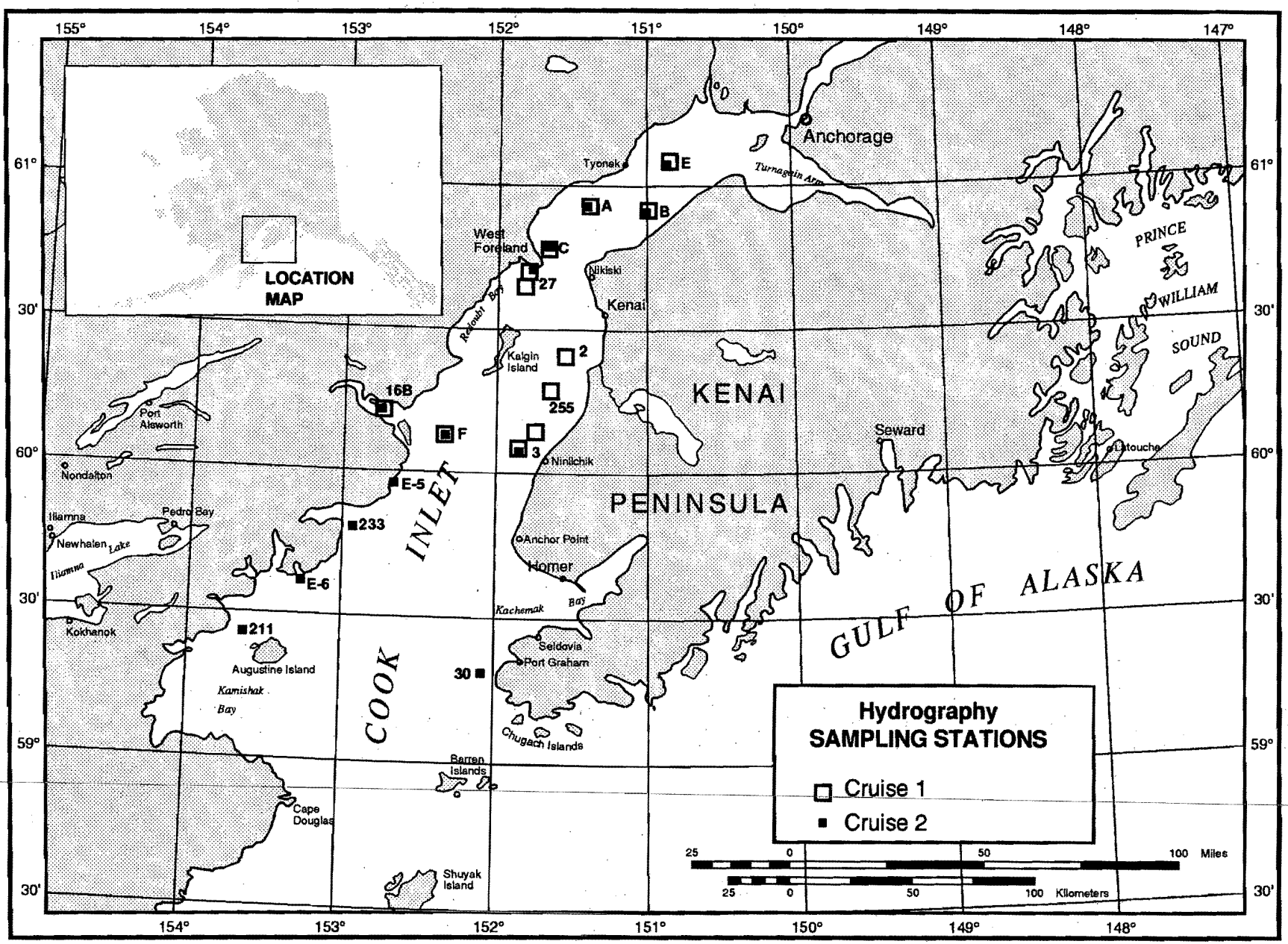


Figure 5. Hydrography sampling stations.

Table 13. Cruise 2 biota sampling stations.

Sample No.	Station	Tissue/Hydrocarbon	NORM
2001	Tuxedni Bay	1	1
2002	Fossil Point	1	1
2003	Chinitna Bay	1	1
2004	Jakolof Bay	1	1
2005	Kasitsna Bay	1	1
2006	Homer	1	1

Note: All benthos collected for both tissue and shell analyses were *M. edulis*.

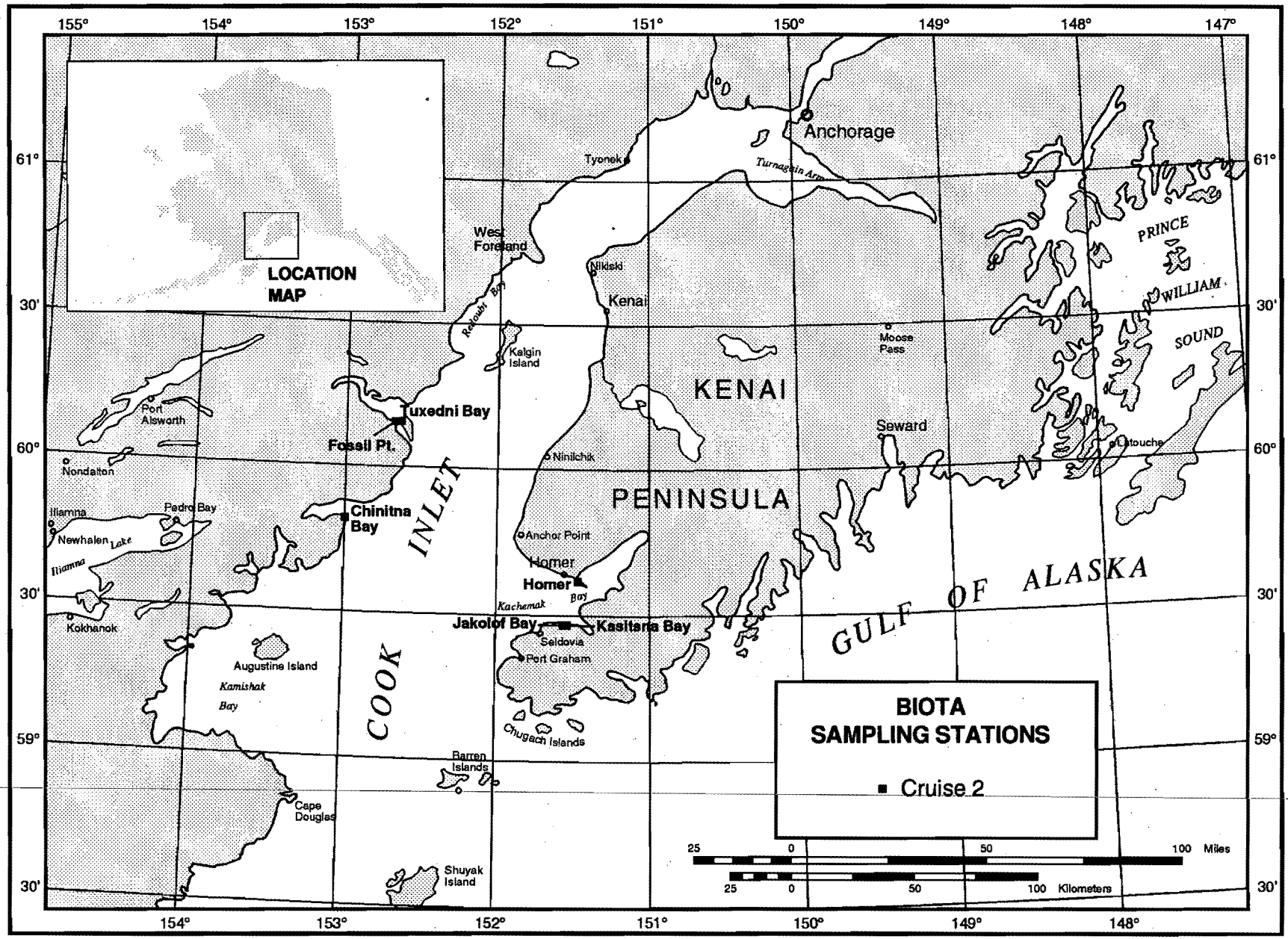


Figure 6. Biota sampling stations.

Table 14. Cruise 2 water bioassay sampling stations.

Sample No.	Date	Time	Tide[1]	Station	Lat (N)	Long (W)
2001	8/19/93	19:17	R	30	59° 29.80′	152° 2.87′
2002	8/21/93	3:30	F	3	60° 5.80′	151° 50.95′
2003	8/21/93	3:30	F	3	60° 5.80′	151° 50.95′
2004	8/22/93	2:00	F	E	61° 4.15′	150° 50.79′
2005	8/22/93	3:54	F	B	60° 54.50′	150° 59.39′
2006	8/23/93	5:00	F	A	60° 55.38′	151° 23.84′
2007	8/23/93	7:00	R	C	60° 47.16′	151° 39.23′
2008	8/24/93	4:53	R	F	60° 7.81′	152° 19.94′
2009	8/25/93	0:01		211	59° 26.10′	153° 37.50′
2010	8/29/93	13:00		30	59° 22.07′	152° 2.50′

[1] R = rising, F = falling.

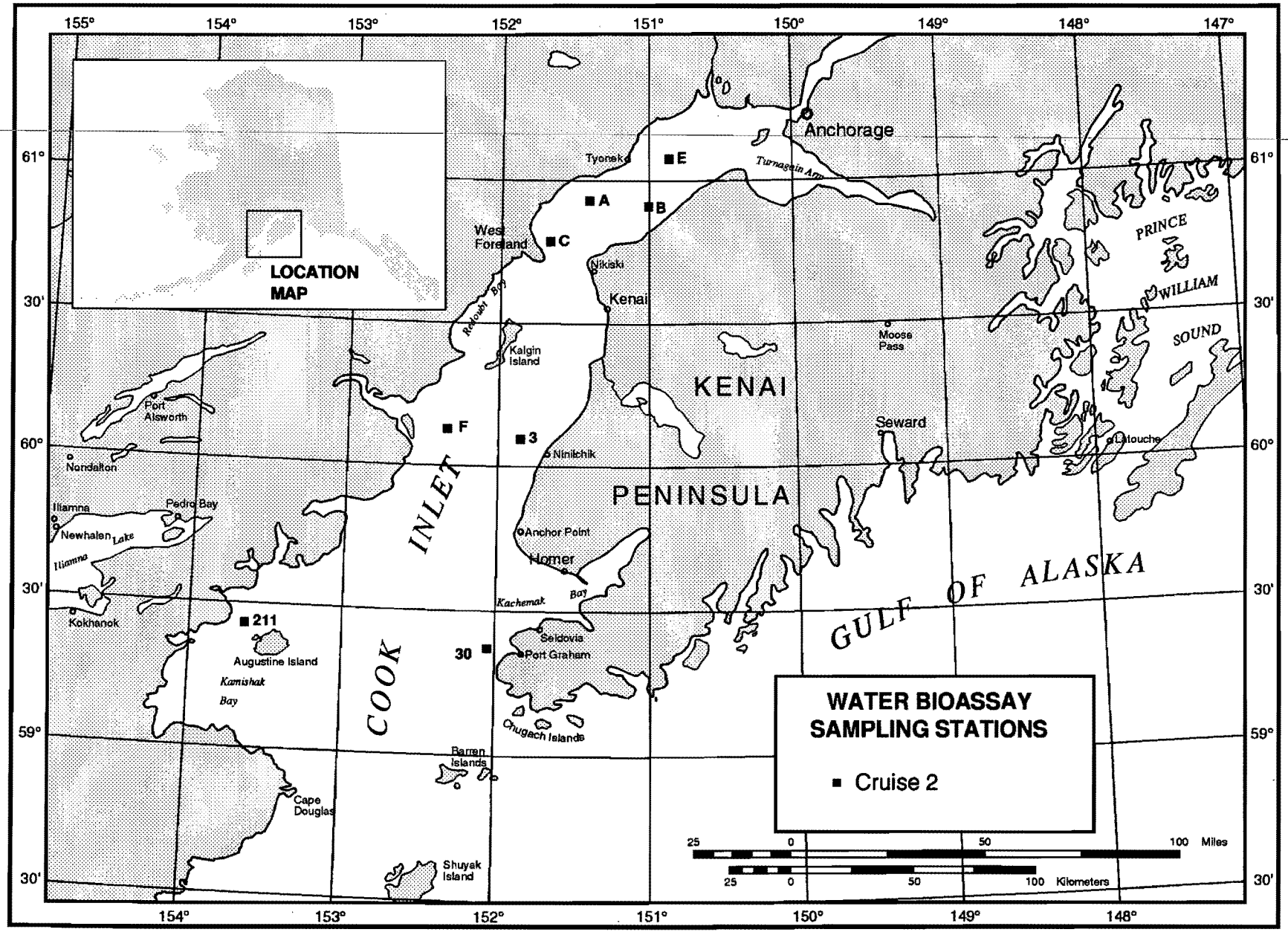


Figure 7. Water bioassay sampling stations.

Table 15. Cruise 2 sediment bioassay sampling stations.

Sample No.	Date	Time	Station	Depth (m)	Lat (N)	Long (W)
2001	8/20/93	3:00	227	92.1	59° 33.60′	151° 36.37′
2002	8/21/93	0:00	Alt E		61° 6.44′	151° 5.46′
2003	8/22/93	12:36	B	24.4	60° 54.19′	150° 59.85′
2004	8/23/93	7:00	Alt C	25.6	60° 50.37′	151° 43.35′
2005	8/23/93		Alt A	8.2	60° 57.49′	151° 31.87′
2006	8/23/93	13:10	27	4.6	60° 42.39′	151° 45.92′
2007	8/24/93	4:53	F	54.0	60° 7.81′	152° 19.94′
2008	8/24/93	9:00	16B	5.5	60° 13.00′	152° 45.00′
2009	8/24/93	17:05	233	18.3	59° 48.50′	152° 55.73′
2010	8/29/93	17:00	227	95.1	59° 33.05′	151° 35.94′
2011	8/30/93	10:08	New E7	28.4	59° 49.42′	151° 56.46′
2012	8/30/93	12:25	New E8	33.5	60° 2.24′	151° 53.58′
2013	8/31/93	10:00	Alt 265	19.2	60° 34.67′	151° 49.58′
2014	8/31/93	15:45	Alt 22	24.1	60° 23.31′	152° 5.46′

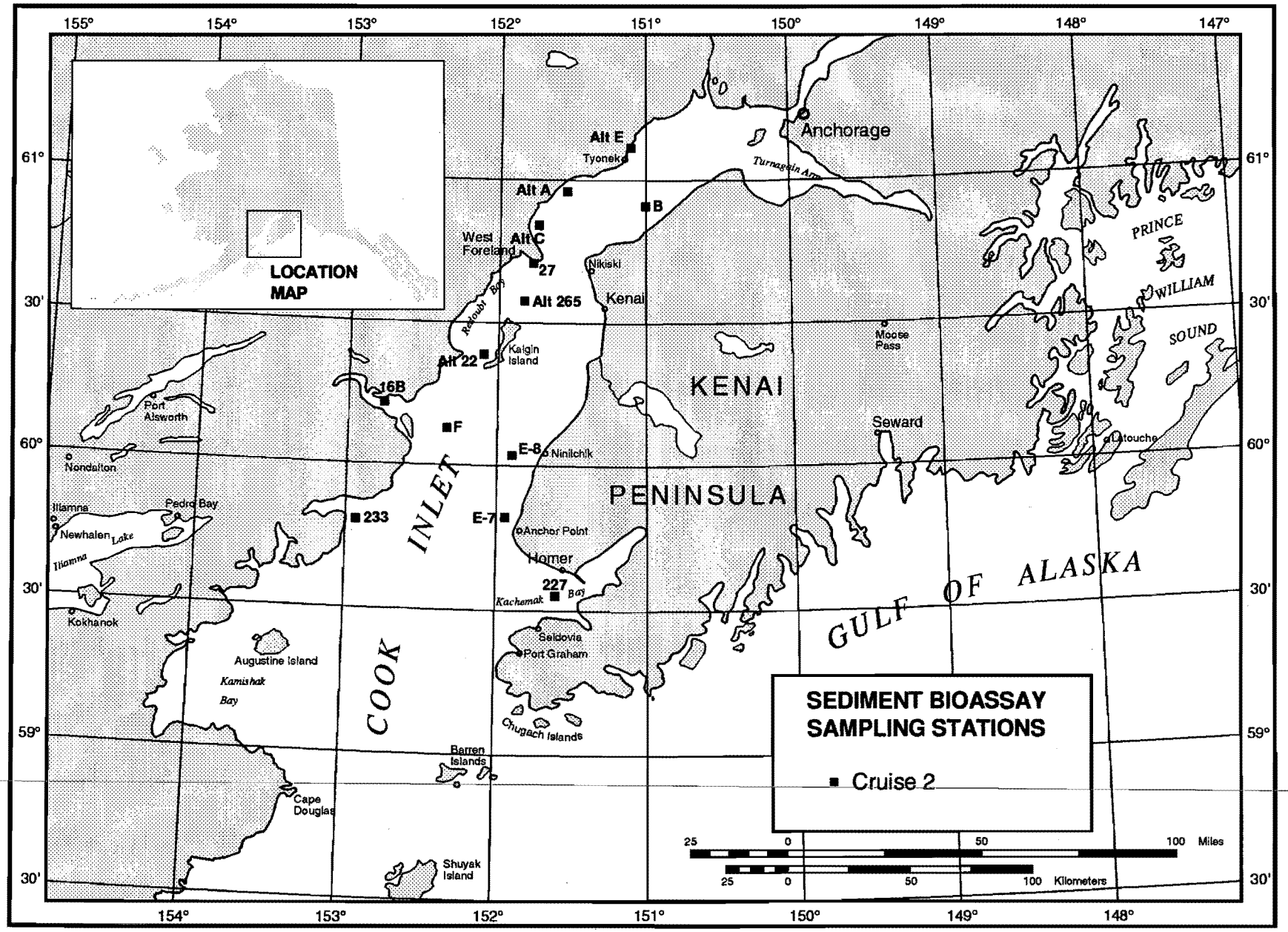


Figure 8. Sediment bioassay sampling stations.

Table 16. Cruise 2 Microtox® sampling stations.

Sample No.	Date	Time	Station	Depth (m)	Lat (N)	Long (W)
2001	8/20/93	3:00	227	92.1	59° 33.60′	151° 36.37′
2002	8/21/93	0:00	Alt E		61° 6.44′	151° 5.46′
2004	8/23/93		Alt A	8.2	60° 57.49′	151° 31.87′
2005	8/23/93	13:10	27	4.6	60° 42.39′	151° 45.92′
2006	8/24/93	4:53	F	54.0	60° 7.81′	152° 19.94′
2007	8/24/93	9:00	16B	5.5	60° 13.00′	152° 45.00′
2008	8/24/93	17:05	233	18.3	59° 48.50′	152° 55.73′
2009	8/30/93	10:08	New E7	28.4	59° 49.42′	151° 56.46′
2010	8/30/93	12:25	New E8	33.5	60° 2.24′	151° 53.58′
2011	8/31/93	11:30	Alt 265	19.2	60° 34.67′	151° 49.58′
2012	8/31/93	15:45	Alt 22	24.1	60° 23.31′	152° 5.46′

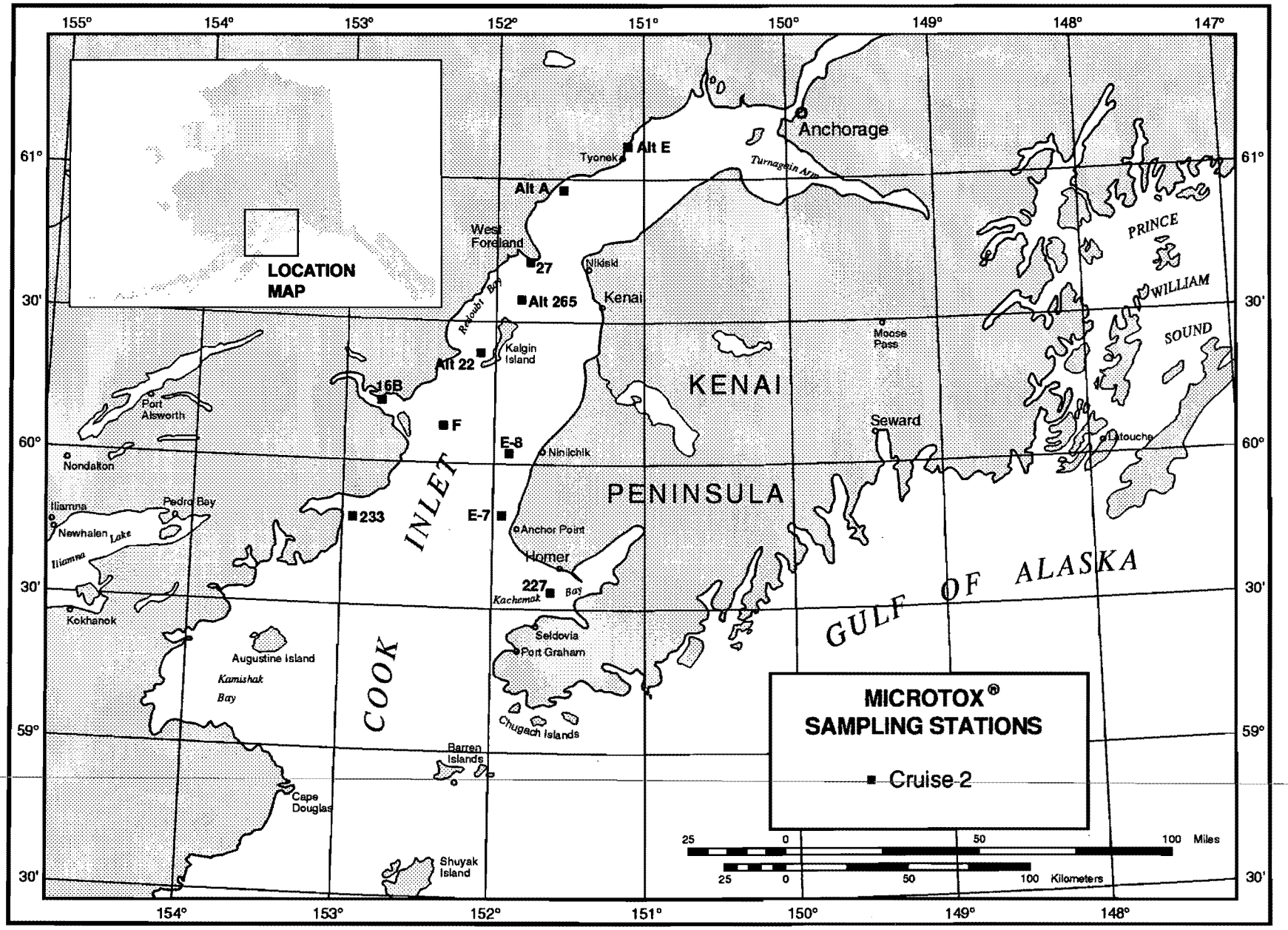


Figure 9. Microtox® sampling stations.

identification number was assigned. Station coordinates were recorded for each sample collected. Sampling success and other comments were noted.

Sample identification tags and survey logs provided primary documentation for identification of field samples. Samples were assigned four-digit numeric identification numbers that were logged on the forms. Sample types and replicates were also recorded. Each sample collected was confirmed and recorded on a transmittal form that accompanied samples in transit from the Kenai Peninsula to MSL, JEAL, or ENRI. Upon arrival, all samples were checked against the appropriate forms to validate transfer; they were then immediately transported to appropriate storage.

LABORATORY ANALYSES

WATER

VOA

Seawater samples were collected in 40 mL EPA-level-2 cleaned glass VOA vials with Teflon-lined septa. Five milliliter aliquots of collected samples were analyzed using both a Tekmar autosampler and purge-and-trap outfitted with a No. 3 trap (Tekmar, Cincinnati, OH), followed by a Varian 3400 GC with a DB-624 column (75 m x 0.53 millimeter [mm], 3 μ film thickness) (J&W, Folsom, CA) and Tracor model No. 703 Photo Ionization Detector. Results were quantitated using a data station outfitted with Maxima software (Waters' Dynamic Solutions, Millipore, Ventura, CA). Samples were analyzed according to EPA method 602 (40 Code of Federal Regulations, part 49:209) with the following modifications: the reagent water specified in the method was replaced with Copenhagen Water (Kahl Instruments, El Cajon, CA), a standard seawater, for matrix matching. All calibration standards, laboratory control standards, and quality control (QC) standards were prepared using Copenhagen Water as the solvent of choice. Linear calibration was performed using five points ranging in concentration from 2 μg/L to 40 μg/L for benzene, toluene, ethylbenzene, the m,p-xylenes, and o-xylene (Supelco 8020 mix, Supelco, Bellafonte, PA).

Calibration was verified using Accustandard M-8020 mix (Accustandard, New Haven, CT) at a midrange concentration. All standards were prepared in 40 mL VOA vials using Hamilton gas-tight syringes (Hamilton, Sparks, NV). When necessary, intermediate dilutions were made using Class A volumetric flasks with residue grade methanol as solvent. All standards were prepared immediately before first use and stored at -20°C (zero headspace) in GC autosampler vials with Teflon-lined septa and screw caps for no more than 6 months from the date of initial preparation. MDLs were established for each analyte using signal-to-noise ratio and were all 1 μg/L or less for each calibrated component. Travel blanks, which accompanied the collection of the field samples, were also analyzed using this protocol.

Semivolatile Organic Compounds

Four-liter volumes of collected seawater were extracted aboard ship using residue grade methylene chloride (JT Baker Resi Analyzed or Fisher Optima Residual Analyzed Reagent grade). Combined methylene chloride extracts were received at JEAL in EPA-level-2 cleaned amber-glass bottles with Teflon-lined lids, and they were stored at 4°C until final preparation before analysis. Extracts were then dried over methylene chloride washed anhydrous sodium sulfate and concentrated to 1 mL final volume by Kuderna-Danish concentration and nitrogen evaporation. Concentrated extracts were stored in GC autosampler vials at -20°C until analysis. Samples were analyzed using a Hewlett Packard 5890 series II GC with a Hewlett Packard 7673 autosampler. The GC was coupled to a Hewlett Packard 5971 mass selective detector. The MS was tuned to manufacturer's specifications and configured to scan from mass 35 to mass 500.

Data were acquired and analyzed using a Hewlett Packard 486/33 Vectra personal computer with Hewlett Packard G1034C ChemStation software. The chromatography column used was a J&W Scientific DB-5, 0.25 mm ID, 30 m length, and 0.25 mm film thickness (J&W Scientific, Folsom, CA). Helium was used as a carrier gas. A split/splitless injection technique was used, with the split vent being opened after 0.8 min. The GC injector temperature was maintained at 290°C, and the MS

transfer line was maintained at 280°C. The GC oven was initially started at 50°C, holding for 2 min, ramping to 310°C at 8°C/min, and holding for 10.5 min for a total instrument analytical time of 45 min.

The instrument was calibrated for alkane hydrocarbons with a seven-point calibration curve where possible. Alkane calibration standard concentrations were 0.0005 μg/L, 0.001 μg/L, 0.005 μg/L, 0.02 μg/L, 0.05 μg/L, 0.1 μg/L, and 0.2 μg/L. PAHs were calibrated with a six-point calibration curve where possible, with PAH standard concentrations of 0.0005 μg/L, 0.001 μg/L, 0.005 μg/L, 0.02 μg/L, 0.05 μg/L, and 0.1 μg/L. Alkane standards were prepared by weighing neat compounds with an analytical balance into benzene (JT Baker "Baker Analyzed"), pentane (B&J High Purity Solvent), and methylene chloride and diluting it volumetrically with methylene chloride to the needed concentrations. PAH standards were similarly prepared by weighing to prepare stock standards and volumetric dilution to working concentrations.

The MDL, based on 2-methylnaphthalene, was determined using signal-to-noise ratio as specified in EPA manual SW846 and was less than 0.01 μg/L (EPA 1992). Table 17 lists the quantitated analytes, surrogates, and internal standards.

Trace Metals Analysis

Mercury analysis was performed as follows. A sample of 100 mL of seawater was placed in a biochemical oxygen demand bottle. Five milliliters of sulfuric acid and 2.5 mL of concentrated nitric acid were added and mixed after each addition. Then 125 mL of potassium permanganate were added. The sample was shaken and additional potassium permanganate added, if necessary, until a purple color was maintained. Eight milliliters of potassium persulfate solution were added, and the sample was heated for 2 h in a water bath at 95°C. The solution was cooled, and 6 mL of sodium chloride-hydroxylamine sulfate were added to reduce the excess permanganate. After at least 30 seconds (s), the sample bottle was attached to the aeration apparatus of a cold vapor atomic absorption (CVAA) mercury analyzer. The water sample was mixed in line with a stannous chloride solution. Multiple aliquots of sample were reduced and purged until the mercury from 10 mL had been collected on the gauze of the mercury analyzer. The gauze was then heated and the released mercury swept with argon into a flameless cell Perkin-Elmer 2500 CVAA spectrophotometer for analysis.

Iron analysis was performed by flame atomic absorption (FAA) of a diluted seawater sample, and arsenic analysis was performed as follows. Fifty milliliters of seawater were placed in a 100 mL beaker. Five milliliters of concentrated nitric acid and 6 mL of 18 normal sulfuric acid were added. The sample was evaporated on a hot plate until white sulfur trioxide fumes were observed. Additional nitric acid was added, if necessary, until the sample remained colorless or straw-yellow colored during the evolution of sulfur trioxide fumes. The sample was cooled and transferred to a 100 mL volumetric flask. Twenty milliliters of concentrated hydrochloric acid were added, and the volume was made up with water. A 25 mL aliquot of this sample was taken, and 5 mL of nitric acid and 6 mL of sulfuric acid were added. The volume was reduced to 10 mL by heating on a hot plate at 95°C. Two aliquots of 1.5 mL of nitric acid were added, and the sample was heated until white fumes began to form after the second addition of nitric acid. Arsenic and antimony were then determined by hydride generation and atomic absorption.

SEDIMENT

Suspended Solids

Several methodologies were used to determine trace metals in suspended sediments. These included CVAA for mercury; graphite flame atomic absorption (GFAA) for arsenic; FAA for iron; and inductively coupled plasma (ICP)/MS for barium, cadmium, chromium, copper, lead, nickel, silver, thallium, vanadium, and zinc. For all analyses except mercury, the filter containing the suspended solids was weighed and transferred to a conical beaker. Ten milliliters of 1:1 nitric acid were added, and the sample was mixed and covered by a watch glass. It was heated to 95°C and refluxed for 10 to 15 min without boiling. After cooling, 5 mL of concentrated nitric acid were added and the watch glass replaced. The sample was heated and refluxed for 30 min. This last step was repeated one more time, and then the sample was allowed to evaporate to 5 mL without boiling. The sample was

Table 17. Semivolatile organic compounds in waters, sediments, and tissues.

Compound Name	Abbreviation	Source
Alkanes		
Internal Standards		
n-Pentadecane-d32	C15-d32	Cambridge Isotope Lab
n-Nonadecande-d40	C19-d40	Cambridge Isotope Lab
Surrogates		
n-Dodecane-d26	C12-d26	Cambridge Isotope Lab
n-Eicosane-d42	C20-d42	Isotech
n-Triacontane-d62	C33-d62	Isotech
Target Compounds		
n-Octane	C8	Altech
n-Nonane	C9	Aldrich
n-Decane	C10	Aldrich
n-Undecane	C11	Aldrich
n-Dodecane	C12	Aldrich
n-Tridecane	C13	Aldrich
n-Tetradecane	C14	Altech
n-Pentadecane	C15	Aldrich
n-Hexadecane	C16	Aldrich
n-Heptadecane	C17	Aldrich
Pristane		Altech
n-Octadecane	C18	Aldrich
Phytane		Altech
n-Nonadecane	C19	Aldrich
n-Eicosane	C20	Aldrich
n-Heneicosane	C21	Aldrich
n-Docosane	C22	Aldrich
n-Tricosane	C23	Aldrich
n-Tetracosane	C24	Aldrich
n-Pentacosane	C25	Aldrich
n-Hexacosane	C26	Aldrich
n-Heptacosane	C27	Aldrich
n-Octacosane	C28	Aldrich
n-Nonacosane	C29	Aldrich
n-Triacontane	C30	Aldrich

Table 17. Semivolatile organic compounds in waters, sediments, and tissues (continued).

Compound Name	Abbreviation	Source
n-Dotriacontane	C32	Supelco
n-Tritriacontane	C33	Aldrich
n-Tetratriacontane	C34	Altech
n-Hexatriacontane	C36	Supelco
PAHs		
Internal Standards		
Naphthalene-d8		Cambridge Isotope Lab
Phenanthrene-d10		Cambridge Isotope Lab
Surrogates		
Acenaphthene-d10		Supelco
Chrysene-d12		Supelco
Perylene-d12		Supelco
Target Compounds		
1-Methylnaphthlene		Supelco
Biphenyl		Supelco
1-Ethylnaphthalene		Aldrich
3-Methyl-1,1'-biphenyl		Aldrich
4-Ethylbiphenyl		Aldrich
9-Ethylfluorene		Aldrich
1-Methylfluorene		Aldrich
Dibenzothiophene		Aldrich
2-Methylphenanthrene		Aldrich
9-Methylanthracene		Aldrich
2-Ethylanthracene		Aldrich
2-Tertbutylanthracene		Aldrich
Perylene		Supelco
Naphthalene		Supelco TCL PAH mix
Acenapthene		Supelco TCL PAH mix
Phenanthrene		Supelco TCL PAH mix

Table 17. Semivolatile organic compounds in waters, sediments, and tissues (continued).

Compound Name	Abbreviation	Source
Anthracene		Supelco TCL PAH mix
Fluoranthene		Supelco TCL PAH mix
Pyrene		Supelco TCL PAH mix
Benzo(a)anthracene		Supelco TCL PAH mix
Chrysene		Supelco TCL PAH mix
Benzo(b)fluoranthene		Supelco TCL PAH mix
Benzo(k)fluoranthene		Supelco TCL PAH mix
Benzo(a)pyrene		Supelco TCL PAH mix
Indeno(1,2,3-cd)pyrene		Supelco TCL PAH mix
Dibenz(a,h)anthracene		Supelco TCL PAH mix
Benzo(g,h,i)perylene		Supelco TCL PAH mix

cooled, and 2 mL of distilled water and 3 mL of 30% hydrogen peroxide were added. The beaker was covered by a watch glass and returned to the hot plate. It was warmed to start the peroxide reaction. The sample was heated until the effervescence subsided and then cooled. Thirty percent hydrogen peroxide was added in 1 mL increments with warming until the effervescence was minimal. Five mL of concentrated hydrochloric acid and 10 mL of distilled water were added, and the sample was refluxed without boiling for 30 min. The sample was allowed to evaporate without boiling until the volume was reduced to about 5 mL. After cooling, the sample was diluted to 100 mL with distilled water. The sample was filtered or centrifuged to remove particulates.

Arsenic was determined by injection into a stabilized temperature platform GFAA spectrophotometer (Perkin-Elmer 3300). Iron was determined by FAA, and the other metals (barium, cadmium, chromium, copper, lead, nickel, silver, thallium, vanadium, and zinc) were determined by ICP-MS using a VG Plasma Quad ICP-MS, pulse counting, 320 μs, 25 channels per atomic mass units, 1.5 min sample uptake, 1 min sample read time, and 10 min rinse time. Three replicate injections were made. A method blank was made by performing a mock digestion. Reagents were added to a beaker containing no sample and put through the same procedure as beakers containing a sample.

Mercury analysis was performed as follows. The dried filter containing the suspended solids was weighed and placed in a biochemical oxygen demand bottle. Five milliliters of distilled water were added followed by 5 mL of Aqua Regia. The bottle was heated for 30 min in a water bath at 95°C. The sample was allowed to cool. Fifty milliliters of distilled water were added, followed by 15 mL of potassium permanganate solution and 8 mL of potassium persulfate solution. The bottle was returned to the water bath for 90 min. The bottle was cooled, and 6 mL of sodium hydroxylamine sulfate solution were added to reduce the excess permanganate. Fifty-five milliliters of distilled water were added, followed by 5 mL of stannous sulfate solution.

The bottle was immediately attached to the aeration apparatus of a CVAA mercury analyzer. Mercury was collected on the gauze of the mercury analyzer. The gauze was heated and the released mercury swept with argon into a flameless cell Perkin-Elmer 2500 CVAA spectrophotometer for analysis. The sample was allowed to stand without agitation, and the circulating pump was allowed to run continuously at 1.8 L per min. The absorbance maximum was observed on the CVAA mercury analyzer within 30 s.

Grain Size

All sediment samples were weighed to determine a wet weight and then air-dried. Distribution of particle sizes larger than 4 phi (ϕ) (0.0625 mm) was determined by sieving, while distribution of particle sizes smaller than 4ϕ was determined by pipetting. Any sample containing significant fractions of clay and sand particles was analyzed by decantation and sieving methods (Folk 1968).

Samples consisting primarily of sand were weighed to determine dry weight. The sample was split to analyze a portion of approximately 100 g. It was placed on the top screen of a series of nested screens in 0.5 ϕ increments from > -1ϕ to 4.5ϕ and shaken on a Ro-Tap Sieve Shaker for 30 min (American Society for Testing and Materials [ASTM] 1963, Padell and Hillman 1993). Sediments retained by each ϕ size sieve were weighed on an electronic balance, accurate to 0.0001 g, and the weights were recorded.

Samples consisting primarily of silt and clay were analyzed using the pipetting method. A sample of approximately 15 g was taken from the total air-dried sample for analysis. This portion of the sample was rehydrated with distilled water in a 1000 mL graduated cylinder column and mixed thoroughly to distribute the particles uniformly. Aliquots of 20 mL were withdrawn by pipette at specific time intervals and depths: 20 cm at 58 s; 10 cm at 1 min, 56 s; 10 cm at 7 min, 44 s; 10 cm at 31 min; 10 cm at 2 h, 3 min; 10 cm at 8 h, 10 min; and 10 cm at 16 h, 21 min. These samples were oven-dried and weighed on an electronic balance.

Samples composed of a mixture of sand and silt were analyzed by the decantation method, and this was followed by sieving the larger particle sizes of the sample. The decantation process washed the finer sediment particles into suspension with distilled water and allowed the coarse particles to settle

out. Suspension was drawn off after sufficient time was allowed for the coarse particles to settle. The process was repeated until the water washing the sediment was clear. Fine sediments, removed by decantation, were air-dried and weighed. Coarse particle sediments were air-dried, weighed, sieved, and weighed again by ϕ size and reported in percent gravel, sand, silt, and clay.

CHN

Total CHN in sediments were determined instrumentally with two analyzers. Total carbon and hydrogen were determined on a Coulometrics Modified Model 50-20 analyzer, and nitrogen was determined on a Carlo Erba NA 1500 analyzer. The standard reporting limit for both instruments is 0.01% by weight. Approximately 10 mg per sample were analyzed for both instruments. In some cases, nitrogen sample sizes were slightly larger to maximize response on the machines. All samples were analyzed on a dried-sample basis. To improve resolution, coarser samples were ground after loss on drying was determined and prior to any other analyses. Loss on drying was determined under vacuum at ambient temperature to a constant weight and reported on an as-received sample basis.

Semivolatile Organic Compounds

Sediment samples in amber-glass jars with Teflon-lined screw caps were thawed to 4°C. Thirty-gram aliquots of homogenized sediment were removed from each of the samples provided. Each aliquot was spiked with 1 mL of surrogate solution containing n-Dodecane-d26, n-Eicosane-d42, n-Triacontane-d62, Acenaphthalene-d10, Chrysene-d12, and Perylene-d12, each at a concentration of 100 μg/mL. Samples were then Soxhlet extracted with residue-grade methylene chloride overnight (12–16 h). Extracts were then dried over methylene chloride washed anhydrous sodium sulfate and concentrated to 1 mL final volumes by Kuderna-Danish concentration and nitrogen evaporation. The concentrated extracts were stored in GC autosampler vials at -20°C until analysis. Samples were analyzed using the same protocol and equipment that was previously described for the water chemistry analyses. Ions selected for quantitation are listed in Table 18.

Trace Metals Analysis

Three different analytical methods were used for trace metal identification. FAA methodology was used to determine aluminum, iron, and zinc. A wet sample containing 1 g of dry solid was tared into a Teflon beaker. Dry weight was calculated based on percent moisture data. Using a bottle-mounted dispenser, 10 mL of concentrated nitric acid were added to the beaker. The beaker was swirled to suspend the particles and break up clumps. It was heated on a hot plate at 40°C until a brown gas was emitted. When brown gas was no longer visible, or when approximately ⅔ of the sample were evaporated, 10 mL of hydrofluoric acid were pipetted into the beaker with a repeating pipetter. The beaker was placed back onto the hot plate.

After approximately ⅔ of the acid were evaporated, 4 mL of perchloric acid were pipetted into the beaker with a repeating pipetter. The beaker was then placed back on the hot plate. After approximately ⅔ of the acid were again evaporated, hot plate temperature was increased to 100°C. The beaker was covered with a Teflon disc to allow reflux. The sequential addition of nitric hydrofluoric and perchloric acid was repeated two more times, but with the hot plate temperature maintained at 100°C. The beaker was covered with the Teflon disc for 15 min after the addition of each acid.

The sample was watched closely to prevent it from evaporating to dryness. The Teflon disc was removed, and the sample/acid mixture was allowed to evaporate to near dryness. The digested sample was resuspended in 20 mL of 2% nitric acid, and the beaker was swirled to mix it. Once the digested sample was dissolved, it was poured into a 125 mL Nalgene filtering apparatus. The residual sample was rinsed from the beaker into the filter using another 10 mL of 2% nitric acid. The sample was vacuum filtered. The filtrate was transferred to a pretared sample bottle (60 mL Nalgene LDPE). The residual filtrate was rinsed into the bottle with a small amount of 2% nitric acid.

Additional 2% nitric acid was added to each bottle until the final sample weight was 50 g. A portion of the sample was diluted to 1:50 with 2% nitric acid, and the diluted sample was analyzed by FAA. Teflon beakers were scrubbed between uses with Micro detergent, rinsed in quartz double-distilled water, and stored in an acid bath. A method blank was made by performing a mock digestion. The

Table 18. Selected ions for quantitation in water, sediment, and tissue.

M/E Ion Search	Compound	M/E Ion Search	Compound
128	Naphthalene	212	C2 Dibenzothio-phenes
142	Methyl Naphthalenes	226	C3 Dibenzothio-phenes
156	C2 Naphthalenes	57	C_{10} - C_{36}
170	C3 Naphthalenes		
184	C4 Naphthalenes		
152	Acenaphthene		
154	Biphenyl		
166	Fluorene		
180	Methyl Fluorenes		
194	C2 Fluorenes		
208	C3 Fluorenes		
178	Phenanthrene, Anthracene		
192	Methyl Phenanthrenes		
206	C2 Phenanthrenes		
220	C3 Phenanthrenes		
234	C4 Phenanthrenes		
202	Fluoranthene, Pyrene		
216	Methyl Fluoranthenes, Methyl Pyrene		
228	Chrysene, Benzo-(a) anthracene		
242	Methylchrysene		
256	C2 Chrysene		
252	Benzo(a) & (e) Pyrenes, Benzofluoranthene, Perylene		
184	Dibenzothiophene		
198	Methyldibenzo-thiophenes		

reagents were added to a beaker containing no sample and put through the same procedure as beakers containing a sample. FAA was performed with a Perkin-Elmer 3300 FAA spectrophotometer using air/acetylene gas for zinc and iron and nitrous oxide/acetylene for aluminum.

CVAA methodology was used to determine mercury. Dry sediments of 0.2 g were weighed and placed in a biochemical oxygen demand bottle. Five mL of distilled water were added followed by 5 mL of Aqua Regia. The bottle was heated for 30 min in a water bath at 95°C. The sample was allowed to cool, and 50 mL of distilled water were added followed by 15 mL of potassium permanganate solution and 8 mL of potassium persulfate solution. The bottle was returned to the water bath for 90 min. The bottle was then cooled, and 6 mL of sodium hydroxylamine sulfate solution were added to reduce excess permanganate.

Fifty-five milliliters of distilled water were added followed by 5 mL of stannous sulfate solution. The bottle was immediately attached to the aeration apparatus of a CVAA mercury analyzer. Mercury was collected on the gauze of the mercury analyzer. The gauze was then heated and the released mercury swept with argon into a flameless cell Perkin-Elmer 2500 CVAA spectrophotometer for analysis. To do this, the sample was allowed to stand without agitation and the circulating pump was allowed to run continuously at 1.8 L per min. The absorbance maximum was observed on the CVAA mercury analyzer within 30 s.

GFAA methodology was used to determine arsenic and antimony. Dry sediments of 1 g to 2 g were weighed and transferred to a conical beaker. Ten milliliters of 1:1 nitric acid were added, and the sample was mixed and covered by a watch glass. It was then heated to 95°C and refluxed for 10 to 15 min without boiling. After cooling, 5 mL of concentrated nitric acid were added. The watch glass was replaced, and the sample was heated and refluxed for 30 min. This last step was repeated one more time, and the sample was allowed to evaporate to 5 mL without boiling.

