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ENVIRONMENTAL CONDITIONS NEAR PORTLOCK AND ALBATROSS BANKS (GULF OF ALASKA) MAY 1972

by

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CONTENTS

FIGURES

1. A portion of U.S. Commission of Fish and Fisheries Chart No. 1, Alaskan Region (from Rathbun, 1894) showing the general outlines of Portlock and Albatross Banks (soundings in fathoms). The shoreward cruise track of the <u>King George</u> in May 1786 and the location of the first sounding of 70 fathoms have been inserted.

2. Bathymetry of the area derived from (USC and GS Chart No. 8502, 17th ed. June 1971) showing numerous shoals with depths less than 50 m and Numerous channels (indicated by arrows) with depths greater than 100 m.

3. Locations of oceanographic stations (STD casts), RV <u>George B. Kelez</u> Cruise No. K72-2 (a series of seven replicate casts were made at three stations between Sta. Nos. 51 to 71) (from Ingraham and Fisk, 1973). Cruise period, 27 April to 10 May 1972.

4. Vertical profile of geostrophic velocities (referred to 1500 db), cm/sec, seaward of the continental shelf, and geopotential topography at the surface.

5. Geopotential topography (referred to 1000 db, dyn m - (•) indicates extrapolated data) along the shelf edge. Velocities between two indicated pairs (dashed lines) of stations along each line of stations (indicated by ▣) along each line varied from 33 to 80 cm/sec and had a mean value of 50 cm/sec (about 1 knot). Maximum velocity (referred to 1500 db) between Sta. Nos. 99 and 100 (indicated by *) was 98 cm/sec (nearly 2 knots).

6. Time series relations between: (A) tidal heights (m) at Seldovia and Kodiak reference stations for 5-6 May 1972 (GCT); (B) anomalies of dynamic height (dyn m) and depth of 26.7 sigma-t surface at inshore, middle, and offshore repetitive stations (see Fig. 3); (C) fluctuation of in situ depth (m) of 26.70 sigma-t surface; and (D) mean southwest velocities between inshore and offshore stations.

7. Release and recovery locations of seabed drifters (after Ingraham and Hastings, 1974) showing general southwestward drift of inshore releases. No recoveries have been made from releases near the shelf edge.

8. Continuity of geostrophic current patterns (referred to 50 db) over the shelf indicating the presence of a large cyclonic gyre between the inshore and offshore southwestward flow and the shear zones near the edge of the shelf.

9. Distribution of surface salinity ($^{o}/_{oo}$) showing location and continuity of areas of minima and maxima and reflecting geostrophic flow patterns.

10. Surface salinity ($^{o}/_{oo}$) data obtained between repetitive stations (see Fig. 3) by continuously recording thermosalinograph showing fluctuations in position of the surface salinity front in the vicinity of the shelf edge (near 56°25'N) during 5-6 May 1972 (station location and time indicated by ■).

11. Vertical sections of temperature (°C) along lines of stations normal to the shelf (note southernmost one is shown as straight line) indicating the warm water (>4°C) at depth seaward of the shelf edge, the depth of

the temperature-minimum stratum (dotted line at approx. 100 m), and cold water (< 2°C) inshore (station locations shown by ticks, and Sta. Nos. of inshore and offshore stations are indicated).

12. Approximate bottom temperatures (°C - inferred by temperature distributions and trends in the water column at individual stations and by bottom topography) showing the band of warm (>4°C) water at the edge of the continental shelf and the shoreward intrusions of 3°C water in various channels between shoals except around and northward of Portlock Bank where warmer conditions existed.

13. Schematic diagram of temperature-salinity relations of bottom conditions: (A) seaward of shelf edge, (B) in the channels between shoals of Portlock and Albatross Banks, (C_1) over the shoals in the vicinity of Portlock Bank, (C_2) over the shoals of Albatross Bank, (D_1) north end of Shelikof Strait, (D_2) south of Shelikof Strait. Cold, dilute conditions at Sta. No. 21 are also indicated.

14. Distribution of walleye pollock eggs and larvae (nos. in parens) indicating large concentrations south of Shelikof Strait--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).

15. Distribution of eggs and larvae of flathead sole (nos. of larvae in parens) indicating concentrations in the warm water north and east of Afognak Island. Few were caught in the area southwest of Kodiak Island--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).

16. Distribution of eggs of Rex sole and larvae of Pacific sand lance (nos. in parens)--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).

ABSTRACT

Southwestward volume transport (referred to 1500 db) out of the Gulf of Alaska, seaward of the continental shelf in May 1972 was 12.5 sv, and 71% of this flow occurred within 50 km of the shelf edge. Mean geostrophic velocities of about 50 cm/sec occurred in a band 20 km wide, which extended 500 km along the shelf edge; a maximum velocity of 98 cm/sec (nearly 2 knots) was obtained. Bottom flow along the inshore part of the shelf as determined by seabed drifters was generally onshore at 0.5 cm/sec. Evidence is presented of a large cyclonic gyre on the shelf encompassing the Portlock and Albatross Banks, perturbations in flow along the shelf edge, and relations between coastal tidal heights and fluctuations in geopotential topography at the shelf edge.

Bottom conditions over Portlock and Albatross Banks, and in the intervening channels, are described. Relations of conditions to groundfish distributions and ichthyoplankton catches are discussed.

INTRODUCTION

The extensive oceanographic investigations in the northern North Pacific Ocean and Bering Sea conducted by the Northwest Fisheries Center (and its predecessor the Bureau of Commercial Fisheries Seattle Biological Laboratory) under the supervision of the American Section of the International North Pacific Fisheries Commission (Dodimead, Favorite, and Hirano, 1963; Favorite, Dodimead, and Nasu, 1974) were terminated in summer 1971 and the activities of this group were shifted to investigations associated with the newly initiated Marine Resources, Monitoring, Assessment and Prediction (MARMAP) program. An initial exploratory cruise was conducted off the Washington-British Columbia coast in fall 1971 (Ingraham, et al., 1973; Naplin, Dunn, and Niggol, 1973[1/]) to test new automated equipment.

A major multi-discliplinary cruise, RV George B. Kelez, Cruise No. K72-2, was conducted in spring 1972 to ascertain environmental conditions in the vicinity of Portlock and Albatross Banks. Oceanographic data in this part of the northern Gulf of Alaska are fragmentary, consisting largely of isolated lines of stations across the continental shelf at various locations and time intervals. The possibility or the necessity, for the Bureau of Land Management to grant offshore leases for oil drilling and production has intensified interest in this and other areas. Kelez Cruise No. K72-2 is perhaps the most thorough attempt to define environmental conditions in the northwestern part of the gulf, and the purpose of this report is to summarize the physical oceanographic data obtained in the vicinity of Portlock and Albatross Banks in spring 1972 as well as to show associations between environmental conditions and processes.

BACKGROUND

HISTORICAL

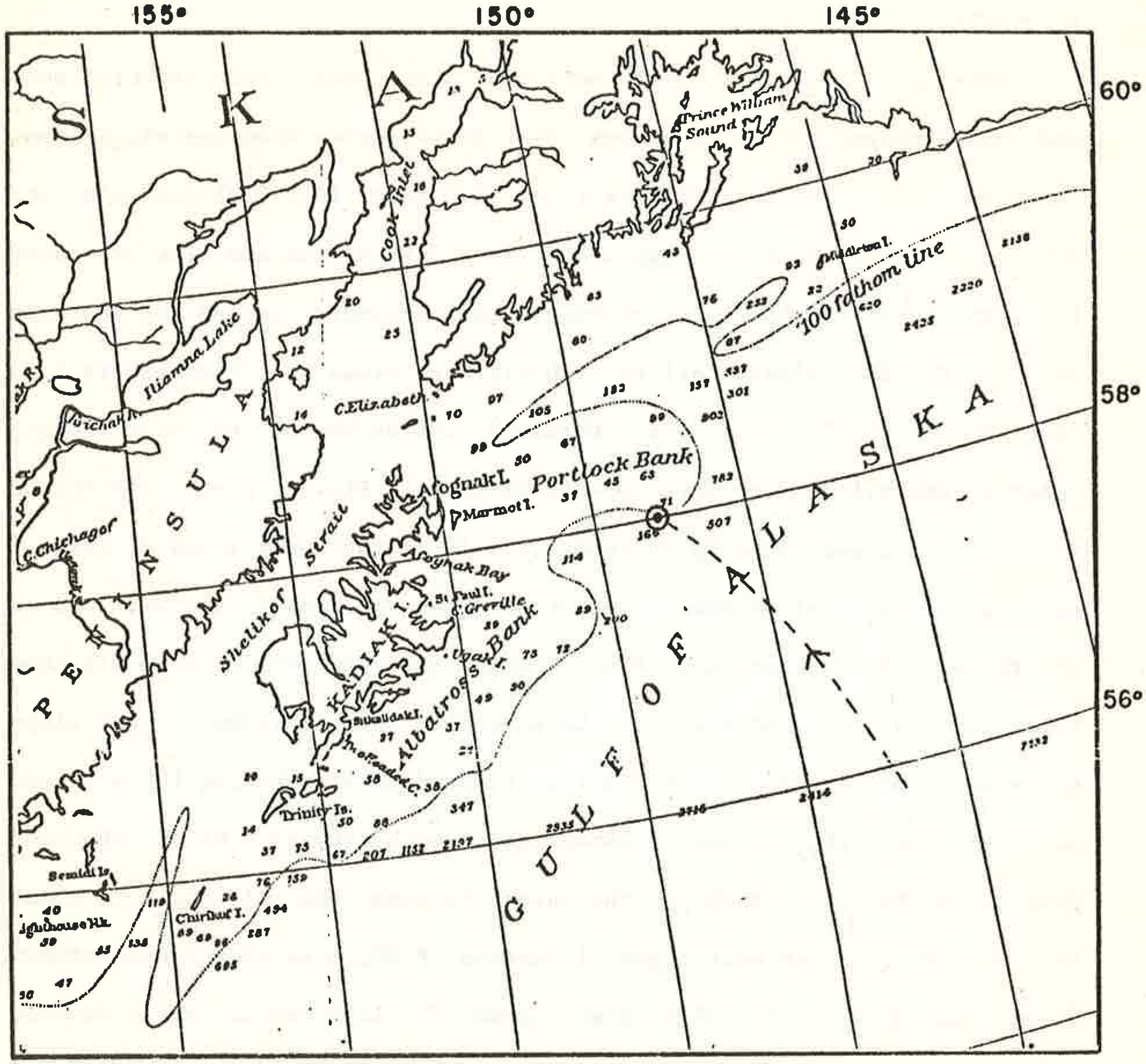
Both Captains Vitus Bering and Alexei Chirikof sailed westward along the coast of the Gulf of Alaska on their return voyages to Kamchatka in the St. Peter and St. Paul in 1741 after having been separated during what was the first transpacific expedition in northern waters--present day Yakutat was originally Bering Bay, and Chirikof Island lies southwest of Kodiak Island. Captain James Cook and Charles Clerke in the Resolution and Discovery, followed much the same route in 1778 but, because their task was to ascertain whether present day Alaska (the coastline had been generally outlined by Russian explorations) was actually part of the American continent or consisted of one or more large islands, they entered and named Prince William's Sound; to the west of this, they explored a large inlet which the Earl of Sandwich subsequently named Cook's River known today as Cook Inlet.