The sample was cooled, and 2 mL of distilled water and 3 mL of 30% hydrogen peroxide were added. The beaker was covered by a watch glass, returned to the hot plate, and warmed to start the peroxide reaction. The sample was heated until the effervescence subsided and the sample was cooled. Thirty percent hydrogen peroxide was added in 1 mL increments with warming until the effervescence was minimal. The sample was allowed to evaporate without boiling until the volume was reduced to about 5 mL. After cooling, the sample was diluted to 100 mL with distilled water. The sample was filtered or centrifuged to remove particulates, and antimony and arsenic were determined by injection into a stabilized temperature platform GFAA spectrophotometer (Perkin-Elmer 3300).

The geochemistry QC measures followed during these analyses were part of the formal laboratory quality assurance program instituted at JEAL. This program requires a demonstration of laboratory capability through participation in the National Institute of Standards and Technology (NIST) Intercomparison Exercise Program. Specific measures taken before and during the course of this study included a rigorous training program using analysis of triplicate samples and blanks, adherence to strict sample transfer and custody procedures, laboratory audits, documented calibration of the GC/flame ionization detector (FID) and GC/MS instruments, and an ongoing analytical QC program. This ongoing program includes analysis of method blanks with every batch of sediment or water examined, analysis of spiked blanks for the determination of recoveries of selected compounds, and matrix spikes or re-extraction of samples to monitor the efficiency of extraction.

HYDROGRAPHY

Hydrographic field data were processed at ENRI to provide temperature in degrees Celsius, salinity in Practical Salinity Units (PSU) after the method of Perkin and Lewis (1980), transmissivity in percent, and saltwater depth in meters. These data are presented as a series of plots in Appendix A.

BIOTA

Tissues

Semivolatile Organic Compounds. Tissue samples in plastic bottles were thawed to 4°C. The composite of tissues contained in each bottle was homogenized to ensure the subsample taken for hydrocarbon analysis was representative of the entire sample. About 7 g to 10 g of homogenized tissue were transferred to a 400 mL beaker, and 1 mL of surrogate solution (see semivolatile sediment analysis) was added to the tissue. Seventy grams of sodium sulfate and 50 mL of hexane were added to each beaker, and the composite was ground for 1 min with a Polytron tissue grinder. The extract was then decanted through glass wool into a Kuderna-Danish concentration apparatus. The tissue sample was extracted with two more 50 mL portions of hexane by the same method. The hexane extract was subsequently concentrated to about 1 mL by Kuderna-Danish concentration. Polar compounds and debris were removed from the concentrated extract using a silica gel column and hexane as eluent. The cleaned hexane extracts were then concentrated to 1 mL by Kuderna-Danish and nitrogen evaporation. Concentrated final extracts were stored in GC autosampler vials at -20°C until they were analyzed using the same protocol and equipment previously described for the water chemistry analyses.

Trace Metals Analysis. The filter containing suspended solids was weighed and transferred to a conical beaker. Ten mL of 1:1 nitric acid were added. The sample was mixed and covered by a watch glass, heated to 95°C, and refluxed for 10 to 15 min without boiling. After cooling, 5 mL of concentrated nitric acid were added. The watch glass was then replaced, and the sample was heated and refluxed for 30 min. This last step was repeated one more time, and then the sample was allowed to evaporate to 5 mL without boiling. The sample was subsequently cooled and 2 mL of distilled water and 3 mL of 30% hydrogen peroxide were added. The beaker was covered by a watch glass, returned to the hot plate, and warmed to start the peroxide reaction.

The sample was heated until the effervescence subsided and then cooled. Thirty percent hydrogen peroxide was added in 1 mL increments, with warming until the effervescence was minimal. Five mL of concentrated hydrochloric acid and 10 mL of distilled water were added, and the sample was refluxed without boiling for 30 min. The sample was allowed to evaporate without boiling until the volume was reduced to about 5 mL. After cooling, the sample was diluted to 100 mL with distilled water. It was filtered or centrifuged to remove particulates.

Antimony and arsenic were determined by injection into a stabilized temperature platform GFAA spectrophotometer (Perkin-Elmer 3300). Aluminum, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, silver, thallium, vanadium, and zinc were determined by ICP-MS. ICP-MS was performed using a VG Plasma Quad ICP-MS, pulse counting, 320 μs, 25 channels/atomic mass units, 1.5 min sample uptake, 1 min sample read time, and 10 min rinse time. Three replicate injections were made. ICP-MS was used for barium, vanadium, chromium, manganese, nickel, copper, silver, cadmium, tin, barium, thallium, and lead. FAA was performed with a GFAA spectrophotometer (Perkin-Elmer 3300) using air/acetylene gas for zinc and iron and nitrous oxide/acetylene for beryllium and aluminum. In each case, three replicate instrumental analyses were done. A method blank was made by performing a mock digestion. Reagents were added to a beaker containing no sample, and they were put through the same procedure as a beaker containing a sample.

Mercury analysis was performed as follows. A sample of dry tissue weighing 0.2 g was placed in a biochemical oxygen demand bottle. Five milliliters of distilled water were added followed by 5 mL of Aqua Regia. The bottle was heated for 30 min in a water bath at 95°C. The sample was allowed to cool, and 50 mL of distilled water were added followed by 15 mL of potassium permanganate solution and 8 mL of potassium persulfate solution. The bottle was returned to the water bath for 90 min. The bottle was cooled, and 6 mL of sodium hydroxylamine sulfate solution were added to reduce the excess permanganate. Fifty-five milliliters of distilled water were added followed by 5 mL of stannous sulfate solution. The bottle was immediately attached to the aeration apparatus of a CVAA mercury analyzer. The sample was allowed to stand without agitation, and the circulating pump was allowed to run continuously at 1.8 L per min. The absorbance maximum was observed on the CVAA mercury analyzer within 30 s.

NORM. Mussel shells from six locations were analyzed for NORM testing of radium-226 and radium-228. The six samples were counted for 19.2 h to 44.9 h on a 36% intrinsic germanium detector. The analysis of radium-228 was based on the assumption that the observed gamma rays of actinium-228 (half-life of 6.1 h) were in equilibrium with the parent radium-228 (half-life of 5.75 year), as shown in Figure 10. The analysis of radium-226 was based on the assumption that the daughters were in equilibrium and that there was no loss of radon-222. This is shown in Figure 11.

Mussel shells were broken into small pieces, put into glass specimen jars, and sent to MSL in Sequim for analysis. Assuming the samples were sealed in jars for 4 days, the samples were at equilibrium with respect to measurement of radium-228, since at least 15 half-lives had passed when counting started. However, assuming radon-222 (3.8 day half-life) is the limiting isotope that has to grow back for the radium-226 measurement, samples were counted with partial equilibrium achieved.

Samples were counted by placing the jar on the face of an upward-looking germanium detector (active volume of 162 cm^3, 36% efficient, and 2.0 kilo-electron volt [keV] full-width half maximum for the 1332 keV line of cobalt-60). Counts were recorded by a multichannel analyzer, and data were transferred to a computer for storage and analysis. Geometry was calibrated by spiking 75 ml of water with 0.100 ml of a mixed multielement radionuclide liquid standard supplied by Amersham (NIST traceable) in a SPEX jar like those holding the samples. The 75 ml water geometry was chosen to represent an average sample in the jar. This standard was counted, and an efficiency curve was generated that allowed calculation of activity in disintegrations per minute when the data were analyzed by the RAYGUN analysis code.

The analysis of radium-226 involved analyzing the gamma-ray peaks of lead-214 (main peak, 352 keV) and bismuth-214 (main peak, 609.3 keV), which are daughters of radium-226. It was assumed the daughters were in equilibrium with the parent to calculate the activity and that there was no loss of radon (radon-222). In addition, a gamma-ray of radium-226 (186 keV) was also measured. Although it suffers from interference from uranium-235, it was felt it would lend credence to any positive values reported from using the lead-214 and bismuth-214 peaks.

The analysis of radium-228 involved analyzing the gamma-ray peaks of actinium-228 (main peak, 911 keV), which is a daughter of radium-228. It was assumed the daughter was in equilibrium with the parent.

BIOASSAY

Microtox®

Microtox® bioassay techniques use lysed cells of a luminescent marine bacteria as an indicator of sediment toxicity. They depend upon the metabolic activity of the lysed cells of the reagent organism *Photobacterium phosphoreum*. Exposure to substances in the sediment that are toxic to biotic organisms causes a reduction in the luminescence of the bacteria proportional to the degree of toxicity. The reduction in metabolic luminescence is reported as a median effective concentration (EC50) for each sample. Microtox® bacterial bioassay is becoming accepted as a cost-effective and sensitive method to evaluate possible sediment contamination as evidenced by protocols developed for Puget Sound (Tetra Tech, Inc. 1986, EPA 1987).

Microtox® results are used as an indication of overall toxicity. A comparison between fresh bacteria and bacteria rehydrated from freeze-dried cultures does not show any significant loss in light intensity (Ribo 1984). Microtox® is especially useful for indicating toxicity of neutral, nonionic organic compounds such as aromatic and chlorinated hydrocarbons (Tetra Tech, Inc. 1986). It is also useful for indication of toxicity caused by some heavy metals, but it is sometimes difficult to extract metals and highly acidic and basic compounds from the sediment particles (Tetra Tech, Inc. 1986). The Microtox® test has been compared favorably with other bioassays in terms of sensitivity, accuracy, precision, and evaluation of results obtained (Ribo and Kaiser 1987).

Figure 10. Simplified thorium-232 decay.

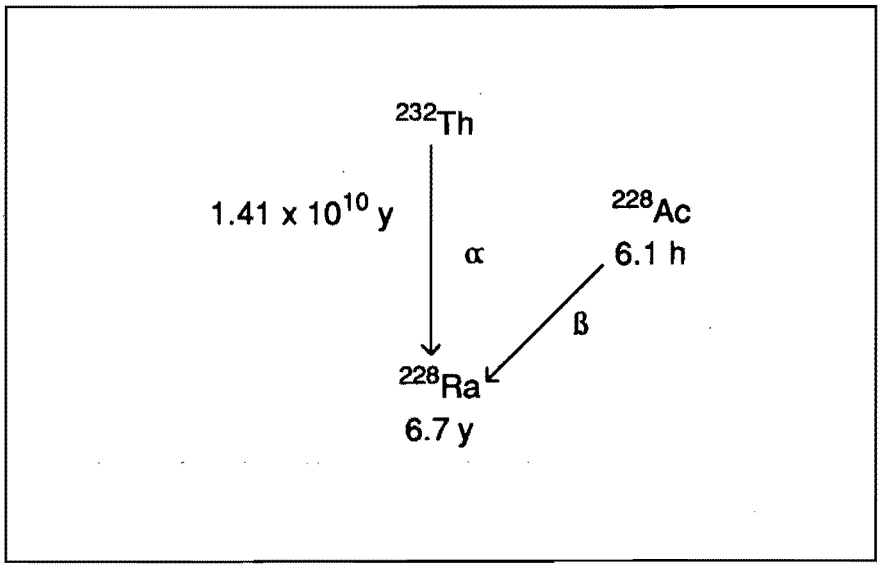
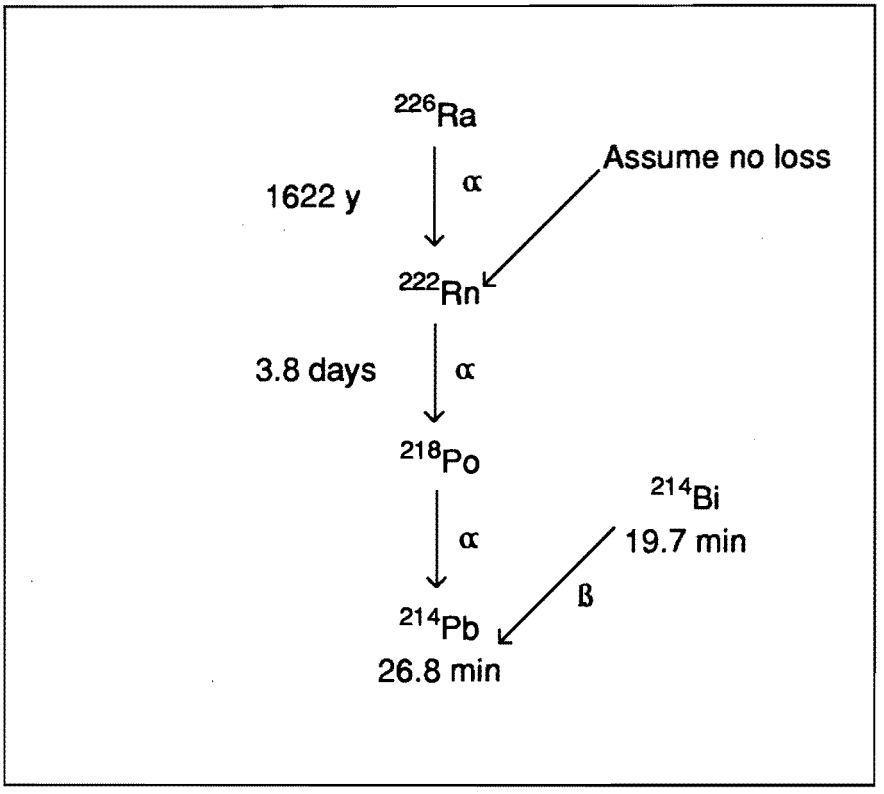


Figure 11. Simplified radium-226 decay.



Effects of anoxia are not relevant to the Microtox® bioassay, as the sample is well oxygenated from normal pipetting procedures during the bioassay. Optimal living conditions and, therefore, light emission for *P. phosphoreum* are between pH values of 5 and 9 (Ribo 1984). Ammonia levels have no particular effect on the Microtox® bioassay as long as the pH range is maintained at these optimum conditions.

The bioassay uses freeze-dried luminescent bacteria as the test organism. *P. phosphoreum* cells are harvested, centrifuged, and lyophilized. The bacteria's light-producing mechanism is tied to the metabolic processes of the cell. If these processes are inhibited or damaged by the presence of a toxic substance, a reduction in light output results. The bioassay is based on detecting these changes in light output. The solid-phase test measures light output after a 20 min exposure of the bacteria to the sediment. A blank ratio serves as the control against which the resulting measurements are compared to calculate an EC50 value. The gamma function is used to determine the EC50 value:

$$\text{Gamma} = \frac{\text{amount of light lost during test}}{\text{light remaining at end of test}}$$

$$\text{Blank ratio} = \frac{\text{light emission of blank at end of test}}{\text{initial emission of blank at start of test}}$$

A log-log graph of gamma versus concentration is plotted and an EC50 value determined by interpolation using a data-reduction program provided by Microtox®. The technique measures the rate of biological activity rather than a count of the organisms affected as in more conventional bioassays.

Three sediment samples were collected from each of the 11 stations and run with the Microtox® solid-phase bioassay to determine any potential toxicity in Cook Inlet sediments. Samples were stored at 2°C to 8°C and tested within 48 h. Excess water was extracted by filtration from the homogenized sample, and 0.3 g were removed for analysis. Solid-phase diluent was added in a 2:1 dilution scheme from an initial sample concentration of 10%. After temperature equilibration of the sample and diluent, the reagent was reconstituted and 20 L of reagent were added to each solid-phase test tube. Samples were mixed well and allowed to incubate for 20 min. The filtrate was then extracted and transferred to Microtox® cuvettes in the Microtox® incubation block. The control sample was used to calibrate the light readings after a 5 min temperature equilibration period. Sample light readings were then recorded and EC50s calculated.

Toxicity Tests

Four toxicity tests with two marine species were used to evaluate the toxicity of sediment and water samples from Cook Inlet. Sediment and water samples were collected and shipped to MSL in Sequim via Goldstreak. All samples tested arrived within 24 h of collection. Upon receipt, samples were placed in a 4°C cold room until needed for testing. Sediments were tested for benthic effects using the acute 10-day static amphipod test with the phoxocephalid amphipod *Rhepoxynius abronius*. Sediment pore-water toxicity was evaluated using the sublethal sperm-cell test with the echinoderm *Dendraster excentricus*. Water-column toxicity was assessed using the acute 48 h developmental test and the sublethal sperm-cell test, both with the echinoderm *D. excentricus*. Standard EPA protocols were used to conduct standard 10-day *R. abronius* and 48 h *D. excentricus* tests to assess the toxicity of the sediments, pore-water, and effluent samples.

Standard EPA protocols are used to ensure consistent water quality standards in which the toxicity of sediments can be assessed using sample protocols. Reference toxicant tests are used to assess the sensitivity of different populations or seasonal variation in sensitivity of a field-collected population. Protocols established by EPA and ASTM recommend using cadmium chloride as a reference toxicant for amphipod tests. There is a historical database at MSL and around the country for reference toxicant test results using cadmium for amphipod tests and copper for larval tests.

Solid-phase Static Test. The 10-day solid-phase static test with the *R. abronius* followed the procedures outlined in ASTM 1990. The amphipod *R. abronius* and control sediment were collected

by MSL staff from West Beach, Whidbey Island, WA, using a specially designed anchor dredge deployed from a 17 ft Boston Whaler. The dredge collected sediment to a depth of about 4 cm. Sediment was sieved through a 2 mm mesh screen to remove large debris and predatory organisms. Amphipods were kept in coolers partially filled with native sediment and seawater until they were delivered to a holding tank at MSL. The *R. abronius* were acclimated in large holding tanks containing their native sediment and supplied with continuously flowing 15°C Sequim Bay seawater. Organisms were not fed during the holding period.

The amphipod test was performed in 1 L glass static mason jars that were filled to a depth of 2 cm with test sediment and then brought to a total volume of 750 mL with 0.45 μm filtered Sequim Bay seawater. Test chambers were placed in randomly assigned positions on a 15°C (± 2°C) water table. Gentle aeration was done through glass pipettes. After an overnight acclimation period, initial water quality parameters were measured for each test chamber and recorded on water quality forms.

To initiate the test, the *R. abronius* were gently sieved from the holding tank, counted, and then placed in small transfer containers. The number of organisms was checked by a second observer prior to their placement into the test chamber. A total of 20 organisms were added to each chamber. Initiation date and time were recorded on the jar lids and data forms. The *R. abronius* were observed daily. The number of organisms floating on the surface, swimming in the jar, and lying on the sediment was tabulated. Floating amphipods were gently pushed below the water surface with a pipette tip, and their ability to rebury was recorded.

Water temperature, salinity, pH, and dissolved oxygen were recorded for all test chambers at initiation and termination. Daily water quality was performed on one replicate of each treatment throughout the test. Acceptable water quality parameters during the experiment were as follows:

Dissolved Oxygen	≥5.0 mg/L
pH	7.8 ± 0.5 units
Salinity (PSU)	30 ± 2
Temperature	15°C ± 2°C

Water quality data indicate that all parameters were within range of the acceptable water quality control limits for both the 10-day static, solid-phase test, and 4-day water only reference toxicant test with the *R. abronius*. At the end of the 10-day test period, the *R. abronius* were collected by sieving test sediments through 0.5 mm Nytex screens. The organisms were placed in clean seawater and the number of live and dead counted using a dissecting microscope. At least 10% of the counts were checked by a second observer. Test organism sensitivity was measured by conducting a 4-day, water-only reference toxicant test with cadmium chloride (0.25 mg/L, 0.5 mg/L, 1.0 mg/L, and 2.0 mg/L of cadmium).

Sperm-Cell Test. The sublethal sperm-cell toxicity test with the *D. excentricus* followed the procedures outlined in Dinnel et al. (1987). Sand dollars were collected at Travis Spit, WA, and held in tanks with flowing, unfiltered, Sequim Bay seawater. The *D. excentricus* were allowed to feed in Sequim Bay sediments during the holding period.

Pore-water samples were prepared by a centrifugation method. Approximately 300 mL of sediment were placed in a 500 mL Teflon jar with a stainless steel spoon. The jar was then sealed with a Teflon lid and centrifuged at 1750 revolutions per minute for approximately 15 min. The supernatant was poured off into a glass jar and held at 4°C until needed for testing.

Test containers (16 x 100 mm borosilicate glass test tubes) were filled with 10 mL of pore water or receiving water (depending on the test) and placed into randomly assigned positions in a test tube rack. They were then placed on a 14°C (± 2°C) water table. Adult sand dollars were spawned by injecting 0.5 molar (M) potassium chloride into the oral cavity. Reddish eggs were collected from at least two females by inverting the sand dollar over a 100 mL beaker filled with control seawater. White sperm were collected dry with a glass pasteur pipette and stored in a sealed vial. Sperm from at least two males were combined in dilution water to create a stock solution. The concentration of

viable sperm in the stock solution was determined by testing the efficiency of fertilization success using various sperm-to-egg ratios (700:1, 1200:1, and 1500:1).

The appropriate stocking density was the sperm-to-egg ratio that yielded a fertilization rate within the target range of fertilization (70% to 90%). To initiate the test, 0.1 mL of adjusted sperm-stock solution was placed in the test tubes, and the sperm solution was exposed for 1 h. After 1 h, 1 mL of egg solution (2000 eggs/mL) was introduced into each test tube. Fertilization was allowed to take place for 20 min, at which time each vial was fixed with 5 drops of Lugol's iodine solution. Percent fertilization was then determined by counting 100 embryos and noting the presence or absence of a fertilization membrane. Damaged eggs or eggs with a partial fertilization membrane were not included in the results.

A reference toxicant test was also conducted to establish the health and sensitivity of each batch of gametes. The *D. excentricus* sperm were exposed to a seawater control plus three concentrations of copper sulfate (2.9 μg/L, 9 μg/L, 30 μg/L, and 100 μg/L of copper), using three replicates of each treatment.

Receiving Water Larval Test. The 48 h larval test with the *D. excentricus* followed a modified protocol in Oshida and Goochey (1981). Sand dollars were collected at Travis Spit, WA, and held in tanks with flowing, unfiltered, Sequim Bay seawater. The *D. excentricus* were allowed to feed in Sequim Bay sediments during the holding period.

Control seawater was collected from the Strait of Juan de Fuca, WA, by MSL. A seawater-cured polypropylene carboy was submerged approximately 152 mm below the surface, unsealed, allowed to fill with subsurface seawater, then resealed. Control seawater was filtered with a 20 μm Nytex screen to remove plankton and detritus, then stored in a 4°C cold room until needed for testing. Immediately prior to testing, control seawater was filtered with a 0.45 μm cartridge filter.

Receiving water samples from Cook Inlet ranged in salinity from 13 to 30. Salinity was adjusted to 30 using a seawater brine stock. The brine stock was prepared by thawing 0.45 μm filtered control seawater, pouring off the hypersaline liquid, filtering the resulting brine through a 2 μm paper filter, and storing it in a glass jar at 4°C. To detect any brine effect, brine controls were run concurrently with each water test.

Test chambers for the echinoderm larval test were 500 mL glass jars labeled with water treatment code, position number, and replicate number. Test chambers were placed in random positions on a water table and provided with gentle aeration. After the test chambers reached testing temperatures (14°C ± 2°C), initial water quality was measured in all replicates. Because all treatments could not be tested concurrently, a separate reference toxicant test was performed with each set of tests to compare gamete sensitivity to a known toxicant.

Adult sand dollars were spawned by injecting 0.5 M potassium chloride into the oral cavity. Reddish eggs were collected from at least two females by inverting the sand dollar over a 100 mL beaker filled with control seawater. White sperm were collected dry with a glass pasteur pipette and stored in a sealed vial. Sperm from at least three males were pooled, and 3 drops of concentrated sperm were added to 45 mL of control seawater. Approximately 3 mL of this sperm stock were then added to the egg stocks. Egg-sperm solutions were mixed every 10 min with a perforated plunger. Fertilization proceeded for 30 min, and then the fertilization rate (percent fertilized) was determined by removing a subsample and observing the number of multicell stage embryos.

Fertilization was considered successful if greater than 90% of the eggs were in the multicell stage. Embryo stock density was estimated by removing a 0.1 mL subsample, counting all multicell embryos, and then multiplying by 10 to yield embryo density (embryos/mL). Stock solution was diluted or concentrated to yield 7500 to 9000 embryos/mL. The test was initiated by introducing 1 mL of stock solution into each test chamber to produce embryo densities of 25 to 30 embryos/mL. Test initiation date and time were recorded on data sheets. Following initiation, 10 mL stocking density subsamples

were removed from each container and preserved in 10% formaldehyde to determine actual stocking density.

Water quality parameters were measured in one replicate per treatment daily throughout the test. The following were acceptable ranges for water quality parameters:

Dissolved Oxygen	≥ 4.0 mg/L
pH	ambient ± 0.5 units
Salinity (PSU)	ambient ± 2
Temperature	14°C ± 2°C

Water quality data indicate that all parameters were within range of the acceptable water quality control limits for the 48 h echinoderm larval test and the reference toxicant test. The echinoderm larval test was terminated after 48 h if greater than 80% of the larvae in the controls had reached the pluteus stage. Final water quality parameters were recorded for all replicates. The contents of each chamber were then homogenized with a perforated plunger. A 10 mL subsample was subsequently removed and placed in a 20 mL scintillation vial, which was then fixed with 1 mL of 50% formalin in seawater. Samples were scored for the appearance of normal pluteus larvae, abnormal and blastula larvae, and total number of larvae. At least 10% of the counts were confirmed by a second observer.

A 48 h reference toxicant test was conducted with each batch of test larvae to establish the health and expected response of the test organisms. The reference toxicant test was set up and conducted in the same manner as the liquid-phase tests. The *D. excentricus* larvae were exposed to a filtered Sequim Bay seawater control plus four concentrations of copper sulfate (2.9 µg/L, 9 µg/L, 30 µg/L, and 100 µg/L of copper), with three replicates per test.

WATER

HYDROCARBONS

All 35 samples analyzed from the eight water chemistry stations during this study had <MDL (<1 μg/L) of VOA (Tables 19 and 20). Eight VOA compounds were targeted by these analyses: benzene, toluene, ethylbenzene, p,m-xylenes, o-xylene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichlorobenzene. The lowest observed effect levels for acute toxicity from VOAs were 400 to 6000 times higher than the MDL used in this study (Table 21). Acute toxicity is defined as effects occurring in a short time period (exposures of 24 to 96 h), often ending in death (EPA 1986). ENRI found <MDL (0.01 μg/L) of PAH in all water samples from the eight stations in Cook Inlet (Tables 22 and 23). The lowest observed effect levels for acute toxicity were 2350 μg/L for naphthalene and 980 μg/L for acenaphthalene (EPA 1991b). Traces of several alkanes were detected in the water samples (Tables 24 and 25).

Table 19. Cruise 1 water chemistry VOA results.

Sample No.	Tide[1]	Station	VOAs μg/L
1001	R	3	<MDL
1002	F	3	<MDL
1003	R	B	<MDL
1004	F	B	<MDL
1005	R	E	<MDL
1006	F	E	<MDL
1007	R	C	<MDL
1008	R	C	<MDL
1009	R	C	<MDL
1010	F	C	<MDL
1011	F	C	<MDL
1012	F	C	<MDL
1013	R	A	<MDL
1014	F	A	<MDL
1015	F	F	<MDL
1016	R	F	<MDL

[1] R = rising, F = falling.

VOAs: Benzene, Toluene, Ethylbenzene, p,m-Xylenes, o-Xylene, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2-Dichlorobenzene.

MDL ~ 1 μg/L.

Table 20. Cruise 2 water chemistry VOA results.

Sample No.	Tide[1]	Station	VOAs µg/L
2001	F	30	<MDL
2002	R	30	<MDL
2003	R	3	<MDL
2004	R	3	<MDL
2005	R	3	<MDL
2006	F	3	<MDL
2007B	F	3	<MDL
2008B	F	3	<MDL
2007	R	E	<MDL
2008	F	E	<MDL
2009	F	B	<MDL
2010	R	B	<MDL
2011	R	A	<MDL
2012	F	C	<MDL
2013	F	A	<MDL
2014	R	C	<MDL
2015	R	F	<MDL
2016	F	F	<MDL
2017		211	<MDL

[1] R = rising, F = falling.

VOAs: Benzene, Toluene, Ethylbenzene, p,m-Xylenes, o-Xylene, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2-Dichlorobenzene.

MDL ~ 1 µg/L.

Table 21. EPA marine water quality criteria for VOAs.

Compound	Acute µg/L	Chronic µg/L
Benzene	5,100	700
Toluene	6,300	5,000
Ethylbenzene	430	
Dichlorobenzenes	1970	

Source: EPA 1991b.

Table 22. Cruise 1 water chemistry PAH results.

Sample No.	Station	Tide[1]	PAHs µg/L
1001	3	R	<MDL
1002	3	F	<MDL
1003	B	R	<MDL
1004	B	F	<MDL
1005	E	R	<MDL
1006	E	F	<MDL
1007	C	R	<MDL
1008	C	R	<MDL
1009	C	R	<MDL
1010	C	F	<MDL
1011	C	F	<MDL
1012	C	F	<MDL
1013	A	R	<MDL
1014	A	F	<MDL
1015	F	F	<MDL
1016	F	R	<MDL

[1] R = rising, F = falling.

PAHs: Naphthalene, (Methyl, Ethyl, Biphenyl), Acenaphthylene, Fluorene (Methyl, Ethyl), Acenaphthene, Dibenzothiophene, Phenanthrene (Methyl), Anthracene (Methyl, Ethyl, Tertbuhyl, Benzo, Dibenz), Fluoranthene (Benzo), Pyrene (Benzo, Indeno), Chrysene, Benzoperylene.

MDL ~ 0.01 µg/L.

Table 23. Cruise 2 water chemistry PAH results.

Sample No.	Station	Tide[1]	PAHs µg/L
2001	30	F	<MDL
2002	30	R	<MDL
2003	3	R	<MDL
2004	3	R	<MDL
2005	3	R	<MDL
2006	3	F	<MDL
2007B	3	F	<MDL
2008B	3	F	<MDL
2007	E	R	<MDL
2008	E	F	<MDL
2009	B	F	<MDL
2010	B	R	<MDL
2011	A	R	<MDL
2012	C	F	<MDL
2013	A	F	<MDL
2016	F	F	<MDL
2017	211		<MDL

[1] R = rising, F = falling.

PAHs: Naphthalene, (Methyl, Ethyl, Biphenyl), Acenaphthylene, Fluorene (Methyl, Ethyl), Acenaphthene, Dibenzothiophene, Phenanthrene (Methyl), Anthracene (Methyl, Ethyl, Tertbuhyl, Benzo, Dibenz), Fluoranthene (Benzo), Pyrene (Benzo, Indeno), Chrysene, Benzoperylene.

MDL ~ 0.01 µg/L.

Table 24. Cruise 1 saturated hydrocarbon concentrations for water.

Sample No	Station	Tide	n-Alkanes Concentration µg/L													
			C8-C10	C11	C12	C13	C14	C15	C16	C17	Pris	C18	Phy	C19	C20	C21
1001	3	R	<MDL	<MDL	<MDL	0.06	0.12	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.08	<MDL	0.02
1002	3	F	<MDL	<MDL	<MDL	0.05	0.10	0.03	<MDL	0.06	0.04	0.04	0.03	0.04	0.04	0.02
1003	B	R	<MDL	<MDL	0.03	0.05	0.06	<MDL	0.02	0.03	0.03	0.01	0.01	0.01	0.02	0.01
1004	B	F	<MDL	<MDL	<MDL	0.05	0.06	<MDL	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
1005	E	R	<MDL	<MDL	0.04	0.05	0.07	<MDL	0.02	0.01	0.02	0.01	<MDL	0.01	0.01	0.01
1006	E	F	<MDL	<MDL	0.04	0.06	0.07	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.01	0.02	0.02
1007	C	R	<MDL	<MDL	<MDL	0.02	0.05	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.01
1008	C	R	<MDL	<MDL	<MDL	0.03	0.09	0.01	0.04	<MDL	<MDL	<MDL	<MDL	<MDL	0.01	0.01
1009	C	R	<MDL	0.04	0.09	0.06	0.11	0.03	0.06	<MDL	<MDL	<MDL	<MDL	<MDL	0.02	0.02
1010	C	F	<MDL	<MDL	<MDL	0.03	0.05	<MDL	0.04	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.02
1011	C	F	<MDL	<MDL	<MDL	0.02	0.05	<MDL	0.03	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
1012	C	F	<MDL	<MDL	<MDL	0.03	0.05	<MDL	0.03	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
1013	A	R	<MDL	<MDL	<MDL	0.02	0.05	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
1014	A	F	<MDL	<MDL	<MDL	0.03	0.04	<MDL	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.02
1015	F	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
1016	F	R	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL

R = rising, F = falling.

MDL ~ 0.002 µg/L

Table 24. Cruise 1 saturated hydrocarbon concentrations for water (continued).

Sample No.	Station	Tide	n-Alkanes Concentration µg/L													
			C22	C23	C24	C25	C26	C27	C28	C29	C30	C32	C33	C34	C36	TALK
1001	3	R	<MDL	<MDL	<MDL	<MDL	<MDL	0.05	0.05	0.07	0.09	0.16	0.06	0.08	0.04	0.88
1002	3	F	0.02	0.02	<MDL	0.02	0.04	0.04	0.03	0.05	0.06	0.07	0.04	0.05	0.02	0.91
1003	B	R	0.01	0.02	<MDL	0.03	0.02	0.03	0.03	0.04	0.04	0.06	0.02	0.03	<MDL	0.61
1004	B	F	0.01	0.01	0.09	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.02	0.02	<MDL	0.60
1005	E	R	0.01	0.01	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.03	<MDL	<MDL	<MDL	0.46
1006	E	F	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.02	<MDL	<MDL	0.51
1007	C	R	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	<MDL	<MDL	0.33
1008	C	R	0.01	0.01	<MDL	0.02	0.02	0.02	0.02	0.02	0.02	0.02	<MDL	<MDL	<MDL	0.35
1009	C	R	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.01	<MDL	<MDL	0.66
1010	C	F	0.01	0.01	0.02	0.02	0.02	0.03	0.02	0.03	0.03	<MDL	<MDL	<MDL	<MDL	0.33
1011	C	F	<MDL	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	<MDL	<MDL	<MDL	<MDL	0.21
1012	C	F	<MDL	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	<MDL	<MDL	<MDL	<MDL	0.20
1013	A	R	<MDL	<MDL	0.01	0.01	0.02	0.02	0.02	0.02	0.02	<MDL	<MDL	<MDL	<MDL	0.19
1014	A	F	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.05	0.04	0.03	<MDL	<MDL	<MDL	0.51
1015	F	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.00
1016	F	R	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.00

R = rising, F = falling.

MDL ~ 0.002 µg/L

Table 25. Cruise 2 saturated hydrocarbon concentrations for water.

Sample No.	Station	Tide	n-Alkanes Concentration µg/L															
			C10	C11-C17	C18	C19-C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C32	C33	TALK
2001	30	F	0.40	<MDL	<MDL	<MDL	0.15	0.18	0.24	0.20	0.17	0.16	0.12	0.10	0.07	<MDL	<MDL	1.79
2002	30	R	1.48	<MDL	<MDL	<MDL	<MDL	0.10	<MDL	<MDL	0.08	0.07	<MDL	<MDL	<MDL	<MDL	<MDL	1.73
2003	3	R	2.23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	2.23
2004	3	R	1.37	<MDL	<MDL	<MDL	0.22	0.30	0.38	0.42	0.33	0.24	0.24	0.15	0.12	0.11	0.06	3.94
2005	3	R	1.43	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	1.43
2006	3	F	1.24	<MDL	<MDL	<MDL	0.20	0.21	0.20	0.23	0.21	0.21	0.18	0.17	0.12	0.08	<MDL	3.05
2007B	3	F	3.01	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	3.01
2008B	3	F	2.15	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.16	0.08	0.09	0.09	0.08	0.06	<MDL	<MDL	2.71
2007	E	R	1.11	<MDL	<MDL	<MDL	<MDL	0.14	0.25	0.21	0.10	0.11	0.17	0.04	0.05	<MDL	<MDL	2.18
2008	E	F	2.07	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	2.07
2009	B	F	2.82	<MDL	<MDL	<MDL	0.19	0.13	<MDL	0.22	<MDL	0.13	<MDL	<MDL	<MDL	<MDL	<MDL	3.49
2010	B	R	0.27	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.27
2011	A	R	1.04	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	1.04
2012	C	F	0.95	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.95
2013	A	F	0.70	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.70
2016	F	F	0.77	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.77
2017	211		2.58	<MDL	0.22	<MDL	0.75	<MDL	<MDL	0.14	<MDL	<MDL	0.45	<MDL	<MDL	<MDL	<MDL	4.14

R = rising, F = falling.

MDL ~ 0.002 µg/L

Total saturated hydrocarbons in water ranged from <MDL (0.002 μg/L) to 4.14 μg/L (Tables 24 and 25). Key definitions and terms used in saturated hydrocarbon analysis are provided in Tables 26 and 27. The n-alkanes ranged in chain lengths from 10 to 36 carbon atoms. The presence of n-decane at a relatively consistent concentration in every Cruise 2 sample is puzzling. Since no hydrocarbons were detected from the trip blanks and it occurred only during Cruise 2, it could reflect undetected contamination of the water samples during collection. Although there is no certainty, one possible scenario is that an undetected fuel leak from the sampling vessel contaminated the surface waters during collection. In the Marathon Oil study in upper Cook Inlet, no saturated hydrocarbons and only trace PAHs were detected from seawater samples (Neff and Douglas 1994).

METALS

Total (dissolved plus weak-acid dissolvable particulate) metals concentrations for water taken during Cruises 1 and 2 are given in Tables 28 and 29. These data are as yet incomplete; further metals data will be added as an appendix to this document when they become available. Iron is by far the metal of highest concentration, and it shows a definite geographic distribution pattern. Stations F, 3, 30, and 211, which are in the middle inlet and further south, have much lower iron concentrations. No geographic distribution patterns are noticeable for other metals. Metal concentrations are similar to those reported in global marine waters (Table 30), but mercury appears to be somewhat high. Substantial proportions of these metals may be present on suspended particles and may be dissolved upon acidification of the sample.

According to EPA water quality criteria for metals (Table 31), a few samples are above the designated chronic criteria for mercury. The word *criteria* should not be used interchangeably with or as a synonym for *standard*. Criteria represents a constituent concentration or level associated with a degree of environmental effect upon which scientific judgment may be based (EPA 1986). It has come to mean that a designated concentration, when not exceeded, will protect an organism. Toxicity is generally expressed in terms of acute (short-term) or chronic (long-term) effects. Acute toxicity refers to effects occurring in a short time period (24 h to 96 h), with death often being the end point (EPA 1986). Chronic toxicity refers to effects through an extended time period. It may be expressed in terms of a period equal to the lifetime of an organism or to the time span of more than one generation. Some chronic effects may be reversible, but most are not (EPA 1986).

Although well below the reported acute level, some Cook Inlet water samples are above the chronic level (0.025 μg/L) for mercury. The majority of these (13 of 16) are from the upper inlet, and they were all taken during Cruise 1. This indicates the mercury is from terrestrial sources, as it is more prevalent during higher freshwater runoff. The highest mean levels were recorded at stations E and B, the stations farthest north in the inlet.

SEDIMENT

SUSPENDED SOLIDS

TSS

As indicated earlier in this document, suspended sediment input from the head of Cook Inlet is very high; and it is overwhelmingly comprised of very fine-grained glacial till. Samples from the eight water sampling stations were analyzed for TSS, and measured concentrations ranged from 3 mg/L to 440 mg/L (Table 32). Due to dynamic mixing in the northern inlet and the heavy sediment loads of rivers that flow into it, stations in the upper inlet have the highest sediment concentrations (440 mg/L for station E). Stations in the middle to lower inlet had far lower readings (3 mg/L to 19 mg/L for stations 3, 30, and F).

Metals

Metals within the water column are strongly partitioned onto the suspended sediment. In Cook Inlet, this latter material is overwhelmingly inorganic (glacially ground rock flour). Tables 33 and 34 give a summary of the metal concentrations found in suspended solids from seven stations in the inlet; no

Table 26. Saturated hydrocarbon quantitative parameters.

Parameter	Relevance
TALK	Quantifies the total n-alkanes (n-C10 to n-C34).
LALK	Low molecular weight n-alkanes (n-C10 to n-C20); crude petroleum is high in these alkanes.
PRIS	Isoprenoid 1708 (Pristane); an abundance of pristane in sediments is indicative of recent biogenic inputs.
PHY	Isoprenoid 1810 (Phytane); uncontaminated sediments are low in phytane but crude oil has significant amounts of this isoprenoid.
TOT	Total saturated hydrocarbons.

Table 27. Saturated hydrocarbon source ratios.

Parameter	Relevance
ISO/TALK	Relative abundance of branched isoprenoid alkanes to straight chain alkanes; useful indicator of biodegradation.
LALK/TALK	Diagnostic alkane compositional ratio used to determine the relative abundance of n-C10 to n-C20 alkanes (characteristic of light crude and refined oils) to total alkanes, which includes those of biogenic (background) origin.
PRIS/PHY	Source of phytane is mainly petroleum while pristane is derived from both biological matter and oil. This ratio is high in clean samples and decreases as oil is added.
TOT/TALK or n-alkanes/TOC	Ratio of saturated hydrocarbons to total organic carbon; used to monitor oil inputs.
CPI	Odd-even carbon preference index; describes the relative amounts of odd and even chain alkanes. As oil additions increase, the CPI is lowered.

Table 28. Cruise 1 total metal concentrations for water.

Sample No.	Station	Tide	Metals µg/L		
			As	Fe	Hg
1001A	3	R	4.74	1482.2	0.0410
1001B	3	R	2.52	1137.8	0.0021
1002A	3	F	2.09	563.7	0.0621
1002B	3	F	3.30	313.1	0.0208
1003A	B	R	2.25	10960.1	0.0410
1003B	B	R	4.31	7452.9	0.0418
1004A	B	F	2.34	6377.7	0.0209
1004B	B	F	4.18	6367.3	0.3528
1005A	E	R	5.74	9216.9	0.1660
1005B	E	R	6.29	9436.1	0.0625
1006A	E	F	2.23	6054.2	0.0939
1006B	E	F	2.47	5908.0	0.0208
1007A	C	R	1.98	3924.8	0.0208
1007B	C	R	1.92	3726.4	0.0208
1008A	C	R	2.90	3058.4	0.0624
1008B	C	R	1.99	3089.7	0.0208
1009A	C	R	1.84	3413.3	0.0208
1009B	C	R	2.12	3444.6	0.0208
1010A	C	F	0.17	5500.9	0.0416
1010B	C	F	2.23	5605.3	0.0209
1011A	C	F	2.19	5490.5	0.0209
1011B	C	F	2.23	5563.6	0.0208
1012A	C	F	2.15	5563.6	0.1660
1012B	C	F	2.23	5793.2	0.0209
1013A	A	R	1.84	3288.0	0.0623
1013B	A	R	1.92	3298.5	0.0415
1014A	A	F	2.03	4311.0	0.0209
1014B	A	F	2.03	4290.1	0.0209
1015A	F	F	1.50	344.5	<MDL
1015B	F	F	1.48	198.3	<MDL
1016A	F	R	1.50	354.9	<MDL
1016B	F	R	1.50	459.3	<MDL
AVG µg/L			2.51	4249.7	0.048

R = rising, F = falling.

Table 29. Cruise 2 total metal concentrations for water.

Sample No.	Station	Tide	Metals µg/L		
			As	Fe	Hg
2001A	30	F	1.305	135.7	0.0042
2001B	30	F	1.399	156.6	0.0042
2002A	30	R	2.338		
2002B	30	R			
2003A	3	R			
2003B	3	R	1.294	250.5	0.0042
2004A	3	R	1.273	271.4	0.0062
2004B	3	R	1.367	219.2	0.0042
2005A	3	R	1.566	187.9	0.0092
2005B	3	R	1.367	187.9	0.0042
2006A	3	F	1.566	1430.0	0.0042
2006B	3	F	1.555		0.0042
2007bA	3	F	1.472	10125.1	0.0021
2007bB	3	F			
2008bA	3	F	2.380	19415.1	0.0021
2008bB	3	F	4.175	1492.7	0.0021
2007A	E	R	4.134	7244.1	0.0030
2007B	E	R	2.860	8841.2	0.0122
2008A	E	F	4.468	15761.7	0.0151
2008B	E	F	5.271	19728.2	0.0193
2009A	B	F	5.125	25051.7	0.0230
2009B	B	F	4.718	32776.0	0.0331
2010A	B	R	2.964	14404.7	0.0061
2010B	B	R	3.612	11273.3	0.0060
2011A	A	R	2.004	4446.7	0.0060
2011B	A	R	2.077	4864.2	0.0196
2012A	C	F	1.112	2233.8	0.0323
2013A	A	F	3.090	8204.4	0.0333
2013B	A	F	2.672	7515.5	0.0230
2014A	C	F		6262.9	0.0240
2014B	C	F		7108.4	0.0122
2015A	F	R	1.712	605.4	0.0065
2015B	F	R	1.399	782.9	0.0061
2016A	F	F	1.305	281.8	0.0030
2016B	F	F	1.482	240.1	0.0030
2017A	211		1.357	198.3	0.0031
2017B	211		1.347	271.4	0.0030
AVG µg/L			2.368	6624.025	0.0104

R = rising, F = falling.

Table 30. Mean total metal concentrations in marine waters.