The discovery of Portlock Bank is attributed to Captain Nathaniel Portlock. Early in the morning of 16 July 1786, in thick and foggy weather, Portlock, in the King George, was proceeding northward in the Gulf of Alaska, expecting a landfall. These were not unfamiliar waters because he had accompanied Cook, but a change in color of the water detected the previous day prompted the taking of frequent soundings with a 190 fathom (347.5 m) line as a navigational precaution. The King George was followed by the Queen Charlotte, commanded by George Dixon, who also had accompanied Cook, and the two vessels, dispatched by the King George's Sound Company to explore the possibility of conducting a fur trade from the west coast of America to China, were proceeding northward from the Sandwich (Hawaiian) Islands to Cook's River. At eight o clock on that morning Portlock (1789) reported:

> "...we struck the ground in seventy fathoms water[2/] over a bottom of fine grey sand with black specks; and at seven o'clock in the evening the fog dispersing we saw the coast of America extending from North by East to West by North, distant from the nearest land, and which appeared to be a projecting point, about twelve leagues. In this situation we had a fifty-seven fathom water, over a bottom of shells and mud."

It is interesting to note that on Portlock's chart present day Afognak Island was shown as "Kodiac" Island and Cape Grenville was tentatively considered to be part of the mainland. The subsequent expeditions of Capt. George Vancouver (1792-94) and U.S. Coast Survey contributed to soundings in the area.

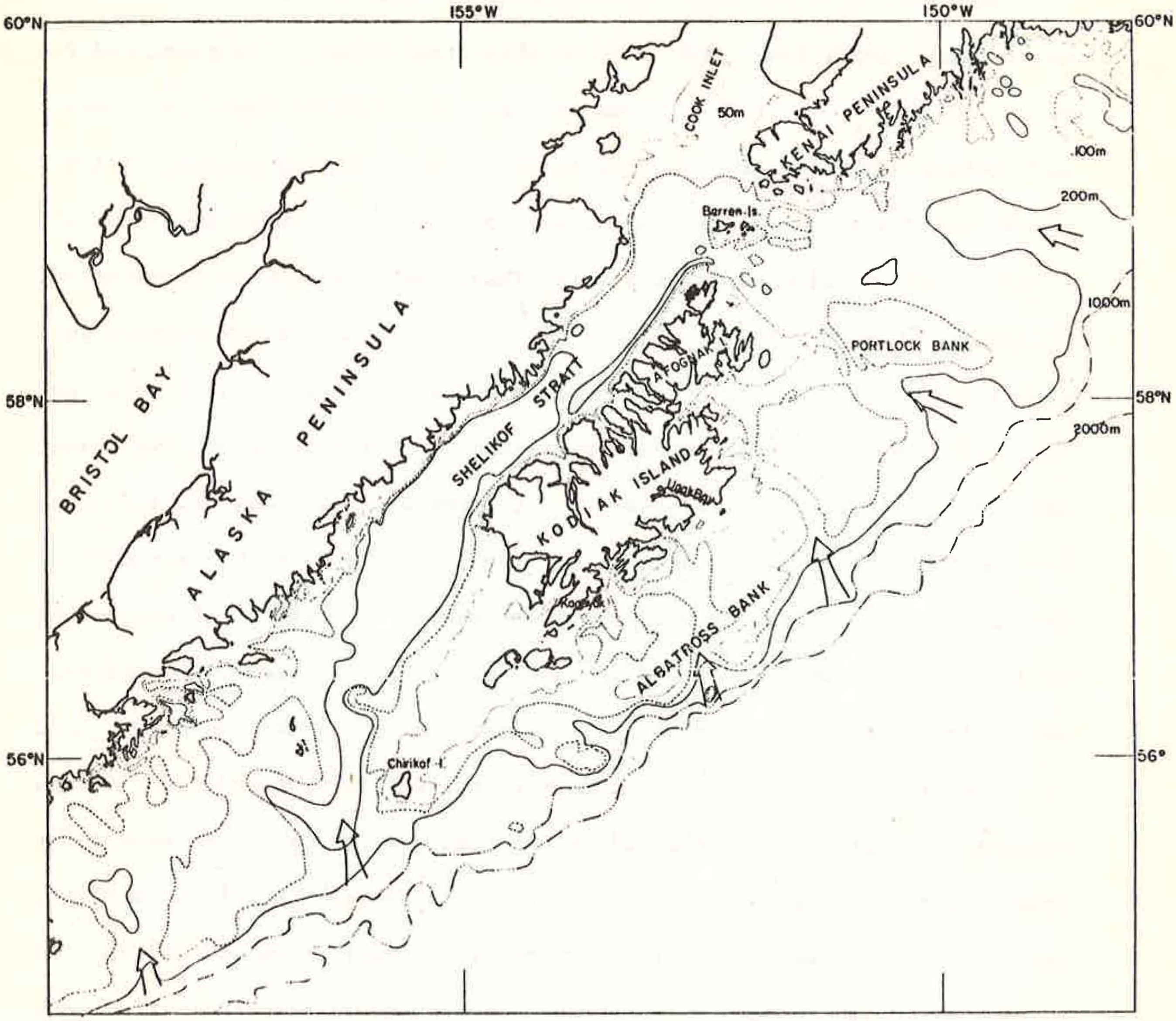
In 1866, 3 years after the U.S. fishery for Pacific cod, *Gadus macrocephalus*, commenced in the Okhotsk Sea, extensive fishing began in the Shumagin Islands. By 1870, it was recognized that productive fishing grounds extended from Yakutat (or Bering Bay) to the Aleutian Islands (Tanner, 1890), and that: "The cod banks are generally in the vicinity of land, yet off-shore banks have been and will continue to be discovered, though the fishermen endeavor to retain the secret of such discoveries." By 1888, Portlock Bank was considered to extend not only northeast but also southeast of "Kadiak" Island. However, the cruises of the U.S. Fish Commission steamer *Albatross* in Alaskan waters in 1888 defined the former area as Portlock Bank and the latter as Albatross Bank (Tanner, 1890). The general configurations of the two banks were shown (Fig. 1) in the U.S. Commission of Fish and Fisheries Chart No. 1, Alaskan Region (Rathbun, 1894).



1. A portion of U.S. Commission of Fish and Fisheries Chart No. 1, Alaskan Region (from Rathbun, 1894) showing the general outlines of Portlock and Albatross Banks (soundings in fathoms). The shoreward cruise track of the <u>King George</u> in May 1786 and the location of the first sounding of 70 fathoms has been inserted.

BATHYMETRY

Extensive soundings have been made since these early explorations, and the bathymetry of the area (Fig. 2) indicates numerous significant features. Portlock Bank is isolated by deep (> 150 m) channels, and Albatross Bank is actually composed of four distinct shoals also separated by deep channels--the most southward shoal extending around the southern end of Kodiak Island. All five shoals have areas where depths are less than 50 m (27.3 ftm). The shoreward intrusion of the 200-m isobath (nearly equivalent to the 100-ftm isobath in Fig. 1) north of Portlock Bank has been more clearly defined, as well as the sharp seaward gradient of the continental slope east of Afognak and Kodiak Islands. Inshore of these islands the sea floor slopes downward fairly gradually from the head to the entrance of Cook Inlet where a rather abrupt slope descends from 75 to 165 m and from there depths exceeding 100 m extend eastward past the Barren Islands and southwestward through Shelikof Strait. North and south of the Barren Islands, the sill depth is about 150 m and a trough with depths in excess of 200 m extends southwestward along the west coast of Afognak Island. Shelikof Strait, which extends from the entrance to Cook Inlet southwestward along the west side of Afognak and Kodiak Islands slopes irregularly, but gradually, from 165 m to 275 m at the southern end, where the channel turns southward. However, offshore and onshore flow is restricted to the upper 200 m because of a sill along the shelf edge southwest of Chirikof Island. Thus, bottom water in this area is replaced only by flushing.



2. Bathymetry of the area derived from (USC and GS Chart No. 8502, 17th ed. June 1971) showing numerous shoals with depths less than 50 m and numerous channels (indicated by arrows) with depths greater than 100 m.