Metals	Gulf of Alaska (Burrell 1978) µg/L	Cook Inlet[1] (ENRI 1994) µg/L	Global	
			Bowen (1979) µg/L	Millero & Sohn (1992) µg/L
Al			2.0	2.0
As		2.4 - 2.5	3.7	23.0
Ba			13.0	100.0
Cd	0.03		0.11	0.7
Cr			0.3	4.0
Cu	0.2		0.25	4.0
Fe		4250 - 6624	2.0	1.0
Pb	0.04		0.03	0.001
Mn			0.2	0.5
Hg	0.007	0.01 - 0.05	0.03	0.005
Ni	0.65		0.56	8.0
Ag			0.04	0.003
V	1.5		2.5	25.0
Zn	0.3		4.9	6.0

[1] Mean range for Cruises 1 and 2.

Table 31. EPA marine water quality criteria for metals.

Metal	Acute µg/L	Chronic µg/L
Sb	1500[1]	500[1]
Cd	43	9.3
Cr	1100	50
Cu	2.9	
Pb	220	8.5
Hg	2.1	0.025
Ni	75	8.3
Ag	7.2[1]	0.92[1]
Tl		13
Zi	95	86

[1] pending.

Source: EPA 1991b.

Table 32. TSS in Cook Inlet water samples.

Sample No.	Tide[1]	Station	TSS mg/L
2001	F	30	6
2002	R	30	5
2003	R	3	4
2004	F	3	19
2005A	R	E	144
2005B	R	E	187
2005C	R	E	115
2006A	F	E	290
2006B	F	E	440
2006C	F	E	352
2007B	F	B	285
2008B	R	B	290
2009A	R	A	89
2009B	R	A	102
2009C	R	A	92
2010A	F	C	65
2011A	F	A	186
2011B	F	A	139
2011C	F	A	159
2012B	R	C	124
2013	R	F	17
2014	F	F	3

[1] R = rising, F = falling.

Table 33. Summary of total metals in suspended solids.

Sample No.	Station	Tide	Metals µg/g (dry weight)													
			Sb	As	Ba	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Ag	Tl	V	Zn
2001	30	F	0.23	2.25	26.3	8.32	50.8	173.0	1780	162.0	0.11	20.8	<MDL	0.43	33.3	297.0
2002	30	R	1.19	3.35	41.2	61.30	83.7	50.5	2220	388.0	0.11	36.2	<MDL	0.31	8.9	1220.0
2003	3	R	<MDL	10.00	239.0	9.40	66.8	230.0	15300	109.0	0.12	32.4	0.10	0.93	52.4	248.0
2004	3	F	0.36	5.67	464.0	1.12	90.0	81.5	29400	40.6	0.20	47.9	0.24	0.68	111.0	152.0
2005A	E	R	0.73	1.08	478.0	0.27	73.8	88.8	25200	24.3	0.13	41.8	0.16	0.50	118.0	148.0
2005B	E	R	0.68	5.78	423.0	0.44	70.2	93.7	25800	50.3		39.2	0.17	0.51	117.0	199.0
2005C	E	R	1.23	7.86	724.0	0.71	104.0	74.6	36200	62.1		56.1	0.28	0.60	142.0	238.0
2006A	E	F	1.25	1.34	637.0	1.37	108.0	70.7	30700	87.9	0.08	55.8	0.23	0.55	136.0	219.0
2006B	E	F	0.76	1.62	665.0	0.17	86.8	64.7	38400	27.2		44.7	0.22	0.47	132.0	150.0
2006C	E	F	0.94	1.45	698.0	0.45	90.3	60.9	41500	25.9		48.5	0.25	0.52	143.0	165.0
2007A	B	F									<MDL					
2007B	B	F	1.55	8.52	476	0.84	100	90.9	37200	108	<MDL	49.4	0.21	0.69	131	290.0
2007C	B	F									<MDL					
2008A	B	R									0.11					
2008B	B	R	1.17	1.33	714	0.19	80.1	64.8	39600	30.1	0.06	42.3	0.17	0.63	128	176.0
2008C	B	R									0.05					
2009A	A	R	0.96	6.13	650	0.41	47.2	81.5	35400	21.2	0.06	35.7	0.15	0.57	122	128.0
2009C	A	R	1.19	7.24	463	0.74	78.5	63.4	32500	42.4		39.3	0.24	0.52	128	160.0
2010A	C	F									0.07					
2010B	C	F									0.07					
2010C	C	F									0.11					
2011A	A	F	8.22	1.17	598	0.18	70.7	46.8	30700	15.1	0.21	35.4	0.14	0.42	117	111.0
2011B	A	F	1.14	7.06	650	0.31	51.7	56.3	30200	16.7		38.4	0.13	0.50	112	129.0
2011C	A	F	1.17	1.50	669	0.21	91.1	60.7	49600	29.7		45.1	0.23	0.49	140	168.0
2012A	C										0.24					
2012B	C	R	1.21	9.29	766	0.37	84	65.4	50100	43	0.27	45.6	0.16	0.60	137	204.0
2012C	C										0.29					
2013	F	R	0.99	4.71	535	0.64	28.7	40.1	27800	17	0.42	26.8	0.13	0.37	85.3	132.0
AVG			1.31	4.60	521.9	4.60	76.7	82.0	30505	68.4	0.13	41.1	0.17	0.54	110.2	238.6
MDL µg/g			0.002	0.1	1.1	0.4	2.9	0.8	0.02	3.7	0.03	2.1	0.07	0.02	2.4	4.1

R = rising, F = falling.

Table 34. Concentration of total metals in suspended solids.

Sample No.	Station	Tide	Metals µg/L													
			Sb	As	Ba	Cd	Cr	Cu	Fe	Pb	Hg	Ni	Ag	Tl	V	Zn
2001	30	F	0.00	0.01	0.2	0.05	0.3	1.0	10.7	1.0	0.001	0.1	<MDL	0.003	0.2	1.8
2002	30	R	0.01	0.02	0.2	0.31	0.4	0.3	11.1	1.9	0.001	0.2	<MDL	0.002	0.0	6.1
2003	3	R	<MDL	0.04	1.0	0.04	0.3	0.9	61.2	0.4	0.000	0.1	0.000	0.004	0.2	1.0
2004	3	F	0.01	0.11	8.8	0.02	1.7	1.5	558.6	0.8	0.004	0.9	0.005	0.013	2.1	2.9
2005A	E	R	0.11	0.16	68.8	0.04	10.6	12.8	3628.8	3.5	0.018	6.0	0.022	0.072	17.0	21.3
2005B	E	R	0.13	1.08	79.1	0.08	13.1	17.5	4824.6	9.4	0.000	7.3	0.031	0.096	21.9	37.2
2005C	E	R	0.14	0.90	83.3	0.08	12.0	8.6	4163.0	7.1	0.000	6.5	0.032	0.069	16.3	27.4
2006A	E	F	0.36	0.39	184.7	0.40	31.3	20.5	8903.0	25.5	0.022	16.2	0.068	0.158	39.4	63.5
2006B	E	F	0.34	0.71	292.6	0.08	38.2	28.5	16896.0	12.0	0.000	19.7	0.098	0.208	58.1	66.0
2006C	E	F	0.33	0.51	245.7	0.16	31.8	21.4	14608.0	9.1	0.000	17.1	0.089	0.183	50.3	58.1
2007A	B	F									<MDL					
2007B	B	F	0.44	2.43	135.7	0.24	28.5	25.9	10602.0	30.8	<MDL	14.1	0.059	0.196	37.3	82.7
2007C	B	F									<MDL					
2008A	B	R														
2008B	B	R	0.34	0.39	207.1	0.05	23.2	18.8	11484.0	8.7	0.016	12.3	0.050	0.181	37.1	51.0
2008C	B	R														
2009A	A	R	0.09	0.55	57.9	0.04	4.2	7.3	3150.6	1.9	0.005	3.2	0.013	0.051	10.9	11.4
2009C	A	R	0.11	0.67	42.6	0.07	7.2	5.8	2990.0	3.9	0.000	3.6	0.022	0.048	11.8	14.7
2010A	C	F									0.005					
2010B	C	F														
2010C	C	F														
2011A	A	F	1.53	0.22	111.2	0.03	13.2	8.7	5710.2	2.8	0.039	6.6	0.025	0.078	21.8	20.6
2011B	A	F	0.16	0.98	90.4	0.04	7.2	7.8	4197.8	2.3	0.000	5.3	0.017	0.070	15.6	17.9
2011C	A	F	0.19	0.24	106.4	0.03	14.5	9.7	7886.4	4.7	0.000	7.2	0.037	0.078	22.3	26.7
2012A	C															
2012B	C	R	0.15	1.15	95.0	0.05	10.4	8.1	6212.4	5.3	0.034	5.7	0.020	0.075	17.0	25.3
2012C	C															
2013	F	R	0.02	0.08	9.1	0.01	0.5	0.7	472.6	0.3	0.007	0.5	0.002	0.006	1.5	2.2
AVG			0.23	0.56	95.8	0.10	13.1	10.8	5598.5	6.9	0.007	7.0	0.031	0.084	20.0	28.3

R = rising, F = falling.

anomalous trends are evident. Very little metal chemistry data on suspended sediment are available for comparison. Data on metal content of sediment extracts taken in lower Cook Inlet during the OCSEAP program (Burrell 1978) showed lower concentrations for cadmium, copper, nickel, zinc, and iron than those found in this study. A comparison between station 69 from the OCSEAP study and station F from this study is given in Table 35. Station 69 was the northernmost sampling location for the OCSEAP study, and it is in the same area as this study's station F. Lower values for the OCSEAP samples are not surprising, because a weak acid leach was used for the metals extraction. It was less efficient than the total dissolution method used in this study.

Table 35. Comparison of total metals in suspended solids for ENRI station F and OCSEAP station 69.

Station	Date	Metals µg/g					
		Cd	Cu	Ni	Zn	Fe	Mn
F	8/93	0.6	40.1	26.8	132	27,800	
69	4/76	<0.25	11.9	2.9	10.0	1240	62

As expected, station 30 from the lower inlet showed a much lower concentration of iron than was found from the more northern stations. Station 30 did have somewhat higher concentrations of zinc, cadmium, and lead in the suspended particles when compared to other stations. This station is probably more influenced by material coming in from the Gulf of Alaska than from upper Cook Inlet. Also, lower inlet stations have a much lower TSS value, and the mass dry weight available for metals analysis is so small that it makes the accuracy of the determinations less reliable than those from the upper inlet.

GRAIN SIZE

Results of this study's sediment grain-size analysis are reported as average percent weight gravel (<-1ϕ), sand (-0.5 to 4.0 ϕ), silt (4.5 to 8ϕ), and clay (9 to 10ϕ) in Table 36. Of the 46 sediment samples analyzed from 16 stations, most were composed primarily of sand (Figure 12). The preponderance of sand is in agreement with past studies. Although not discernable in Figure 12, much of the sand component was fine sand. Two stations (Alt E and Alt 30) exhibited a large fraction of gravel. Alt E is the farthest north of any of the stations sampled, and Alt 30 is the farthest south. It should be noted sediment from Alt 30 contained a large amount of broken shell material that sieved out in the gravel fraction. Three stations (Alt E, 227, and E8) had samples with over 10% silt in the sediment. (Stations 227 and E8 both had samples with over 20% silt.) Station 227 is in Kachemak Bay, and station E8 is offshore from Ninilchik.

CHN

Total organic carbon (TOC) content of sediments from this study ranged from 0.05% to 4.09% (Tables 37 and 38). With the exception of the value of 4.09% observed at station Alt 30, the range was 0.05% to 1.59%, which is almost identical to that described for Cook Inlet by Kaplan and Venkatesan (1985). This is characteristic of unpolluted marine sediments. The station with the highest carbon (Alt 30) was the most southerly station sampled in Cook Inlet. This might indicate a tendency for organic matter to be transported in from the Gulf of Alaska to the south and to accumulate in this area. The higher value may also be due to high primary productivity. Organic carbon contents are commonly higher in Kachemak Bay and Shelikof Strait than in the upper inlet (Kaplan and Venkatesan 1985). However, it is most likely that this high sample (4.09%) is an outlier, as the high concentration was only found in one of three samples and probably represents a piece of vegetation (wood or coal) in the sample.

Table 36. Results of grain-size analysis.

Station	Sample No.	Grain Size %			
		Gravel	Sand	Silt	Clay
Alt E	2003	35.0	54.0	12.0	0.0
C	2005A	0.0	97.0	3.0	0.0
	2005B	0.0	98.0	2.0	0.0
	2005C	0.0	98.0	2.0	0.0
Average		0.0	97.7	2.3	0.0
Alt A	2006A	3.0	92.0	2.0	2.0
	2006B	0.1	93.0	6.0	0.3
	2006C	2.0	94.0	4.0	0.0
Average		1.7	93.0	4.0	0.8
27	2007A	0.3	95.0	5.0	0.0
	2007B	1.0	95.0	5.0	0.0
	2007C	0.3	94.0	5.0	0.0
Average		0.5	94.7	5.0	0.0
F	2009A	0.0	99.0	1.0	0.0
	2009B	0.0	97.0	2.0	0.3
	2009C	0.0	98.0	2.0	0.0
Average		0.0	98.0	1.7	0.1
16B	2010A	0.0	99.0	1.0	0.0
	2010B	0.0	98.0	2.0	0.0
	2010C	0.0	97.5	2.0	0.1
Average		0.0	98.0	1.7	0.0
E5	2012A	1.0	97.0	1.0	0.0
	2012B	5.0	90.0	5.0	0.0
	2012C	2.0	83.0	5.0	10.0
Average		2.7	90.0	3.7	3.3
233	2013A	0.0	99.0	0.5	0.0
	2013B	0.0	99.0	1.0	0.0
	2013C	0.0	99.0	1.0	0.0
Average		0.0	99.0	1.0	0.0
E6	2014A	7.0	83.0	7.0	3.0
	2014B	2.0	88.0	7.0	2.0
	2014C	2.0	84.0	8.0	6.0
Average		3.0	85.0	7.3	3.7
Alt 30	2015A	16.0	83.0	0.2	0.0
	2015B	13.0	86.0	0.1	0.0
	2015C	45.0	56.0	0.1	0.0
Average		24.7	75.0	0.1	0.0

Table 36. Results of grain-size analysis (continued).

Station	Sample No.	Grain Size %			
		Gravel	Sand	Silt	Clay
227	2016A	0.0	75.0	20.0	5.0
	2016B	0.0	97.0	2.0	0.1
	2016C	0.0	97.0	2.0	1.0
Average		0.0	89.7	8.0	2.0
E7	2017A	2.0	98.0	0.1	0.0
	2017B	8.0	92.0	0.0	0.0
	2017C	7.0	93.0	0.1	0.0
Average		5.7	94.3	0.1	0.0
E8	2018A	2.0	96.0	2.0	0.0
	2018B	0.3	79.0	21.0	0.0
	2018C	0.1	84.0	16.0	0.0
Average		0.2	86.3	13.0	0.0
Alt 265	2019A	0.1	99.5	0.1	0.0
	2019B	0.2	99.0	0.1	0.0
	2019C	0.1	99.0	0.1	0.0
Average		0.1	99.0	0.1	0.0
Alt 22	2020A	0.0	99.0	1.0	0.1
	2020B	0.0	98.0	2.0	0.1
	2020C	0.0	99.0	1.0	0.0
Average		0.0	98.7	1.3	0.1
Alt 23	2021A	0.0	100.0	0.0	0.0
	2021B	1.0	99.0	1.0	0.0
	2021C	0.4	99.0	0.1	0.0
Average		0.4	99.3	0.4	0.0

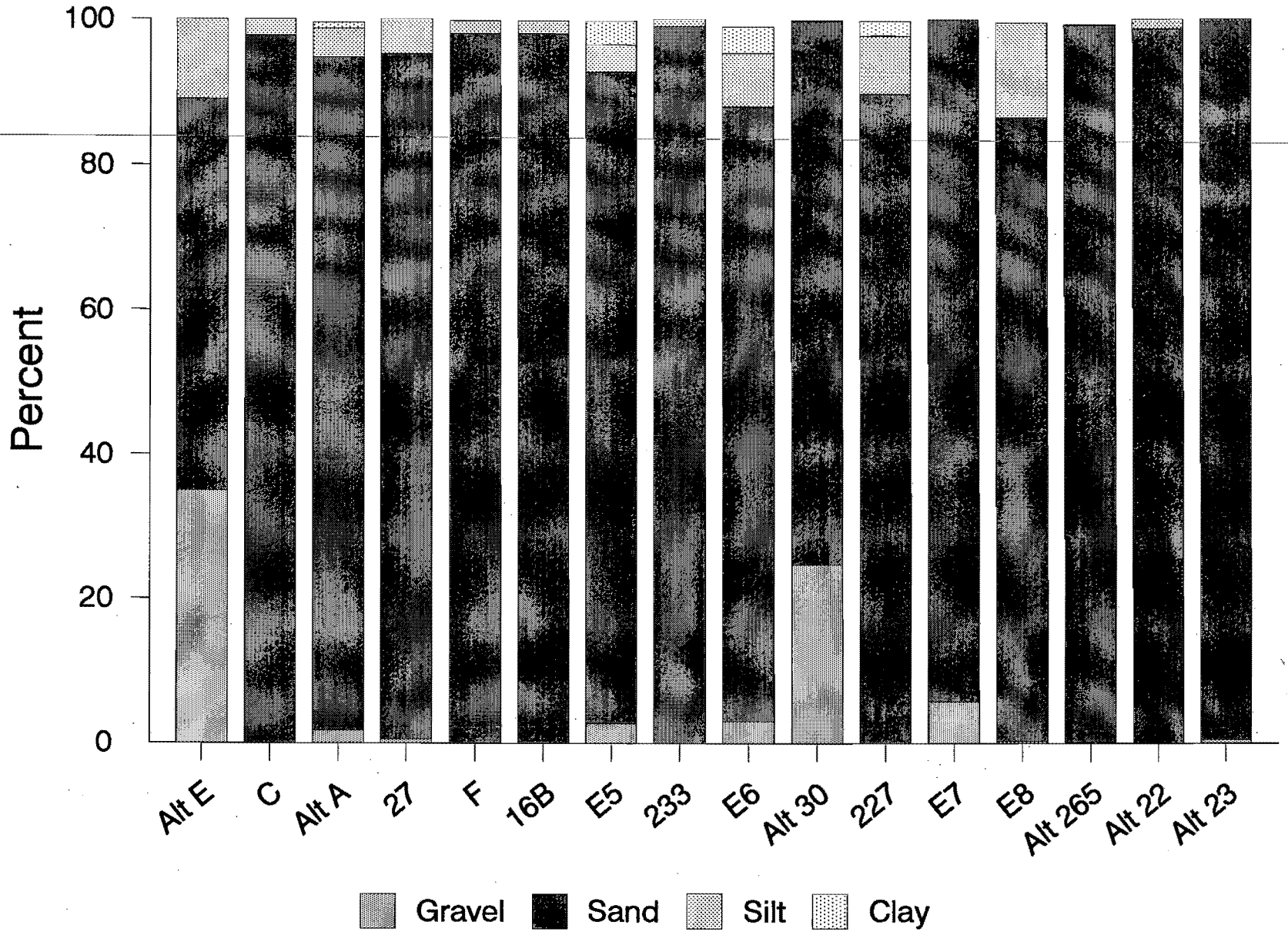


Figure 12. Grain-size composition by station in Cook Inlet.

Table 37. Cruise 1 CHN analysis.

As-Received Basis				
Sample No.	Station	Carbon %	Hydrogen %	Nitrogen %
1013	Alt C	0.62	1.47	0.04
1014	Alt A	0.44	1.88	0.03
1019	27	0.12	0.58	<0.01
1022	F	0.81	1.22	0.04
1023	16B	0.29	0.17	0.02

Dried Basis					
Sample No.	Station	Dry-Loss %	Carbon %	Hydrogen %	Nitrogen %
1013	Alt C	38.09	0.76	0.44	0.03
1014	Alt A	34.52	0.74	0.22	0.02
1019	27	15.56	0.21	<0.05	<0.01
1022	F	35.94	0.64	0.31	0.04
1023	16B	24.04	0.08	0.16	<0.01

Note: The samples were first analyzed for CHN on an as-received sample basis. They were also analyzed after drying, and sample 1019 was ground.

Table 38. Cruise 2 CHN analysis on dried basis.

Sample No.	Station	Dry-Loss %	Carbon %	Hydrogen %	Nitrogen %
2003[1]	Alt E	10.87	0.49	0.23	0.01
2005	C	43.79	0.61	0.37	0.03
2006[1]	Alt A	16.87	0.12	0.17	<0.01
2007[1]	27	19.60	0.05	0.11	<0.01
2009	F	39.06	0.58	0.31	0.02
2010[1]	16B	36.47	0.17	0.29	<0.01
2012[1]	New E-5	24.90	0.10	0.24	<0.01
2013	233	30.29	0.58	0.38	0.01
2014[1]	New E-6	22.97	0.19	0.23	<0.01
2015[1]	Alt 30	21.13	4.09	0.24	0.02
2016	227	54.20	1.43	0.58	0.10
2017[1]	New E-7	15.60	1.59	0.14	0.01
2018[1]	New E-8	25.92	0.69	0.18	0.01
2019[1]	265	15.88	0.08	0.10	<0.01
2020	22	30.33	0.37	0.24	0.02
2021[1]	Alt 23	16.91	0.13	0.14	0.01

[1] These samples were ground after loss on drying was determined and prior to all other analysis.

Little nitrogen was detected in sediments from any of the stations (Table 38). The organic matter in these sediments had moderate-to-high carbon to nitrogen ratios, which are indicative of either allochthonous (terrestrial origin) or autochthonous (marine origin) matter. Generally, allochthonous organic matter has an expected carbon to nitrogen ratio of about 50:1, while autochthonous material has an expected ratio of about 12:1. Station 227 near Homer in Kachemak Bay was the station with the highest nitrogen concentration, but it had a moderate carbon to nitrogen ratio of 15:1, which is indicative of marine origin. Primary productivity is higher in this part of the inlet, and the area is somewhat isolated in circulation and, thus, from deposition of particulate matter from strong incoming currents out of the Gulf of Alaska as well as outgoing waters laden with terrestrial sediment from Upper Cook Inlet.

HYDROCARBONS

Hydrocarbon analyses performed on sediments as part of this study yielded concentrations of individual saturated (normal and isoprenoid alkanes) and aromatic hydrocarbons. Key source diagnostic ratios were calculated to provide information on probable sources of the hydrocarbons found in the sediments. Key definitions and terms used in the hydrocarbon analyses are provided in Tables 26 and 27 on page 55 and in Tables 39 and 40.

Saturated Hydrocarbons

Table 41 presents the saturated hydrocarbon concentrations for all sediment replicates. Total alkanes (TALK), with chain lengths from 12 through 33 carbon atoms, ranged from 62 ng/g to 5388 ng/g throughout the study area. The low molecular weight alkanes (LALK), with chain lengths from 12 through 20 carbon atoms, ranged from <MDL (1.3 ng/g) to 674 ng/g. The sediment concentrations of pristane and phytane were low, and both were detectable together in only eight locations.

Saturated hydrocarbons were dominated by n-alkanes with a strong odd-even preference and low LALK/TALK ratios (Table 41). The n-alkanes with chain lengths from 21 through 29 carbon atoms, especially 27 and 29, dominated. This distribution is consistent with a prevalent biogenic input of hydrocarbons from terrigenous plant material, and it most likely results from transport of riverine-suspended particulate matter. A carbon preference index (CPI) close to 1 is an indication of petroleum, and higher values indicate biogenic input (Kinnetic Laboratories Incorporated 1993). The generally high CPI values and low LALK/TALK ratios are indicative of clean environments. Six stations showed low pristane to phytane ratios. The source of phytane is mainly petroleum, while pristane is derived from both petroleum and biological matter. Low ratios could indicate some petroleum input in the area; however, this is speculative as the number and concentrations of isoprenoid alkanes were so low that it is impossible to make a clear diagnosis (10 of 39 samples at 9 ng/g to 120 ng/g).

In general, the highest saturated hydrocarbons concentrations are associated with sediments taken from nearshore stations in the middle inlet. Station E-7, near Anchor Point, had the highest concentration of saturated hydrocarbons. Concentrations of hydrocarbons detected in sediments from this study are similar to those found by Kaplan and Venkatesan (1985) in Cook Inlet (10 ng/g to 3666 ng/g), lower than those found by Boehm et al. (1987) in the Beaufort Sea (700 ng/g to 19,000 ng/g), and about the same as those found by Kinnetic Laboratories Incorporated (1993) in areas of Prince William Sound unaffected by the *Exxon Valdez* oil spill (157 ng/g to 961 ng/g). Comparisons of saturated hydrocarbon concentrations for similar stations in Cook Inlet between this study and the OCSEAP study are given in Table 42. No anomalous trends are evident. The mean high CPI for station 233 is due to one particularly high sample (2013C), and this could be due to a piece of vegetation (wood or coal) being in that sample. All saturated hydrocarbon concentrations indicated terrigenous material.

PAH

PAH concentrations for station replicates are presented in Table 43. Overall, mean PAH concentrations were very low and followed trends similar to those of saturated hydrocarbons. The highest PAH concentrations were found in sediments in the lower inlet and nearshore in the middle inlet. Total PAH (TPAH) concentrations from the ten stations where detectable concentrations were found ranged from 2 ng/g to 958 ng/g (Table 43). This is similar to the concentrations found in the past in Cook

Table 39. PAH quantitative parameters.

Parameter	Relevance
N	Naphthalene series (C0N + C1N + C2N + C3N + C4N).
F	Fluorene series (C0F + C1F + C2F + C3F).
P	Phenanthrene/Anthracene series (C0P/A + C1P/A + C2P/A + C3P/A + C4P/A).
D	Dibenzothiophene series (C0D + C1D + C2D + C3D).
C	Chrysene series (C0C + C1C + C2C + C3C + C4C).
TPAH	Sum of 2- to 6-ring polynuclear aromatic hydrocarbons.
4,5,6-PAH	4-, 5-, and 6-ring polynuclear aromatic hydrocarbons; origin is usually pyrogenic.

Table 40. PAH ratios and diagnostic source parameters.

Parameter	Relevance
AHD	Alkyl Homologue Distribution; used to show the relative importance of pyrogenic and petrogenic PAH sources. Combustion sources are generally characterized by a greater relative abundance of parent compounds while petroleum contains greater relative quantities of the alky homologues.
FFPI	Fossil Fuel Pollution Index; ratio of fossil fuel-derived PAH to total PAH. (N+F+P+D)/TPAH x 100. FFPI is near 100 for petrogenic and near 0 for pyrogenic.
PAH ratios	P/D indicator of petrogenic input. N/P particularly diagnostic for inputs of fresh petroleum. C2D/C2P vs. C3D/C3P a double ratio which is useful in source determination of hydrocarbons.

Table 41. Summary of saturated hydrocarbon concentrations for sediment replicates.

Sample No.	Station	Alkane Concentration ng/g												
		C12	C13	C14	C15	C16	C17	Pris	C18	Phy	C19	C20	C21	C22
2003	Alt E	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	30	22
2005	C	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	50	52
2006	Alt A	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	19	18
2007	27	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	20	<MDL
2009	F	<MDL	<MDL	<MDL	<MDL	<MDL	29	<MDL	36	<MDL	<MDL	<MDL	130	140
2009	F	<MDL	<MDL	<MDL	<MDL	37	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2010A	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2010B	16B	<MDL	<MDL	<MDL	<MDL	32	79	47	125	100	190	92	120	130
2010C	16B	<MDL	<MDL	<MDL	<MDL	<MDL	21	12	38	<MDL	<MDL	84	150	180
2012A	New E5	50	71	96	110	<MDL	150	110	150	120	250	150	160	160
2012B	New E5	12	17	15	<MDL	28	33	<MDL	40	<MDL	<MDL	7	120	120
2012C	New E5	53.98	62.83	75.7	75	65	68.92	54	39.94	<MDL	61	56.96	70.2	69.64
2013A	233	<MDL	13.55	14.95	23	<MDL	20.99	9	<MDL	<MDL	14	<MDL	25.33	18.68
2013B	233	<MDL	<MDL	<MDL	<MDL	34	93	54	120	110	200	110	110	140
2013C	233	<MDL	14.22	17.74	19	<MDL	<MDL	<MDL	<MDL	<MDL	24.04	<MDL	39.79	30
2014A	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	26	15	34	<MDL	<MDL	<MDL	170	200
2014B	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	14.99	18.3	23.72	24.23
2014C	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	54	28	68	62	130	84	140	170
2015A	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	17	<MDL	58	47	110	<MDL	78	84
2015B	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	23	<MDL	26	<MDL	<MDL	<MDL	44	55
2015C	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	32.53
2016A	227	39	<MDL	25	64	48	120	93	100	74	<MDL	87	150	130
2016B	227	<MDL	<MDL	<MDL	<MDL	<MDL	33	<MDL	31	<MDL	<MDL	<MDL	39	50
2016C	227	<MDL	<MDL	<MDL	<MDL	<MDL	27.76	23.85	<MDL	<MDL	<MDL	<MDL	29.43	26.14
2017A	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	32	<MDL	26	<MDL	<MDL	44	45	49
2017B	New E7	<MDL	<MDL	<MDL	<MDL	18	70	41	85	74	<MDL	74	94	120
2017C	New E7	24.19	6.54	12.23	24	21.95	35.4	16.41	21.01	<MDL	99.43	49.15	130	97.74
2018A	New E8	<MDL	<MDL	<MDL	16	15.12	20.78	12.81	13.02	<MDL	28.01	8.25	23.62	22.25
2018B	New E8	<MDL	<MDL	<MDL	<MDL	<MDL	25	<MDL	<MDL	<MDL	<MDL	<MDL	32	52
2018C	New E8	<MDL	<MDL	<MDL	18	29	80	53	130	110	180	71	100	120
2019A	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	11.07	<MDL	8.18	<MDL	11.78	16.82	25.55	36.69
2019B	Alt 265	<MDL	<MDL	<MDL	10	23	54	32	65	62	<MDL	56	67	100
2019C	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	21	<MDL	27	<MDL	<MDL	<MDL	90	110
2020A	Alt 22	<MDL	<MDL	<MDL	<MDL	31	62	40	100	85	190	100	120	100
2020B	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	29	<MDL	36	<MDL	<MDL	<MDL	130	140
2020C	Alt 22	<MDL	<MDL	<MDL	13	<MDL	23	11	25	18	29	31	37	49
2021A	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	9	<MDL	4	<MDL	6	6	8	8
2021B	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	16	10	13	<MDL	15	15	21	27
2021C	Alt 23	<MDL	<MDL	<MDL	<MDL	8	<MDL	<MDL	<MDL	<MDL	7	<MDL	9	9

MDL ~ 1.3 ng/g
ERR = Insufficient compound detection to determine ratio.

Table 41. Summary of saturated hydrocarbon concentrations for sediment replicates (continued).

Sample No.	Station	Alkane Concentration ng/g										TALK	CPI	LALK/ TALK
		C23	C24	C25	C26	C27	C28	C29	C30	C32	C33			
2003	Alt E	57	<MDL	140	36	490	180	520	<MDL	<MDL	140	1615	5.78	0.00
2005	C	77	120	93	38	260	26	160	<MDL	<MDL	<MDL	876	2.71	0.00
2006	Alt A	32	<DL	35	19	66	<MDL	50	<MDL	<MDL	<MDL	240	5.41	0.00
2007	27	<MDL	<MDL	<MDL	<MDL	42	<MDL	<MDL	<MDL	<MDL	<MDL	62	ERR	0.00
2009	F	123	25	70	<MDL	<MDL	<MDL	55	<MDL	<MDL	<MDL	608	2.02	0.11
2009	F	18.44	<MDL	50.56	<MDL	110	20	70	<MDL	<MDL	<MDL	306	4.34	0.12
2010A	16B	<MDL	<MDL	<MDL	<MDL	140	<MDL	76.84	<MDL	<MDL	<MDL	217	ERR	0.00
2010B	16B	120	24	75	50	200	<MDL	150	<MDL	<MDL	<MDL	1534	2.06	0.43
2010C	16B	150	25	57	<MDL	100	<MDL	<MDL	<MDL	<MDL	<MDL	817	1.46	0.19
2012A	New E5	120	18	75	70	130	57	120	50	<MDL	<MDL	2217	1.48	0.57
2012B	New E5	120	21	62	70	70	70	70	70	70	70	1085	1.07	0.14
2012C	New E5	83.74	<MDL	<MDL	<MDL	220	<MDL	<MDL	<MDL	<MDL	<MDL	1057	1.78	0.58
2013A	233	27.83	<MDL	70.74	<MDL	230	<MDL	140	<MDL	<MDL	<MDL	608	16.80	0.16
2013B	233	140	23	64	44	76	49	150	<MDL	<MDL	<MDL	1517	1.60	0.48
2013C	233	310	<MDL	450	<MDL	1300	<MDL	510	<MDL	<MDL	<MDL	2715	55.87	0.03
2014A	New E6	180	23	94	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	742	1.83	0.10
2014B	New E6	21.81	<MDL	<MDL	14.93	80.44	<MDL	55.13	30.81	<MDL	<MDL	284	2.22	0.12
2014C	New E6	160	22	77	<MDL	<MDL	47	93	<MDL	<MDL	<MDL	1135	1.67	0.38
2015A	Alt 30	100	23	60	64	84	68	<MDL	<MDL	<MDL	<MDL	793	1.51	0.29
2015B	Alt 30	53	21	34	40	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	296	1.08	0.17
2015C	Alt 30	36.98	<MDL	21.04	<MDL	67.1	14.94	100.49	11.26	<MDL	<MDL	284	3.84	0.00
2016A	227	170	18	200	95	580	100	510	74	<MDL	<MDL	2677	2.51	0.24
2016B	227	41	30	27	67	160	110	140	<MDL	<MDL	<MDL	728	1.53	0.09
2016C	227	49.57	<MDL	50.13	21.59	240	32.63	180	20.6	<MDL	<MDL	702	5.71	0.07
2017A	New E7	110	22	110	45	180	74	400	<MDL	<MDL	<MDL	1137	3.37	0.09
2017B	New E7	110	20	54	46	200	76	170	50	<MDL	170	1472	1.78	0.25
2017C	New E7	280	160	519.52	200	1600	200	1500	110	<MDL	280	5388	4.99	0.06
2018A	New E8	45.16	73.87	77.78	25.51	270	32.19	250	17.82	<MDL	<MDL	952	3.51	0.12
2018B	New E8	55	23	21	<MDL	61	<MDL	<MDL	<MDL	<MDL	<MDL	269	2.59	0.09
2018C	New E8	140	21	80	58	220	84	170	58	<MDL	190	1912	2.06	0.35
2019A	Alt 265	43.09	<MDL	<MDL	15.58	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	169	1.18	0.28
2019B	Alt 265	96	20	67	48	<MDL	<MDL	100	<MDL	<MDL	<MDL	800	1.26	0.38
2019C	Alt 265	100	20	64	50	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	482	1.33	0.10
2020A	Alt 22	88	20	54	39	78	51	130	<MDL	<MDL	<MDL	1288	1.64	0.47
2020B	Alt 22	120	25	70	<MDL	<MDL	<MDL	55	<MDL	<MDL	<MDL	605	2.01	0.11
2020C	Alt 22	65	<MDL	71	26	150	25	110	<MDL	<MDL	<MDL	683	3.19	0.22
2021A	Alt 23	8	<MDL	<MDL	<MDL	<MDL	17	34	<MDL	<MDL	<MDL	100	1.86	0.25
2021B	Alt 23	31	<MDL	94	16	<MDL	<MDL	21	<MDL	<MDL	<MDL	279	2.79	0.25
2021C	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	21	27	30	70	181	1.45	0.08

MDL ~ 1.3 ng/g
ERR = Insufficient compound detection to determine ratio.

Table 42. Comparisons of mean saturated hydrocarbon concentrations for sediment in Cook Inlet.

OCSEAP				ENRI			
Station	Date	TALK ng/g	CPI	Station	Date	TALK ng/g	CPI
16B	5/79	460	5.9	16B	8/93	856	2.1
19	5/79	220	4.9	E8	8/93	1044	2.8
22	5/79	10	ND	22	8/93	859	2.6
23	5/79	10	ND	23	8/93	186	2.4
27	5/79	10	1.2	27	8/93	62	ND
30	5/79	90	3.2	30	8/93	458	2.1
212	4/78	210	3.7	E6	8/93	720	2.0
212	8/78	360	4.6	E6	8/93		
227	11/77	1680	3.1	227	8/93	1369	3.5
233	4/78	480	3.9	233	8/93	1613	38.4
245	4/78	120	4.0	F	8/93	457	7.3
265	4/78	540	1.1	265	8/93	484	1.4

ND = Insufficient compound detection to determine ratio.

Table 43. Summary of PAH concentrations for sediment replicates.

Sample No.	Station	PAH Concentration ng/g									
		Naph-thalene	1-Methyl naph-thalene	Biphenyl	Acenaph-thylene	Fluorene	Phen-anthrene	Anthra-cene	2-Methyl phen-anthrene	Fluor-anthene	Pyrene
2003	Alt E	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2005	C	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2006	Alt A	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2007	27	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2009	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2009	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2010A	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2010B	16B	<MDL	<MDL	<MDL	<MDL	<MDL	5.9	<MDL	<MDL	<MDL	<MDL
2010C	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2012A	New E5	<MDL	<MDL	<MDL	<MDL	<MDL	20.0	<MDL	<MDL	<MDL	<MDL
2012B	New E5	<MDL	4.2	<MDL	<MDL	<MDL	6.7	<MDL	<MDL	<MDL	<MDL
2012C	New E5	<MDL	<MDL	<MDL	<MDL	<MDL	17.0	<MDL	<MDL	<MDL	<MDL
2013A	233	<MDL	<MDL	<MDL	<MDL	<MDL	5.0	<MDL	<MDL	<MDL	<MDL
2013B	233	<MDL	<MDL	<MDL	<MDL	<MDL	7.3	<MDL	<MDL	<MDL	<MDL
2013C	233	<MDL	<MDL	<MDL	<MDL	<MDL	5.2	<MDL	<MDL	<MDL	<MDL
2014A	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	3.3	<MDL	<MDL	<MDL	<MDL
2014B	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2014C	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	4.1	<MDL	<MDL	<MDL	<MDL
2015A	Alt 30	<MDL	1.9	<MDL	14.0	<MDL	82.0	20.0	12.0	89.0	82.0
2015B	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2015C	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2016A	227	16.0	24.0	9.0	<MDL	8.6	31.0	<MDL	17.0	11.0	<MDL
2016B	227	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2016C	227	<MDL	<MDL	<MDL	<MDL	<MDL	8.6	<MDL	<MDL	<MDL	<MDL
2017A	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2017B	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	4.1	<MDL	<MDL	<MDL	<MDL
2017C	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2018A	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	4.1	<MDL	<MDL	<MDL	<MDL
2018B	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2018C	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	5.6	<MDL	<MDL	<MDL	<MDL
2019A	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2019B	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	2.9	<MDL	<MDL	<MDL	<MDL
2019C	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2020A	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	4.7	<MDL	<MDL	<MDL	<MDL
2020B	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2020C	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2021A	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2021B	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2021C	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL

MDL ~ 0.9 ng/g

Table 43. Summary of PAH concentrations for sediment replicates (continued).

Sample No.	Station	PAH Concentration ng/g									
		Benzo(a) anthra-cene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor-anthene	Benzo(e) pyrene	Perylene	Indeno (1,2,3-cd) pyrene	Dibenz (a,h)an-thracene	Benzo (g,h,i) perylene	TPAH
2003	Alt E	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2005	C	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2006	Alt A	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2007	27	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2009	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2009	F	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2010A	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2010B	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	5.9
2010C	16B	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2012A	New E5	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	20.0
2012B	New E5	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	10.9
2012C	New E5	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	17.0
2013A	233	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	5.0
2013B	233	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	7.3
2013C	233	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	5.2
2014A	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	3.3
2014B	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2014C	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	4.1
2015A	Alt 30	34.0	32.0	44.0	35.0	52.0	<MDL	120.0	190.0	150.0	957.9
2015B	Alt 30	<MDL	<MDL	8.4	10.0	10.0	<MDL	<MDL	<MDL	<MDL	28.4
2015C	Alt 30	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2016A	227	<MDL	<MDL	17.0	13.0	<MDL	50.0	70.0	<MDL	<MDL	266.6
2016B	227	<MDL	<MDL	6.5	10.0	9.0	<MDL	<MDL	<MDL	<MDL	25.5
2016C	227	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	8.6
2017A	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2017B	New E7	<MDL	<MDL	5.2	6.6	<MDL	<MDL	<MDL	<MDL	<MDL	15.9
2017C	New E7	<MDL	<MDL	<MDL	<MDL	<MDL	49.0	<MDL	<MDL	<MDL	49.0
2018A	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	4.1
2018B	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2018C	New E6	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	5.6
2019A	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2019B	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	2.9
2019C	Alt 265	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2020A	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	4.7
2020B	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2020C	Alt 22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2021A	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2021B	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0
2021C	Alt 23	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0

MDL ~ 0.9 ng/g

Inlet (10 ng/g to 300 ng/g) (Kaplan and Venkatesan 1985) and to those found recently in Prince William Sound (7 ng/g to 93 ng/g) (Kinnetic Laboratories Incorporated 1993) and in Cook Inlet (10 ng/g to 116 ng/g) (Hyland et al. 1993). The major difference between data from the present study and that from earlier ones is that fewer compounds were detected in the present study. PAHs detected were found in very low concentrations that probably represent baseline conditions and background hydrocarbon inputs.

Concentrations of individual PAHs rarely exceeded 10 ng/g, and values were often near MDL (0.9 ng/g). The exception to this was at stations Alt 30 and 227, which were the most southerly locations sampled as well as the most biologically active. The dominance of the phenanthrene series in these samples indicates most PAHs detected were of petrogenic origin.

One sample each from stations Alt 30 (2015A) and 227 (2016A) showed much higher PAH totals than any other sample. If these two samples were discarded, the overall mean TPAH concentrations would be lower than those shown in the previously mentioned studies. The within-station variance for station Alt 30 is, in fact, greater than the variance across Cook Inlet (Table 44). Sample 2015A is also from the station with organic C levels that are tenfold higher than at other locations, therefore, increasing the likelihood of naturally occurring PAHs. Sample 2016A from station 227 had the second highest TPAH concentration and the highest levels of naphthalene compounds (it was one of only three samples found to contain detectable naphthalene). The more volatile naphthalene compounds are indicative of relatively recent petroleum inputs, and this could be a sign of petroleum pollution in the vicinity of Homer. Since these levels occurred in only one of the three samples, much more extensive sampling would be required to address this possibility.

The appearance of perylene at stations 227 and E-7 may indicate a diagenetic PAH input in these sediments. Although found in crude oil at very low concentrations, perylene is also a naturally occurring PAH that is formed by the chemical transformation of certain biological precursors in sediments during early diagenesis (LaFlamme and Hites 1978). High concentrations of perylene seem to require a very common and abundant precursor with low oxygen concentrations providing the right condition for diagenetic formation. Station E-7 is also the station having the highest concentration of saturated hydrocarbons.

Because of the limited number of compounds detected and the very low concentrations (approaching MDLs), determination of diagnostic ratios is not warranted due to low precision of concentrations determined near the MDLs and the consequent potential for drastically biased ratios. Due to high variability both within and between stations, many samples would be needed to provide statistically significant data and results. A study in Prince William Sound indicated at least six replicates would be needed per station to determine index values (Kinnetic Laboratories Incorporated 1993). In this study, only three samples (one each from stations Alt 30, 227, and E7) showed more than two PAH compounds. These are also the stations with the highest TOC.

METALS

Table 45 presents the metals concentrations for all sediment replicates. The analyses are as yet incomplete, and several more metals are expected to be run. When the results become available, they will be added as an appendix to this document. No geographic area contained significantly lower or higher metals concentrations than other areas. Universally high levels of both aluminum and iron were found throughout the inlet. This would be expected, as past analyses describe 80% to 95% of suspended material in Cook Inlet to be aluminosilicate minerals (Feely and Massoth 1982). The concentration of metals found in Cook Inlet are within the range found elsewhere in Alaska and throughout the world (Table 46).

The mean concentrations of metals throughout the inlet are all lower than the Effects Range Low (ER-L) values of Long and Morgan (1990) (Table 47). ER-L values represent the lowest concentrations of contaminants that adversely affect some marine organisms. Four stations (Alt A, 27, Alt 30, and 227) had higher mercury levels (ER-L 0.15), and one station (C) had higher zinc levels (ER-L 120) than the reported ER-Ls. Alt 30 had the highest mercury levels with a mean of 0.21 μg/g; this is above the ER-L

Table 44. Chemical and statistical results for sediment replicate samples.