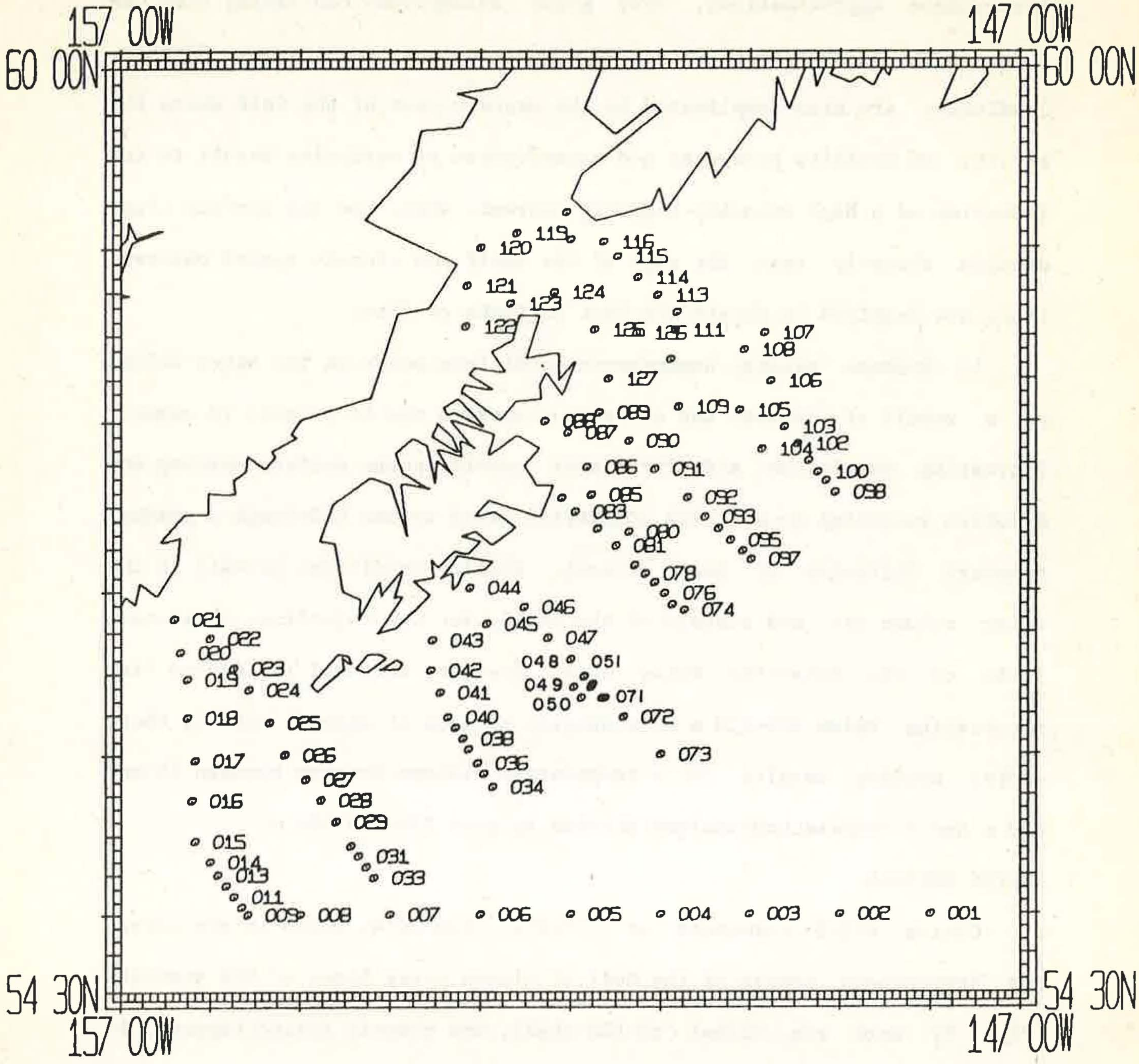
OCEANOGRAPHY

Numerous authors have contributed to the general understanding of oceanic conditions and flow in this area: McEwen, Thompson, and Van Cleve (1930); Doe (1955); Dodimead et al. (1963); Royer (in press); and others. The system is locally wind-driven. During winter, cyclonic winds associated with the Aleutian low pressure system intensify the general cyclonic flow around the gulf. This, combined with an accelerated, vertically upward divergence in the water column in the central gulf and low runoff due to freezing conditions, confines coastal water not only to inshore areas but—this piling up of water along the coast, obvious sea-level data--results in a compensating flow seaward along the bottom. In summer, anticyclonic winds associated with the expanding Central Pacific high pressure system exert a braking effect on the cyclonic flow of water in the gulf. Although there is little evidence that anticyclonic flow is established in summer except perhaps near the shelf as a result of aspirative or boundary effect of the westward flow, forces holding the piled-up water along the coast are relaxed, the vertically upward component of flow in the central part of the gulf is altered, and the abrupt entry of river runoff from local snowsheds occurs--all resulting in an offshore component of dilute water at the surface and a shoreward component of warm, saline water across the shelf. The short-term surface effects lasting a week, month, or even a season, vary considerably, but they exist for too short a time period to significantly alter the deep distribution of mass. Thus, basically, steady state conditions exist below 200-300 m. Because neither the barotropic flow reflecting short-term pressure effects, nor the short-term baroclinic effects are adequately represented by geostrophic approximations, only gross assumptions concerning flow can be made in the absence of extensive direct current measurements. Further, conditions are also complicated in the western part of the Gulf where the effects of Coriolis parameter and conservation of vorticity result in the formation of a high velocity boundary current, where the sea surface slope changes abruptly near the edge of the shelf and closely spaced observations are required to obtain the best estimate of flow.

In inshore waters, homogeneous conditions occur in the water column as a result of turnover and stirring processes due to storms; in summer, increasing insolation and freshwater runoff cause surface warming and dilution resulting in a stable stratified water column (although a gradual downward diffusion of heat occurs). Similar conditions prevail in the water column near and seaward of the shelf, but the halocline, characteristic of the Subarctic Water Mass, prevents seasonal influences from penetrating below 200-300 m or a density surface of sigma-t =26.70; thus, winter cooling results in a temperature-minimum stratum between 75 and 100 m and a temperature-maximum stratum between 250 and 300 m.

CRUISE DETAILS

Cruise K72-2 commenced at 55°00'N, 140°00'W, which is considered the approximate center of the Gulf of Alaska gyre; lines of STD stations (Fig. 3) were run normal to the shelf, and closely spaced (approx. 10 km) stations were obtained near the shelf edge. Along one line, where the continental slope was the most abrupt, a series of repetitive stations (No's. 51-71) were taken to ascertain fluctuations in flow at the shelf edge. In addition, seabed drifters (Ingraham and Hastings, 1974) were



3. Locations of oceanographic stations (STD casts), RV George B. Kelez Cruise No. K72-2 (a series of seven replicate casts were made at three stations between Sta. Nos. 51 to 71) (from Ingraham and Fisk, 1973). Cruise period, 27 April to 10 May 1972.

released at various locations to provide an indication of flow over the shelf. No direct current measurements were made because useful data require records over extended periods of time, and an extensive biological program had to be carried out. No moored current meters, that could be dropped and recovered later, were available to us. All physical station data and explanations of field techniques can be found in Ingraham and Fisk (1973); biological observations have been summarized by Dunn and Naplin (1974).[3/]

ENVIRONMENTAL CONDITIONS

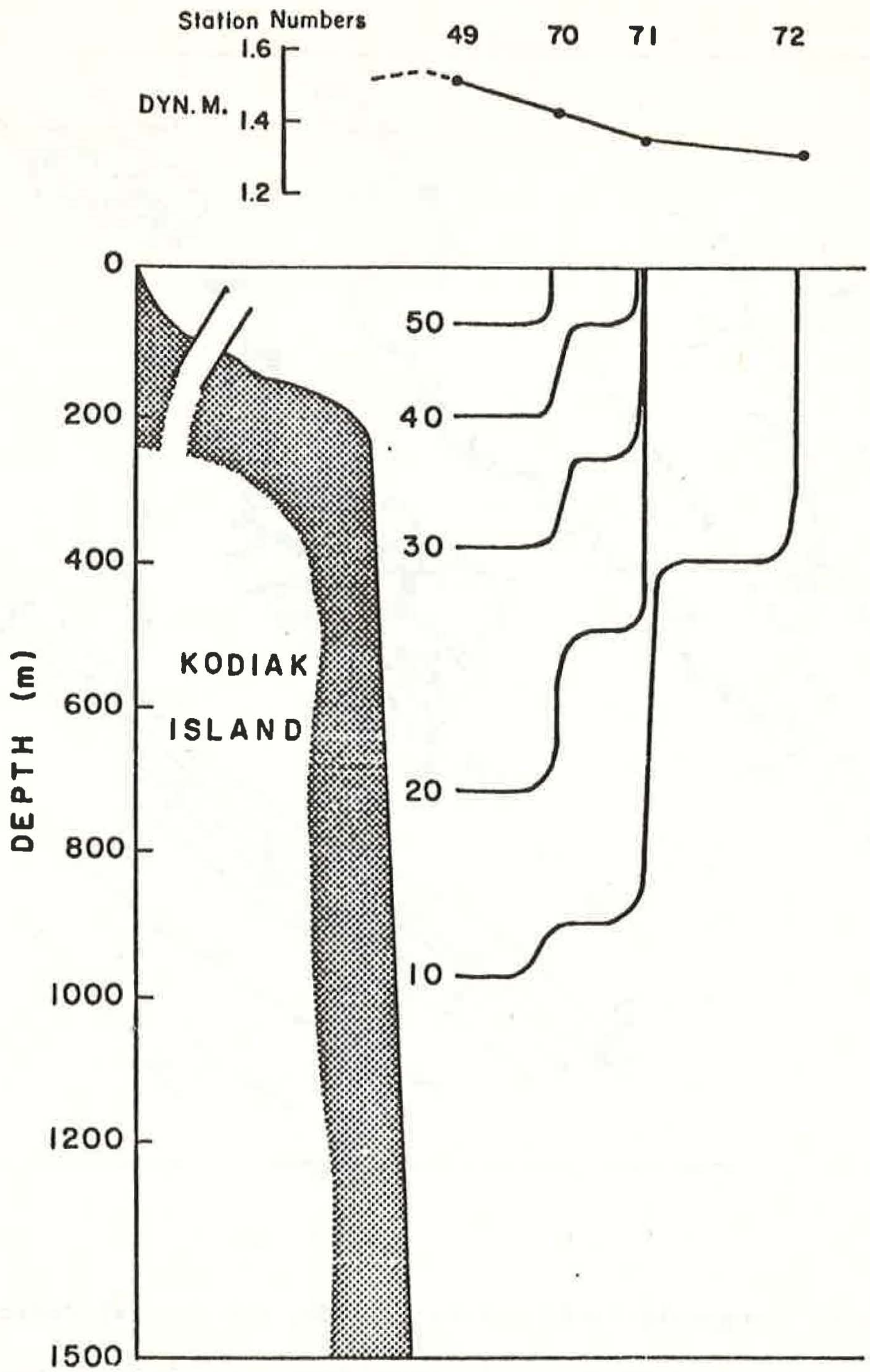
FLOW SEAWARD OF THE SHELF

The selection of a level of no motion for calculations of geostrophic flow is somewhat illusory, but there is some evidence that 3000-4000 db is probably the best choice for this general area (Favorite, 1974), because the anomaly of dynamic height increases monotonically with depth to this stratum. However, the STD data extend only to a maximum of 1500 db, and current speeds and transports presented will be relative to this, or a shallower level. Although current directions are representative, current speeds will be less than values that would be obtained if the data extended to deeper levels, and maximum speeds are obtained just seaward of the shelf. The physical presence of the land mass places severe limitations on the dynamic method of calculating flow, but there is evidence that geostrophic calculations reflect actual flow conditions (Reed and Taylor, 1965, Ingraham and Favorite, 1968).

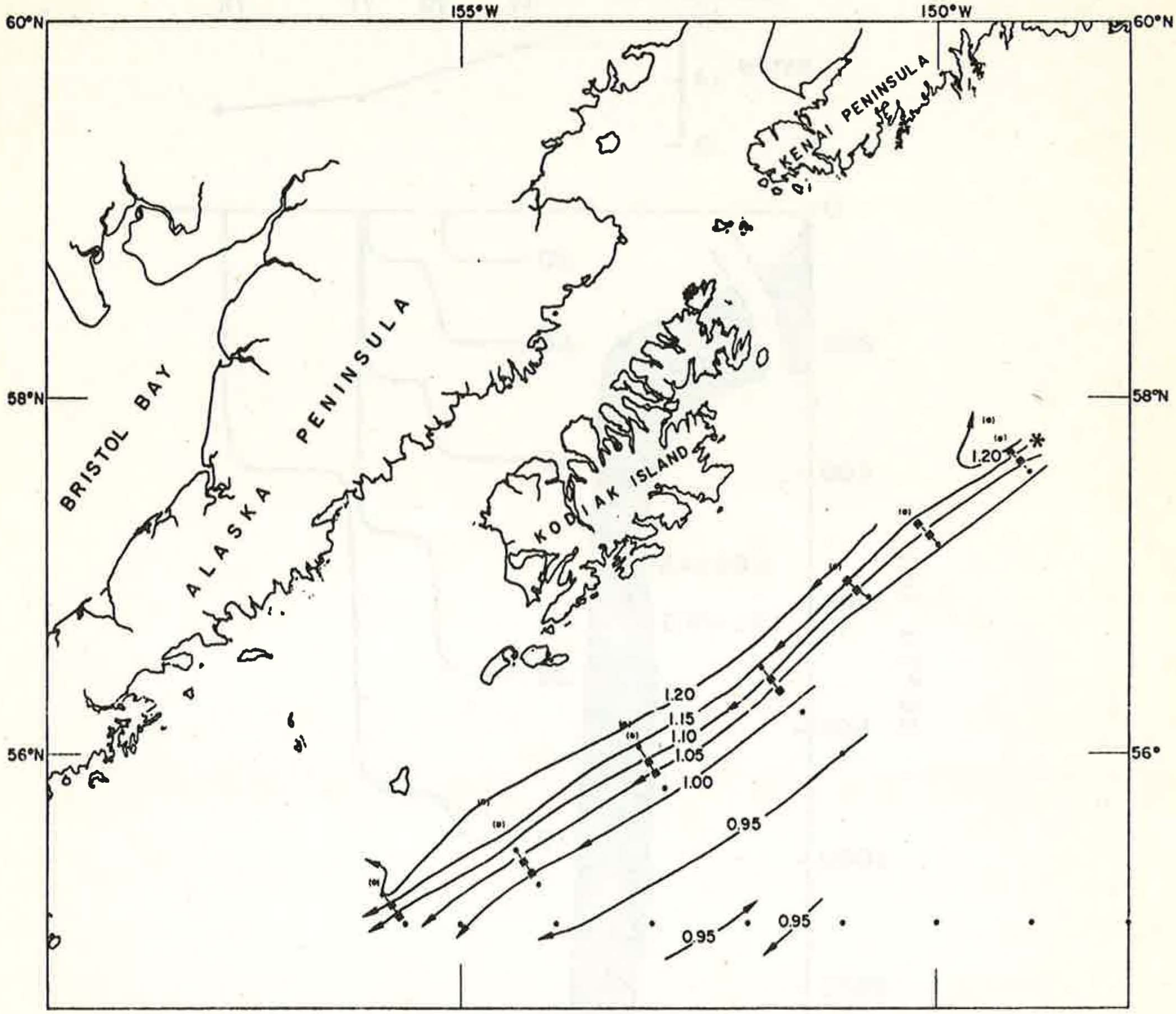
Calculations of volume transport relative to 1500 db from the center of the Gulf of Alaska (Sta. No. 1) along a line nearly normal to the shelf (Sta. Nos. 72 and 49) indicate that 71% of the southward flow, 12.5 sv[4/] occurred within about 50 km of the shelf edge. The vertical current structure between Sta. Nos. 72 and 49 (Fig. 4) indicates the general nature of the flow (relative to 1500 db) at the edge of the shelf; speeds greater than 50 cm/sec (about 1 knot) occur in the upper 100 m of the water column.

The station spacing along this line is not adequate to show another flow characteristic usually found seaward of the alongslope flow in this area; this is the presence of an offshelf countercurrent or northeast flow. However, this feature is clearly evident along the initial line of stations (Sta. Nos. 1-9) between Sta. Nos. 5 and 6. The explanation of this flow (surface velocity 4 cm/sec, volume transport 1.5 sv) is not clear, but Tabata[5/] (1975) believes that this countercurrent is continuous around the Gulf of Alaska.

In order to show the current structure closer to the shelf edge a reference level of 1000 db has been used and, in several instances, values at stations located in slightly shallower depths have been extrapolated to 1000 db. The isolines of the geopotential topography of the sea surface at the shelf edge between the seven lines of stations normal to the coastline trend in a remarkably straight northeast-southwest direction suggesting the absence of any large perturbations; the uniform, seaward slope of the sea surface, indicating a southwest flow, is apparent except at the northernmost and southernmost lines of stations (Fig. 5). The maximum geostrophic velocity between two adjacent stations on each



4. Vertical profile of geostrophic velocities (referred to 1500 db), cm/sec, seaward of the continental shelf, and geopotential topography at the surface.



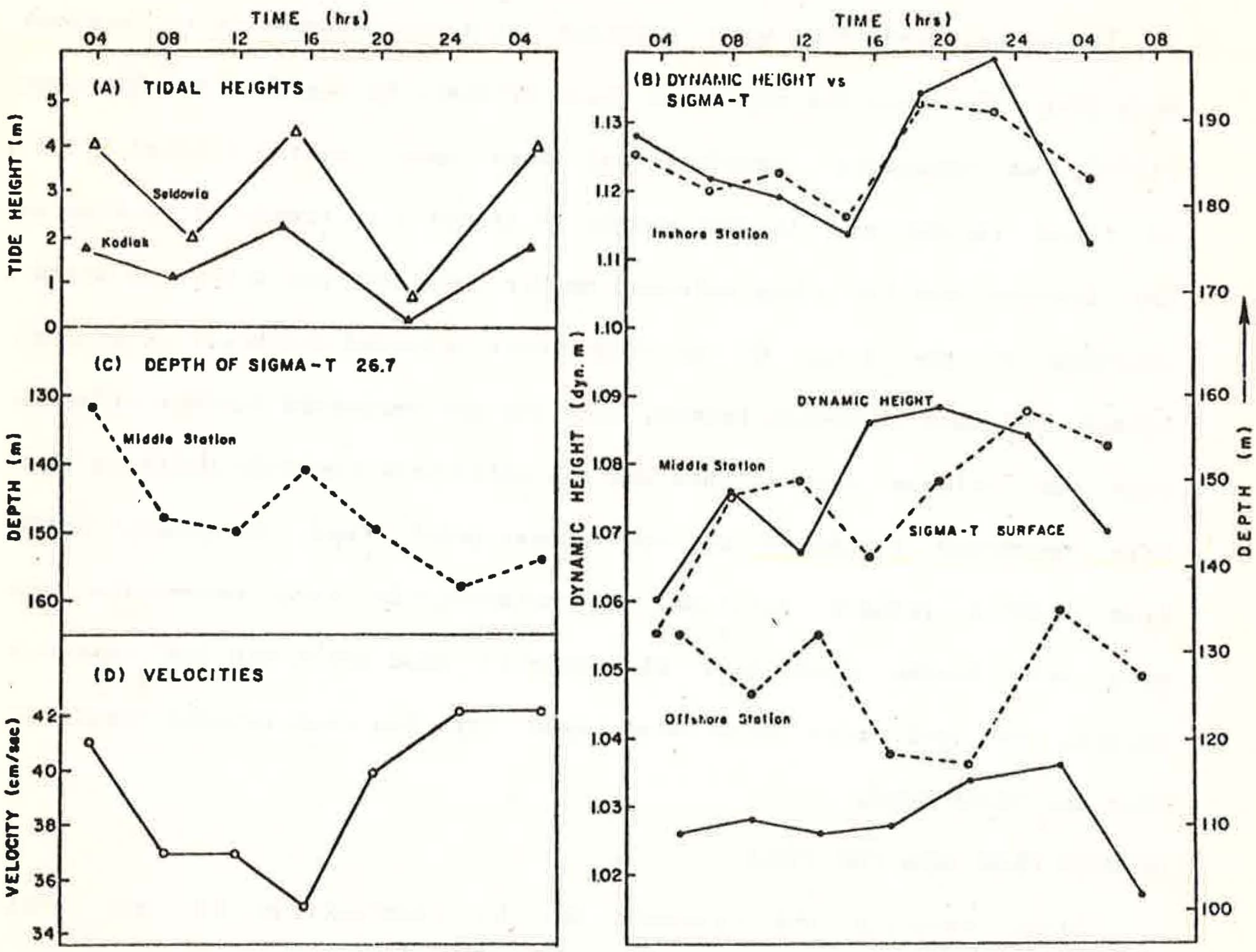
5. Geopotential topography (referred to 1000 db, dyn m - (•) indicates extrapolated data) along the shelf edge. Velocities between two indicated pairs (dashed lines) of stations along each line of stations (indicated by ▣) along each line varied from 33 to 80 cm/sec and had a mean value of 50 cm/sec (about 1 knot). Maximum velocity (referred to 1500 db) between Sta. Nos. 99 and 100 (indicated by *) was 98 cm/sec (nearly 2 knots).

of the seven lines of stations varied from 33 to 80 cm/sec, the overall mean being 50 cm/sec. Data at four of these station pairs, including the pair (Sta. Nos. 99-100) from which the 80 cm/sec was derived, extended to 1500 m, and the proportionate increases in velocity as a result of using the deeper reference level varied from 18 to 26%; thus, a calculated maximum velocity of 98 cm/sec (nearly 2 knots) was obtained. The overall mean velocity (referred to 1000 db) for two adjacent pairs of stations along each of the seven lines (14 values) was 44 cm/sec. This indicates that maximum surface velocities of nearly 100 cm/sec occurred in a narrow band of about 10 km width seaward of the shelf edge (near the 1000 to 3000 m isobaths) and that velocities in excess of this value could exist in a narrower band; further, a main flow of 30-50 cm/sec occurred in a band of about 50 km width.