Sample No.	Station	HYDROCARBONS ng/g					
		TPAH	AVG	S.D.	TALK	AVG	S.D.
2003	Alt E	0.0			1615		
2005	C	0.0			876		
2006	Alt A	0.0			240		
2007	27	0.0			62		
2009	F	0.0			608	457	151
2009	F	0.0			306		
2010A	16B	0.0	2.0	2.8	217	856	538
2010B	16B	5.9			1534		
2010C	16B	0.0			817		
2012A	New E5	20.0	14.6	5.7	2217	1453	540
2012B	New E5	6.7			1085		
2012C	New E5	17.0			1057		
2013A	233	5.0	5.8	1.0	608	1613	863
2013B	233	7.3			1517		
2013C	233	5.2			2715		
2014A	New E6	3.3	2.5	1.8	742	720	348
2014B	New E6	0.0			284		
2014C	New E6	4.1			1135		
2015A	Alt 30	956.0	328.1	444.1	793	458	237
2015B	Alt 30	28.4			296		
2015C	Alt 30	0.0			284		
2016A	227	226.6	86.9	99.0	2677	1369	925
2016B	227	25.5			728		
2016C	227	8.6			702		
2017A	New E7	0.0	21.6	20.4	1137	2666	1930
2017B	New E7	15.9			1472		
2017C	New E7	49.0			5388		
2018A	New E8	4.1	3.2	2.4	952	1044	674
2018B	New E8	0.0			269		
2018C	New E8	5.6			1912		
2019A	Alt 265	0.0	1.0	1.4	169	484	258
2019B	Alt 265	2.9			800		
2019C	Alt 265	0.0			482		
2020A	Alt 22	4.7	1.6	2.2	1288	859	305
2020B	Alt 22	0.0			605		
2020C	Alt 22	0.0			683		
2021A	Alt 23	0.0	0.0	0.0	99	186	74
2021B	Alt 23	0.0			279		
2021C	Alt 23	0.0			180		
TOTAL		1401.8	35.9	153.6	38830	996	975

Table 45. Summary of total metals in sediments.

Sample No.	Station	Metals µg/g (dry weight)					
		Al	Sb	As	Fe	Hg	Zn
2003	Alt E	27000	<MDL		16200	0.062	41.9
2005A	C	63700	0.098	17.6	50600	0.116	163.0
2005B	C	27300	<MDL	10.8	37300	0.065	133.0
2005C	C	26400	0.213	6.0	34700	0.063	103.0
2006A	Alt A	40600	0.036	2.0	16200	0.060	92.2
2006B	Alt A	74300	<MDL	8.9	50500	0.206	162.0
2006C	Alt A	72500	0.081	2.7	40100	0.242	88.8
2007A	27	26300	<MDL	4.0	25500	0.266	80.6
2007B	27	51600	0.058	5.3	22500	0.191	60.2
2007C	27	64200	<MDL	2.8	34100	0.126	74.8
2009A	F		0.026	19.3	55900	0.092	139.0
2009B	F		0.095	10.0	38200	0.110	114.0
2009C	F		<MDL	6.2	34600	0.078	104.0
2010A	16B		0.067	4.3	54300	0.113	110.0
2010B	16B		<MDL	6.2	43800	0.116	87.8
2010C	16B		<MDL	7.5	44500	0.194	115.0
2012A	New E5		0.045	7.2	62300	0.110	82.7
2012B	New E5		0.040	7.3	46100	0.060	89.3
2012C	New E5		0.165	10.1	42500	0.105	95.8
2013A	233		<MDL	10.2	38300	0.111	129.0
2013B	233		<MDL	9.2	36500	0.118	97.1
2013C	233		0.026	10.2	34700	0.148	107.0
2014A	New E6		0.055	4.7	39200	0.107	82.1
2014B	New E6		0.631	8.8	42000	0.060	127.0
2014C	New E6		0.133	7.7	46100	0.050	73.0
2015A	Alt 30	40700	<MDL	<MDL	23400	0.176	42.3
2015B	Alt 30	47000	<MDL	5.0	26400	0.266	51.8
2015C	Alt 30	31900	<MDL	2.2	26400	0.186	40.7
2016A	227	46100	<MDL	2.9	27700	0.338	74.3
2016B	227	68600	0.081	6.6	40200	0.066	110.0
2016C	227	70000	0.037	6.5	40800	0.111	103.0
2017A	New E7	49800	<MDL	7.8	25200	0.075	50.9
2017B	New E7	55400	<MDL	6.6	20200	0.050	43.5
2017C	New E7	44500	0.063	11.9	20300	<MDL	54.0
2018A	New E8	63000	0.048	6.4	26600	<MDL	58.3
2018B	New E8	63900	0.021	3.4	28600	0.073	77.9
2018C	New E8	51900	0.094	4.3	24900	0.037	71.3
2019A	Alt 265	66200	0.102	<MDL	27200	0.044	66.8
2019B	Alt 265	57200	0.010	3.1	24100	0.042	56.6
2019C	Alt 265	67800	<MDL	1.8	22700	0.061	58.9
2020A	Alt 22	60000	0.026	6.8	35400	0.111	80.0
2020B	Alt 22	73300	<MDL	7.9	33400	0.074	86.8
2020C	Alt 22	33800	0.029	7.2	63800	0.116	81.2
2021A	Alt 23	57900	0.065	<MDL	25200	0.158	55.6
2021B	Alt 23	39000	0.051	5.2	26100	0.088	66.8
2021C	Alt 23	36100	0.024	4.9	19100	0.085	61.3
MDL = 0.0001 µg/g							
AVG		51548	0.053	6.4	34661	0.111	85.7

Table 46. Mean total metal concentrations in marine sediments.

Metals	Beaufort Sea		Cook Inlet		Global
	Boehm et al. (1987) µg/g	Naidu et al. (1982) µg/g	Lower Inlet (Burrell 1979) µg/g	ENRI (1994) µg/g[1]	Bowen (1979) µg/g
Al				51,548	72,000
Sb				0.05	1.2
As				6.4	7.7
Ba	348				460
Cd	0.14		<0.08		0.17
Cr	49	45			72
Cu	16	17	24		33
Fe		20,000	>10,000	34,661	41,000
Pb					19
Mn		260	203		770
Hg				0.11	0.19
Ni		23	15		52
Ag					0.06
V	80	70			105
Zn	62	75	31	86	95

[1] Mean values.

Table 47. ER-L and ER-M values for metals in sediments (Long and Morgan 1990).

Metal	ER-L µg/g	ER-M µg/g
Sb	2.0	25.0
As	33.0	85.0
Cd	5.0	9.0
Cr	80.0	145.0
Cu	70.0	390.0
Pb	35.0	110.0
Hg	0.15	1.3
Ni	30.0	50.0
Ag	1.0	2.2
Zi	120.0	270.0

of 0.15 but far below the Effects Range Medium (ER-M) of 1.3. It should be noted the average global marine sediment level reported for mercury by Bowen (1979) is 0.19 μg/g, which is also above the reported ER-L. The few higher values found were dispersed throughout the inlet; no patterns are discernable.

HYDROGRAPHY

Vertical profiles of all hydrographic data are presented in Appendix A. Cruise 1 data at depths of 10 m showed water temperatures of 11°C to 12°C north of the forelands and 9°C to 10°C south of the forelands (Figure 13). In general, salinity increased north to south from a low of 17 in the upper inlet (station E), to 25 in the vicinity of the forelands, to 31 in the vicinity of Ninilchik (Figure 14). Transmissivity increased from 0% in the northern inlet to 10% at the forelands. It remained less than 20% south to the Clam Gulch area but increased to 70% or more in the Ninilchik area (Figure 15).

Cruise 2 temperature data (Figure 16) at depths of 10 m showed an increase in temperatures at all stations over Cruise 1 data. Temperature decreased from highs of 14°C to 15°C in the upper inlet, 13°C to 14°C at the forelands, 11°C to 12°C at Ninilchik, and 9°C at English Bay in the lower inlet. Salinity data (Figure 17) show some lower values in the region north of the forelands. Those for the region south of the forelands are in reasonable agreement with Cruise 1 data. Transmissivity data from Cruise 2 (Figure 18) are in reasonable agreement with Cruise 1 data. They increase from 0% near Tyonek in the north to 98% near English Bay in the south.

BIOTA

TISSUES

Hydrocarbons

Species collected for tissue analysis represented the basic feeding type that filter seawater and potentially acquire anthropogenic chemical contaminants from the water column. Mussels and other aquatic organisms bioaccumulate pollutants from water, suspended particles, and food. Although mussels do not readily metabolize pollutants such as PAHs, they can depurate pollutants from their body tissues over time in clean water. As a result, any accumulation from an acute (short-term) exposure may be eliminated with time, although repeated chronic exposure may introduce sources that build up as net accumulation.

Detectable but very low concentrations of PAH were found in four of the six mussel tissue samples (Table 48). These tissues contained few individual target PAHs at concentrations ranging from near MDL (3.8 ng/g) to 230 ng/g. These levels were equal to or lower than those found in caged mussels in Cook Inlet (Hyland et al. 1993). Mussels with the detectable concentrations of naphthalene compounds came from the western side of the inlet. However, concentrations were so low that this cannot be considered a clear pattern depicting hydrocarbon loading in tissues from any point source of hydrocarbon input.

The saturated hydrocarbon characteristics of the tissues examined are presented in Tables 49 and 50. Unlike PAHs, mussels from the eastern side of the inlet showed higher concentrations and a more diverse array of hydrocarbons. The samples were generally dominated by higher molecular weight alkanes, which are indicative of sediment-associated hydrocarbons.

Metals

Metal concentrations found in mussel tissues from six locations in Cook Inlet are given in Table 51. Data are comparable with those obtained in past studies from Cook Inlet, Gulf of Alaska, and Beaufort Sea (Burrell 1978, Boehm et al. 1987); no anomalous trends are evident. However, different bivalve species were used in the two studies (*Mytilus* in Cook Inlet and *Cyrtodaria* and *Astarte* in the Beaufort Sea), and this makes comparisons less definitive. Mussel tissues from Chinitna Bay show a somewhat elevated concentration of barium and iron. This might be due to these mussels being taken from the

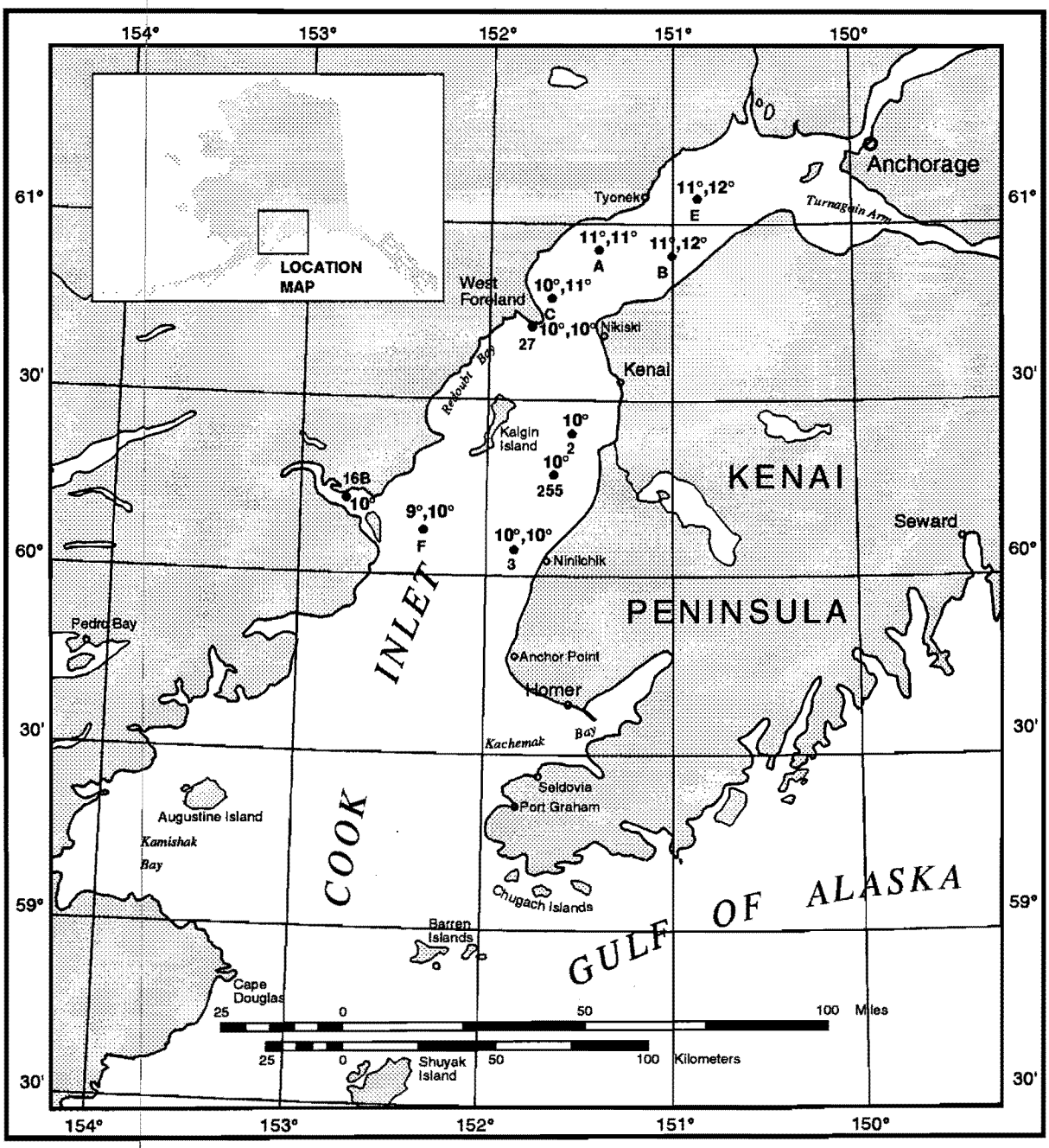


Figure 13. Cruise 1 temperature (C°) at 10 m depth.

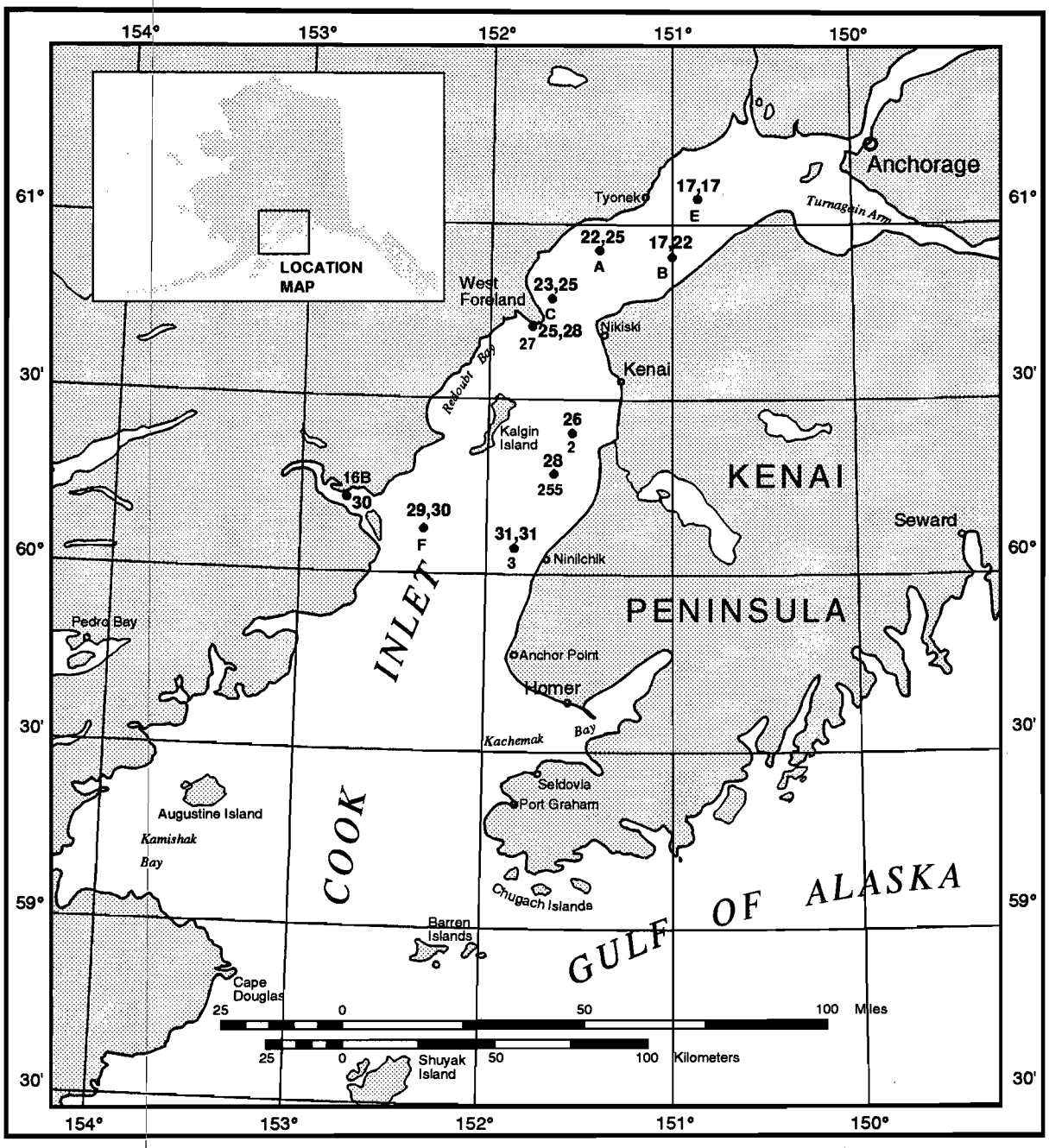


Figure 14. Cruise 1 salinity (PSU) at 10 m depth.

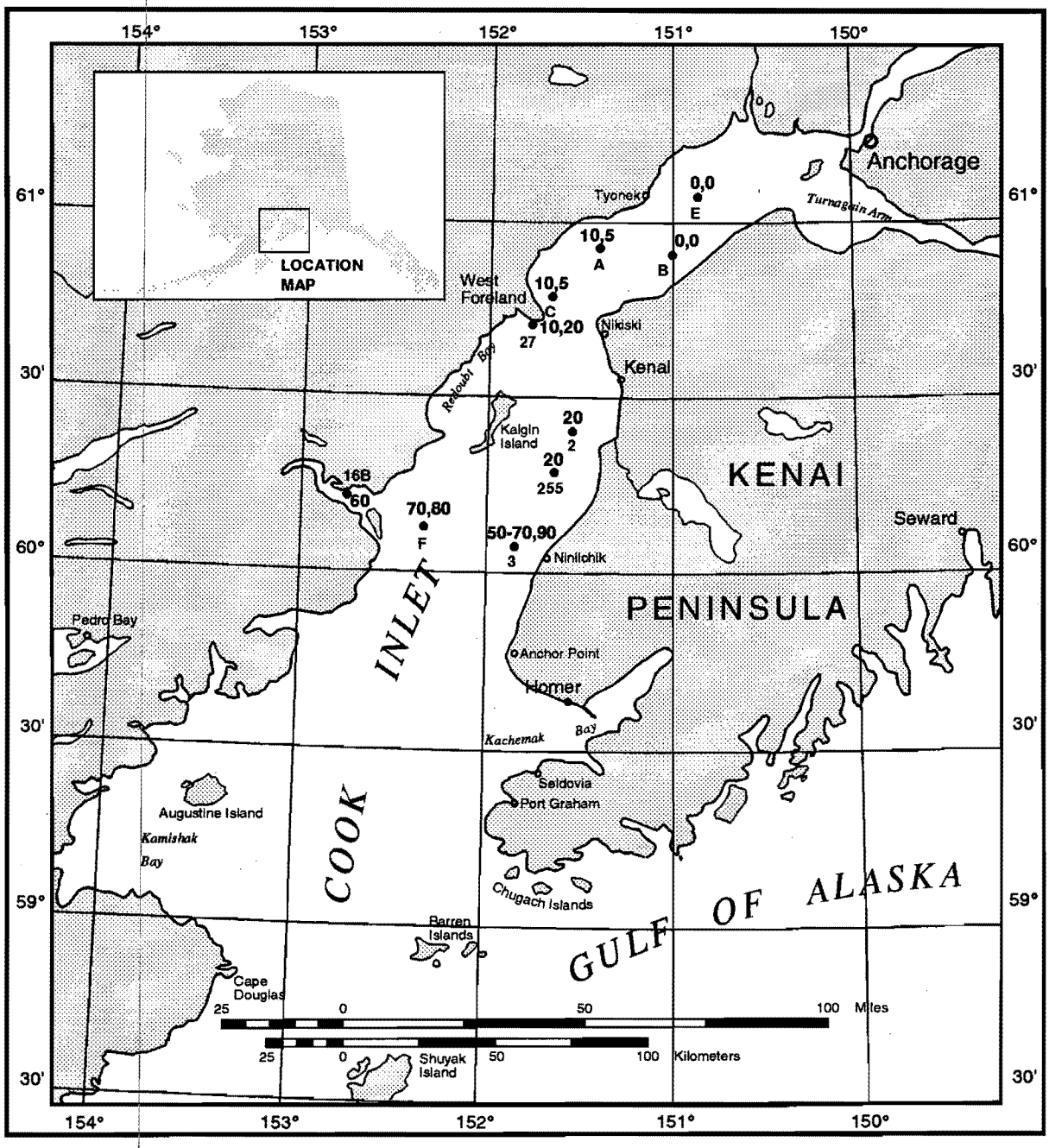


Figure 15. Cruise 1 transmissivity (%) at 10 m depth.

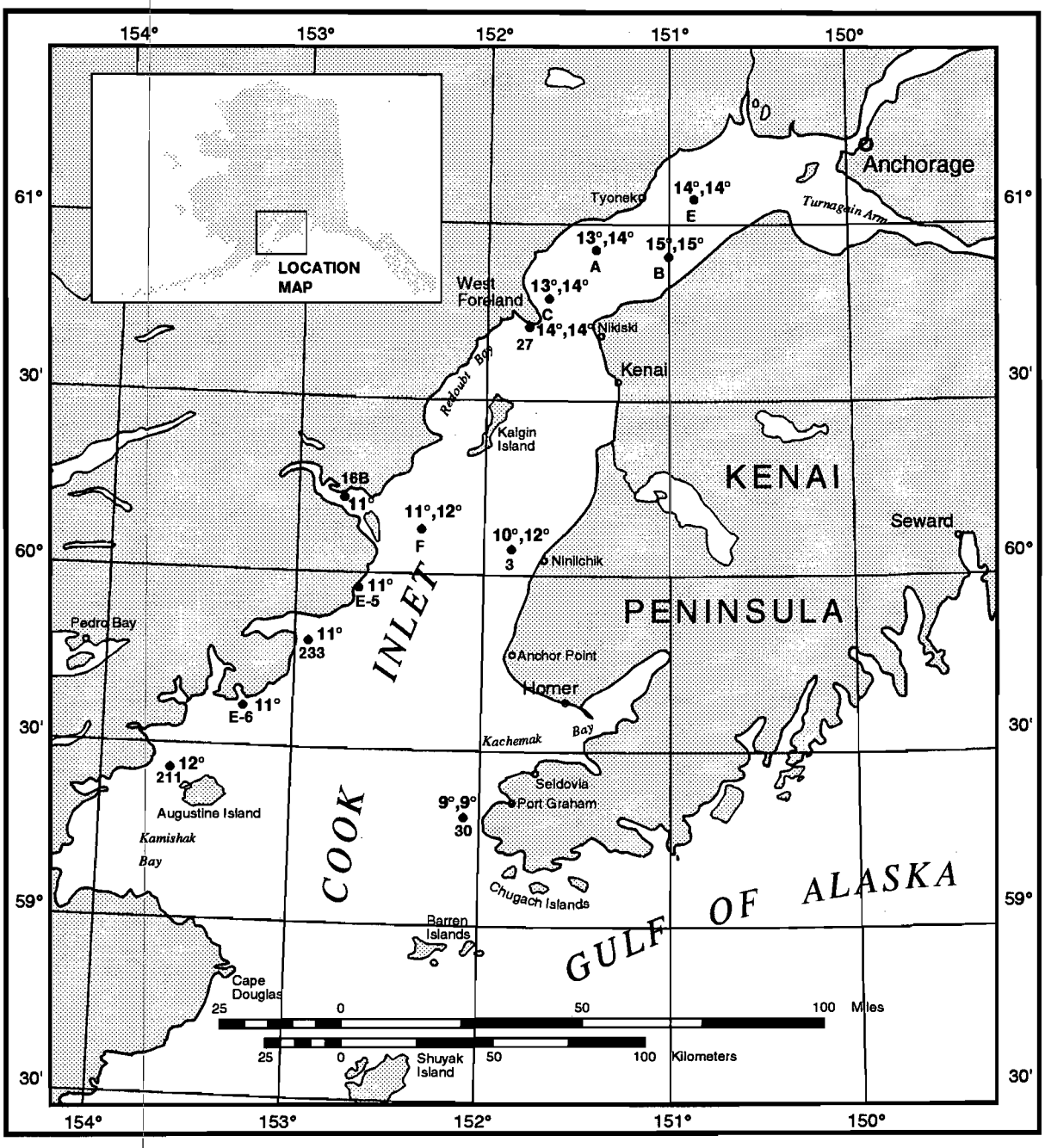


Figure 16. Cruise 2 temperature (C°) at 10 m depth.

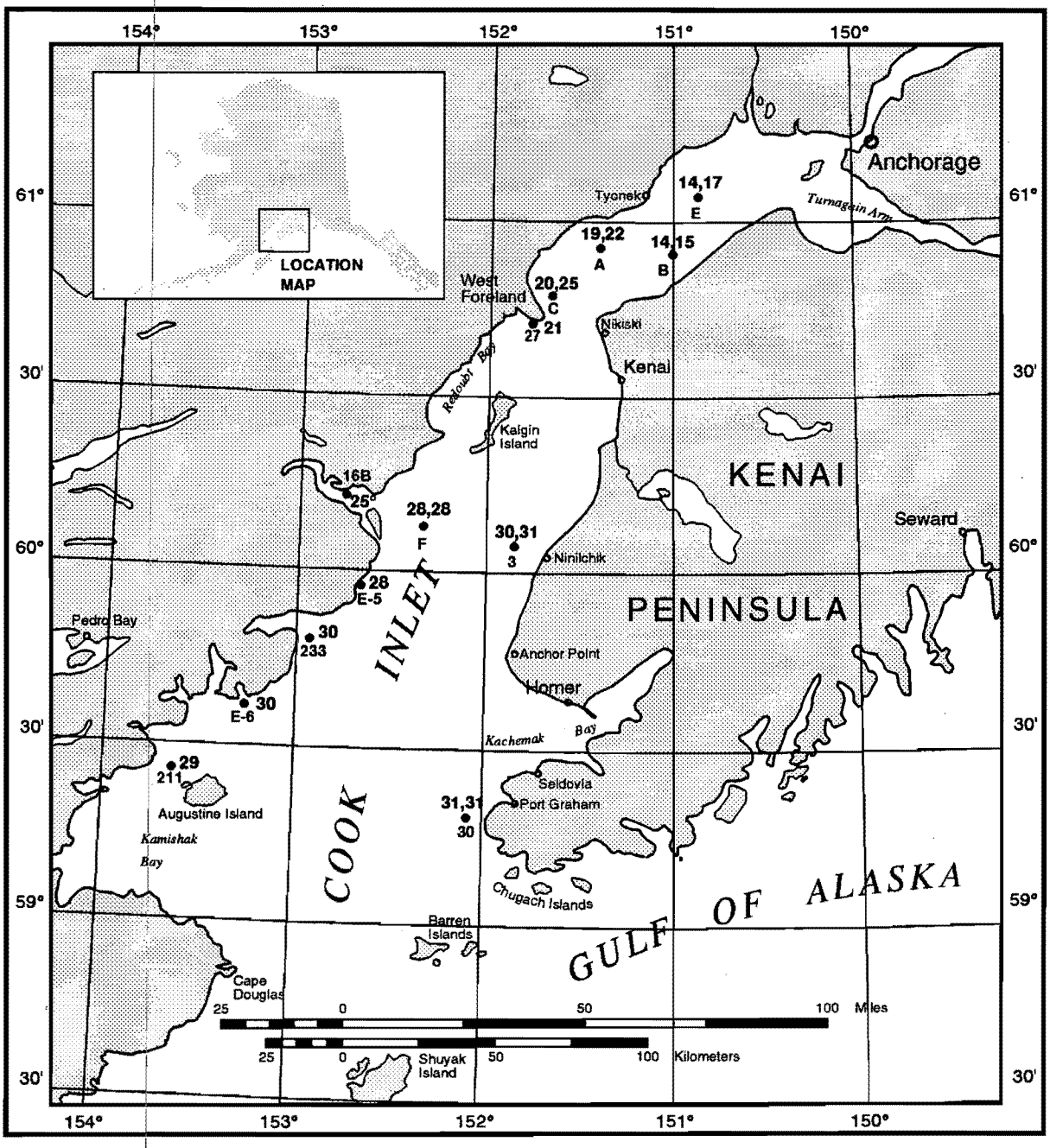


Figure 17. Cruise 2 salinity(PSU) at 10 m depth.

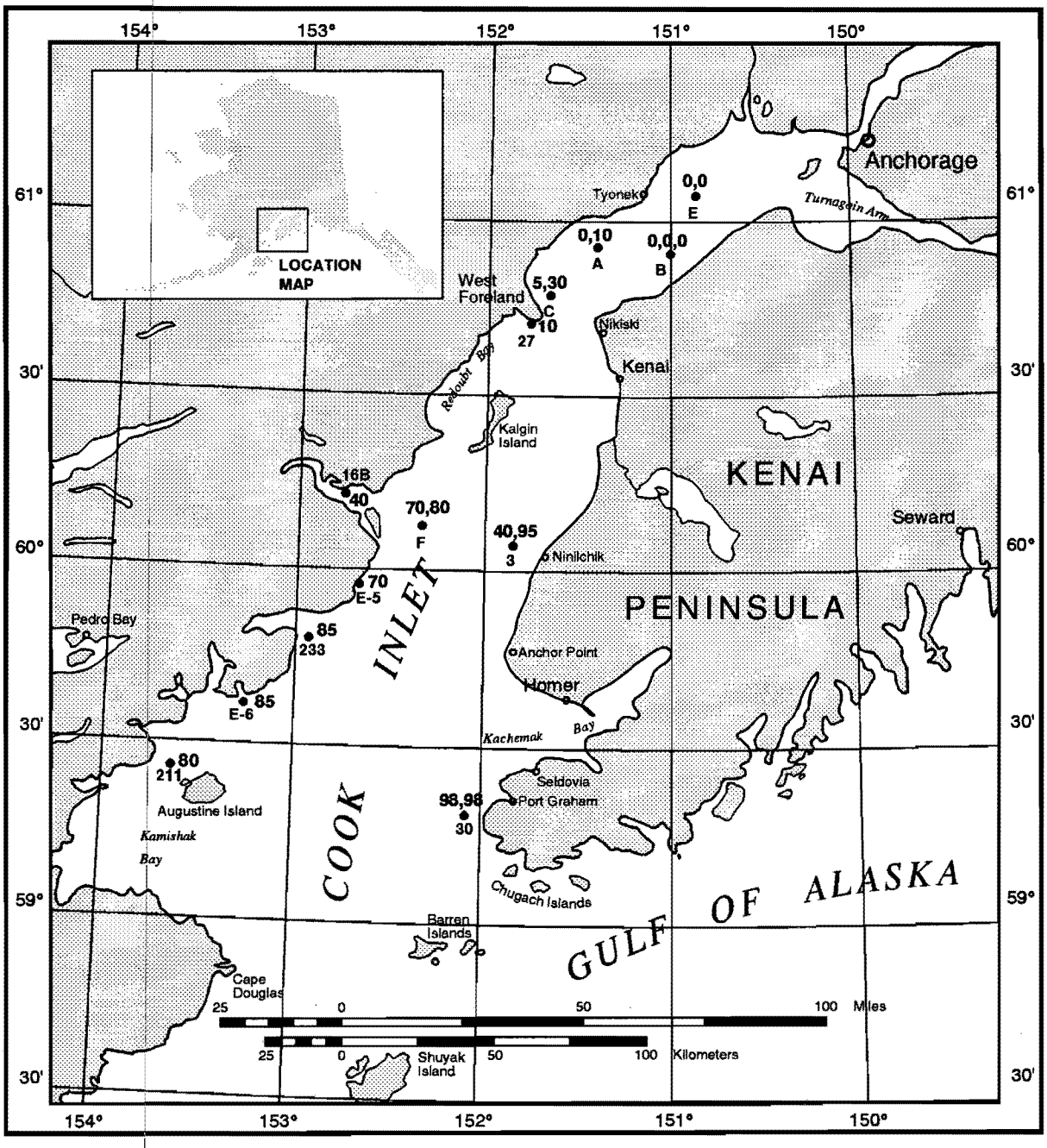


Figure 18. Cruise 2 transmissivity(%) at 10 m depth.

Table 48. Summary of PAH concentrations and diagnostic ratios for tissues.

Sample No.	Station	PAH Concentration ng/g								
		Naphthalene	1-Methyl naphthalene	Biphenyl naphthelene	Phenanthrene	Fluoranthene	Pyrene	Other PAHs	TPAH	N/P
2001	Tuxedni Bay	190	40	55	<MDL	<MDL	<MDL	0	285	NR
2002	Fossil Point	120	65	48	<MDL	<MDL	<MDL	0	233	NR
2003	Chinitna Bay	230	<MDL	170	<MDL	<MDL	<MDL	0	400	NR
2004	Jakolof Bay	16	<MDL	5	23	42	26	0	112	0.23
2005	Kasitsna Bay	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0	0	NR
2006	Homer	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0	0	NR

MDL ~ 3.8 ng/g.

NR = Insufficient compound detection to determine ratios.

Table 49. Summary of saturated hydrocarbon concentrations for mussel tissues.

Sample No.	Station	Alkanes Concentration ng/g										
		C11	C12	C13	C14	C15	C16	C17	Pristane	C18	Phytane	C19
2001	Tuxedni Bay	77	83	130	130	240	180	270	140	180	170	270
2002	Fossil Point	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2003	Chinitna Bay	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2004	Jakolof Bay	<MDL	18	20	41	160	53	120	73	83	100	130
2005	Kasitsna Bay	<MDL	<MDL	<MDL	<MDL	310	78	130	<MDL	53	<MDL	<MDL
2006	Homer	<MDL	<MDL	<MDL	<MDL	340	64	230	170	90	160	<MDL

Sample No.	Station	Alkanes Concentration ng/g										
		C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
2001	Tuxedni Bay	330	550	810	1200	1700	1200	940	1400	1200	1400	1200
2002	Fossil Point	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2003	Chinitna Bay	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
2004	Jakolof Bay	150	340	590	870	1500	1100	1000	1200	980	1000	850
2005	Kasitsna Bay	<MDL	320	650	950	1500	1300	1300	1400	1300	1400	1100
2006	Homer	170	410	870	1600	2300	2100	2100	2100	1900	1900	1500

MDL ~ 5.4 ng/g.

Table 50. Summary of saturated hydrocarbon parameters and diagnostic ratios for tissues.

Sample No.	Station	TALK	LALK	LALK/TALK	CPI
2001	Tuxedni Bay	13800	1110	0.08	0.96
2002	Fossil Point	0	0	NR	NR
2003	Chinitna Bay	0	0	NR	NR
2004	Jakolof Bay	10378	412	0.04	0.90
2005	Kasitsna Bay	11791	518	0.04	0.92
2006	Homer	18004	634	0.04	0.93

NR = Insufficient compound detection to determine ratios.

Table 51. Summary of metal concentrations for mussel tissues.

Sample No.	Station	Metals µg/g (dry weight)											
		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg
2001	Tuxedni Bay	1380	0.01	0.33	55.2	0.1	4.47	15.5	11.0	841	12.8	78.8	0.13
2002	Fossil Point	456	0.02	0.54	29.1	<MDL	4.98	19.3	11.4	298	48.7	103.0	0.14
2003	Chinitna Bay	2030	0.01	0.57	215.0	0.2	6.67	192.0	22.9	1440	68.6	255.0	0.11
2004	Jakolof Bay	101	0.06	0.59	3.0	<MDL	4.13	9.3	7.7	42	29.7	7.4	0.11
2005	Kasitsna Bay	78	0.03	0.50	26.5	<MDL	2.62	13.3	10.8	59	48.3	8.8	0.14
2006	Homer	254	<MDL	0.50	15.3	<MDL	1.76	14.6	11.4	182	70.4	28.8	0.09
MDL		22.8	0.0002	0.09	0.08	0.009	0.07	0.06	0.08	0.05	0.03	0.08	0.03

Sample No.	Station	Metals µg/g (dry weight)				
		Ni	Ag	Tl	V	Zn
2001	Tuxedni Bay	33.7	0.07	0.04	<MDL	57.4
2002	Fossil Point	35.2	0.01	0.02	<MDL	85.3
2003	Chinitna Bay	133.0	0.32	0.09	<MDL	148.0
2004	Jakolof Bay	33.7	0.05	<MDL	<MDL	98.4
2005	Kasitsna Bay	6.8	0.04	0.01	<MDL	138.0
2006	Homer	11.8	0.05	0.02	<MDL	171.0
MDL		0.3	0.01	0.003	0.2	11.9

most exposed station on the west side of Cook Inlet, where they would filter more water containing suspended sediments. Concentrations of heavy metals cadmium, copper, and zinc were determined in mussel tissues at Kasitsna and Kachemak bays in 1977 (Burrell 1978). They are almost identical to those found in this study (Table 52). Concentrations of barium, cadmium, copper, and zinc found in bivalve tissues from the Beaufort Sea (Boehm et al. 1987) and those from this study are also very similar (Table 52).

Table 52. Comparison of mean concentrations of trace metals in bivalve tissues from Cook Inlet.

Metals µg/g	Burrell Study 1978		ENRI Study 1994		Boehm Study 1987
	Kasitsna Bay	Kachemak Bay	Kasitsna Bay	Kachemak Bay	Beaufort Sea
Ba			26.5	15.3	21.5
Cd	1.7	2.5	2.6	1.8	7.3
Cu	4.0	11.0	10.8	11.4	18.7
Zn	113.0	68.0	138.0	171.0	71.1

NORM

Concentrations of NORM were extremely low in all shell samples analyzed. Radium-226, radium-228, and bismuth-214 were not detectable; and lead-214 was found at extremely low concentrations (Table 53). Under the assumption that the daughters were in equilibrium, data for radium-226, lead-214, and bismuth-214 in Table 53 all measure the concentration of radium-226.

Table 53. Radioactive activity of mussel shell samples.

Sample Identification	Station	Weight (g)	Pb-214	Bi-214	Ra-226	Ra-228
2-001	Tuxedni Bay	65	<0.072[1]	<0.28	<0.99	<0.69
2-002	Fossil Point	36	0.15 ± 0.10	<0.47	<1.6	<0.36
2-003	Chinitna Bay	30	0.147 ± 0.108	<2.3	<4.2	<1.8
2-004B	Jakolof Bay	104	0.067 ± 0.048	<0.12	<0.49	<0.14
2-005B	Kasitsna Bay	103	0.0369 ± 0.027	<0.51	<0.46	<0.34
2-006	Homer	70	0.070 ± 0.052	<1.1	<1.0	<0.85

[1] Detection limits were calculated as if the isotope was present at a level 2.5 times the square root of twice the average backgrounds.

MICROTOX®

The Microtox® bioassay using lysed luminescent bacteria cells has gained widespread validation and usage in a variety of applications. Primary advantages of this toxicity bioassay are its speed, simplicity, and relatively low cost. The bioassay's strongest attribute lies in its usefulness as a primary screening test and its monitoring capability over time; however, it should be viewed as only one step in a number of assays to assess overall toxicity levels. For the solid-phase Microtox® bioassay, EC50 values below 2% can be considered to indicate possibly contaminated sediment in Cook Inlet. As shown on Table 54, there is a clear delineation between stations that indicate possible toxicity (<2%) and those that indicate no toxicity.

Results from Cook Inlet sediment showed six stations with no toxicity and five stations with possible toxicity using the 2% EC50 level. With the exception of station 227 in Kachemak Bay, all stations that exhibit possible sediment toxicity through the Microtox® bioassay are located on the western side of the middle inlet. Station 227 showed the lowest EC50 and, on this basis, is the station most likely to have toxic sediments. There appears to be a possible relationship between Microtox® toxicity and sediments that are composed primarily of fine sands. All stations with possible Microtox® toxicity were composed of nearly 100% grain sizes approximating 4 ϕ. A substantial variation exists for EC50 values above 2% that does not relate directly to the level of cleanliness. EC50 values should be compared to a known clean station with similar sediments in the same general study area to verify the toxicity results. In general, Microtox® bioassays indicated none of the sampled Cook Inlet sediments exhibited high toxicity.

TOXIC BIOASSAYS

Solid-Phase Static Amphipod Sublethal Bioassay

The *R. abronius* test results (Table 55) were statistically analyzed using both the Dunnett's test (which compares each sediment treatment to the *R. abronius* control) and Tukey-Kramer Honestly Significant Difference test (which compares all the sediment treatments to each other). Of the 12 stations assayed using both tests, only 2 (Alt C and 227) had statistically significant lower survivals than the controls. Survival rates that differ by more than 20% from controls are often considered to be of concern. Amphipod survival in sediment from station 227 in Kachemak Bay was 21% lower than that observed from the control. Sediments from this station could be considered toxic based on this difference. The *R. abronius* is known to be sensitive to a high proportion of fine-grained sediments, which could confound the interpretation of results (Carr and Chapman 1992). It should be noted the control had a very high survival rate (99%), and the survival rate in the sample (78%) was relatively high. This rate was as high or higher than any of those obtained with sediments from seven stations in Port Valdez that ranged from 49% to 78% (Karle et al. 1994) and five stations in lower Cook Inlet that ranged from 61% to 73% mean survival (Hyland et al. 1993).

Liquid-Phase Sperm-Cell Sublethal Bioassay

Sperm-cell toxicity test results are presented as adjusted and unadjusted values for both pore water and receiving water in Tables 56 and 57. Percent fertilization was adjusted for the control responses using Abbott's formula as stated in *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms* (EPA 1991a). These results were statistically analyzed using the very sensitive two-tailed t-test with an arc sine-square root transformation of the data (Tables 58 and 59).

Sediment pore water from four stations showed statistical differences for percent fertilization when compared to the control. Pore-water toxicity tests are considered more sensitive than the whole sediment amphipod test (Carr and Chapman 1992). One of these samples (233) actually showed higher fertilization rates than the control, while the other three (F, 16B, and Alt 22) were lower. Station Alt 22, near Kalgin Island, had the lowest fertilization rate of only 18%. Station F had a 38.4% fertilization rate, and 16B had a 47.2% fertilization rate. Both are located in the middle inlet. These three stations could be considered to have pore waters that exhibit toxicity.

Table 54. Microtox® summary data.

Sample No.	Station	EC50/Average (%)		Comment
2001/1	227	1.02		Possible toxicity
2		0.90		
3		0.66	0.86	
2002/1	Alt-E	No toxicity		No toxicity
2		59.6		
3		No toxicity		
2004/1	Alt-A	1.78		No toxicity
2		5.46		
3		7.65	4.96	
2005/1	27	No toxicity		No toxicity
2		No toxicity		
3		No toxicity		
2006/1	F	1.61		Possible toxicity
2		1.55		
3		1.65	1.60	
2007/1	16B	1.12		Possible toxicity
2		1.61		
3		1.02	1.25	
2008/1	233	1.49		Possible toxicity
2		2.43		
3		1.80	1.91	
2009/1	New E-7	No toxicity		No toxicity
2		No toxicity		
3		No toxicity		
2010/1	New E-8	No toxicity		No toxicity
2		No toxicity		
3		No toxicity		
2011/1	Alt 265	No toxicity		No toxicity
2		No toxicity		
3		79.6		
2012/1	Alt 22	0.92		Possible toxicity
2		2.20		
3		0.83	1.32	

Note: The higher the EC50 value the less toxic. Anything less than 2% is a possible concern for toxicity.

Table 55. Summary of 10-day solid-phase static test with *R. abronius*.

Sample Identification	Station	Proportion Surviving	Mean Proportion Surviving	Statistically Significant (Dunnett's)[1]	Statistically Significant (HSD)[2]
2-002	Alt E	1.00 1.00 1.00 1.00 1.00	1.00	NS	NS
2-004	Alt C	0.90 0.80 0.90 0.75 0.75	0.82	S	S
2-005	Alt A	0.90 1.00 1.00 1.00 0.90	0.96	NS	NS
2-006	27	1.00 1.00 1.00 1.00 0.95	0.99	NS	NS
2-007	F	0.95 0.90 0.90 0.90 0.95	0.92	S	NS
2-008	16B	1.00 0.95 1.00 1.00 1.00	0.99	NS	NS
2-009	233	0.90 0.95 0.90 0.95 1.00	0.94	NS	NS
2-010	227	0.90 0.70 0.85 0.70 0.75	0.78	S	S

Table 55. Summary of 10-day solid-phase static test with *R. abronius* (continued).

Sample Identification	Station	Proportion Surviving	Mean Proportion Surviving	Statistically Significant (Dunnett's)[1]	Statistically Significant (HSD)[2]
2-011	New E7	0.95 1.00 1.00 0.90 1.00	0.97	NS	NS
2-012	New E8	1.00 1.00 1.00 1.00 1.00	1.00	NS	NS
2-013	Alt 265	1.00 1.00 0.95 1.00 1.00	0.99	NS	NS
2-014	Alt 22	0.85 0.85 1.00 0.90 0.95	0.91	S	NS
R. abronius Control		0.95 1.00 1.00 1.00 1.00	0.99	NA	NA

[1] Statistically significant when compared to the *R. abronius* control sediment using the Dunnett's Test at $\alpha = 0.05$.

[2] Statistically significant when comparing all sediment treatments to each other using the Tukey-Kramer Honestly Significant Difference Test at $\alpha = 0.05$.

NA = Not applicable.

NS = Not statistically significantly different.

S = Statistically significantly different.

Table 56. Summary of pore-water sperm-cell test with *D. excentricus* (includes unadjusted and Abbott's adjusted data).

Sample Identification	Station	Abbott's Adjusted Values[1]			Unadjusted Values		
		Percent Fertilized	Mean % Fertilized	Standard Deviation	Percent Fertilized	Mean % Fertilized	Standard Deviation
2-002	Alt E	100 100 100 92 100	98.4	3.6	96 96 94 85 95	93.2	4.7
2-004	Alt C	94 93 96 100 100	96.6	3.3	87 86 89 93 97	90.4	4.6
2-005	Alt A	99 ND 100 100 100	99.8	0.5	92 ND 96 94 97	94.8	2.2
2-006	27	100 100 100 100 99	99.8	0.4	96 93 97 96 92	94.8	2.2
2-007	F	52 55 30 31 39	41.4	11.6	48 51 28 29 36	38.4	10.6
2-008	16B	58 50 46 49 52	51.0	4.5	54 46 43 45 48	47.2	4.2
2-009	233	100 100 100 100 100	100.0	0.0	70 72 76 78 81	75.4	4.4
2-010	227	ND 100 100 100 95	98.8	2.5	ND 70 67 66 62	66.3	3.3
2-011[2]	E7	NA	NA	NA	NA	NA	NA

Table 56. Summary of pore-water sperm-cell test with *D. excentricus* (includes unadjusted and Abbott's adjusted data) (continued).

Sample Identification	Station	Abbott's Adjusted Values[1]			Unadjusted Values		
		Percent Fertilized	Mean % Fertilized	Standard Deviation	Percent Fertilized	Mean % Fertilized	Standard Deviation
2-012[2]	E8	NA	NA	NA	NA	NA	NA
2-013[2]	265	NA	NA	NA	NA	NA	NA
2-014	Atl 22	32 35 23 28 20	27.6	6.2	21 23 15 18 13	18.0	4.1
Control 1		NA	NA	NA	92 82 96 97 96	92.6	6.2
Control 2		NA	NA	NA	60 58 70 68 70	65.2	5.8
Brine Control		99 97 100	98.7	1.5	92 90 94	92.0	2.0

[1] Values corrected for control response using Abbott's formula (EPA 1991a).

[2] No pore water was generated because the sediment treatments were very coarse grained.

NA = Not applicable.

ND = No data.

Table 57. Summary of receiving water sperm-cell test with *D. excentricus* (includes unadjusted and Abbott's adjusted data).

Sample Identification	Station	Abbott's Adjusted Values[1]			Unadjusted Values		
		Percent Fertilized	Mean % Fertilized	Standard Deviation	Percent Fertilized	Mean % Fertilized	Standard Deviation
2-002	3	91 100 91 94 97	94.6	3.9	64 71 64 66 68	66.6	3.0
2-004	E	76 74 81 86 78	79.0	4.7	53 52 57 60 55	55.4	3.2
2-005	B	83 73 84 71 81	78.4	6.0	58 51 59 50 57	55.0	4.2
2-006	A	98 95 97 89 91	94.0	3.9	94 91 93 85 87	90.0	3.9
2-007	C	93 96 96 97 89	94.2	3.3	89 92 92 93 85	90.2	3.3
2-008	F	96 98 97 98 92	96.2	2.5	92 94 93 94 88	92.2	2.5
2-009	211	100 100 100 95 100	99.0	2.2	92 94 89 82 87	88.8	4.7
2-010	30	73 90 100 100 100	92.6	11.8	58 71 88 96 85	79.6	15.1

Table 57. Summary of receiving water sperm-cell test with *D. excentricus* (includes unadjusted and Abbott's adjusted data) (continued).

Sample Identification	Station	Abbott's Adjusted Values[1]			Unadjusted Values		
		Percent Fertilized	Mean % Fertilized	Standard Deviation	Percent Fertilized	Mean % Fertilized	Standard Deviation
Control 1		NA	NA	NA	76 65 75 65 70	70.2	5.3
Control 2		NA	NA	NA	93 96 98 97 95	95.8	1.9
Control 3		NA	NA	NA	78 91 88 86 88	86.2	4.9
Control 4		NA	NA	NA	76 75 83 82 79	79.0	3.5
Brine Control 1		91 88 90 86 88	88.6	2.1	64 62 63 60 62	62.2	1.5
Brine Control 2		92 94 96 91 94	93.3	2.0	88 90 92 87 90	89.4	1.9

[1] Values corrected for control response using Abbott's formula (EPA 1991a).

NA = Not applicable.

Table 58. T-test determinations for the pore-water sperm-cell test with *D. excentricus*.

Sample Identification	Station	Table t-value	d.f.	Calculated t-value	Statistically Significant[1]
2-002	Alt E	2.306	8	-0.0932	No
2-004	Alt C	2.306	8	0.7453	No
2-005	Alt A	2.365	7	-0.5580	No
2-006	27	2.306	8	-0.6437	No
2-007	F	2.306	8	9.3460	Yes
2-008	16B	2.306	8	10.6624	Yes
2-009	233	2.306	8	-3.1594	Yes
2-010	227	2.365	7	-0.3066	No
2-014	Alt 22	2.306	8	13.9333	Yes

[1] α = 0.05 for two sample t-test comparison.

d.f. = degrees of freedom.

Table 59. T-test determinations for the receiving water sperm-cell test with *D. excentricus*.

Sample Identification	Station	Table t-value	d.f.	Calculated t-value	Statistically Significant[1]
2-002	3	2.306	8	1.3444	No
2-004	E	2.306	8	5.2292	Yes
2-005	B	2.306	8	4.9714	Yes
2-006	A	2.306	8	3.2016	Yes
2-007	C	2.306	8	3.5413	Yes
2-008	F	2.306	8	2.6917	Yes
2-009	211	2.306	8	-0.9092	No
2-010	30	2.306	8	-0.3310	No

[1] α = 0.05 for two sample t-test comparison.

d.f. = degrees of freedom.

Five stations showed statistically significant reduction of fertilization rates for receiving water samples. However, three of these (A, C, and F) had mean percent fertilization values over 90% but had a control of 96%. This is a difference of less than 6% and should not be considered an indication water samples were toxic. Stations E and B exhibited fertilization rates of 55%. This is 15% lower than their control and could be considered an indication the water exhibits toxicity. Stations E and B were the two most northern stations in the inlet, and they had extremely high suspended particulate loads that may contribute to toxicity.

Water-Phase Urchin Larvae Development Bioassays

The urchin larvae test results are presented as mean percent survival and mean percent normal larval development in Table 60. These results were statistically analyzed using the two-tailed t-test with an arc sine-square root transformation of the data (Tables 61 and 62). Percent survival and percent normal development for larvae in receiving water from the eight stations were high. With the exception of survival at station 211 (Table 61), there were no statistically significant differences between sample and control survivals or normal development numbers. Although there was a statistically significant difference in survival between the sample and controls, larvae exposed to water from station 211 had a survival rate of 87%, which is only 9% below the control.

QC RESULTS

STANDARD REFERENCE MATERIALS

JEAL participated in the 1994 NIST Intercomparison Exercise Program during this study.

MDL

MDL calculated from heptadecane and naphthalene signal-to-noise ratios are shown in Table 63. MDLs are given for average sample volume and weight of 30 g dry weight for sediment and 7 g wet weight for tissue samples for comparison with survey data. MDLs determined for the above sample sizes for alkanes are 0.28 μg/kg to 1.30 μg/kg for sediment and 1.20 μg/kg to 5.40 μg/kg for tissues. MDLs for PAHs are 0.16 μg/kg to 0.89 μg/kg for sediment and 0.68 μg/kg to 3.80 μg/kg for tissues.

METHOD BLANKS

Method blanks analyzed by GC/MS revealed total alkane concentration ranging from <MDL to 200 μg/kg for sediments and <MDL to 2100 μg/kg for tissues (Table 64). Method blanks for PAHs ranged from <MDL to 0.34 μg/kg for sediments and <MDL to 65 μg/kg for tissues (Table 65).

TRIP BLANKS

Trip blanks are water samples (ultrapure distilled water) that accompany each shipping container from the field. They are processed with authentic samples to allow evaluation of the effects of collection, handling, and shipment on sample contamination. Presence of target analytes in the blanks is an indication of contamination in the field, during shipment, or in the laboratory. Three trip blanks for seawater samples were produced during the Cruise 2 field survey. These blanks were collected at the end of the cruise and were handled in the same manner as water samples. Concentrations were <MDL in all three blank samples.

SURROGATE COMPOUNDS

Surrogate compounds were spiked into each water, sediment, and tissue sample (including QC samples) prior to processing in order to monitor the efficacy and accuracy of the analytical methods. Acenaphthalene-d8, chrysene-d12, and perylene-d12 were the PAH surrogate compounds used for the GC/MS analysis. N-dodecane-d26, n-Eicosane-d42, and n-Triacontane-d62 were the alkanes surrogate compounds used. Surrogate recoveries for the three PAH analogues were in the range of 15.7% to 85.2% for all seawater samples, 45.3% to 81.6% for sediment samples, and 9.5% to 66.4% for

Table 60. Summary of receiving water larval test with *D. excentricus*.

Sample Identification	Station	Proportion Survival	Mean % Survival	Proportion Normal	Mean % Normal
2-002	3	1.00 0.83 0.84 0.89 0.72	86	0.97 0.78 0.79 0.86 0.68	82
2-004	E	0.84 0.94 0.91 0.97 0.84	90	0.73 0.81 0.81 0.86 0.75	79
2-005	B	0.93 1.00 0.78 1.00 0.82	91	0.82 0.87 0.66 0.90 0.70	79
2-006	A	0.87 0.89 0.91 1.00 0.80	89	0.83 0.84 0.87 0.97 0.75	85
2-007	C	0.91 1.00 0.97 0.96 0.94	96	0.89 1.00 0.89 0.90 0.91	92
2-008	F	0.89 1.00 1.00 0.96 1.00	97	0.86 1.00 0.98 0.91 0.99	95
2-009	211	1.00 0.91 0.82 0.73 0.88	87	0.98 0.91 0.79 0.71 0.88	85
2-010	30	1.00 0.88 1.00 0.99 1.00	97	0.95 0.80 1.00 0.90 0.97	92

Table 60. Summary of receiving water larval test with *D. excentricus* (continued).

Sample Identification	Station	Proportion Survival	Mean % Survival	Proportion Normal	Mean % Normal
Control 1		1.00 0.94 0.88 1.00 0.97	96	1.00 0.91 0.85 0.97 0.93	93
Control 2		1.00 1.00 0.96 1.00 1.00	99	1.00 1.00 0.92 1.00 1.00	98
Control 3		0.93 0.98 0.95 0.93 0.99	96	0.90 0.95 0.91 0.91 0.96	93
Control 4		0.93 0.87 1.00 1.00 1.00	96	0.89 0.84 1.00 0.98 1.00	94
Brine Control 1		1.00 1.00 0.74 1.00 0.94	94	0.96 0.91 0.69 0.99 0.88	89
Brine Control 2		1.00 0.90 1.00 1.00 1.00	98	0.98 0.88 1.00 1.00 1.00	97

Table 61. T-test determinations of percent survival for the 48-h receiving water larval test with *D. excentricus*.

Sample Identification	Station	Table t-value	d.f.	Calculated t-value	Statistically Significant[1]
2-002	3	2.306	8	1.0654	No
2-004	E	2.306	8	-0.6446	No
2-005	B	2.306	8	0.9793	No
2-006	A	2.306	8	-0.7787	No
2-007	C	2.306	8	-1.8828	No
2-008	F	2.306	8	-0.4028	No
2-009	211	2.306	8	4.0200	Yes
2-010	30	2.306	8	-0.4070	No

[1] α = 0.05 for two sample t-test comparison.

d.f. = degrees of freedom.

Table 62. T-test determinations of percent normal for the 48-h receiving water larval test with *D. excentricus*.

Sample Identification	Station	Table t-value	d.f.	Calculated t-value	Statistically Significant[1]
2-002	3	2.306	8	0.9785	No
2-004	E	2.306	8	2.0767	No
2-005	B	2.306	8	1.5893	No
2-006	A	2.306	8	-1.2833	No
2-007	C	2.306	8	-1.7890	No
2-008	F	2.306	8	-2.0334	No
2-009	211	2.306	8	1.2626	No
2-010	30	2.306	8	-0.4717	No

[1] α = 0.05 for two sample t-test comparison.

d.f. = degrees of freedom.

Table 63. Semivolatile organic compound MDL report summary.

Based on Heptadecane			
ALKANES	Curve 1	Curve 2	Sample Size
Calculated IDL	0.0085 µg/mL	0.0380 µg/mL	
Calculated Water MDL	0.0021 µg/L	0.0095µg/L	4 L
Calculated Sediment MDL	0.28 µg/kg	1.30 µg/kg	30 g
Calculated tissue MDL	1.20 µg/kg	5.40 µg/kg	7 g
Based on Naphthalene			
PAHs	Curve 1	Curve 2	Sample Size
Calculated IDL	0.0048 µg/mL	0.0270 µg/mL	
Calculated Water MDL	0.0012 µg/L	0.0067 µg/L	4 L
Calculated Sediment MDL	0.16 µg/kg	0.89 µg/kg	30 g
Calculated Tissue MDL	0.68 µg/kg	3.80 µg/kg	7 g

IDL = Instrument Detection Limit

Note: Calibration Curves used to process data:

Curve 1	Curve 2
Sediments (Set #1)	Tissues
Waters	Sediments (Set #2)
	Sediments (Set #3)

Table 64. Method blanks for alkanes.

Analyte		Sediment Set #1 ng/g	Sediment Set #2 ng/g	Sediment Set #3 ng/g	Tissue ng/g
n-Octane	C8	<MDL	<MDL	<MDL	<MDL
n-Nonane	C9	<MDL	<MDL	<MDL	<MDL
n-Decane	C10	<MDL	<MDL	<MDL	<MDL
n-Undecane	C11	<MDL	<MDL	<MDL	<MDL
n-Dodecane	C12	<MDL	<MDL	<MDL	<MDL
n-Tridecane	C13	<MDL	<MDL	<MDL	<MDL
n-Tetradecane	C14	<MDL	<MDL	<MDL	<MDL
n-Pentadecane	C15	<MDL	<MDL	<MDL	<MDL
n-Hexadecane	C16	<MDL	<MDL	8.1	29
n-Heptadecane	C17	<MDL	22	21	130
Pristane		<MDL	12	5.4	90
n-Octadecane	C18	<MDL	19	33	170
Phytane		<MDL	17	<MDL	220
n-Nonadecane	C19	<MDL	20	66	300
n-Eicosane	C20	<MDL	11	36	330
n-Heneicosane	C21	<MDL	14	94	630
n-Docosane	C22	<MDL	12	120	970
n-Tricosane	C23	<MDL	9.6	100	1600
n-Tetracosane	C24	<MDL	<MDL	18	2100
n-Pentacosane	C25	<MDL	<MDL	59	1400
n-Hexacosane	C26	<MDL	32	44	800
n-Heptacosane	C27	<MDL	55	50	920
n-Octacosane	C28	<MDL	49	15	<MDL
n-Nonacosane	C29	<MDL	66	17	<MDL
n-Triacotane	C30	<MDL	53	<MDL	<MDL
n-Dotriacontane	C32	<MDL	200	<MDL	<MDL
n-Tritriacotane	C33	<MDL	<MDL	<MDL	<MDL
n-Tetratriacontane	C34	<MDL	<MDL	<MDL	<MDL
n-Hexatriacontane	C36	<MDL	<MDL	<MDL	<MDL

Table 65. Method blanks for PAH.

Analyte	Sediment Set #1 ng/g	Sediment Set #2 ng/g	Sediment Set #3 ng/g	Tissue ng/g
Naphthalene	<MDL	<MDL	<MDL	<MDL
1-Methylnaphthalene	<MDL	<MDL	<MDL	<MDL
Biphenyl	<MDL	<MDL	<MDL	<MDL
1-Ethylnaphthalene	<MDL	<MDL	<MDL	<MDL
Acenaphthylene	<MDL	<MDL	<MDL	<MDL
3-Methyl-1,1'-biphenyl	<MDL	<MDL	<MDL	<MDL
Fluorene	<MDL	<MDL	<MDL	<MDL
Acenaphthene	<MDL	<MDL	<MDL	<MDL
4-Ethylbiphenyl	<MDL	<MDL	<MDL	<MDL
9-Ethylfluorene	<MDL	<MDL	<MDL	<MDL
1-Methylfluorene	<MDL	<MDL	<MDL	<MDL
Dibenzothiophene	<MDL	<MDL	<MDL	<MDL
Phenanthrene	<MDL	<MDL	0.34	<MDL
Anthracene	<MDL	<MDL	<MDL	<MDL
2-Methylphenanthrene	<MDL	<MDL	<MDL	<MDL
9-Methylanthracene	<MDL	<MDL	<MDL	<MDL
2-Ethylanthracene	<MDL	<MDL	<MDL	<MDL
Fluoranthene	<MDL	<MDL	<MDL	<MDL
Pyrene	<MDL	<MDL	<MDL	<MDL
2-Tertbutylanthracene	<MDL	<MDL	<MDL	<MDL
Benzo(a)anthracene	<MDL	<MDL	<MDL	<MDL
Chrysene	<MDL	<MDL	<MDL	<MDL
Benzo(b)fluoranthene	<MDL	<MDL	<MDL	31
Benzo(k)fluoranthene	<MDL	<MDL	<MDL	65
Benzo(a)pryene	<MDL	<MDL	<MDL	56
Perylene	<MDL	<MDL	<MDL	<MDL
Indeno(1,2,3-cd)pyrene	<MDL	<MDL	<MDL	<MDL
Dibenz(a,h)anthracene	<MDL	<MDL	<MDL	<MDL
Benzo(g,h,i)perylene	<MDL	<MDL	<MDL	<MDL

tissue samples (Tables 66–68). Surrogate recoveries for the three alkane analogues were in the range of 18.6% to 102.6% for water samples, 32.8% to 101.3% for sediment samples, and 16.8% to 85.7% for tissue samples (Tables 66–68). A few samples, especially those for tissues, were somewhat low (<20%), but overall surrogate recovery was acceptable.

Table 66. Surrogate recoveries from seawater samples.

Sample No.	Station	Tide[1]	PAH % Recovery			Alkanes % Recovery		
			Acenaphthalene	Chrysene	Perylene	n-Dodecane	n-Eicosane	n-Triacontane
2001	30	F	15.7	21.9	21.2	23.1	18.6	31.7
2002	30	R	59.7	71.1	66.5	83.2	58.7	82.2
2003	3	R	52.9	69.5	63.9	66.6	58.4	78.6
2004	3	R	55.0	69.7	65.8	75.8	57.1	78.0
2005	3	R	55.4	70.5	64.9	78.9	60.5	82.8
2006	3	F	56.8	75.5	62.1	86.3	62.8	86.2
2007b	3	F	48.6	67.9	63.9	72.7	60.4	84.6
2008b	3	F	61.9	70.1	63.9	84.4	59.5	85.6
2007	E	R	47.7	62.8	57.6	45.5	50.5	75.9
2008	E	F	56.3	76.7	72.8	83.8	65.7	103.2
2009	B	F	68.1	79.1	73.5	102.6	70.1	97.3
2010	B	R	35.0	67.3	61.6	21.8	56.5	81.2
2011	A	R	54.8	77.2	68.9	89.2	61.6	89.6
2012	C	F	67.8	72.5	65.9	87.5	60.8	81.1
2013	A	F	67.8	70.4	63.0	81.5	60.5	82.1
2016	F	F	69.7	82.8	75.4	95.1	69.5	90.7
2017	211		64.9	85.2	79.7	82.1	71.9	96.8

[1] R = rising, F = falling.

Table 67. Surrogate recoveries from sediment samples.

Sample No.	Station	PAH % Recovery			Alkanes % Recovery		
		Acenaphthalene	Chrysene	Perylene	n-Dodecane	n-Eicosane	n-Triacontane
2003	Alt E	63.0	73.6	76.0	90.0	61.0	79.4
2005	C	51.3	68.4	63.8	76.8	41.7	91.8
2006	Alt A	63.7	77.9	74.2	98.6	35.9	94.7
2007	27	66.2	81.6	77.3	86.1	65.9	106.5
2009	F	61.7	78.1	78.3	75.7	63.7	89.5
2010	16B	62.9	78.7	80.9	87.7	68.6	96.8
2012	New E5	57.7	75.5	58.8	90.9	39.9	81.0
2013A	233	61.1	78.2	64.9	98.0	66.0	97.4
2013C	233	60.4	71.8	61.8	84.6	55.6	81.9
2014	New E6	60.9	81.5	80.2	78.1	64.8	93.5
2015	Alt 30	63.8	80.6	79.9	80.8	32.8	94.3
2016	227	45.3	61.6	53.4	67.6	42.5	70.9
2017	New E7	68.4	72.3	65.9	92.6	65.4	77.7
2018	New E8	66.0	78.0	73.4	86.4	64.1	87.4
2019	Alt 265	64.4	74.0	70.9	86.9	44.2	81.8
2020	Alt 22	69.3	81.3	68.7	101.3	45.8	93.0
2021A	Alt 23	66.7	79.4	70.4	96.1	67.3	88.5
2021B	Alt 23	65.5	77.6	68.4	85.6	44.9	88.2
2021C	Alt 23	60.6	70.6	62.9	89.4	59.6	83.5

Table 68. Surrogate recoveries from tissue samples.

Sample No.	Station	PAH % Recovery			Alkanes % Recovery		
		Acenaphthalene	Chrysene	Perylene	n-Dodecane	n-Eicosane	n-Triacontane
2001	Tuxedni Bay	32.7	14.7	13.8	42.0	38.6	70.1
2002	Fossil Point	61.3	44.0	45.8	46.3	50.0	85.7
2003	Chinitna Bay	66.4	44.8	46.6	47.4	50.3	82.7
2004	Jakolof Bay	16.9	9.5	9.6	17.6	16.8	31.0
2005	Kasitsna Bay	22.9	12.5	13.2	28.2	25.0	45.4
2006	Homer	32.0	14.8	14.7	41.1	35.5	64.3

DISCUSSION 5

Table 69 summarizes the chemical, physical, and bioassay results of the 1993 ENRI Cook Inlet water quality study. Examination of these data shows the inlet has very low concentrations of hydrocarbons and that sediments and water are generally nontoxic. The few samples that did show some evidence of possible toxicity had low hydrocarbon concentrations; therefore, it is reasonable to conclude the measured toxicities are related to factors other than hydrocarbon contamination.

Table 70 summarizes the results of the chemical and physical analyses for sediments by station. At most stations, three replicate grabs were taken for sediment. A fair amount of variance occurred in hydrocarbon concentrations for the replicates at a few stations, especially at station Alt 30 for PAH. One sample from this station (2015A) had a much higher concentration of PAH than the others, but this is not related to grain size since percentages of silts and clays in the replicate samples are similar. Station 227 also had a high variance in PAH, and sample 2016A was both relatively high in PAH and in silt and clay components. A good deal of variation in saturated hydrocarbon concentration was found between stations, but this is not surprising given the low concentrations encountered. Most of the grain-size distribution was uniform except at stations Alt 30 and 227 in the lower inlet.

TOC and sediment grain size were collected as paired concomitant replicates with the sediment PAH and saturated hydrocarbon samples. These data were collected as possible parameters to aid in accounting for some of the PAH and saturated hydrocarbon variability, as pollutant data are often correlated with both fine sediment and organic matter. To determine the correlation with the hydrocarbon data, linear regression was performed on the raw data. The regression analysis compared the independent variables (TOC and fines) against the possible dependant variables (TPAH and TALK) to determine the correlation coefficient and R^2 values. The R^2 value can range from 0 (no linear relationship) to 1 (perfect linear relationship) between two variables.

Pearson's correlation (r) analysis was also used to examine the association between the variables. These were run on both raw and transformed data. Raw TPAH and TALK data were subject to logarithmic transformation using $\log_{10}(x + 1)$, where x represents a parameter's value. Proportioned data, such as TOC and fines, are inherently binomial in distribution and were processed using an arc sine transformation prior to data analysis (Zar 1984). The hypothesis that any two variables are not correlated was tested as a paired t-test for means.

Correlation and regression analyses with the raw data for TPAH, TALK, fines, and TOC showed that only TPAH and TOC had any linear relationship ($r = 0.92$, $R^2 = 0.85$) (Table 71). The correlations run on the transformed data showed TPAH and TOC appear to be the most linearly related parameters but to a lesser degree than shown for the raw data (Table 71). The t-test for significance of correlation between hydrocarbons (TPAH and TALK) showed no significance to fines or TOC (Table 71). If an adjusted probability or less stringent P was used, a significance could be established between TPAH and TOC, which was shown in the linear regression.

Sediments from two stations (C and 227) showed a statistically significant lower amphipod survival than controls, but these sediments did not have elevated levels of hydrocarbons. In each case, the toxicity value derived was low. The cause of the amphipod toxicity results is unknown. There could be a causal relationship to grain size in the case of station 227, as this station had an elevated quantity of silt and clay in the sediment (Table 70). Station 227 sediment also exhibited measurable toxicity in the Microtox® test (Table 69). However, the sperm-fertilization toxicity test for the pore-water sample from this station showed no toxicity.

Table 69. Summary of physical, chemical, and bioassay results.

Station	SEDIMENT/PORE WATER										RECEIVING WATER			
				Grain Size[1] %				Bioassays					Bioassays	
	TPAH[1] ng/g	TALK[1] ng/g	TOC %	Gravel	Sand	Silt	Clay	Amphipod Survival %	Fertilization %	Microtox® EC50	TSS mg/L	TALK ng/g	Larval Survival %	Fertilization %
E	0	1615	0.49	35.0	54.0	12.0	0.0	100	98.4	>2	255	2.1	90	79.0
C	0	876	0.61	0.0	97.7	2.3	0.0	82	96.6		95	1.0	96	94.2
A	0	240	0.12	1.7	93.0	4.0	0.0	96	99.8	>2	128	0.9	89	94.0
27	0	62	0.05	0.5	94.7	5.0	0.0	99	99.8	>2				
F	0	457	0.58	0.0	98.0	1.7	0.1	92	41.4	1.60	10	0.8	97	96.2
16B	2	856	0.17	0.0	98.0	1.7	0.0	99	51.0	1.25				
E5	16	1453	0.1	2.7	90.0	3.7	3.3							
233	6	1613	0.58	0.0	99.0	1.0	0.0	94	100.0	1.91				
E6	2	720	0.19	3.0	85.0	7.3	3.7							
30	329	458	4.09	24.7	75.0	0.1	0.0				6	1.8	97	92.6
227	100	1369	1.43	0.0	89.7	8.0	2.0	78	98.8	0.86				
E7	22	2666	1.59	5.7	94.3	0.1	0.0	97		>2				
E8	3	1044	0.69	0.2	86.3	13.0	0.0	100		>2				
265	1	484	0.08	0.1	99.0	0.1	0.0	99		>2				
22	2	854	0.37	0.0	98.7	1.3	0.1	91	27.6	1.32				
23	0	186	0.13	0.4	99.3	0.4	0.0							
3											12	2.8	86	94.6
B											288	1.9	91	78.4
211												4.1	87	99.0

[1] Mean values.

Table 70. Chemical and physical results for sediment replicate samples.

Sample No.	Station	HYDROCARBONS ng/g						GRAIN SIZE %											
		TPAH	AVG	S.D.	TALK	AVG	S.D.	GRAVEL	AVG	S.D.	SAND	AVG	S.D.	SILT	AVG	S.D.	CLAY	AVG	S.D.
2003	Alt E	0.0			1615			35.0			54.0			12.0			0.0		
2005	C	0.0			876			0.0			97.7			2.3			0.0		
2006	Alt A	0.0			240			1.7			93.0			4.0			0.8		
2007	27	0.0			62			0.5			94.7			5.0			0.0		
2009	F	0.0			608	457	151	0.0	0.0	0.0	99.0	98.0	0.5	1.0	1.7	0.5	0.0	0.1	0.2
2009	F	0.0			306			0.0			98.0			2.0			0.3		
2010A	16B	0.0	2.0	2.8	217	856	538	0.0	0.0	0.0	99.0	98.0	0.6	1.0	1.7	0.5	0.0	0.0	0.0
2010B	16B	5.9			1534			0.0			98.0			2.0			0.0		
2010C	16B	0.0			817			0.0			97.5			2.0			0.1		
2012A	New E5	20.0	14.6	5.7	2217	1453	540	1.0	2.7	1.7	97.0	90.0	5.7	1.0	3.7	1.9	0.0	3.3	4.7
2012B	New E5	6.7			1085			5.0			90.0			5.0			0.0		
2012C	New E5	17.0			1057			2.0			83.0			5.0			10.0		
2013A	233	5.0	5.8	1.0	608	1613	863	0.0	0.0	0.0	99.0	99.0	0.0	0.5	1.0	0.2	0.0	0.0	0.0
2013B	233	7.3			1517			0.0			99.0			1.0			0.0		
2013C	233	5.2			2715			0.0			99.0			1.0			0.0		
2014A	New E6	3.3	2.5	1.8	742	720	348	7.0	3.0	2.4	83.0	85.0	2.2	7.0	7.3	0.5	3.0	3.7	1.7
2014B	New E6	0.0			284			2.0			88.0			7.0			2.0		
2014C	New E6	4.1			1135			2.0			84.0			8.0			6.0		
2015A	Alt 30	956.0	328.1	444.1	793	458	237	16.0	24.7	14.4	83.0	75.0	13.5	0.2	0.1	0.0	0.0	0.0	0.0
2015B	Alt 30	28.4			296			13.0			86.0			0.1			0.0		
2015C	Alt 30	0.0			284			45.0			56.0			0.1			0.0		
2016A	227	226.6	86.9	99.0	2677	1369	925	0.0	0.0	0.0	75.0	89.7	10.4	20.0	8.0	8.5	5.0	2.0	2.1
2016B	227	25.5			728			0.0			97.0			2.0			0.1		
2016C	227	8.6			702			0.0			97.0			2.0			1.0		
2017A	New E7	0.0	21.6	20.4	1137	2666	1930	2.0	5.7	2.6	98.0	94.3	2.6	0.1	0.1	0.0	0.0	0.0	0.0
2017B	New E7	15.9			1472			8.0			92.0			0.0			0.0		
2017C	New E7	49.0			5388			7.0			93.0			0.1			0.0		
2018A	New E8	4.1	3.2	2.4	952	1044	674	2.0	0.2	0.9	96.0	86.3	7.1	2.0	13.0	8.0	0.0	0.0	0.0
2018B	New E8	0.0			269			0.3			79.0			21.0			0.0		
2018C	New E8	5.6			1912			0.1			84.0			16.0			0.0		
2019A	Alt 265	0.0	1.0	1.4	169	484	258	0.1	0.1	0.0	99.5	99.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0
2019B	Alt 265	2.9			800			0.2			99.0			0.1			0.0		
2019C	Alt 265	0.0			482			0.1			99.0			0.1			0.0		
2020A	Alt 22	4.7	1.6	2.2	1288	859	305	0.0	0.0	0.0	99.0	98.7	0.5	1.0	1.3	0.5	0.1	0.1	0.0
2020B	Alt 22	0.0			605			0.0			98.0			2.0			0.1		
2020C	Alt 22	0.0			683			0.0			99.0			1.0			0.0		
2021A	Alt 23	0.0	0.0	0.0	99	186	74	0.0	0.5	0.4	100.0	99.3	0.5	0.0	0.4	0.4	0.0	0.0	0.0
2021B	Alt 23	0.0			279			1.0			99.0			1.0			0.0		
2021C	Alt 23	0.0			180			0.4			99.0			0.1			0.0		

Table 71. Correlation and regression results for sediment samples.

	Raw Data					
	Pearson's Correlation (r)				Regression R^2	
Parameter	TPAH	TALK	Fines	TOC	TPAH	TALK
TPAH	1					
TALK	0.073	1				
Fines	0.0153	0.1394	1		0.000	0.109
TOC	0.924	0.2112	0.031	1	0.854	0.045

	Transformed Data			
	Pearson's Correlation (r)			
Parameter	TPAH	TALK	Fines	TOC
TPAH	1			
TALK	0.5529	1		
Fines	0.0895	0.1699	1	
TOC	0.6921	0.2112	0.031	1

	t-Test					
	Correlation (r)		P		Significance $P \geq 0.05$	
Sediment Variable	TPAH	TALK	TPAH	TALK	TPAH	TALK
Fines	0.090	0.170	7E-08	1E-05	NS	NS
TOC	0.692	0.486	0.010	0.009	NS	NS

Pore-water samples from three stations (F, 16B, and 22) exhibited significantly lower sperm-fertilization rates, and sediment samples exhibited Microtox® toxicity (EC50 <2%) (Table 69). Sediments from these stations showed no significant toxicity in the amphipod survival test. Results of bioassays for the stations suggest toxicity in the sediments could be associated with pore water. Hydrocarbon concentrations in both sediment and water samples from these stations were low and do not appear to contribute significantly to the measured toxicity. It is interesting to note that these stations are proximate to each other; station 22 is at the southern end of Kalgin Island, and stations F and 16B are due south of this location.

Hydrocarbons in solution or dispersion are much more bioavailable than hydrocarbons sorbed to sediments or detritus (Boehm et al. 1987). However, because sediments represent the most concentrated source of hydrocarbons in contaminated environments, they are a major source of chronic contamination of benthic fauna in oil-impacted areas. Since mussels are filter-feeding bivalves that accumulate petroleum hydrocarbons primarily from the water column, it is not surprising the concentrations found in mussel tissues during this study were low. Low concentrations of aromatic hydrocarbons and low molecular weight alkanes found in the mussel tissue indicates the absence of acute levels of hydrocarbons in the water column. Data obtained in this study of Cook Inlet demonstrate no correlation between bioassays and hydrocarbon concentrations that would suggest hydrocarbons are present in the ecosystem at concentrations sufficient to pose a concern for possible toxicity to marine organisms.

The hydrography and transmissivity data correspond with what is generally known about Cook Inlet. Temperatures in the upper inlet reflect the inflow of the relatively warm rivers that drain into the inlet. The river water is warmer in summer (Cruise 2) than it is in spring (Cruise 1) and varies from warmer in the north to cooler in the south. The salinity of Cook Inlet decreases from south to north because of the influx of fresh water from the rivers in the north. Southern Cook Inlet is strongly influenced by the higher saline Gulf of Alaska waters. Salinity in the northern portion of the inlet is lower in summer (higher river flow) than in spring (lower river flow). The transmissivity of northern Cook Inlet is nearly 0% due to the high sediment load. Transmissivity increases toward the south, which is highly influenced by Gulf of Alaska waters. In general, south of the forelands, the inlet widens and current velocities drop. The transmissivity in the southern inlet is nearly 100%. This is likely due to a combination of factors ranging from sedimentation to inflow of Gulf of Alaska waters.

Although some data are still being processed for metals in sediment and water and are unavailable for analysis, preliminary results show no immediate evidence of heavy metal pollution in Cook Inlet. There is, however, some evidence of elevated mercury levels in both water and sediment, especially in the upper inlet. This might be due to spring runoff and related instream sediment loads, which would transport metals from the land. Hydrocarbon concentrations are very low in the sediment and water samples from all stations and are well below those found at historic oil spill sites. They are within the range of concentrations observed in unpolluted offshore and coastal environments in various parts of the world (Reish 1993), as well as those in other parts of Alaska (Table 72).

Table 72. Range of hydrocarbon concentrations in Alaska coastal sediments.

Parameter	Beaufort Sea Boehm (1987)		Prince William Sound Kinnetics (1993)	
	Range ng/g	Mean	Range ng/g	Mean
TALK	780–19,000	5100	152–962	450
TPAH	10–640	120	14–395	173

Parameter	Cook Inlet					
	Hyland (1993)		Neff (1994)		ENRI (1994)	
	Range ng/g	Mean	Range ng/g	Mean	Range ng/g	Mean
TALK			1100–2600	1710	62–5388	935
TPAH	18–116	52	93–116	103	0–958	36

Concentrations of individual PAH compounds and various summed PAH parameters found were one or more orders of magnitude lower than the ER-L values for PAH derived by Long and Morgan (1990) (Table 73). ER-L values are the lowest concentrations of contaminants at which adverse biological effects on some marine organisms have been reported. It should be noted the highest values reported per station were used in this comparison. Most samples had PAH levels <MDL (see Table 73). Concentrations are also below the considerably lower thresholds (500 ng/g to 1000 ng/g) determined by the U.S. National Marine Fisheries Service in 1994 for toxic effects of sediment-associated PAHs on marine biota (Lomax et al. 1994).

Table 73. Comparisons of Cook Inlet sediment PAH concentrations to published ER-Ls.

PAH	ER-L (ng/g)	Cook Inlet (ng/g)
Acenapthene	150	<MDL
Anthracene	85	20
Benzo(a)anthracene	230	34
Benzo(a)pyrene	400	52
Chrysene	400	32
Dibenz(a,h)anthracene	60	190
Fluoranthene	600	89
Fluorene	35	8.6
Napthalene	340	16
Phenanthrene	225	82
Pyrene	350	82
TPAH	4000	958

ABBREVIATIONS, SIGNS, AND SYMBOLS 6

ATOMIC SYMBOLS

Actinium	Ac	Cadmium	Cd	Lead	Pb	Radon	Rn
Aluminum	Al	Carbon	C	Manganese	Mn	Silver	Ag
Antimony	Sb	Chromium	Cr	Mercury	Hg	Thallium	Tl
Arsenic	As	Cobalt	Co	Nickel	Ni	Thorium	Th
Barium	Ba	Copper	Cu	Nitrogen	N	Vanadium	V
Beryllium	Be	Hydrogen	H	Polonium	Po	Zinc	Zn
Bismuth	Bi	Iron	Fe	Radium	Ra		

CHEMISTRY

Carbon-hydrogen-nitrogen	CHN	Phi	ϕ
Carbon preference index	CPI	Polycyclic aromatic hydrocarbon	PAH
Effective concentration	EC	Practical salinity unit	PSU
Effective range low	ER-L	Total alkanes	TALK
Effective range medium	ER-M	Total organic carbon	TOC
Low molecular weight alkanes	LALK	Total petroleum hydrocarbon	TPH
Method detection limit	MDL	Total polycyclic aromatic hydrocarbons	TPAH
Molar	M	Total suspended solids	TSS
Naturally occurring radioactive materials	NORM	Volatile organic analyte	VOA

INSTRUMENTATION

Cold vapor atomic absorption	CVAA	Inductively coupled plasma	ICP
Gas chromatograph	GC	Flame atomic absorption	FAA
Global positioning system	GPS	Flame ionization detector	FID
Graphite flame atomic absorption	GFAA	Mass spectrometer	MS

PREFIXES

kilo (10^3)	k	milli (10^{-3})	m	micro (10^{-6})	μ	nano (10^{-9})	n

TIME AND TEMPERATURE

degrees Celsius	°C	hour	h	minute	min	second	s

WEIGHTS AND MEASURES

centimeter	cm	kilo-electron volt	keV	mile	mi
foot	ft	kilogram	kg	nautical mile	nmi
gallon	gal	liter	L	parts per billion	ppb
gram	g	meter	m	parts per million	ppm

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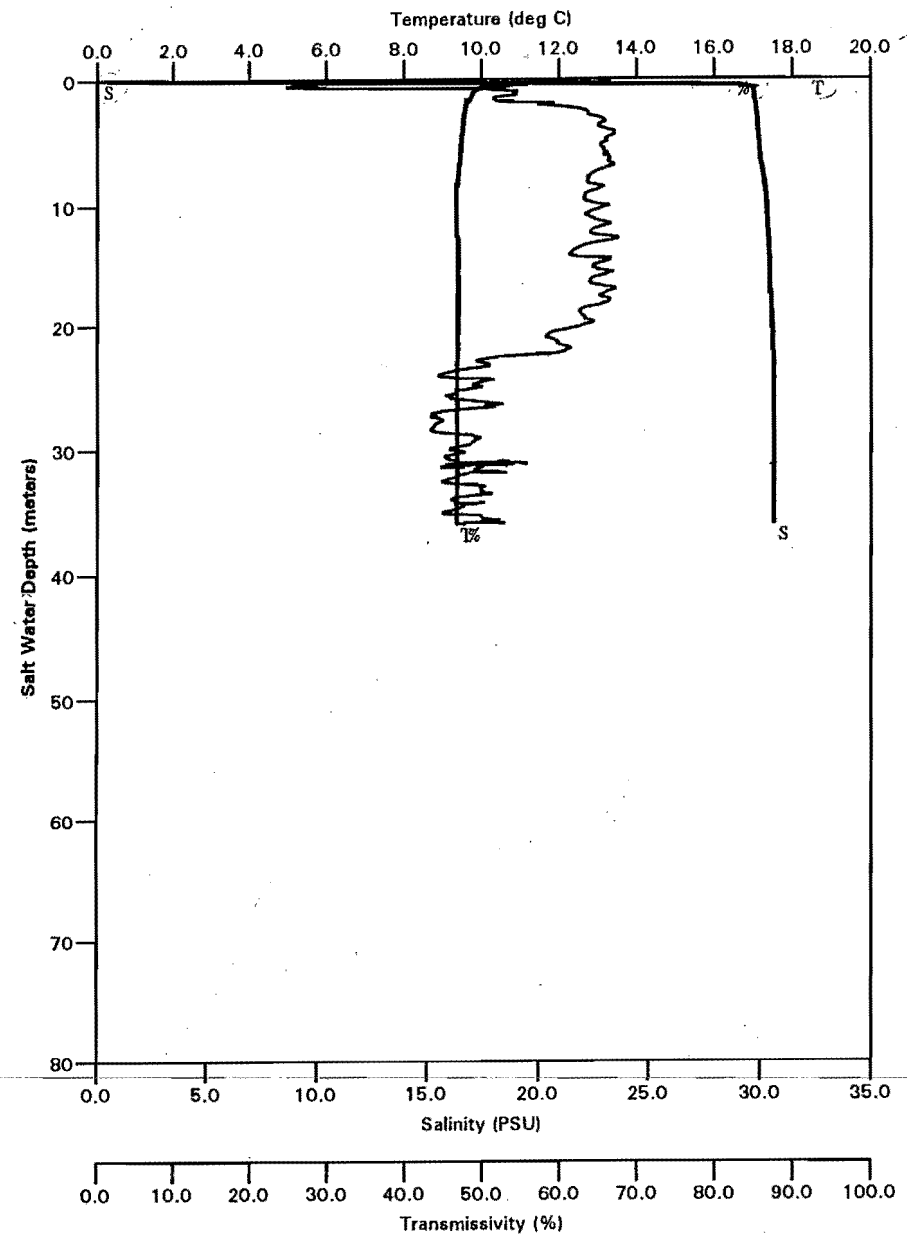
APPENDIX A
VERTICAL HYDROGRAPHIC PROFILES

Vertical profile plots for temperature, salinity, and transmissivity are presented in chronological order in this appendix. The shallowest and deepest value for each parameter are identified as T, S, and % for temperature, salinity, and transmissivity, respectively. Each plot indicates the station number, date, and time of the sample; data filename; and sequence number of the plot.