RELATIONS BETWEEN DYNAMIC HEIGHTS AND COASTAL TIDES

A series of seven replicate STD casts to 1000 db were made at three stations spaced about 10 km apart along one of the lines normal to the coast where the continental slope dropped off precipitously; observations were made at each station in rotation during an approximate 24-hour period on 5 May (56°29'N, 151°51'W; 56°25'N, 151°46'W; and 56°21'N, 151°39'W-- Sta. Nos. 51-53 and 69-71). Velocities between the two sets of adjacent stations (14 values) varied from 25 to 58 cm/sec; in six of the seven instances the highest velocities occurred between the inshore set of stations where the overall mean velocities were 45 cm/sec compared to 35 cm/sec between the offshore set.

An interesting aspect of these data is their relation to coastal tidal heights. Tidal data for the Afognak and Kodiak Islands are computed from both the Seldovia and Kodiak reference stations (U.S. Department of Commerce, 1971). Unfortunately, during this period both stations were characterized by not only a pronounced diurnal inequality but nearly minimum ranges, approximately 4 and 2 m, respectively—about half the ranges that would exist the following week. Comparison of tidal data and time-series dynamic topography at the three locations (Fig. 6) indicates that fluctuations in dynamic heights of 2-3 dynamic centimeters occurred somewhat in phase at all three stations but generally 180° out of phase with tidal heights; this is particularly evident at the middle station. Water properties permit separating the water column in this area into distinct upper and lower strata. This separation occurs at the sigma-t surface of 26.70, which occurs at a depth approximately equal to that of the shelf edge, 200 m. The near synchronous undulation of this surface at the middle station with that of the inshore tidal heights suggests an internal wave at the shelf edge responding to tidal forces. Mean velocities in the southwestward flow between the inshore and offshore stations, as implied by changes in the slope of the dynamic topography between the two stations, indicated a reduced flow (35 cm/sec) during the inshore period of high tide and increased flow (42 cm/sec) during the period of low tide.



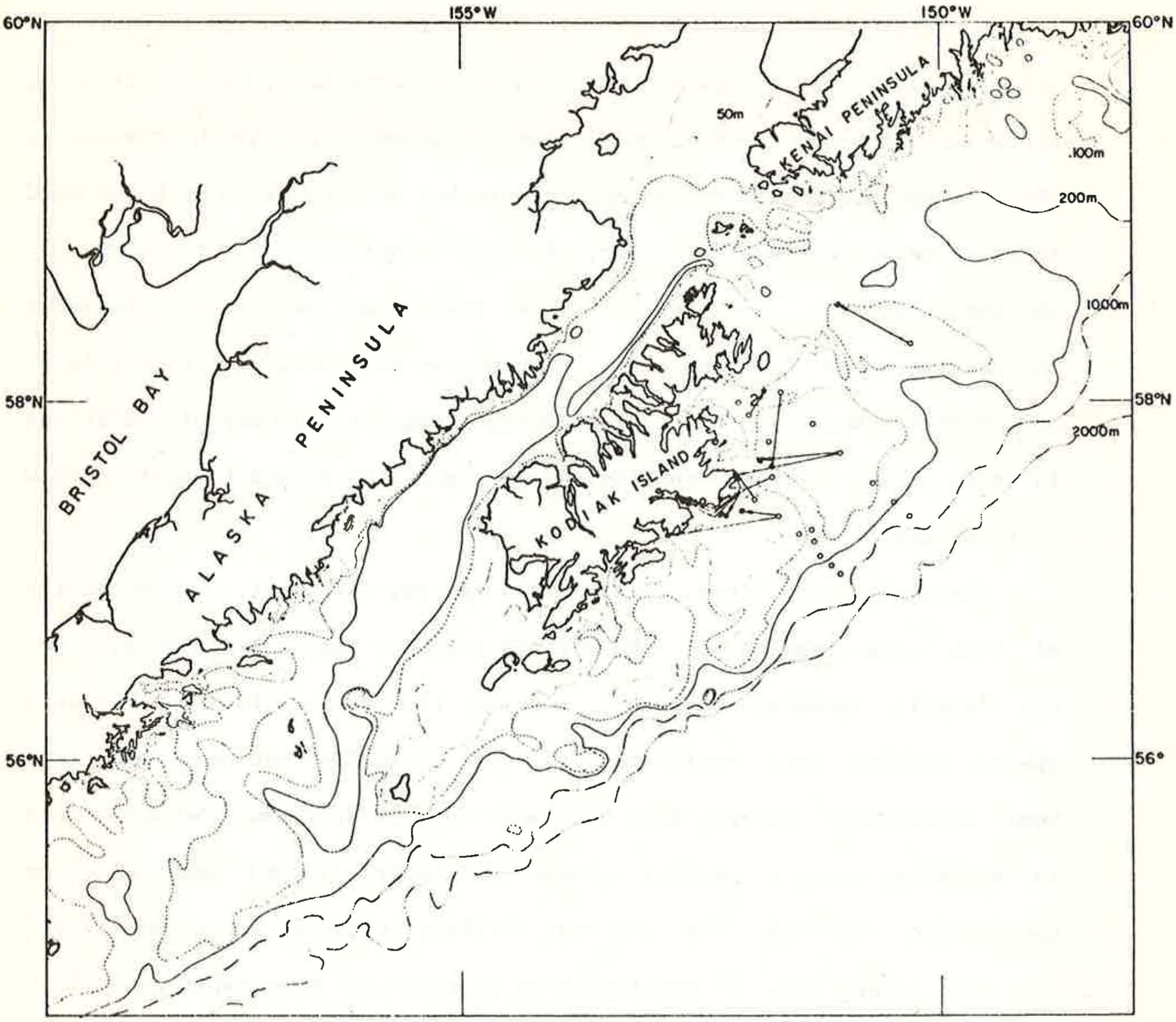
6. Time series relations between: (A) tidal heights (m) at Seldovia and Kodiak reference stations for 5-6 May 1972 (GCT); (B) anomalies of dynamic height (dyn m) and depth of 26.7 sigma-t surface at inshore, middle, and offshore repetitive stations (see Fig. 3); (C) fluctuation of in situ depth (m) of 26.70 sigma-t surface; and (D) mean southwest velocities between inshore and offshore stations.

BOTTOM FLOW ALONG THE SHELF

A total of 475 seabed drifters was released (in groups of 25) at 19 locations, and 100 were released at a single location on Portlock Bank (Fig. 7). Since the report on these drifters by Ingraham and Hastings (1974), an additional recovery has been made, making a total of 16 of these recoveries, 11 were caught in either fish trawls or crab pots. One drifter from the group released on Portlock Bank was recovered northwestward of the bank. Of the 14 drifters released southeast of Afognak Island and east of Kodiak Island, only one was recovered farther offshore than the release point; this and one other were the only drifters that were recovered northward of the release point. Thus, the general drift from inshore release locations was southwesterly. Three recoveries were made well inside Ugak Bay; the overall mean drift was less than 0.5 cm/sec. No recoveries have been made from the nine release locations near the shelf edge.

SURFACE FLOW OVER THE SHELF

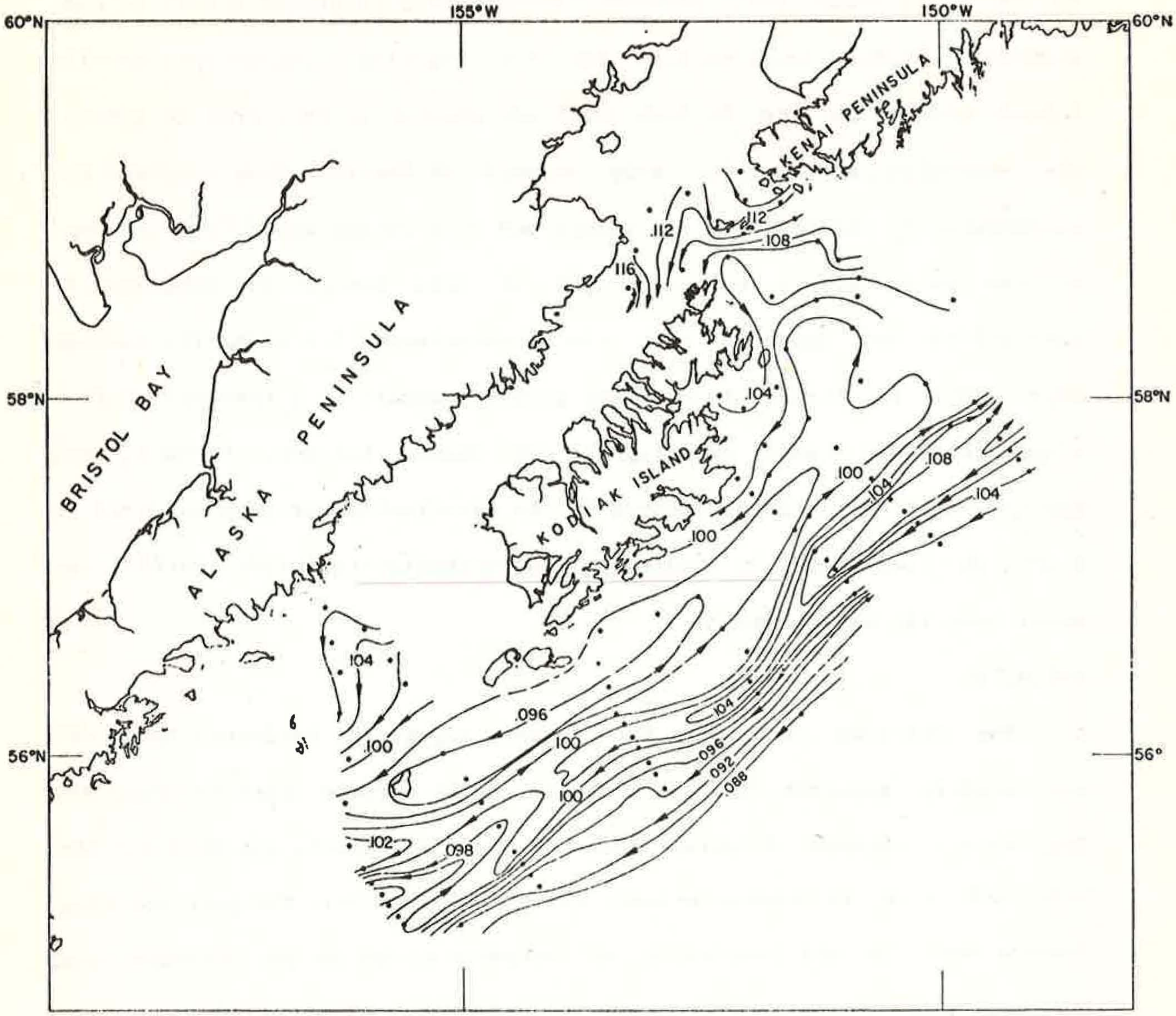
Tidal currents and currents due to fluctuations in sea level certainly dominate flow in coastal waters, but neither are intrinsically resolved by the dynamic method used to obtain geostrophic currents. Tidal heights in the Afognak and Kodiak Islands range from 1 to nearly 10 m. This results in considerably variable tidal excursions and speeds that are not possible to document using station data. Further the effects of slope currents, changes in sea level primarily caused by storm surges, are also difficult to assess without special observations. Nevertheless, a suggestion of surface flow is afforded by plots of the anomalies of dynamic heights in the near surface layer. These geostrophic currents



7. Release and recovery locations of seabed drifters (after Ingraham and Hastings, 1974) showing general southwestward drift of inshore releases. No recoveries have been made from releases near the shelf edge.

reflect the presence of pools or lenses of water of varying temperature and salinity that have been able to maintain a certain integrity in spite of, or as a result of, continuing advective, mixing, stirring processes. However, since only flow relative to the depth selected is obtained by this method and an appreciable but unknown flow can be assumed to exist below this surface layer, absolute velocities are not necessarily obtained; however, the general flow field can be depicted. In order to utilize data from as many stations as possible, a reference level of 50 db has been used (Fig. 8), and the integrated effects of conditions in this layer provide considerable insight with regard to surface flow over the shelf.