Cook Inlet (1993) - downcast



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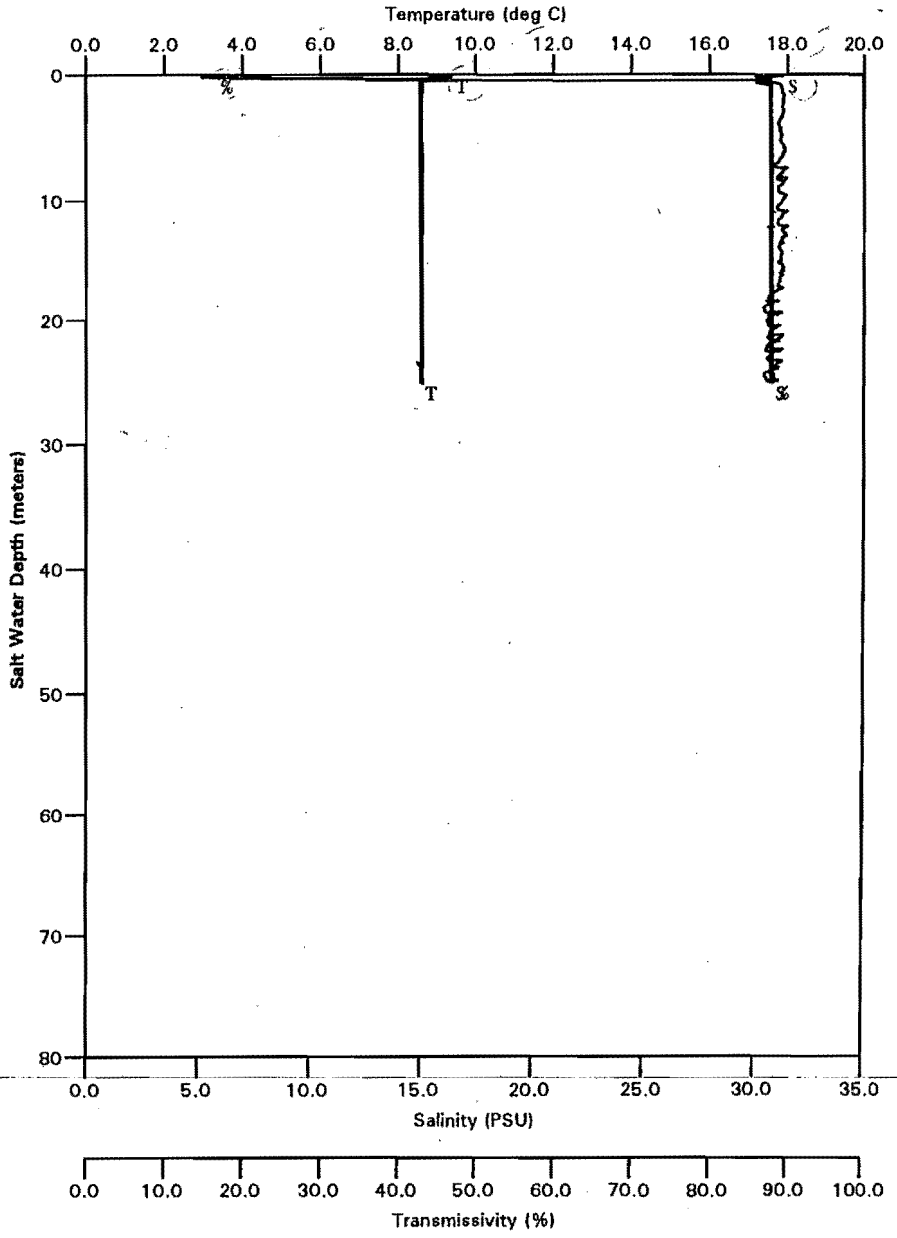
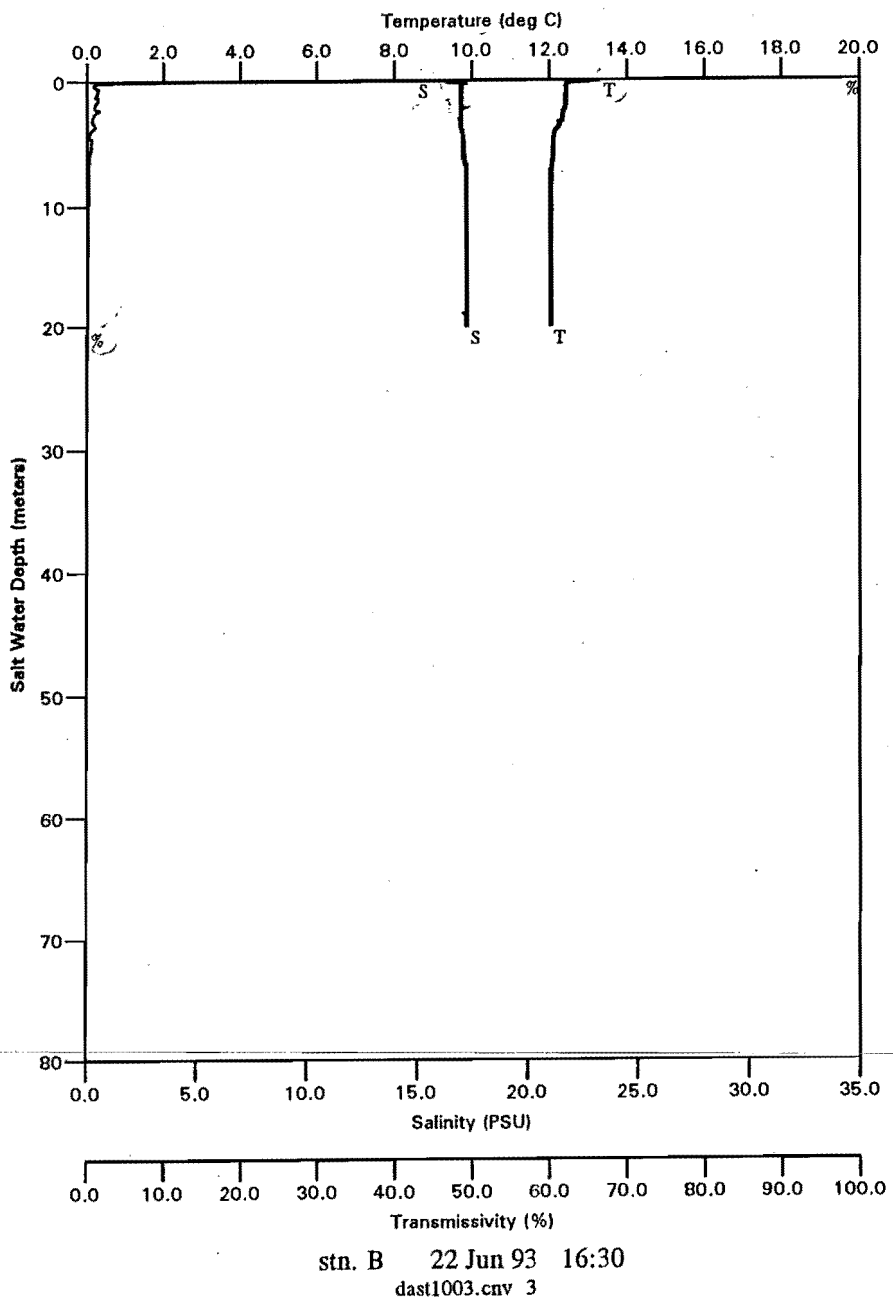


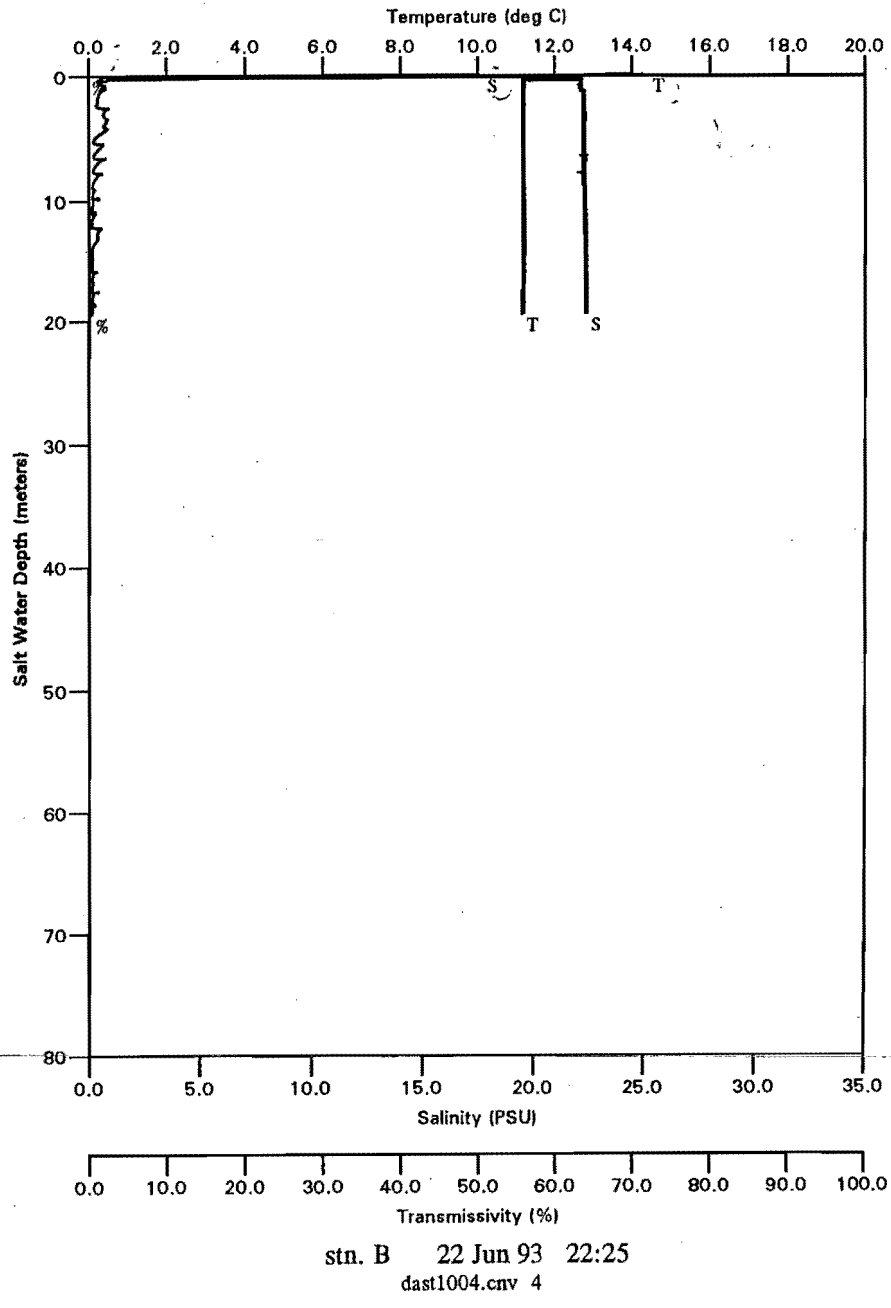
stn. 3 21 Jun 93 19:00
dast1002.cnv 2

A1

Cook Inlet (1993) - downcast



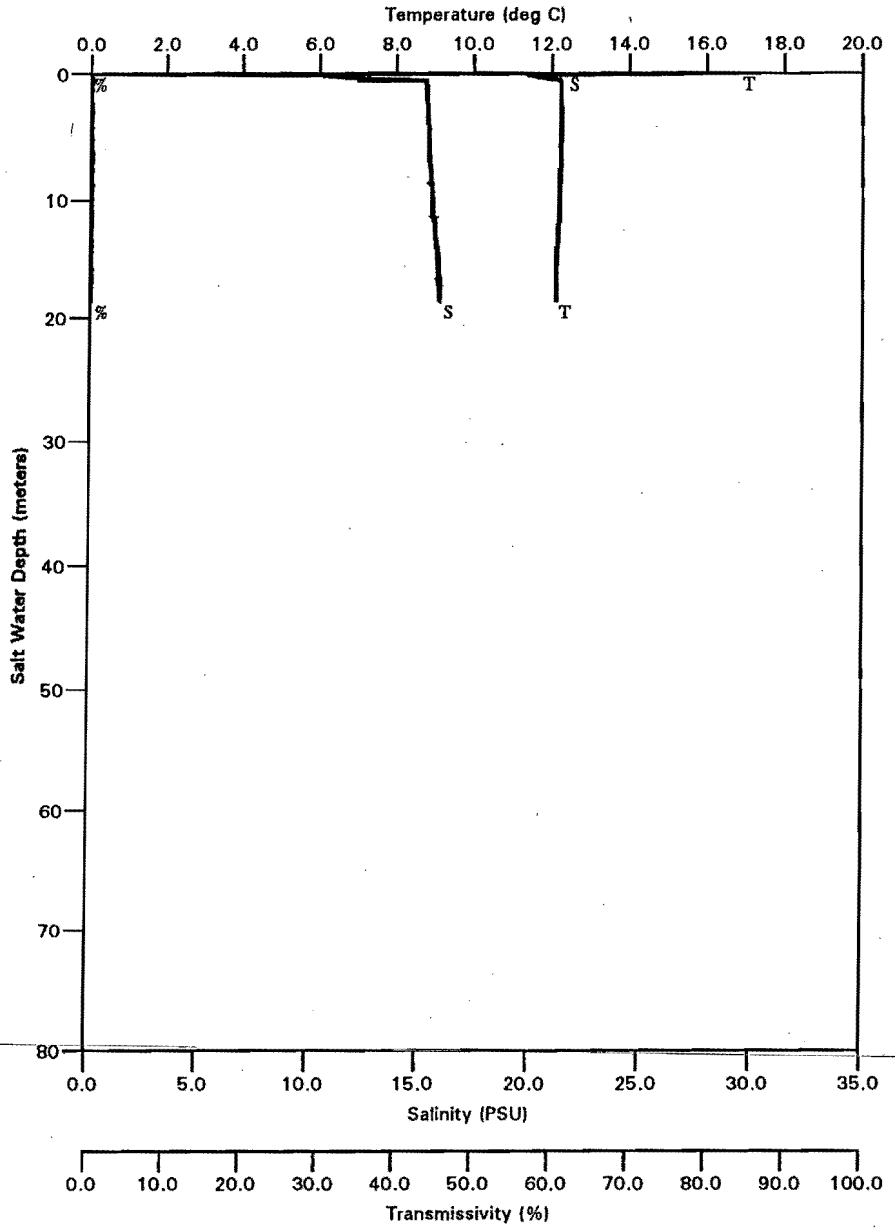
stn. B 22 Jun 93 16:30
dast1003.cnv 3



stn. B 22 Jun 93 22:25
dast1004.cnv 4

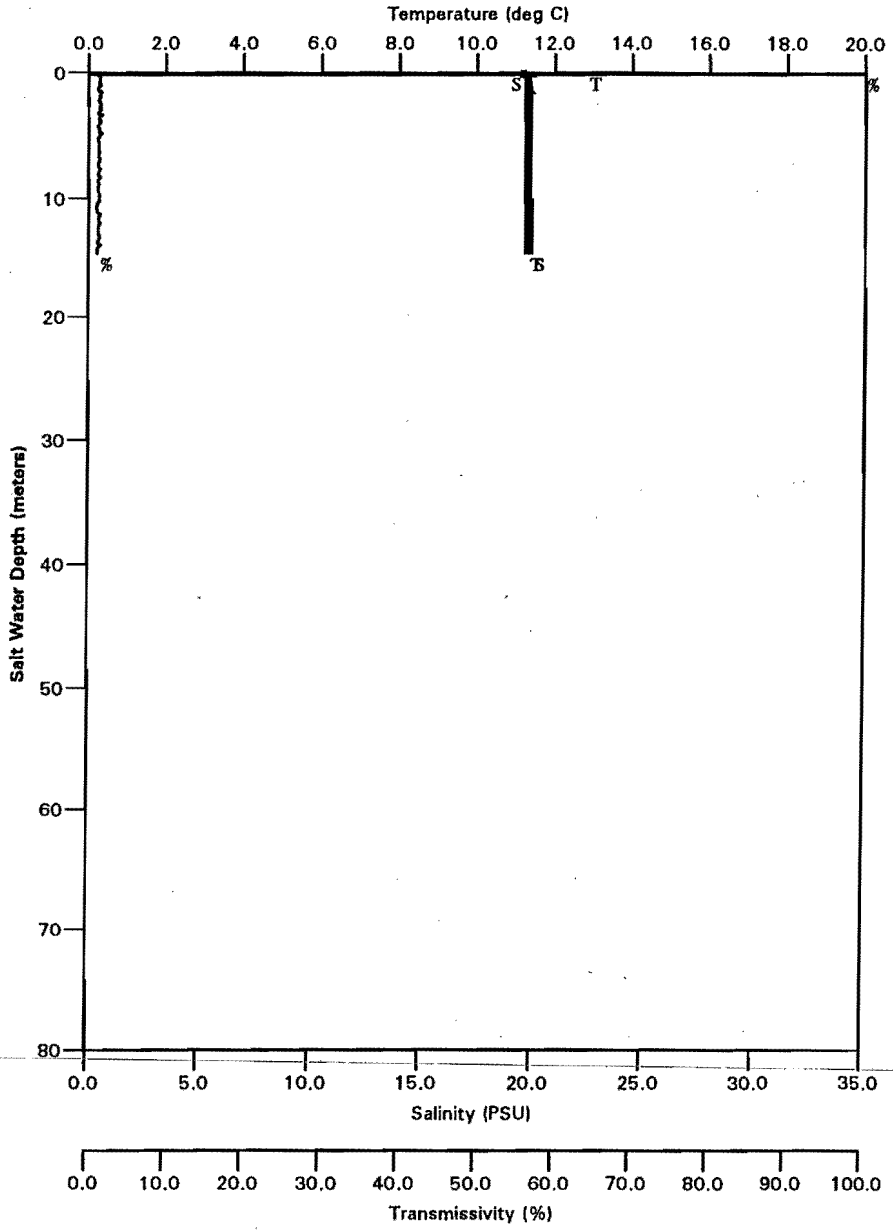
A2

Cook Inlet (1993) - downcast



stn. E 23 Jun 93 03:45

dast1005.cnv 5

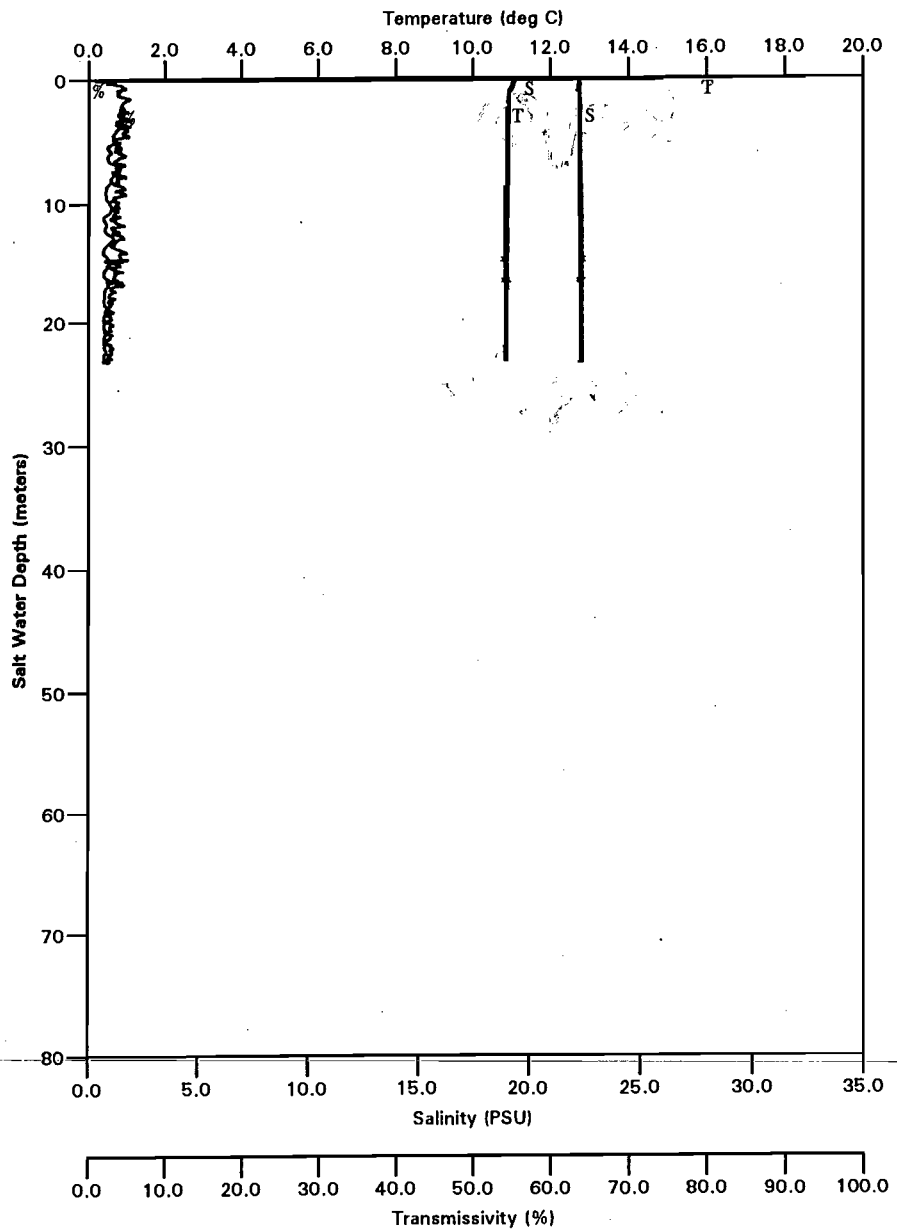


stn. E 23 Jun 93 08:45

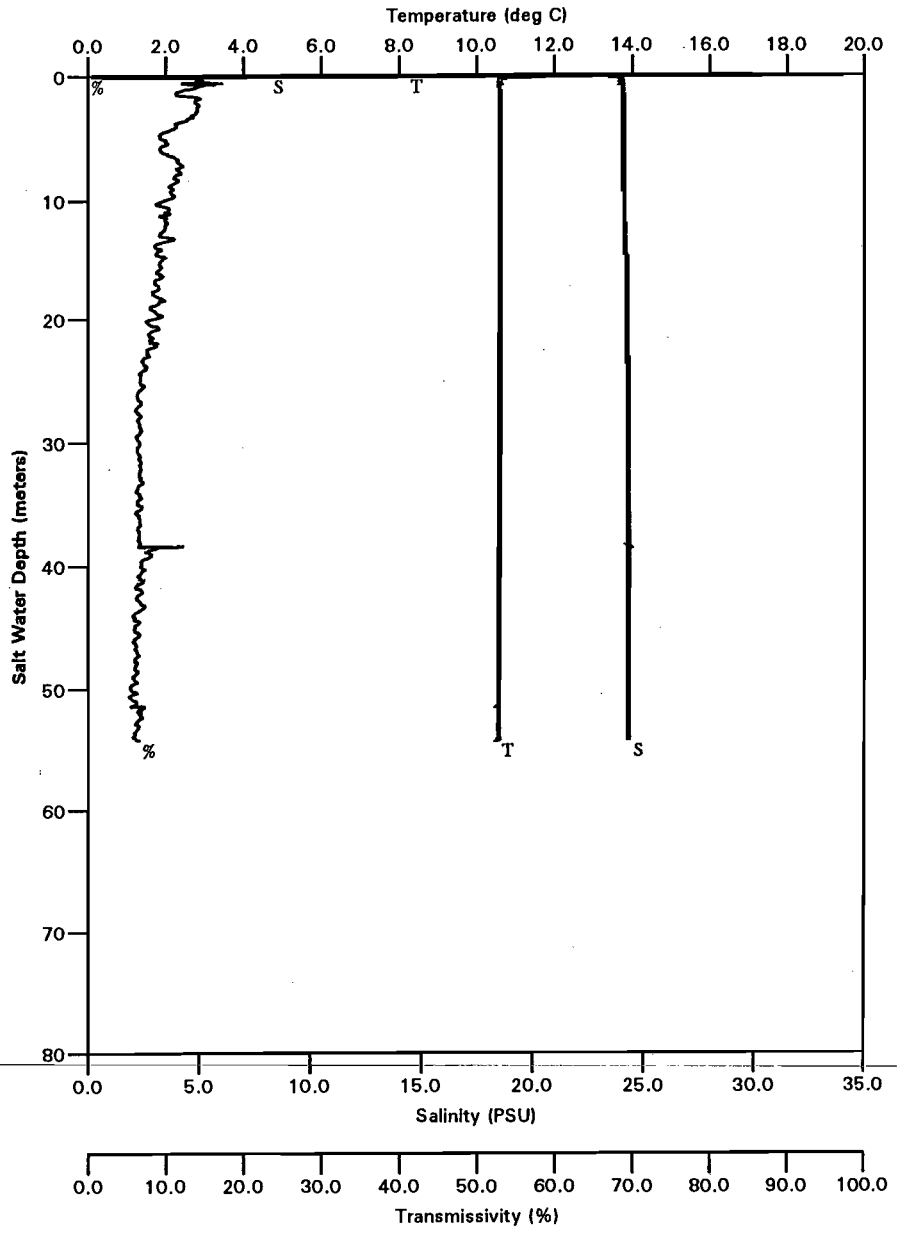
dast1006.cnv 6

A3

Cook Inlet (1993) - downcast



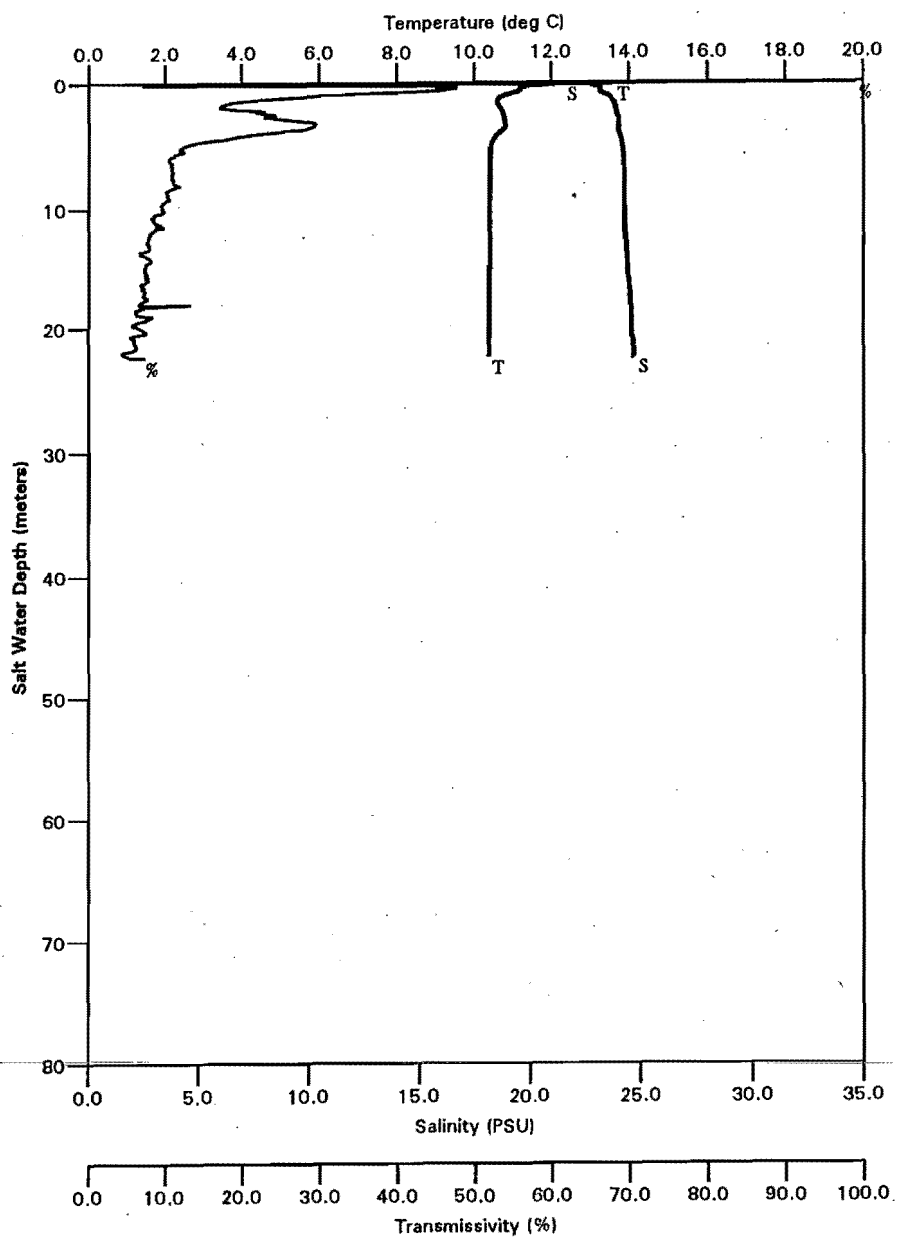
stn. C 24 Jun 93 15:45
dast108B.cnv 9



stn. A 24 Jun 93 23:50
dast1009.cnv 10

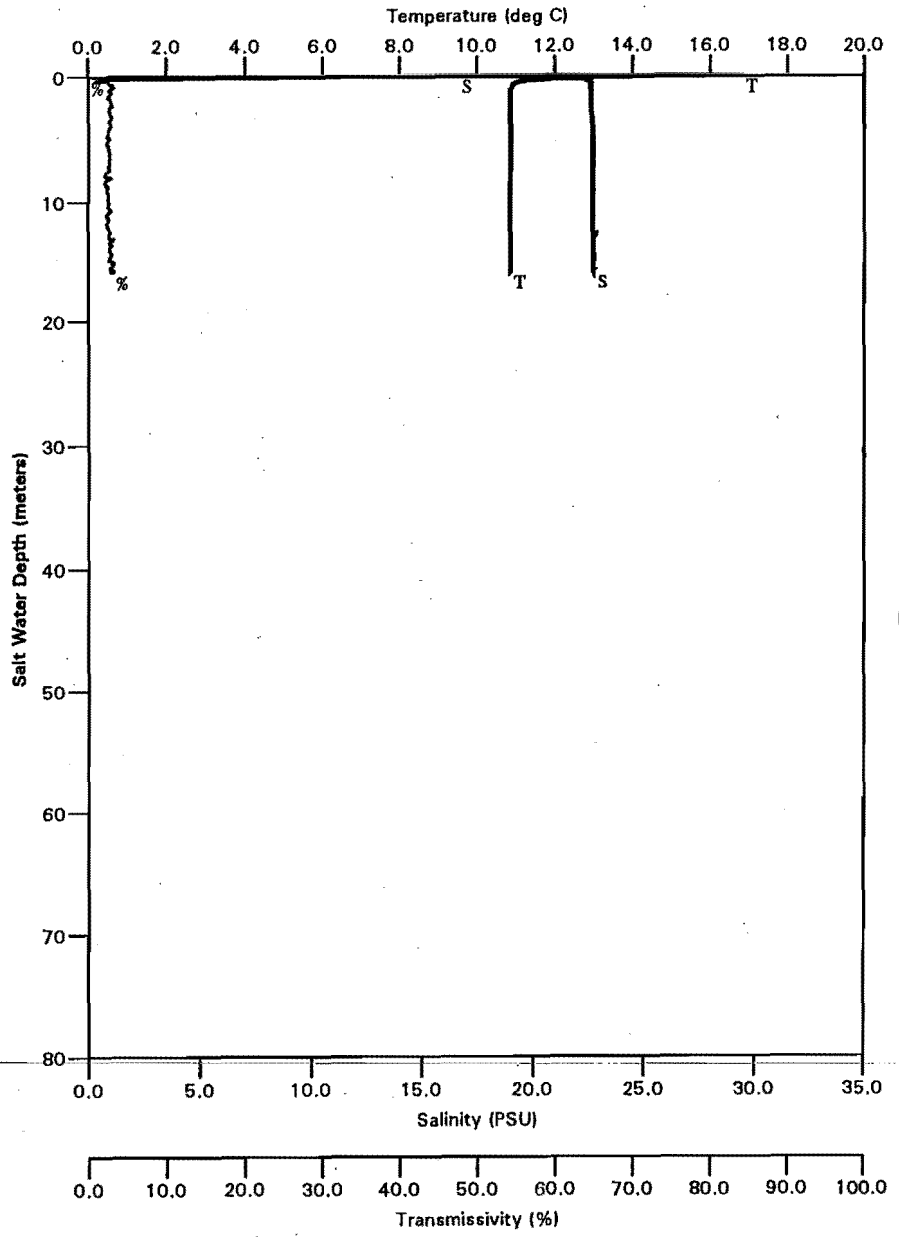
A 4

Cook Inlet (1993) - downcast



stn. C 24 Jun 93 10:00

dast1007.cnv 7

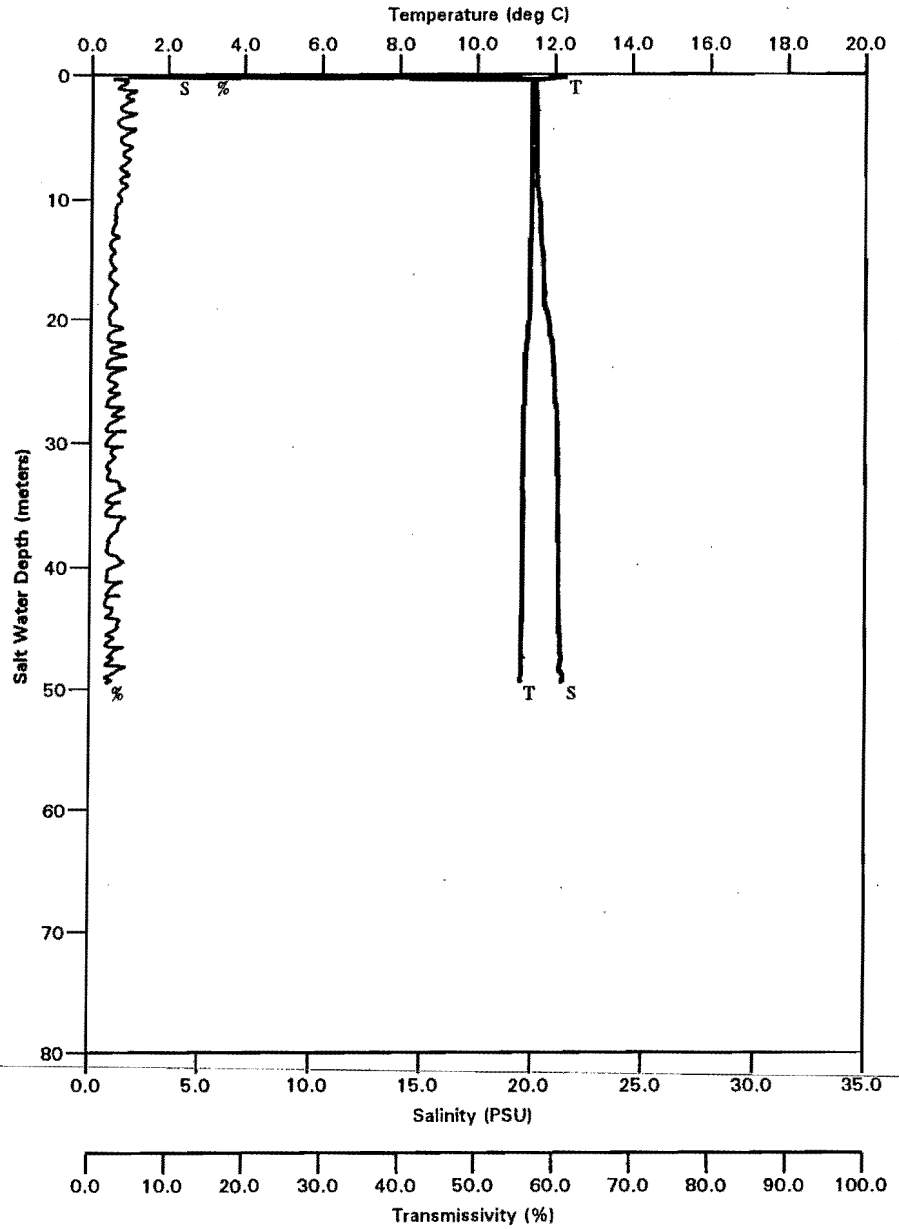


stn. C 24 Jun 93 15:40

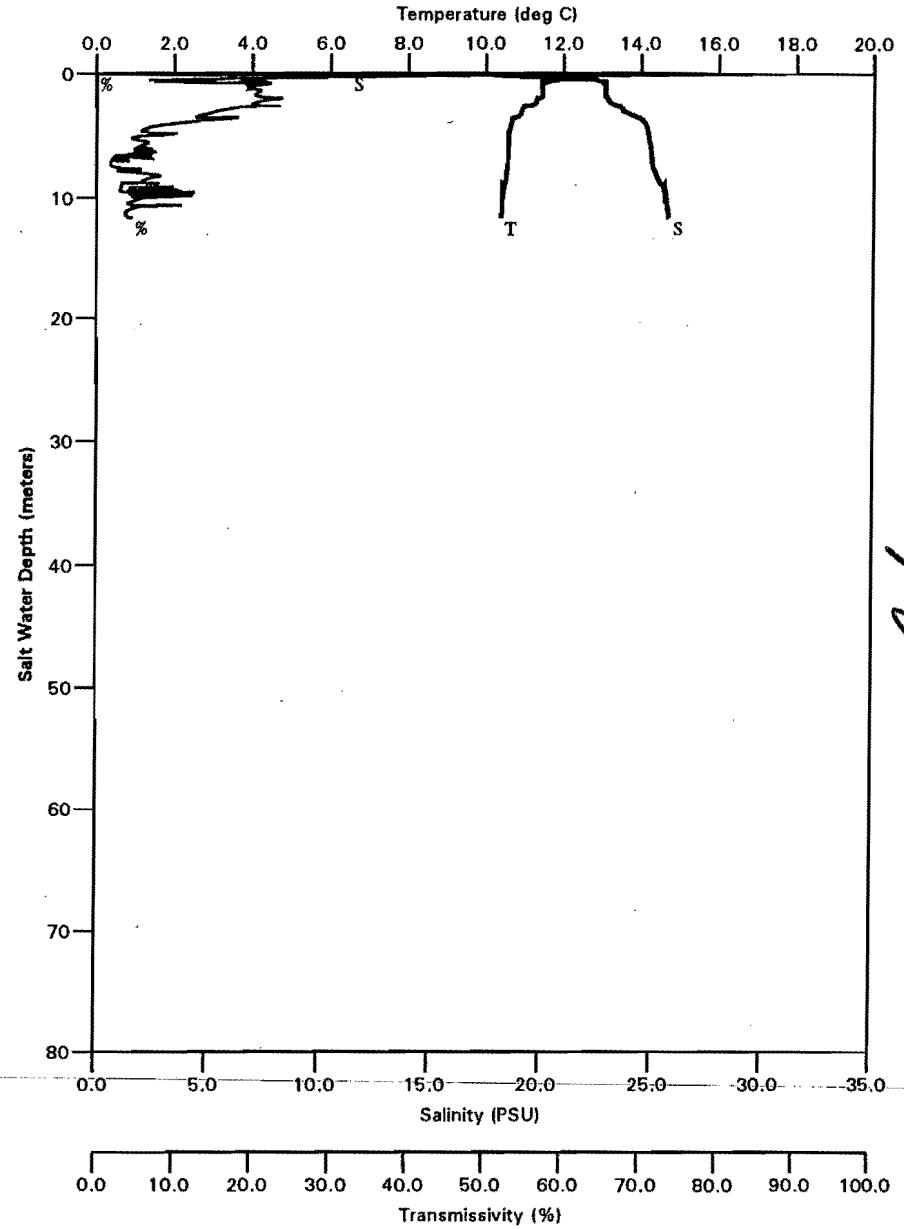
dast108A.cnv 8

A5

Cook Inlet (1993) - downcast



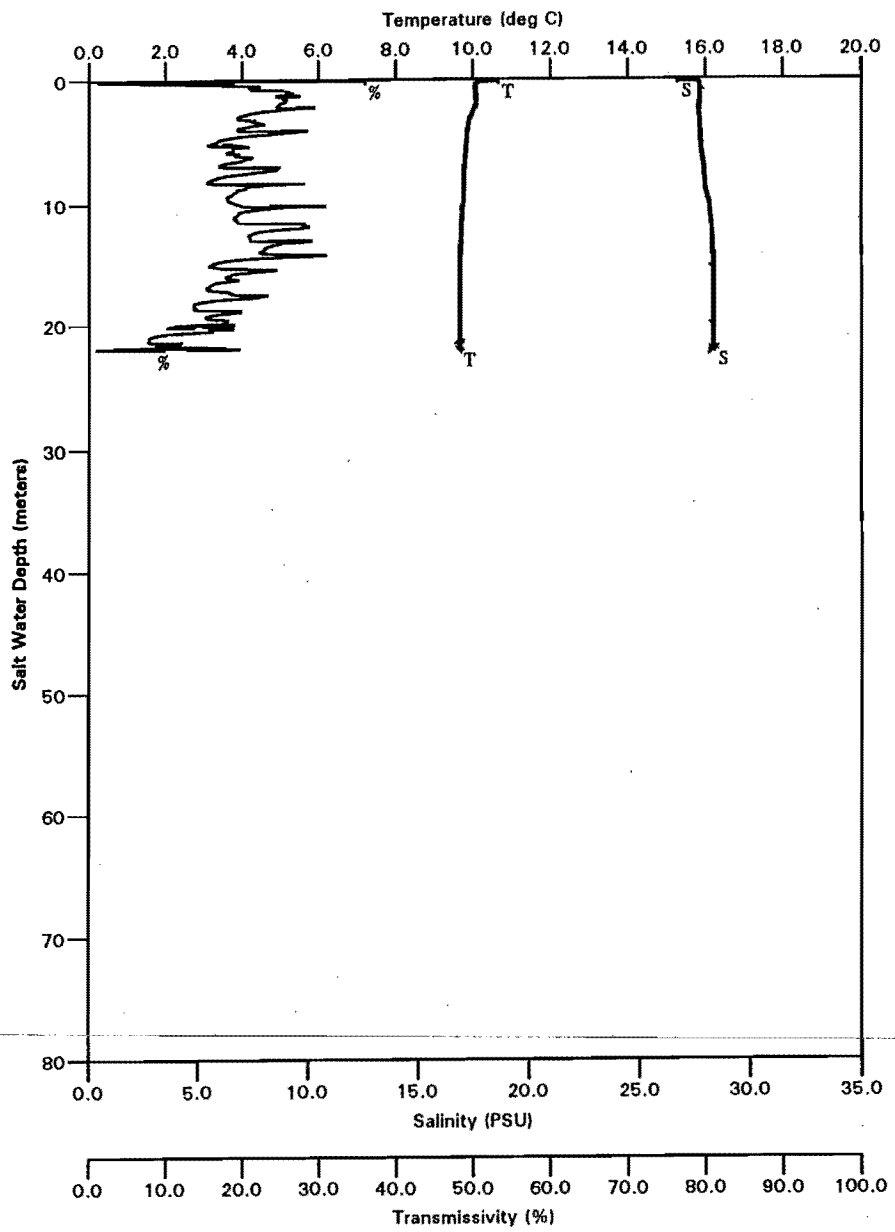
stn. A 25 Jun 93 06:10
dast1010.cnv 11



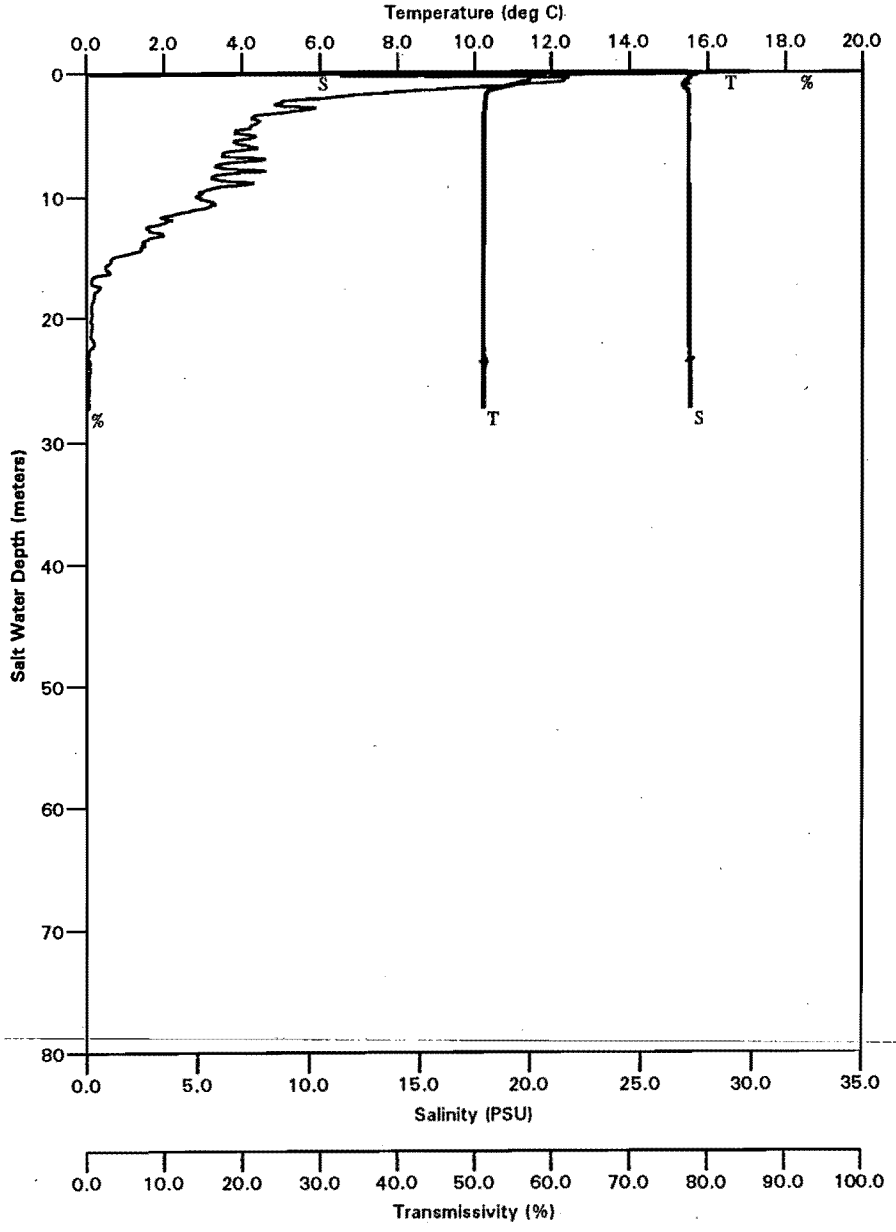
stn. 27 25 Jun 93
dast1011.cnv 12

A6

Cook Inlet (1993) - downcast



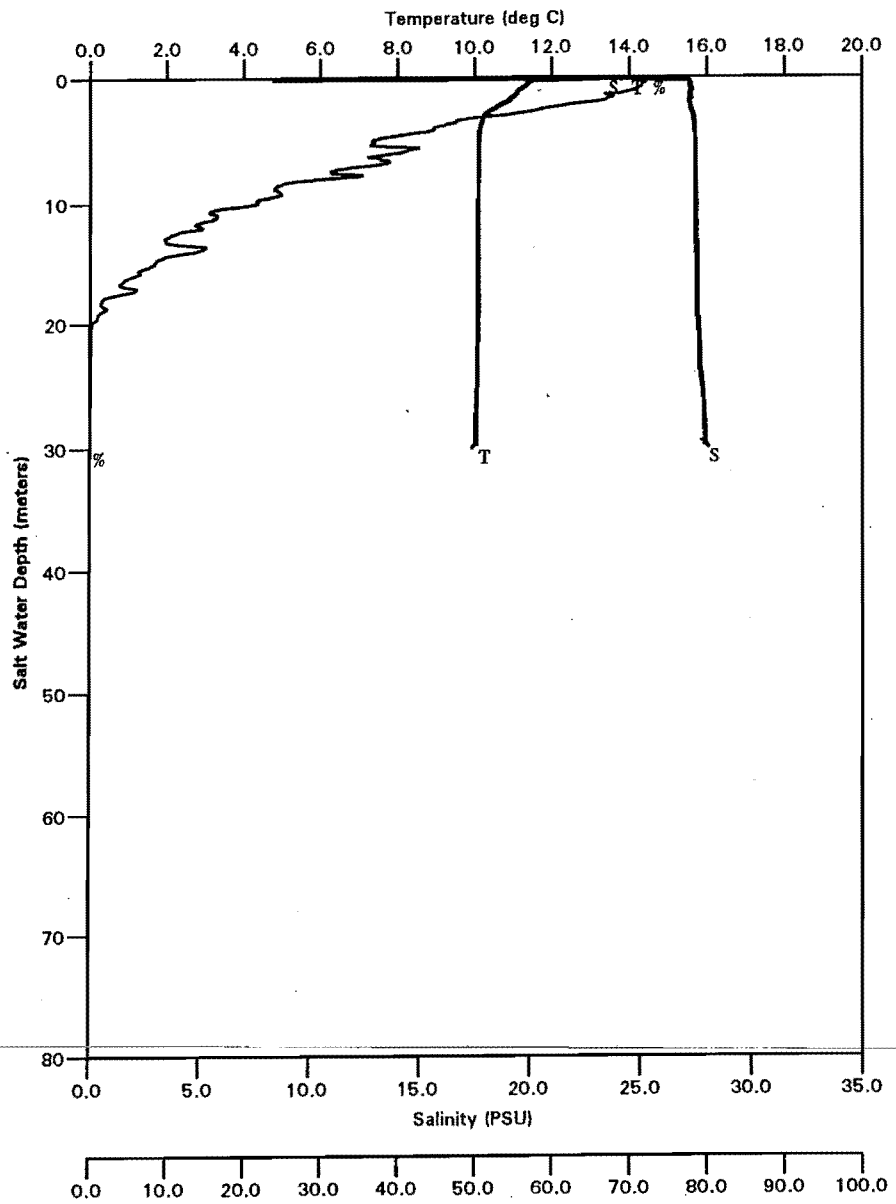
stn. 27-a 25 Jun 93 11:50
dast1012.cnv 13