Obviously the lines of stations are too far apart to show details of flow with respect to the various offshore shoals and channels, but the details revealed certainly suggest that observations on a closely spaced station grid would be not only justified but very rewarding. Some temperature surveys have been made in this area, but the variations in salinity have a greater effect on water density and, thus, on geostrophic currents. The two most striking features, not shown before, are: the large area of the trough of geopotential topography generally, except in the area of Portlock Bank, within the 150 m isobath isolating southwestward flow in the inshore areas from the southwestward flow seaward of the shelf edge; and, the remarkable continuity of the opposing flow in the shear zone near the shelf edge, in spite of the obvious filamentous nature of this flow.

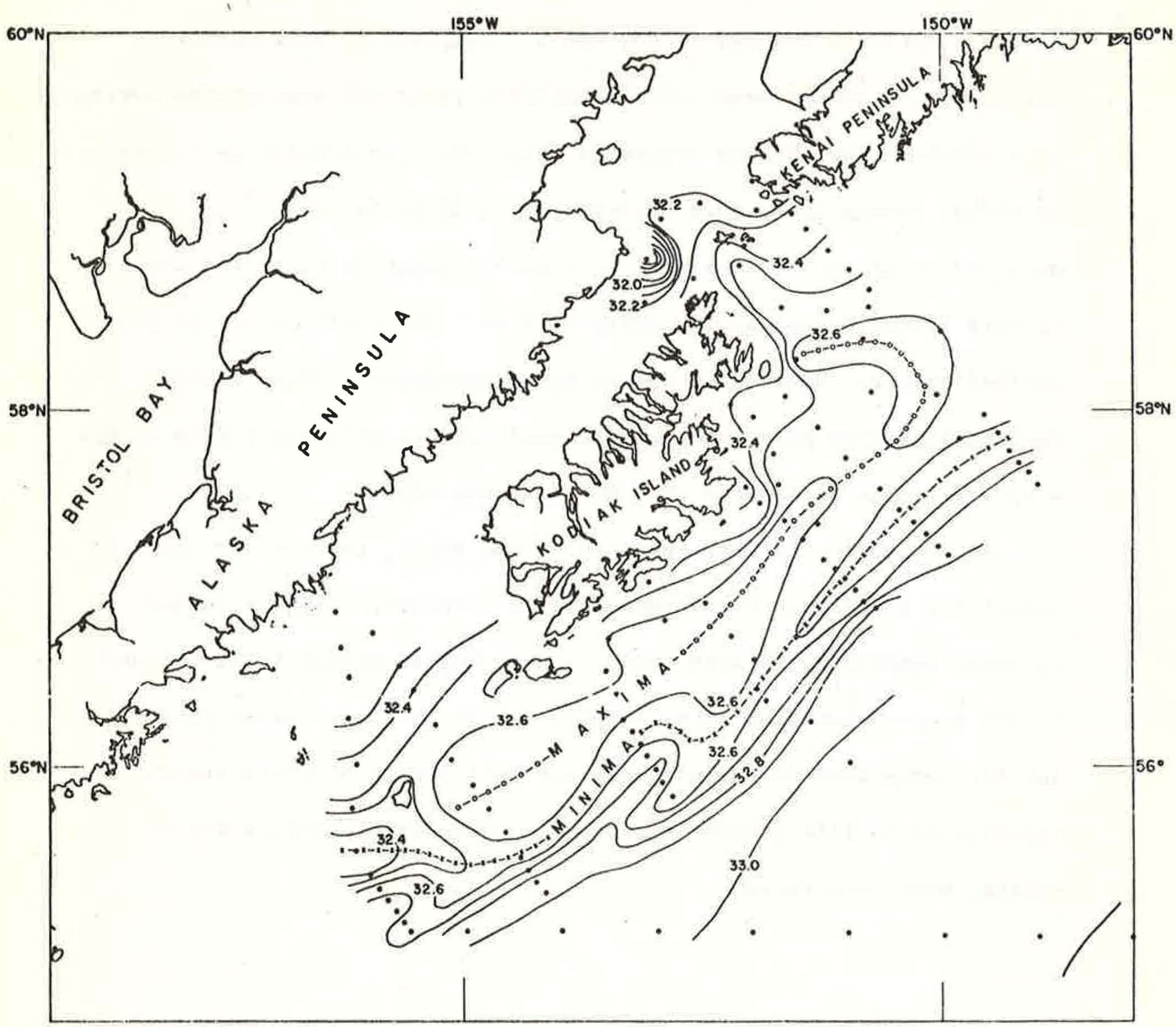


8. Continuity of geostrophic current patterns (referred to 50 db) over the shelf indicating the presence of a large cyclonic gyre between the inshore and offshore southwestward flow and the shear zones near the edge of the shelf.

The westward flow north of Afognak Island indicates the penetration of offshore water into Shelikof Strait and this should result in considerably higher temperatures than the negative temperatures usually formed under the ice in Cook Inlet and present in this area in spring. The extensive anticyclonic eddy seaward of Portlock Bank suggests the southwestward penetration of warmer and less saline water from the head of the gulf. It is apparent that if this penetration subsequently intensified and expanded that the northeastward flow along its inshore edge would be forced inshore and possibly result in a reversal of flow along the east coast of Afognak and Kodiak Islands. Further, this feature--only slightly indicated in the geostrophic currents referred to 1,000 db (see Fig. 5)--indicates that marked perturbations in flow can occur near the shelf edge.

SALINITY

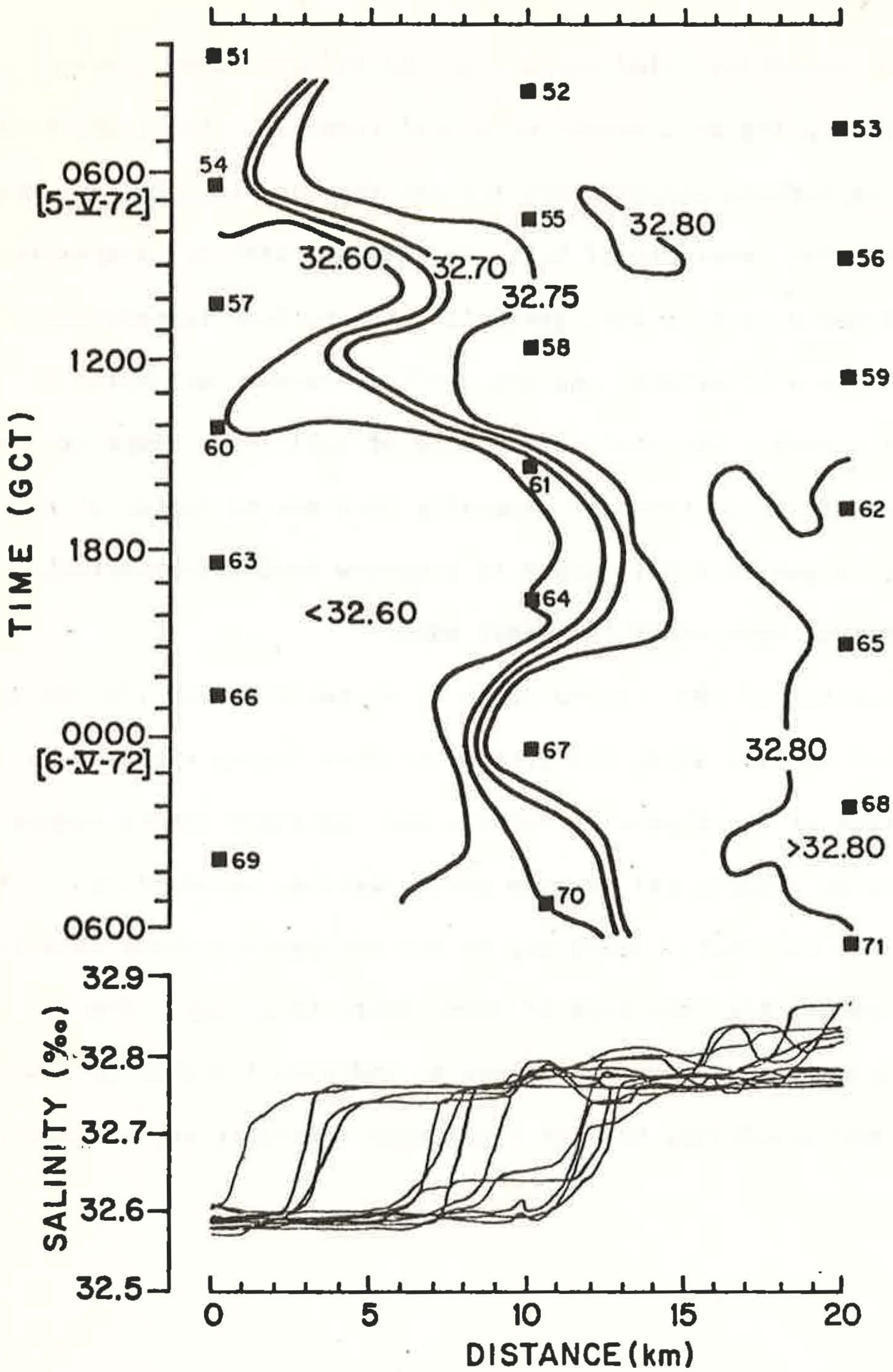
The features shown by the dynamic topography (referred to 50 db) are readily apparent in the distribution of surface salinity (Fig. 9). The normal inshore dilution due to runoff is readily apparent and the mid-shelf area is characterized by salinity maxima. The most striking feature here is the continuity of salinity minima in the offshore area. This feature originates at the eastern end of the northernmost track line and has continuity throughout the entire area of study between the mid-shelf maxima and the higher salinities in the oceanic regime seaward of the shelf. Another perturbation is evident southeast of Kodiak Island at the shelf edge where, although the data are inadequate, it appears that vortices form at the inshore side of the high velocity southwest flow along the shelf edge.