stn. 2 26 Jun 93 13:47
dast1013.cnv 14

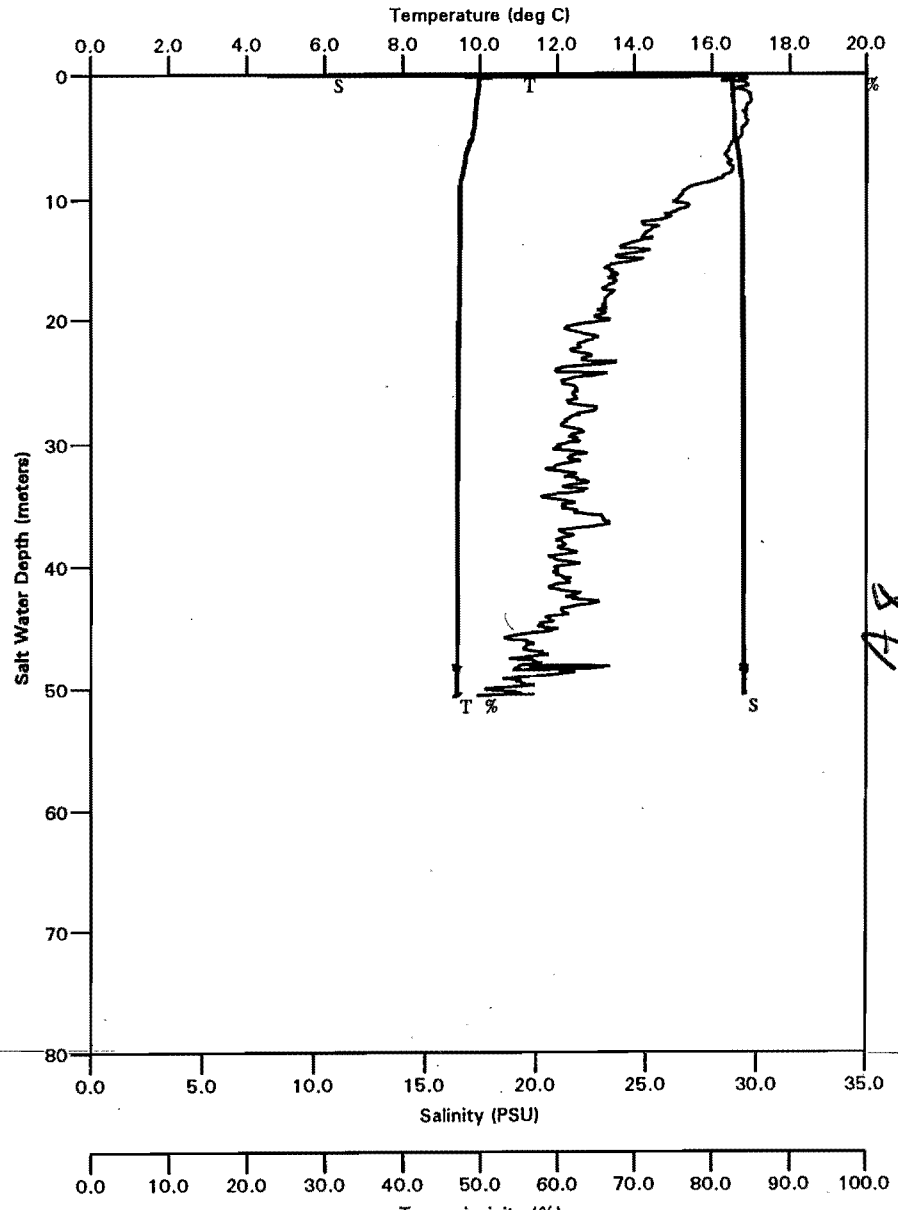
A2

Cook Inlet (1993) - downcast



stn. 255 26 Jun 93 14:51

dast1014.cnv 15

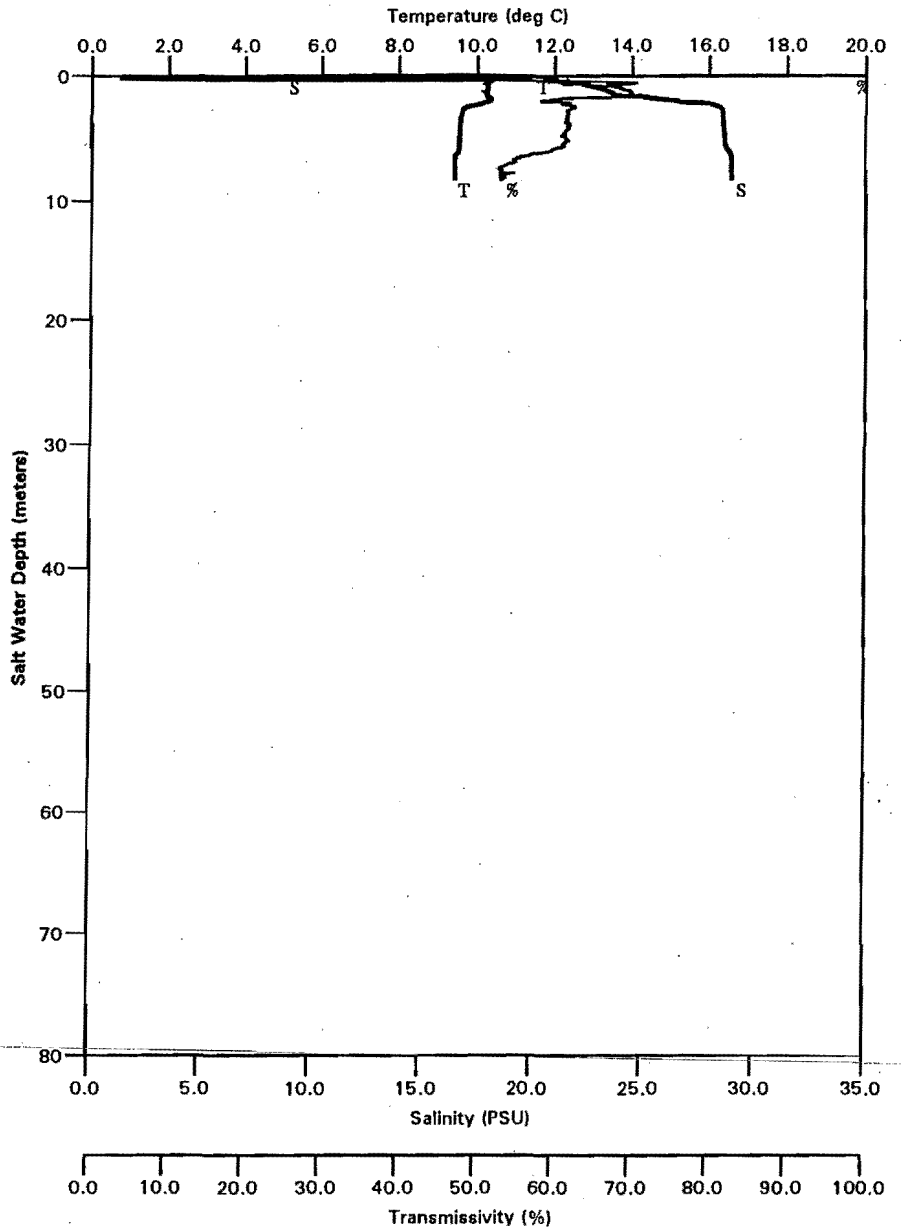


stn. F 26 Jun 93 17:30

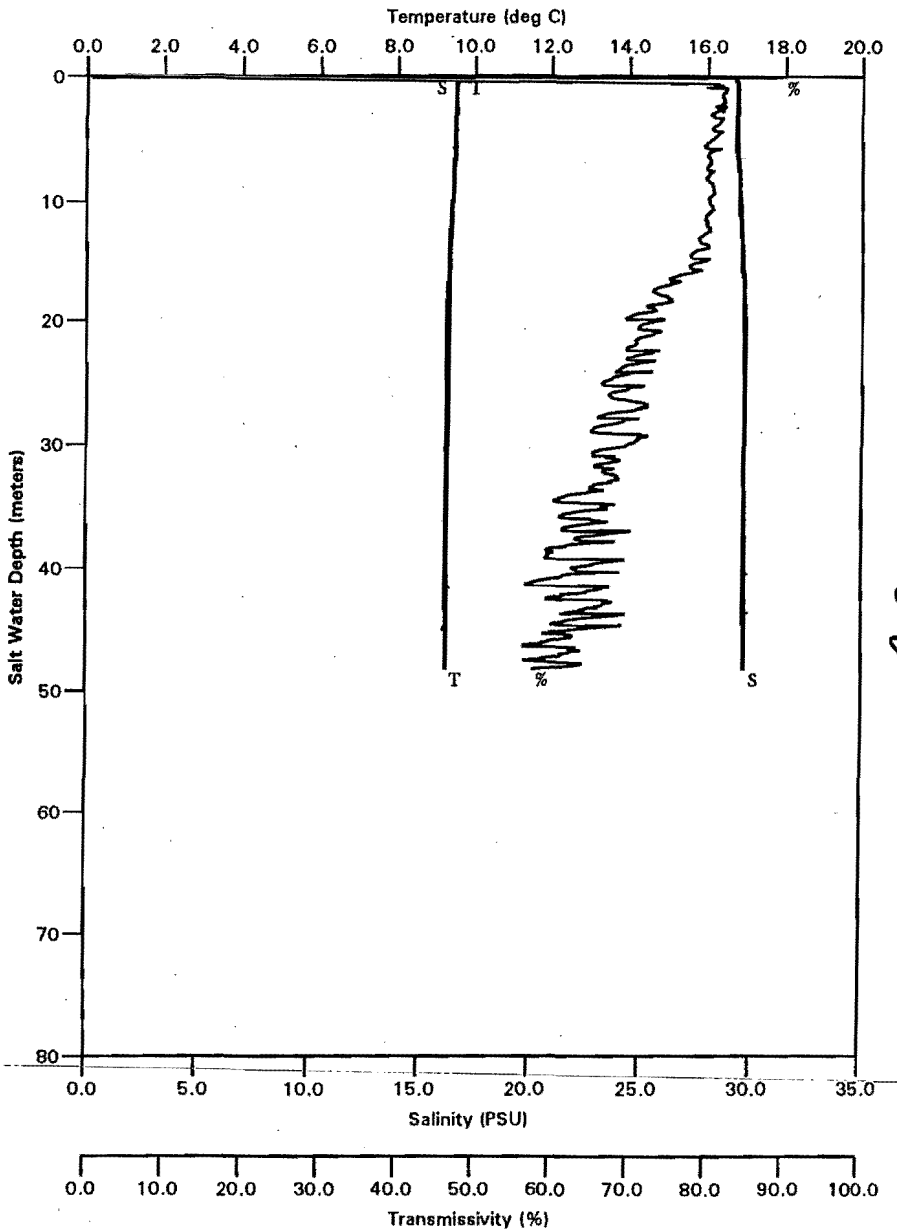
dast1015.cnv 16

18

Cook Inlet (1993) - downcast



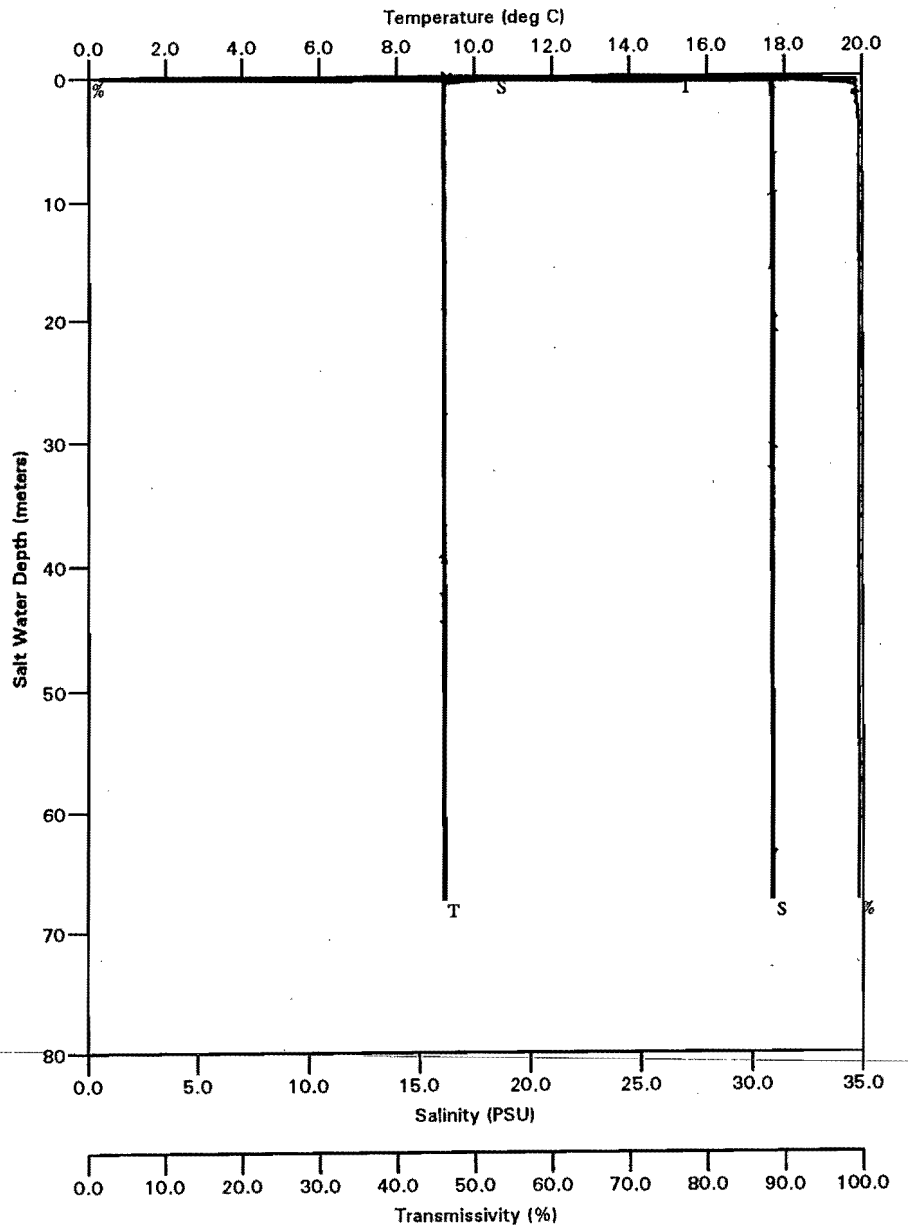
stn. 16B 26 Jun 93 21:30
dast1016.cnv 17



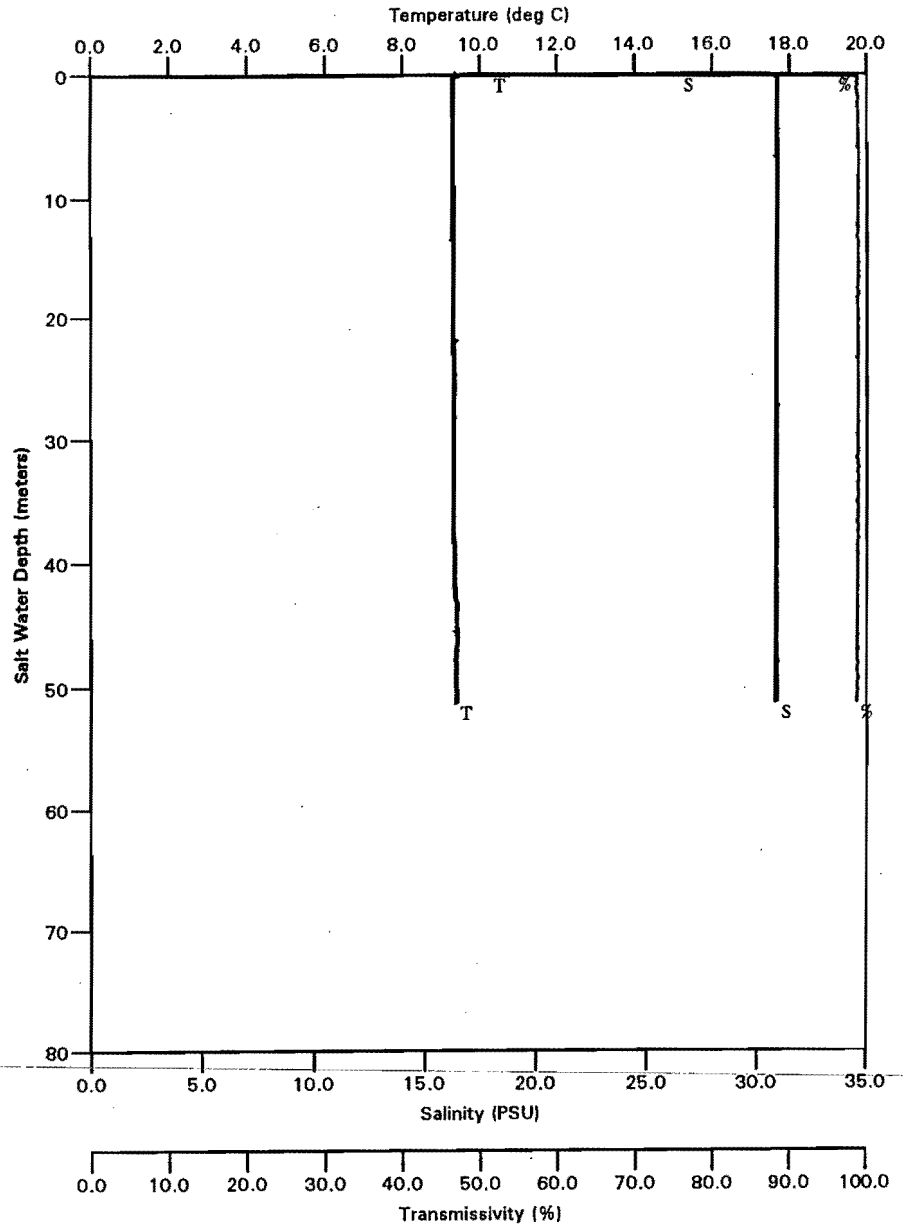
stn. F 27 Jun 93 00:35
dast1017.cnv 18

A9

Cook Inlet (1993) - downcast



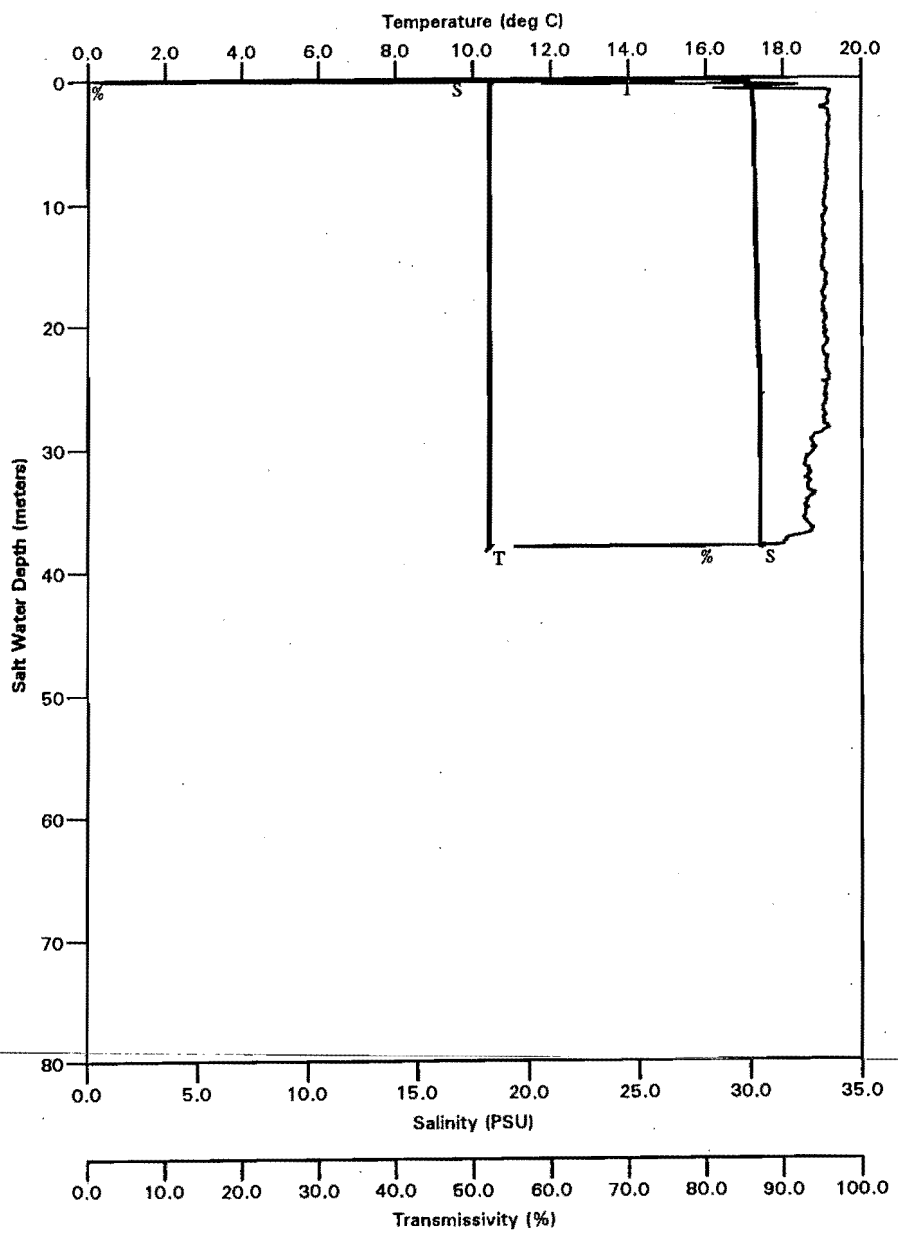
stn. 30 19 Aug 93 19:17
dast2001.cnv 19



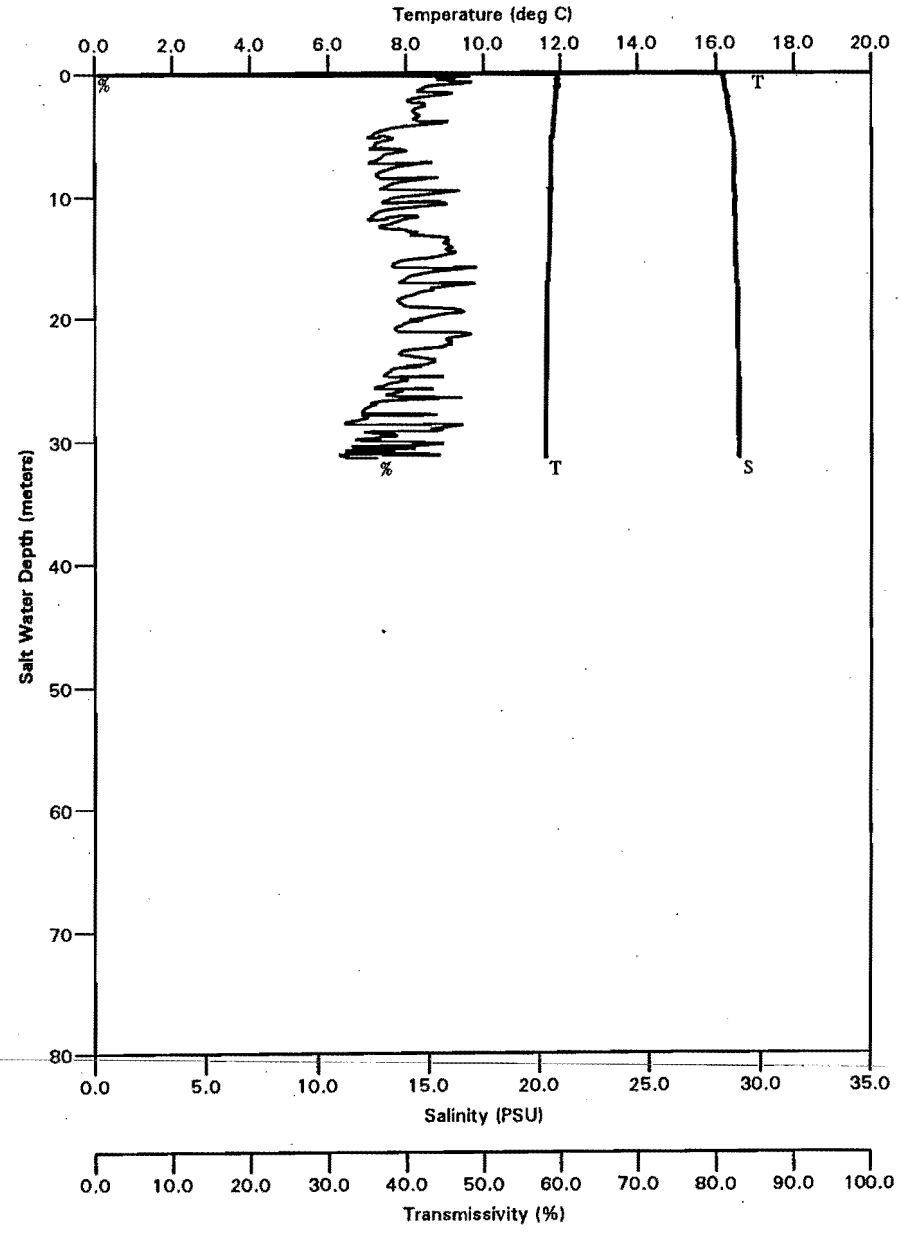
stn. 30 20 Aug 93
dast2002.cnv 20

A 10

Cook Inlet (1993) - downcast



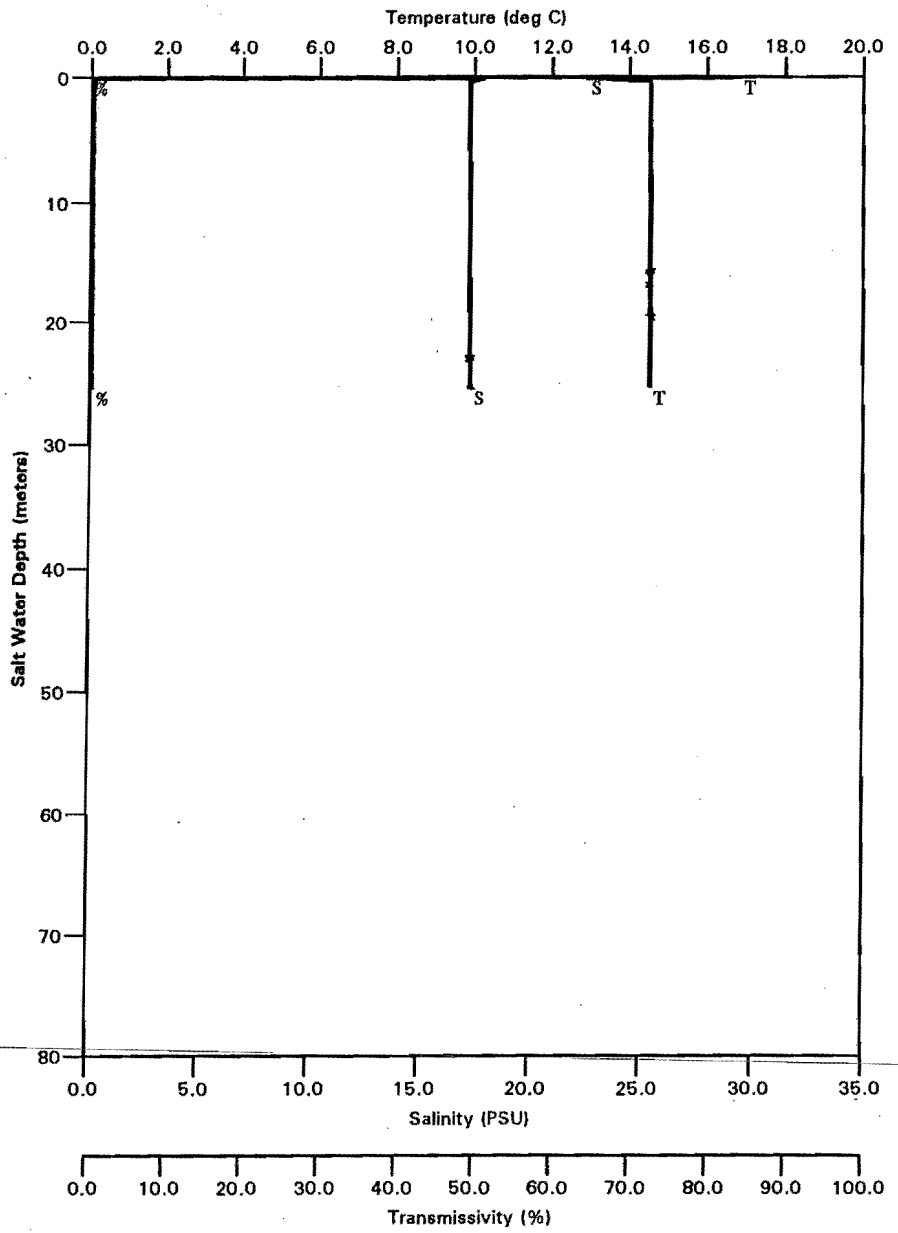
stn. 3 20 Aug 93 19:55
dast2003.cnv 21



stn. 3 21 Aug 93 02:10
dast2004.cnv 22

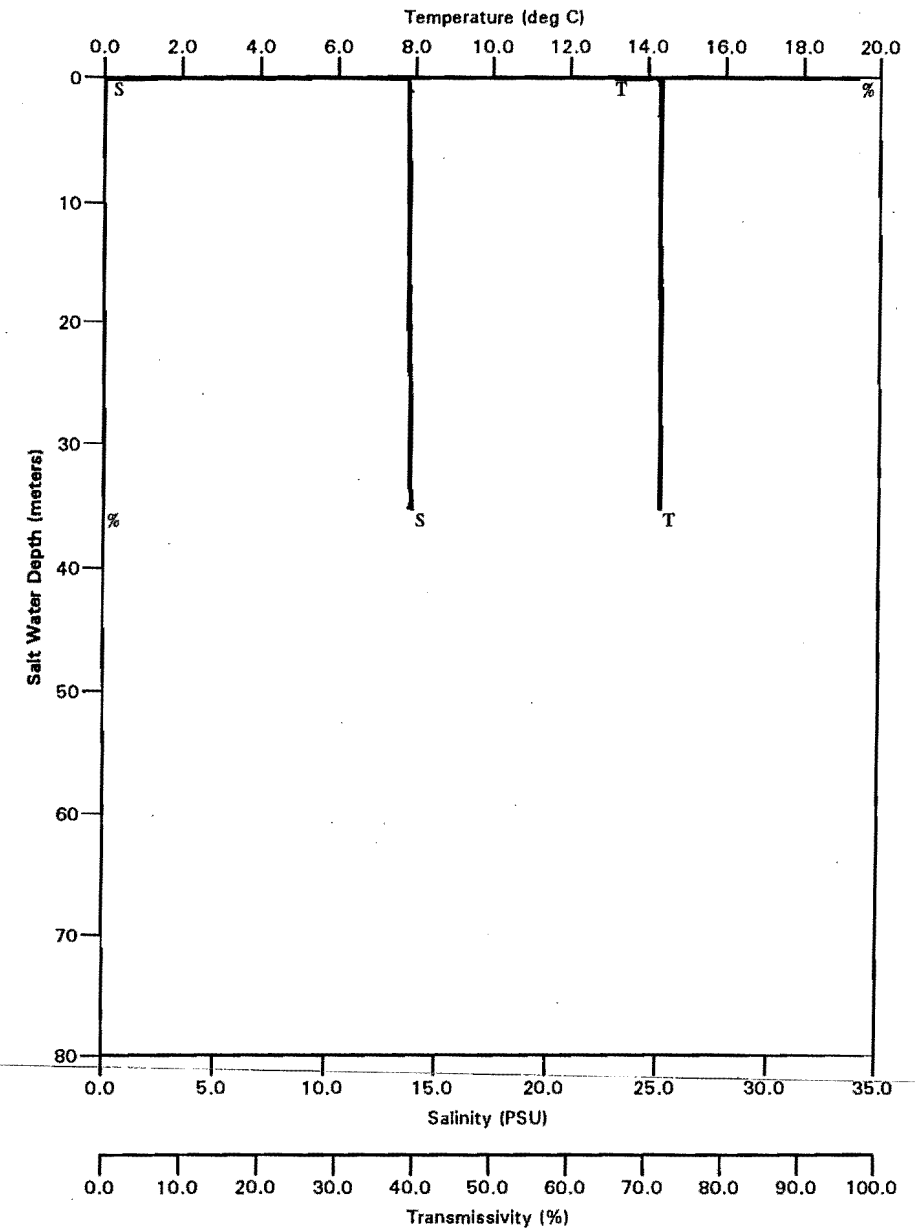
A 11

Cook Inlet (1993) - downcast



stn. E 21 Aug 93 20:40

dast2005.cnv 23

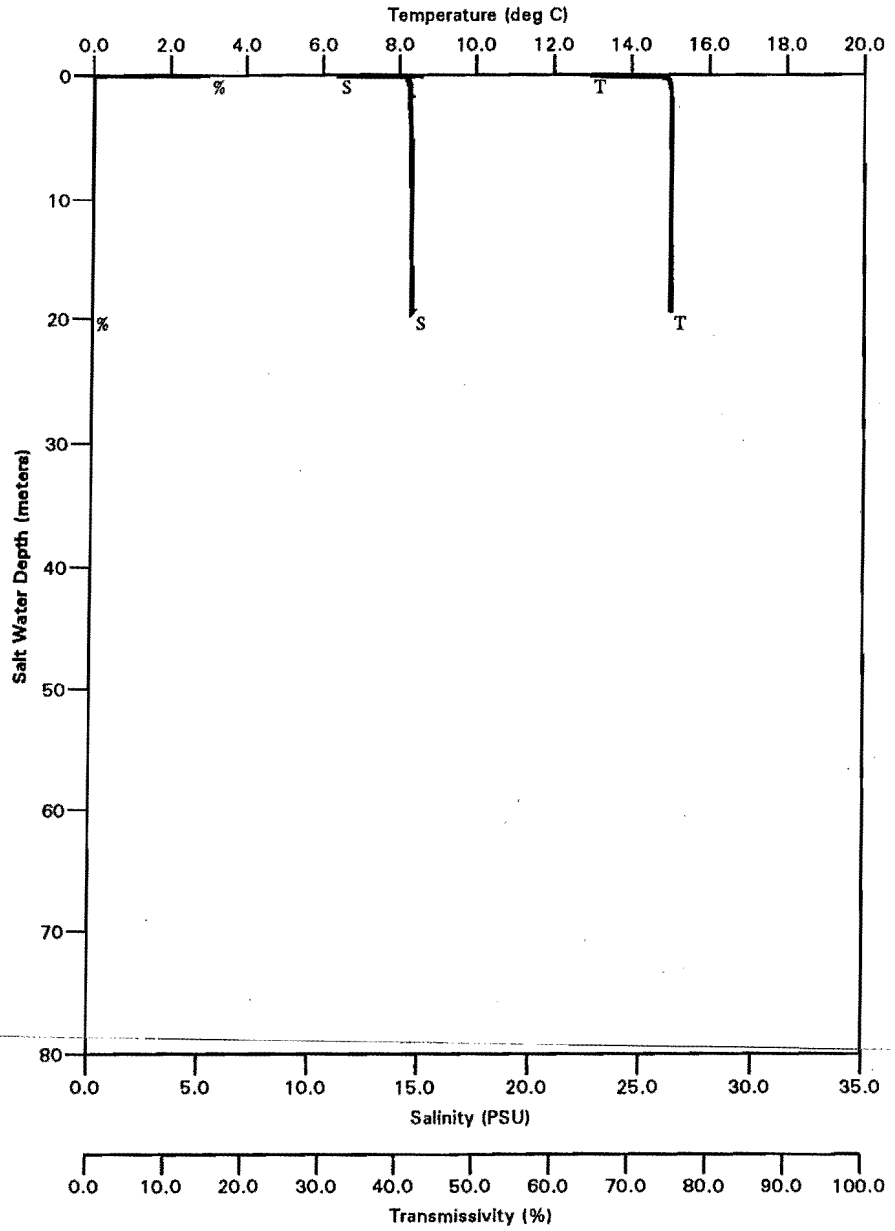


stn. E 22 Aug 93 02:00

dast2006.cnv 24

A12

Cook Inlet (1993) - downcast



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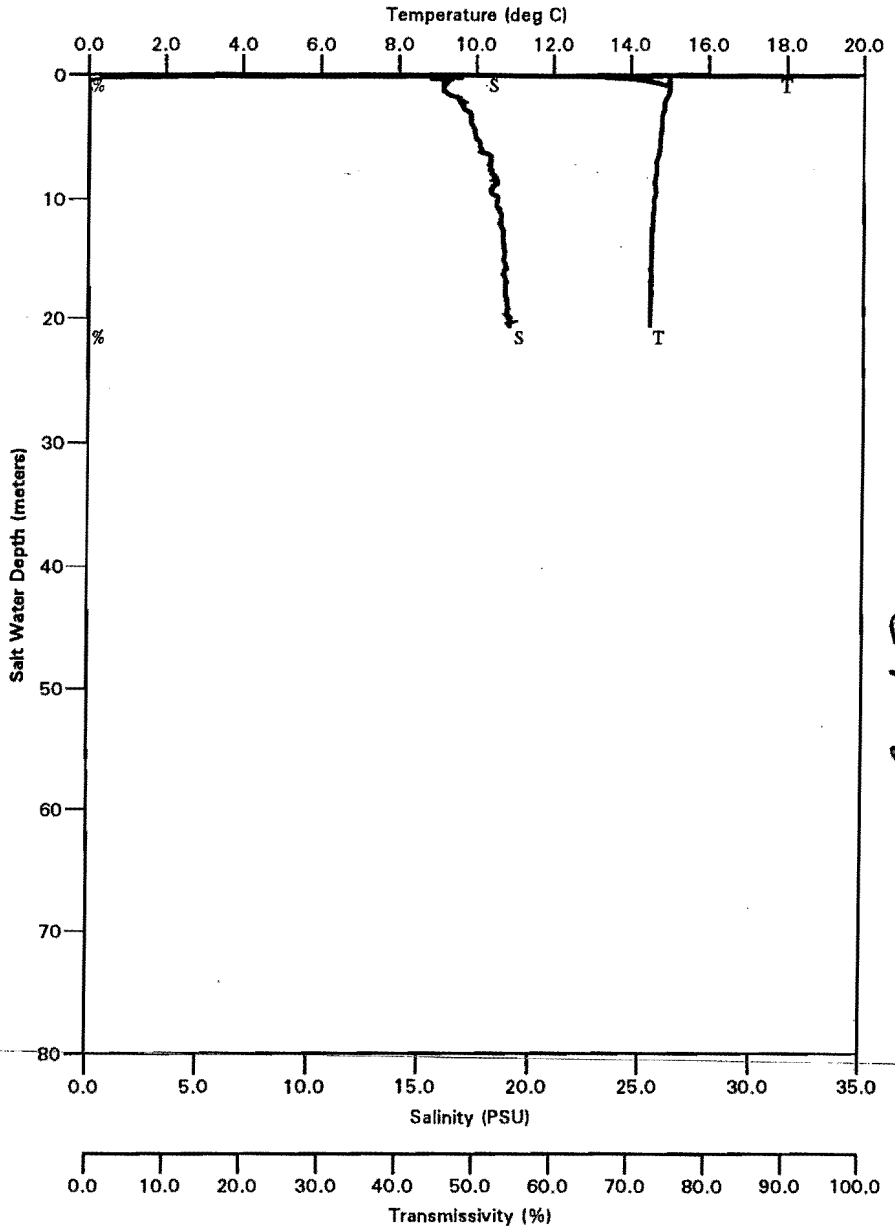
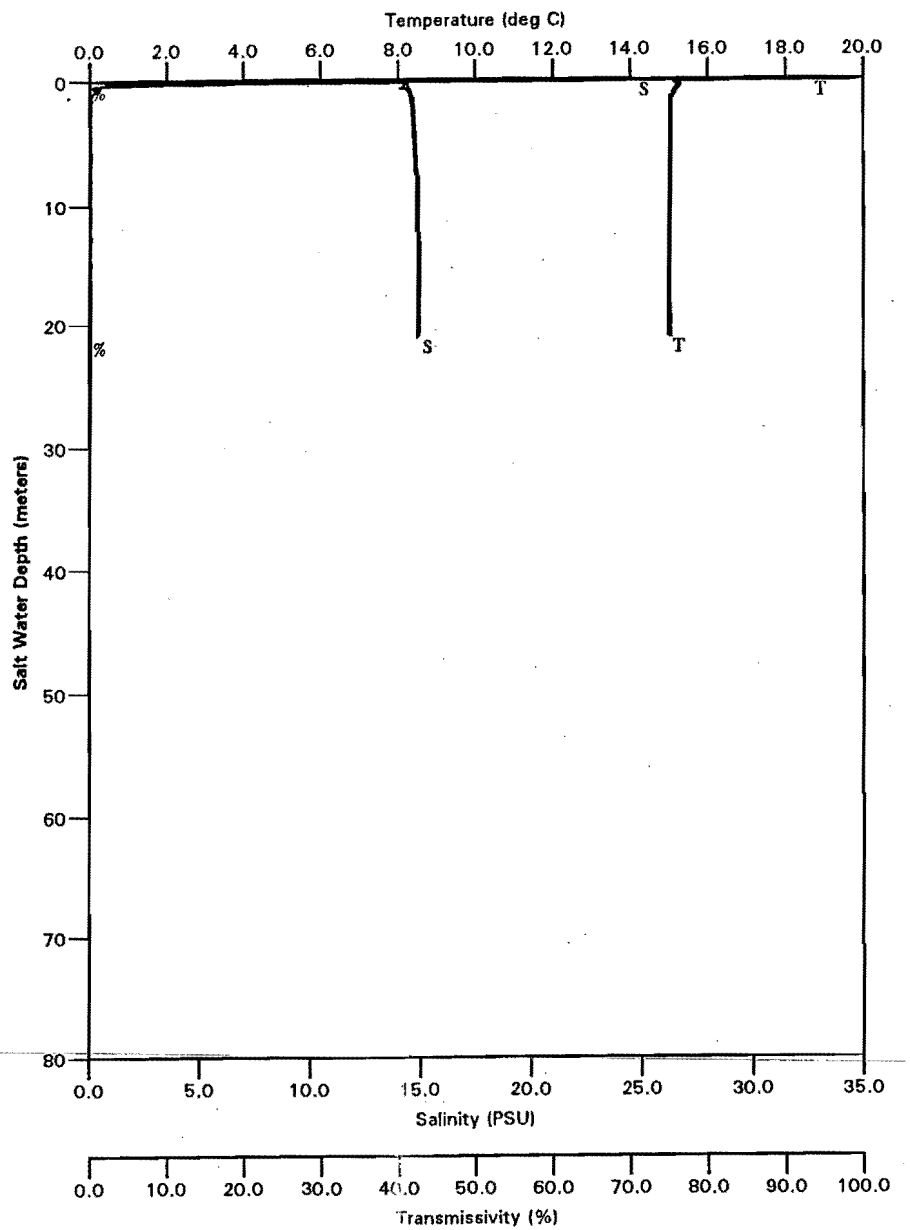
dast2007.cnv 25