9. Distribution of surface salinity (‰) showing location and continuity of areas of minima and maxima, and reflecting geostrophic flow patterns.

A continuously recording surface thermosalinograph was in operation while the vessel was underway between the repetitive stations (Sta. Nos. 51-71). Although changes in sea surface temperature were hardly detectable, a conspicuous surface salinity front was encountered during both offshore and onshore transects (Fig. 10). In several instances an abrupt change in surface salinity, from 32.65 to 32.75 $^{o}/_{oo}$, occurred within a distance of 1 to 3 km, although at times the width of this frontal zone was in excess of 5 km. The position of the front shifted seaward about 10 km during the approximately 30-hr period Observations were made and periodic oscillations of roughly 8 to 10 hrs with amplitudes of about 3 to 5 km were apparent.

As a result of winter turnover on the shelf, the surface layer is relatively isohaline; below the depth of turnover, salinity values increase monotonically with depth. Thus, higher salinities are found in the deeper channels. These higher values influence geostrophic flow, but the variations in salinity are not believed to be particularly significant to life processes, except in the near inshore areas at coastal zone interfaces.

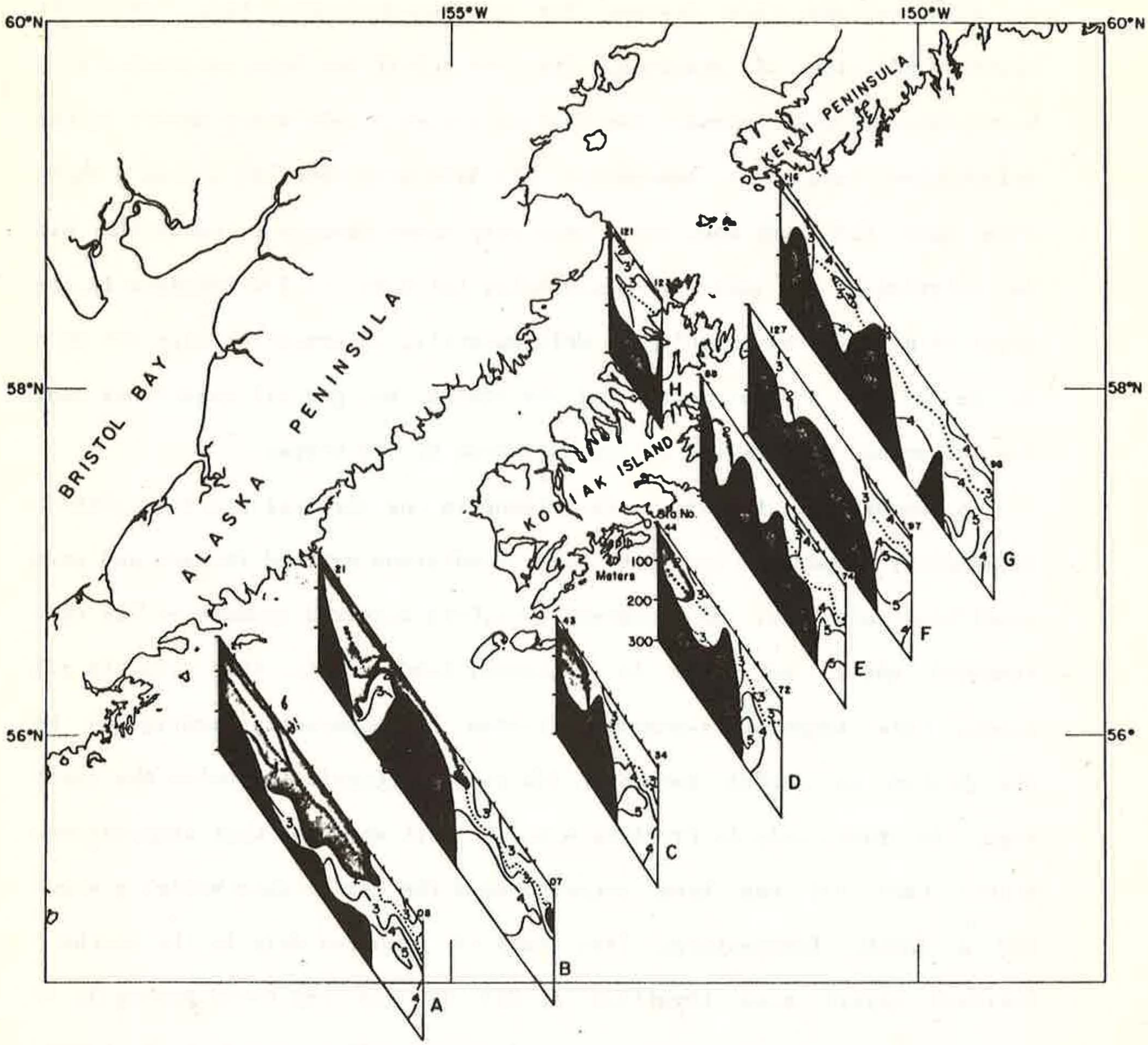


10. Surface salinity ($^{o}/_{oo}$) data obtained between repetitive stations (see Fig. 3) by continuously recording thermosalinograph showing fluctuations in position of the surface salinity front in the vicinity of the shelf edge (near 56°25'N) during 5-6 May 1972 (station location and time indicated by ■).

TEMPERATURE

Isothermal conditions also prevail in the surface layer during winter and early spring as a result of winter turnover. Low temperatures (0-1^{o}C) occur in inshore waters where ice may form and the shallow depths, lacking an extensive reservoir of heat, equilibrate with air temperatures faster than offshore waters; but, generally, the surface temperature regime offshore is a relatively uniform 3-4^{o}C. However, at depth, conditions are somewhat the reverse of those of salinity. Temperatures below the depth of winter turnover generally increase to depths in excess of 300 m; this is particularly marked in a narrow band approximately 50-100 km wide just seaward of the shelf edge.

The combination of the limited depth of winter turnover (75-100 m) and the reversal of flow along the bottom (seaward during winter as a relaxation effect of water pile-up inshore and shoreward during summer because of reverse conditions) permits quite variable temperature conditions on the sea floor, depending on the bathymetry; these effects are reflected in vertical sections of temperature (Fig. 11). The indicated bathymetry stems from soundings at individual stations, rather than from charted soundings, but the topography is highly representative;



11. Vertical sections of temperature (°C) along lines of stations normal to the shelf (note southernmost one is shown as straight line) indicating the warm water (> 4°C) at depth seaward of the shelf edge, the depth of the temperature-minimum stratum (dotted line at approx. 100 m), and cold water (< 2°C) inshore (station locations shown by ticks, and Sta. Nos. of inshore and offshore stations are indicated).

also, some of the lines of stations have been skewed for convenience in illustrations, but (except for the southernmost line, where the north-sound line of stations, Sta. Nos. 15-21 has been orientated in a Northwest-southeast manner for obvious reasons) only minor shifts in the orientation have been necessary. All data were obtained within a short time span (15 days) and, thus, only very minor changes in conditions can be attributed to lack of synopticity (at most a 0.5°C increase in the upper 10 m of the water column). Unfortunately, observations were not made at or within a few meters of the bottom, but general conditions near the bottom can be inferred by extrapolation of STD traces.

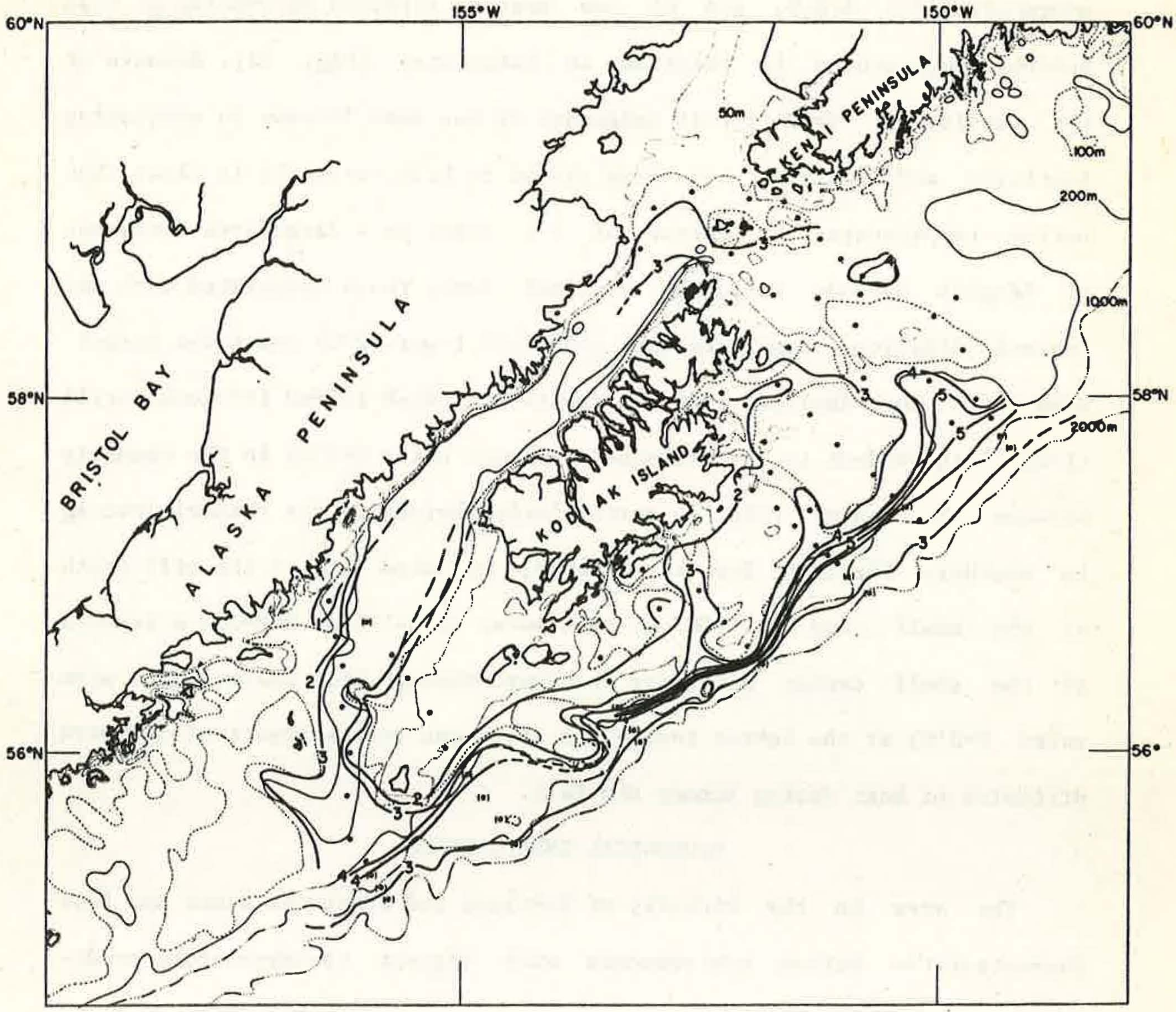
A number of features are evident in the vertical profiles. First, immediately apparent is that cold conditions existed inshore and warm conditions offshore. Warm water (> 5.0°C) occurred seaward of the continental shelf, and this is a normal condition for this area. In all cases, this temperature-maximum stratum is apparently contiguous to the bottom at depths exceeding 200 m--thus technically below the shelf edge. In fact, only in Profiles A and C is it apparent that temperatures higher than 4°C may have occurred near the bottom substantially above 200 m depth. Temperatures less than 1°C occurred only in the southern Shelikof Strait area (Profiles A and B) and were found generally in the upper 200 m, but temperatures less than 2°C occurred at the bottom all along the east coast of Kodiak and Afognak Island (Profiles A to F). Second, conditions north and east of Afognak Island were 2-3°C higher than conditions south of Kodiak Island. This is due primarily to the influence of westward advection of warm offshore waters in the former area and of severe winter conditions in Shelikof Strait in the latter area. And third, because the offshore banks extend above the level of the temperature- minimum stratum, winter turnover and, thus, vigorous vertical mixing penetrated to the bottom in these areas.