stn. B 22 Aug 93 12:36
dast2008.cnv 26

A 13

Cook Inlet (1993) - downcast



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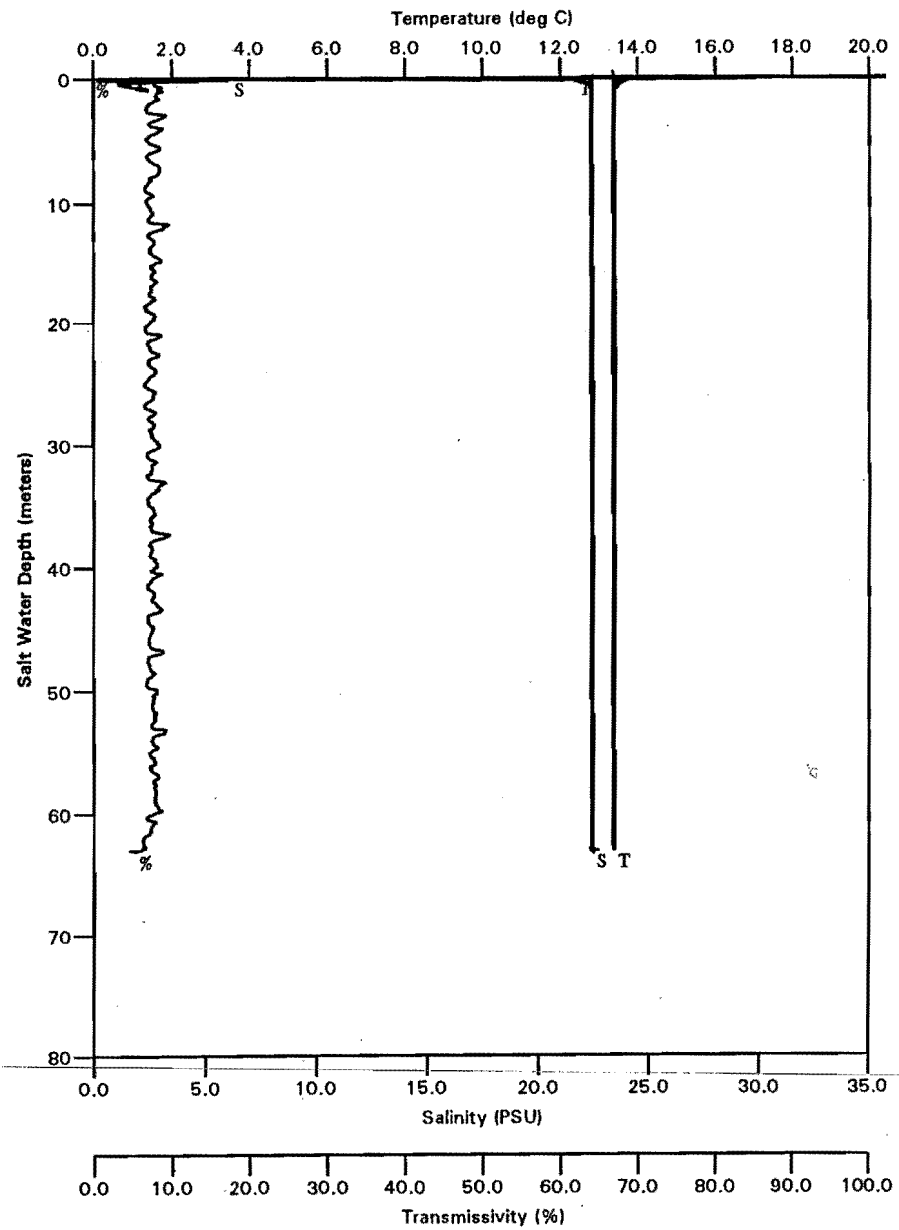
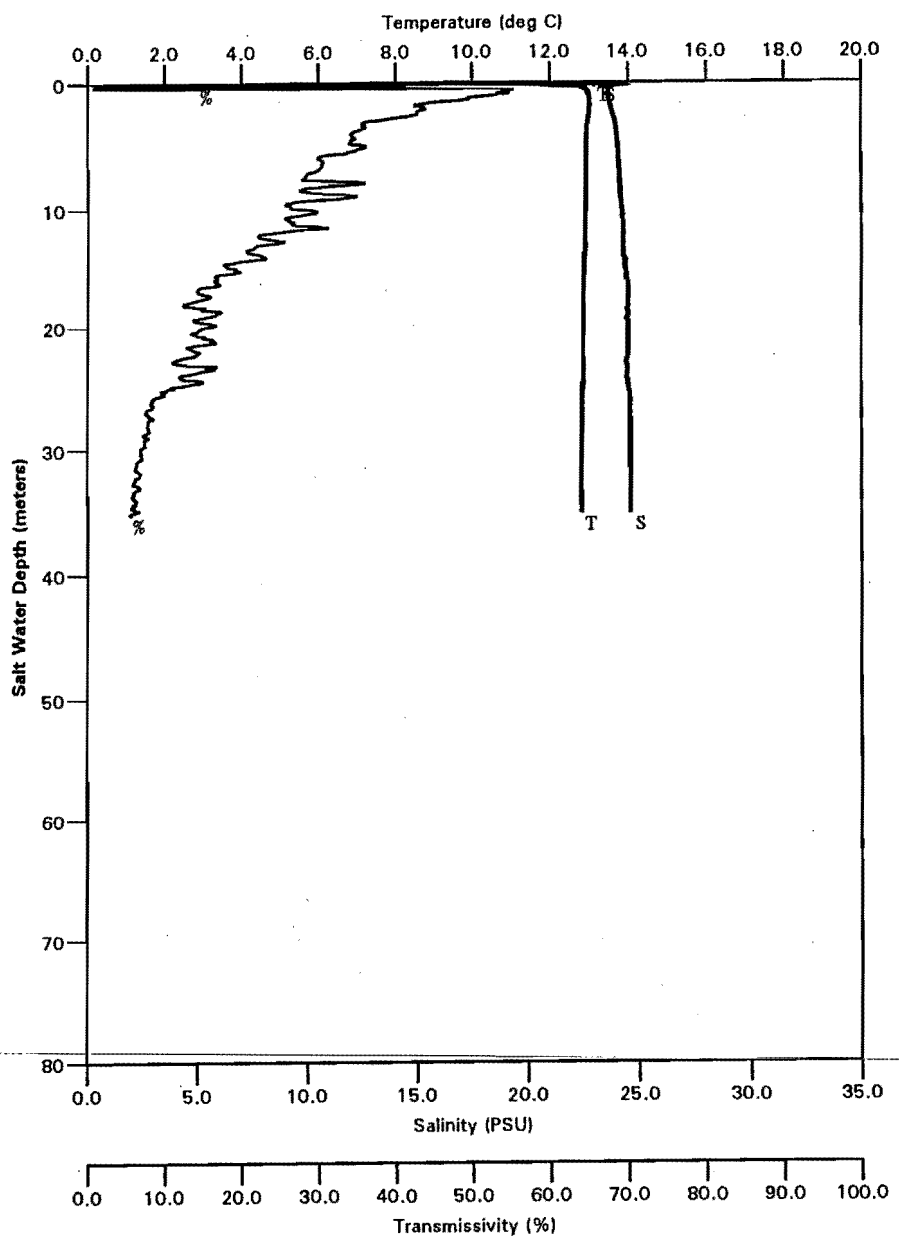
dast2009.cnv 27



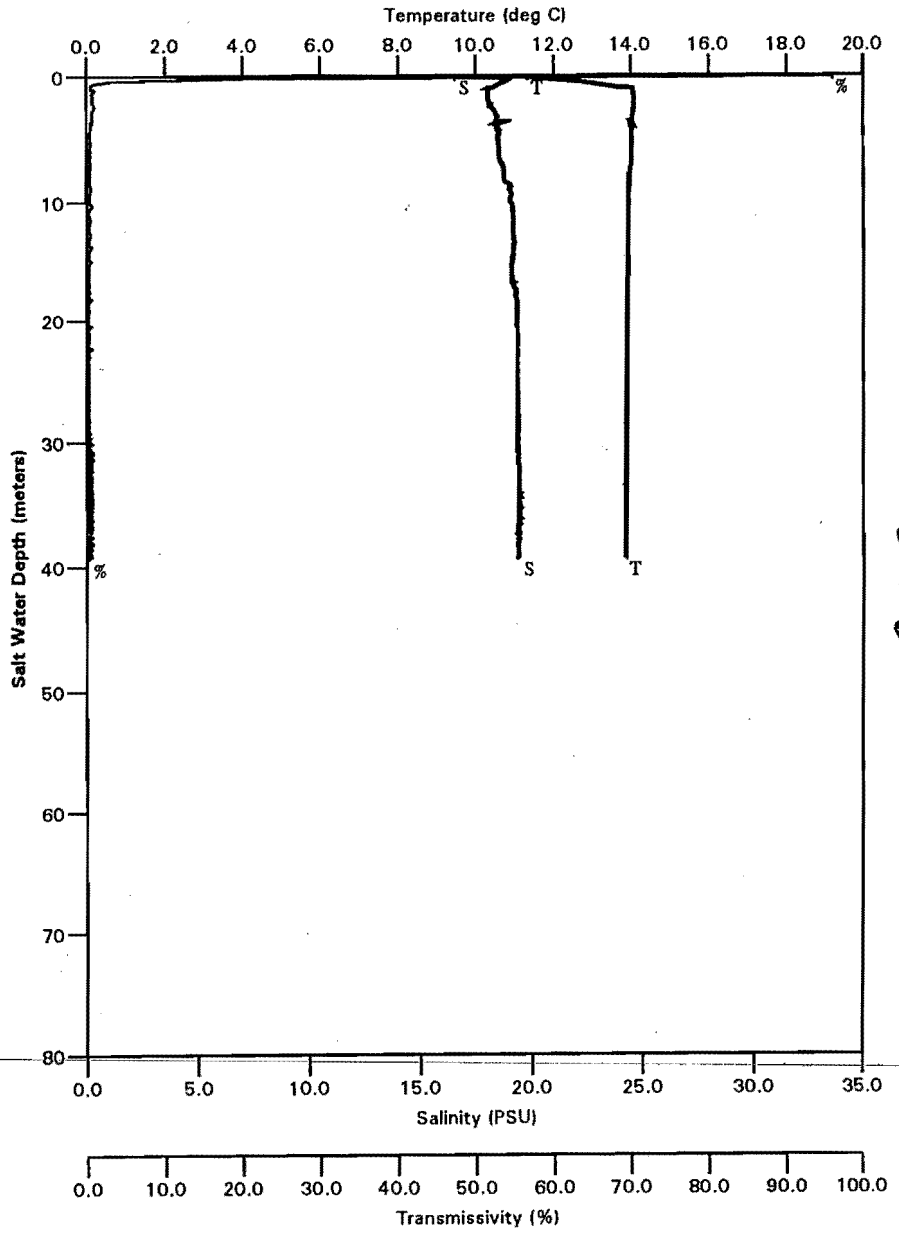
stn. A 22 Aug 93 21:05
dast2010.cnv 28

A 14

Cook Inlet (1993) - downcast



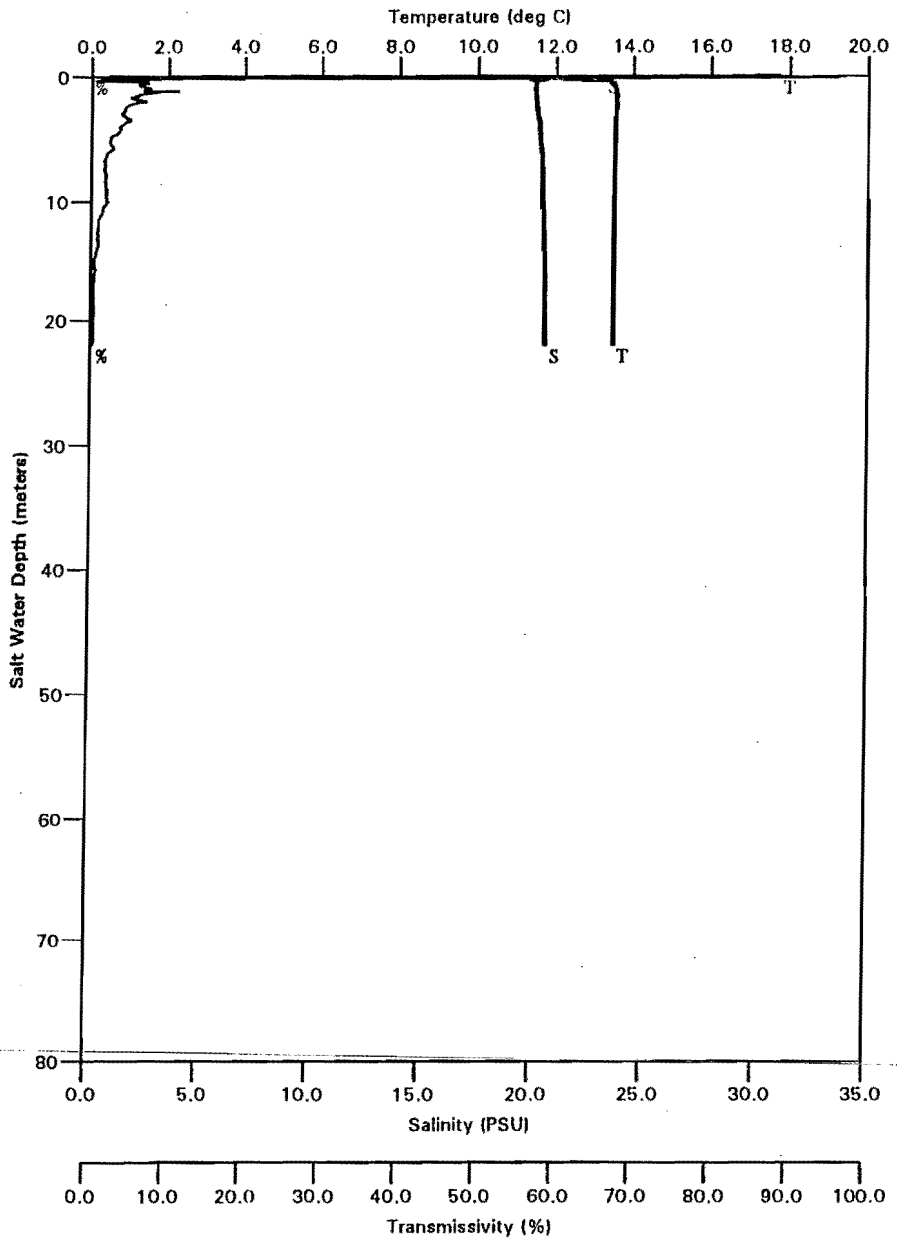
stn. C 22 Aug 93 23:59
dast2011.cnv 29



stn. A 23 Aug 93 05:00
dast2012.cnv 30

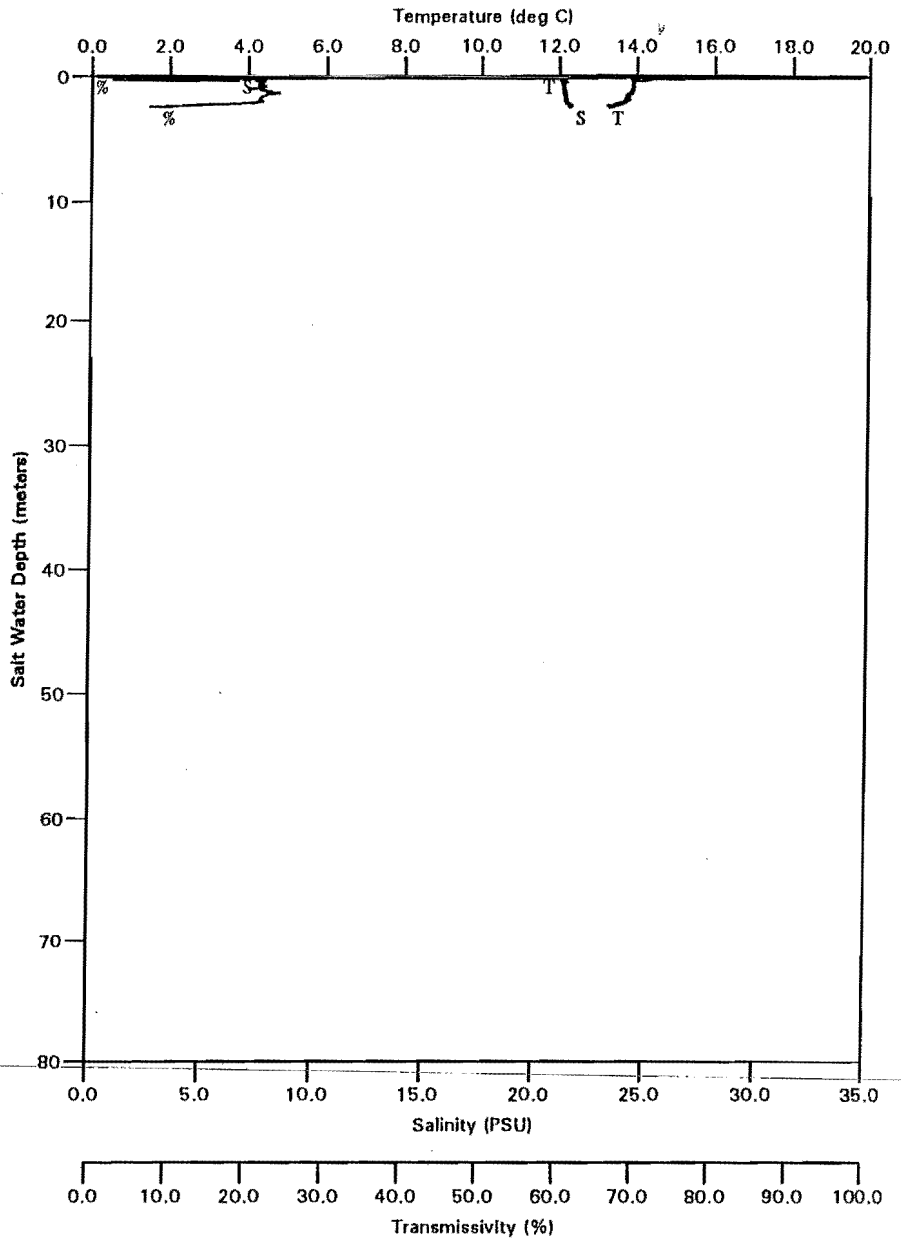
915

Cook Inlet (1993) - downcast



stn. C 23 Aug 93 07:00

dast2013.cnv 31

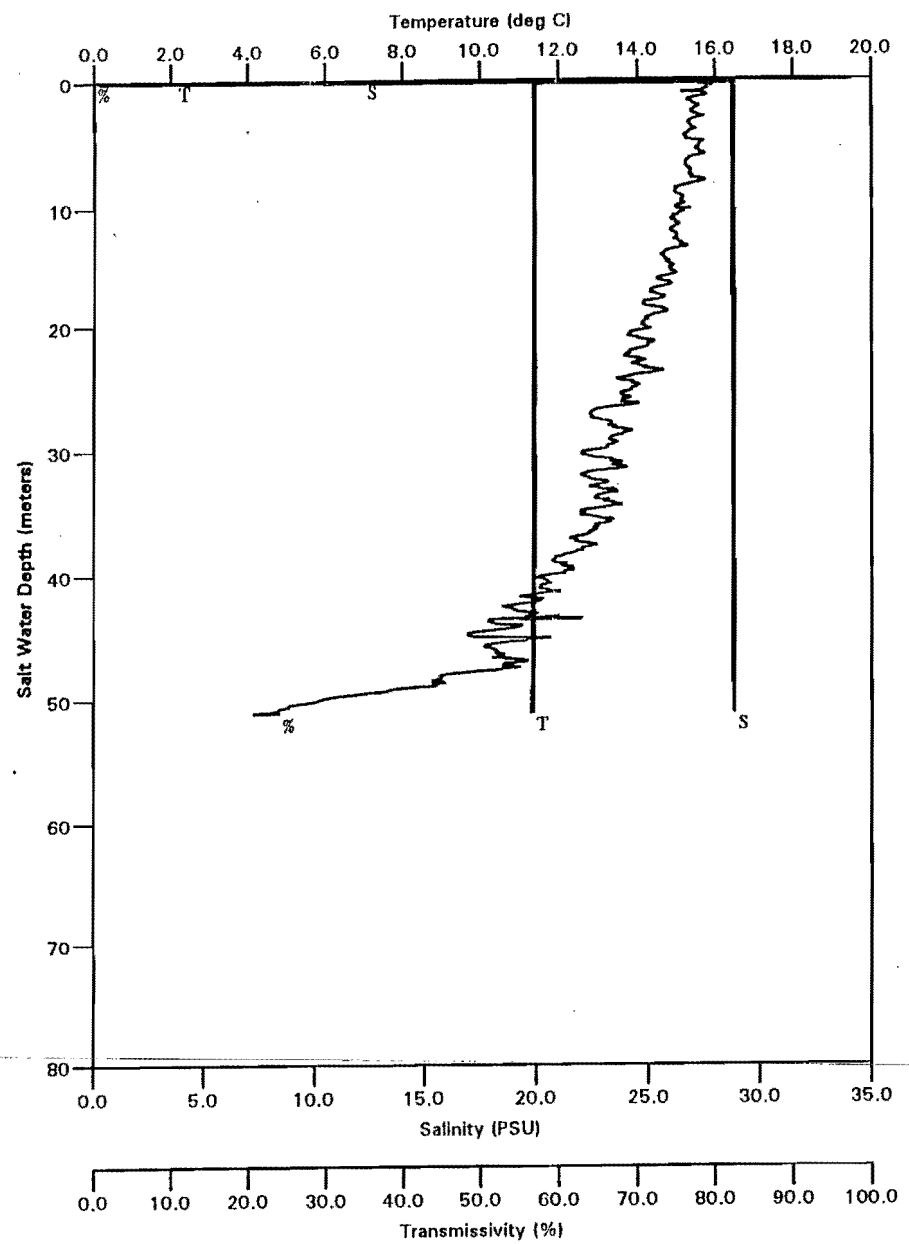


stn. 27 23 Aug 93 13:10

dast2014.cnv 32

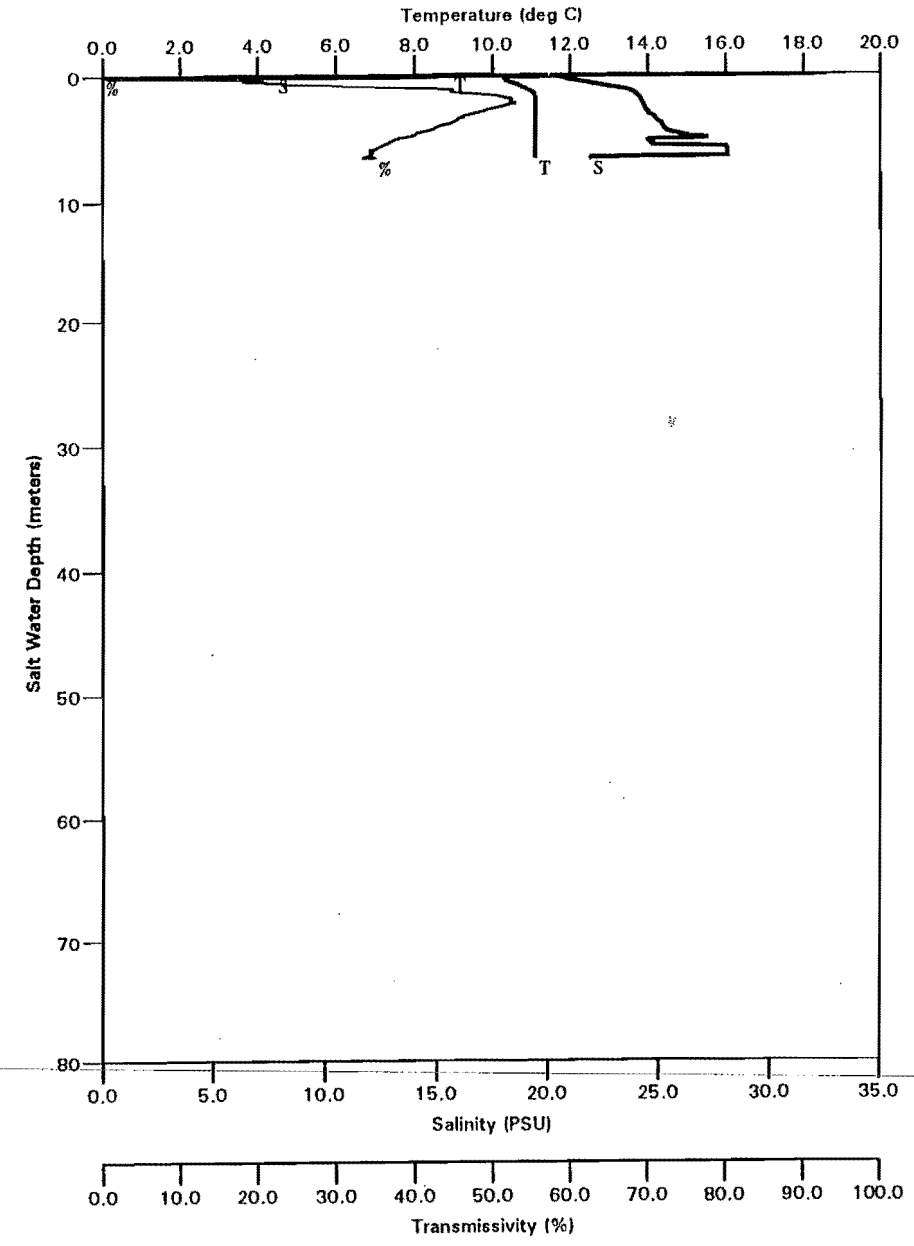
A 16

Cook Inlet (1993) - downcast



stn. F 24 Aug 93 04:53

dast2015.cnv 33

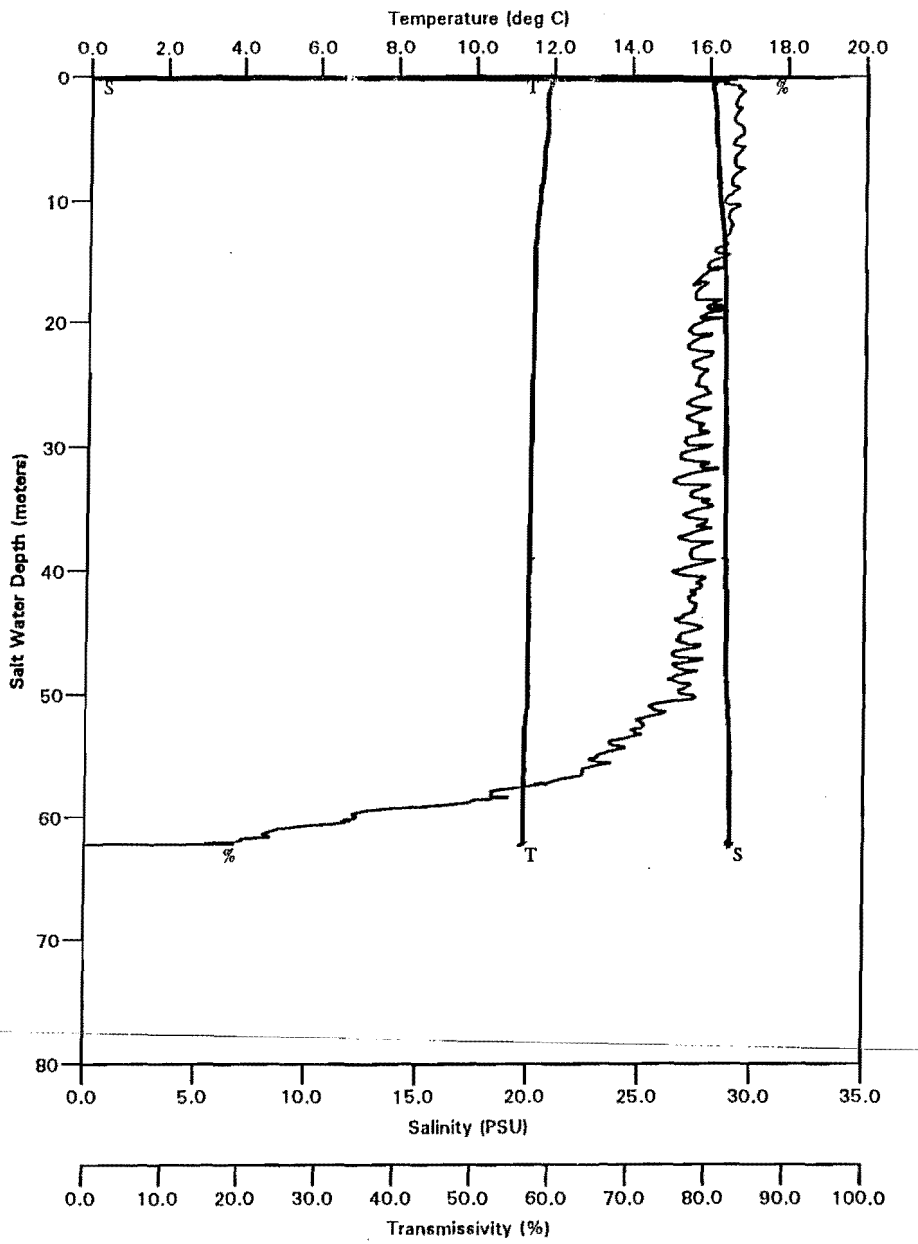


stn. 16B 24 Aug 93 09:00

dast2016.cnv 34

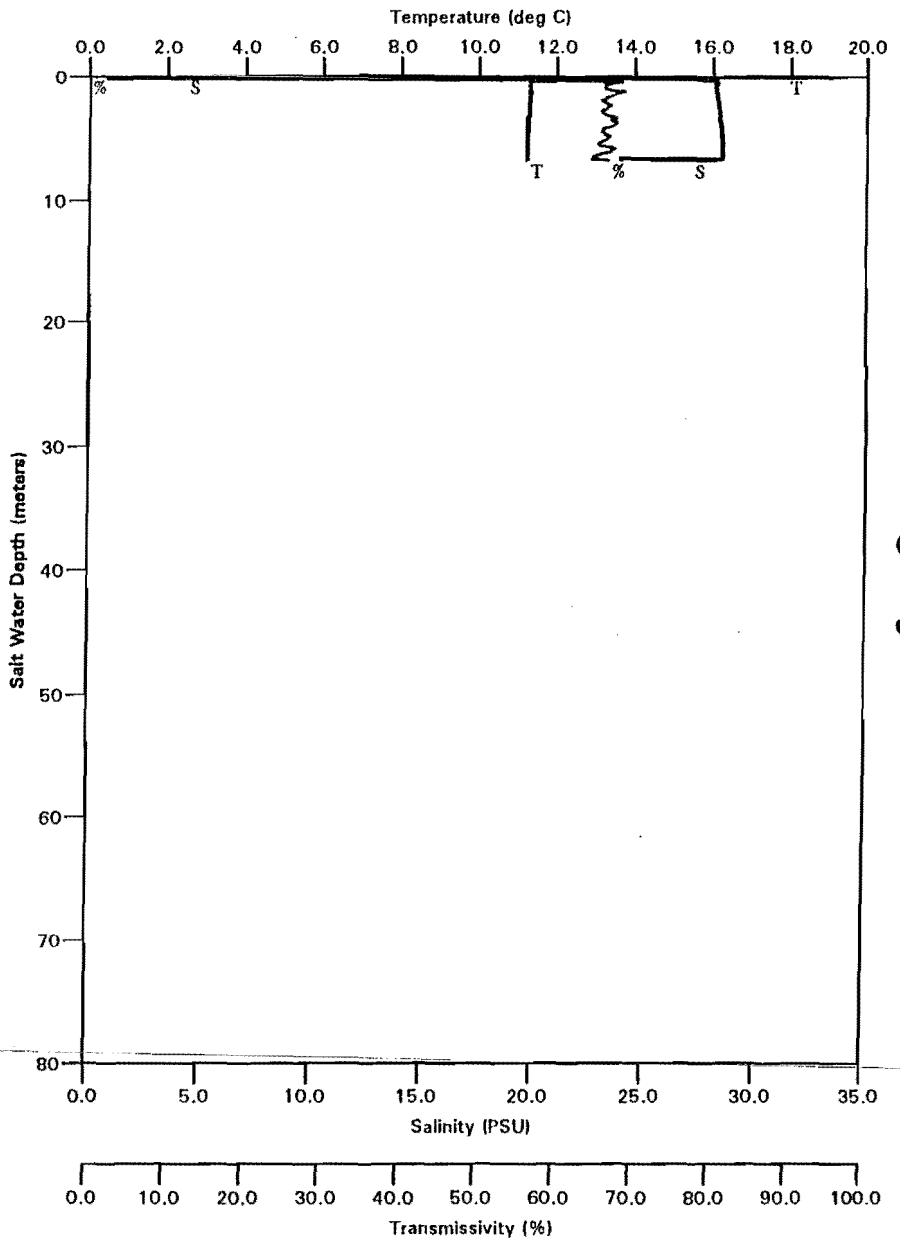
A17

Cook Inlet (1993) - downcast



stn. F 24 Aug 93 13:00

dast2017.cnv 35

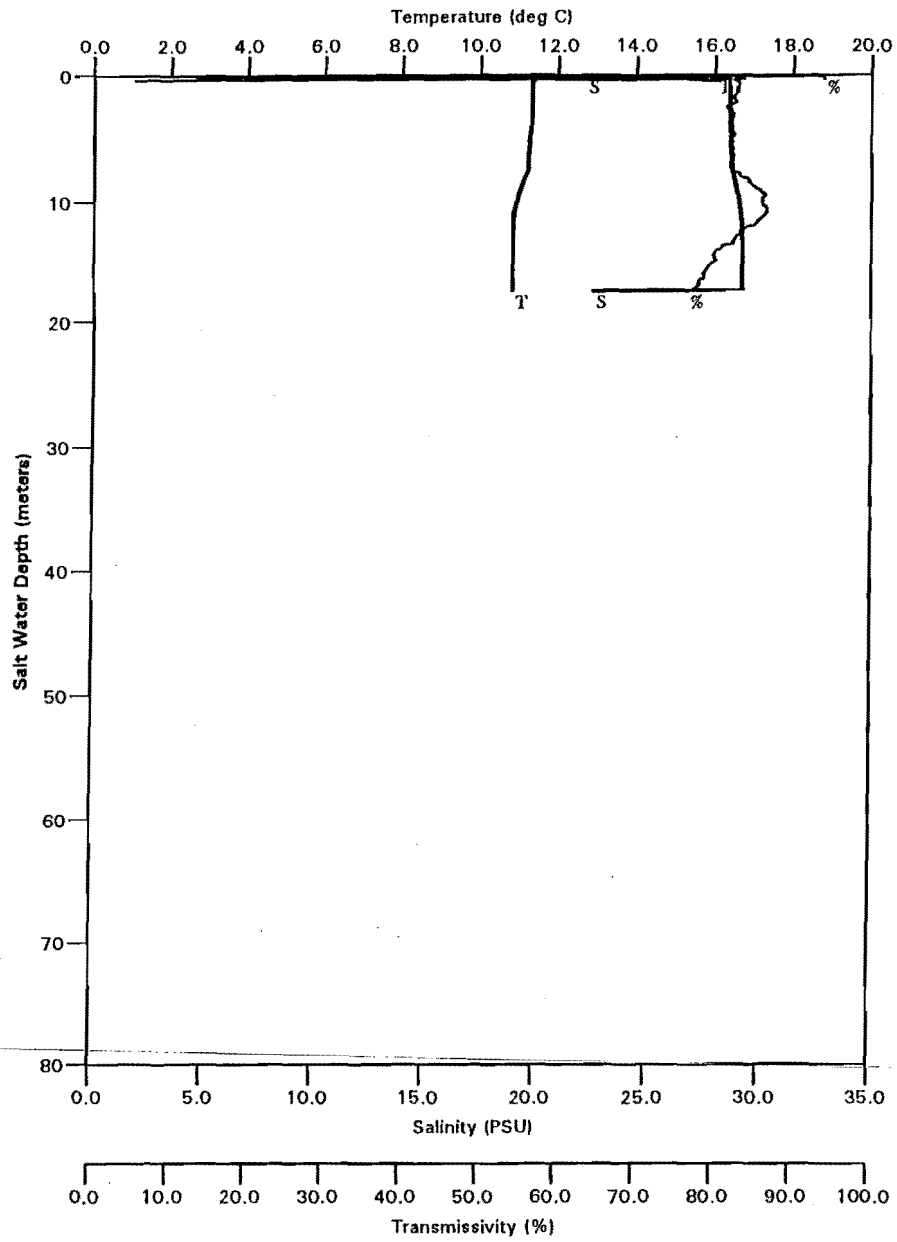


stn. E5 24 Aug 93 14:45

dast2018.cnv 36

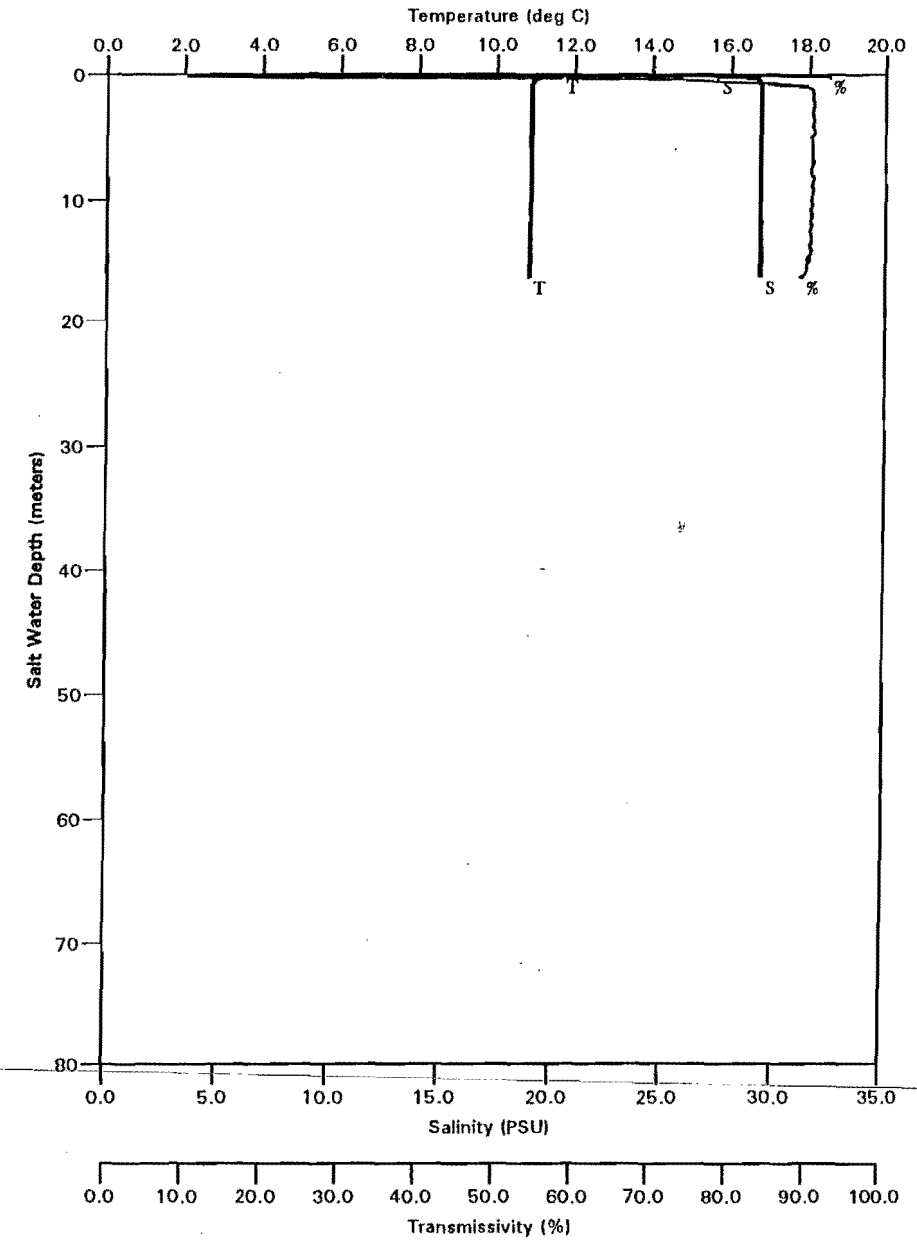
A18

Cook Inlet (1993) - downcast



stn. 233 24 Aug 93 17:05

dast2019.cnv 37

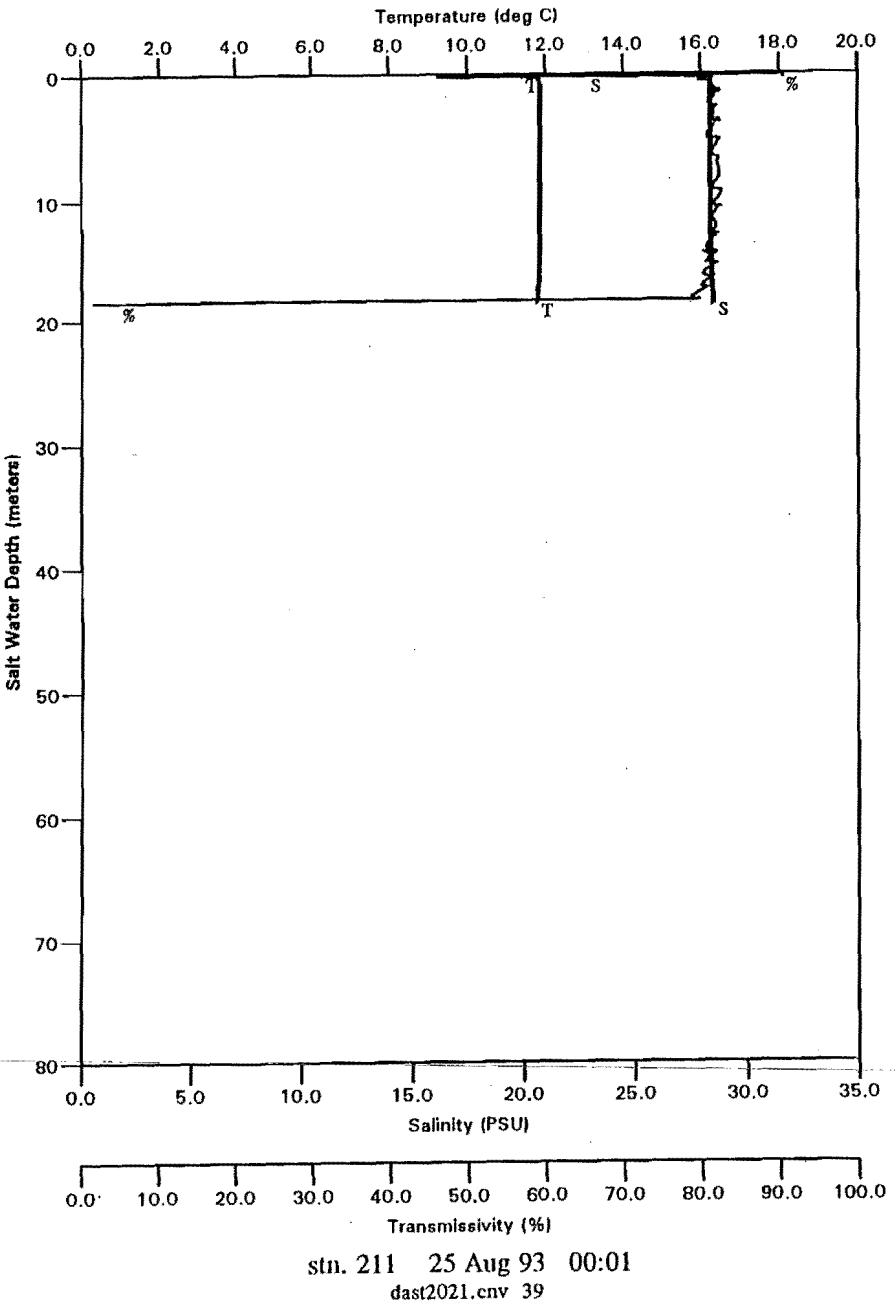


stn. E6 24 Aug 93 21:00

dast2020.cnv 38

A19

Cook Inlet (1993) - downcast



stn. 211 25 Aug 93 00:01

dast2021.cnv 39

A20