The occurrence of pockets of warm water in the bathymetric depressions (Profiles A,B,D, and G) can best be resolved by looking at near bottom temperatures in relation to bathymetry (Fig. 12). Because of the paucity of data it is necessary to use some license in contouring isotherms and emphasis has been placed on bathymetry. It is clear that bottom temperatures in excess of 3°C occur in a large area northeast of Afognak Island, including Portlock Bank; those associated with the general Albatross Bank area were about 1C° lower (2°C) and those associated with the shallow area southwest of Kodiak Island 1C° lower still (1°C). Also evident is the presence of warmer water (>3°C) in the channels between the banks; this is particularly obvious in the channel leading to southern Shelikof Strait. However, as noted earlier the sill depth at the shelf edge is 200 m, thus water of 4-5°C at 200-300 m seaward of the shelf cannot penetrate shoreward through this channel. The warm water (>3°C) at the bottom inside the sill must be the result of downward diffusion of heat during summer and fall.

BIOLOGICAL IMPLICATIONS

The area in the vicinity of Portlock and Albatross Banks has four characteristic bottom environments with respect to temperature conditions.

First, at the edge of the continental shelf and along the upper slope where temperatures of 4-5^{o}C occur year round and southwest velocities of up to 50-100 cm/sec, or higher, also occur.



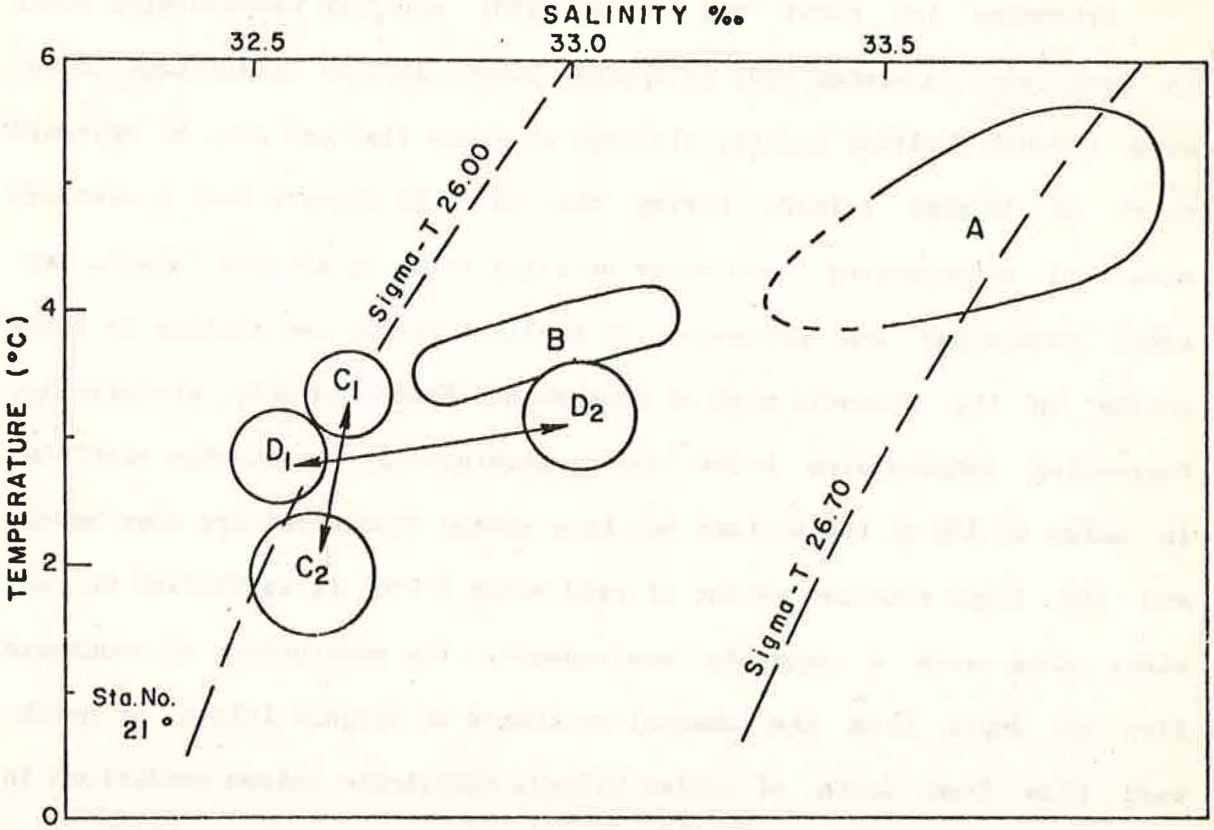
12. Approximate bottom temperatures (°C - inferred by temperature distributions and trends in the water column at individual stations and by bottom topography) showing the band of warm (>4°C) water at the edge of the continental shelf and the shoreward intrusions of 3°C water in various channels between shoals except around and northward of Portlock Bank where warmer conditions existed.

The continental shelf seaward of Afognak and Kodiak Island is cut by several channels that extend shoreward directly into coastal inlets, and these channels form the second type of bottom environment. Because the depths in these channels (>150 m) are greater than the depth of winter turnover, relatively constant conditions can be expected to occur, except for two situations: (1) the presence in winter of low temperatures, ice, and snow-melt near the coast results in temperatures of 0-1°C, and the accompanying increase in the density of the water and the effects of wind and tidal mixing permit these lower temperatures to extend to the bottom; and (2) the dilution caused by runoff does not permit the water to reach a sufficient density for it to flow seaward along the bottom, and it is effectively contained in coastal areas unless impelled by pressure forces in the water column--but current speeds are probably of the order of only a few cm/sec. The overall temperature effects of seaward flow masked by shoreward diffusion of heat from offshore water and those of the onshore flow are inhibited by the necessity of warming inshore sediments cooled by winter temperatures. Thus, although temperature gradients of 4-5C° can exist in these channels in winter, in summer, the downward diffusion and mixing of heat in surface waters can result in fairly uniform bottom temperatures in these channels of 4-5°C. Because onshore and offshore flow is slow and perhaps largely oscillatory, the primary transport of organic matter out of these channels may be dependent on flow normal to the channels and these velocities are not known.

The third environment occurs over the various shoals that penetrate above the depth of winter turnover (approx. 100 m). In winter, homogeneous conditions exist and, depending on the severity of winter conditions, temperatures of 1-2 °C can occur. These are 1-4 °C lower than those in the channels (except along the coast), and nonsessile organisms that are adversely affected by these temperatures could migrate seaward to the shelf edge or merely down into the channels. These shoals, reaching higher in the water column, will have temperatures of 6-9 °C in summer and, thus, more variable conditions than the other environments, except perhaps that of shallow coastal waters and embayments. Obviously, the less the depth of the shoal the greater the range of temperature, but there is another factor and that is the depth of surrounding water. North and south of Portlock Bank the 200 m isobath is deeply indented shoreward permitting the penetration of the warmer offshore water (4-5 °C) at this depth; thus, any horizontal movement of bottom water over the bank will have a warming effect. However, the shoal at the south end of Kodiak Island, isolated from this offshore water, is exposed to low temperatures that occur in winter as a result of turnover. These are maintained by cold conditions in Shelikof Strait, which is the fourth environment.

Extensive ice cover and accompanying negative temperatures occur in Cook Inlet in winter and, in spring, runoff results in drainage southward through Shelikof Strait, although at times flow can even be eastward north of Afognak Island. During May 1972, it appears that a westward flow and accompanying warm water occurred north of Afognak Island. Seasonal conditions and processes in Shelikof Strait are similar to those acting in the channels east of Afognak and Kodiak Islands, essentially, increasing temperatures below the temperature-minimum stratum resulting in water of 3 °C at the bottom; but here winter conditions are more severe and the large vertical extent of cold water (<1 °C) is sufficient to consider this area a separate environment. The possibility of southward flow at depth from the channel northward of Afognak Island, or northward flow from south of Kodiak Island, complicate bottom conditions in this area.

Temperature-salinity relations for the four environments are presented in Figure 13. It is clear that the inshore dilution, resulting in lower density water, isolates the cold inshore waters from those offshore.

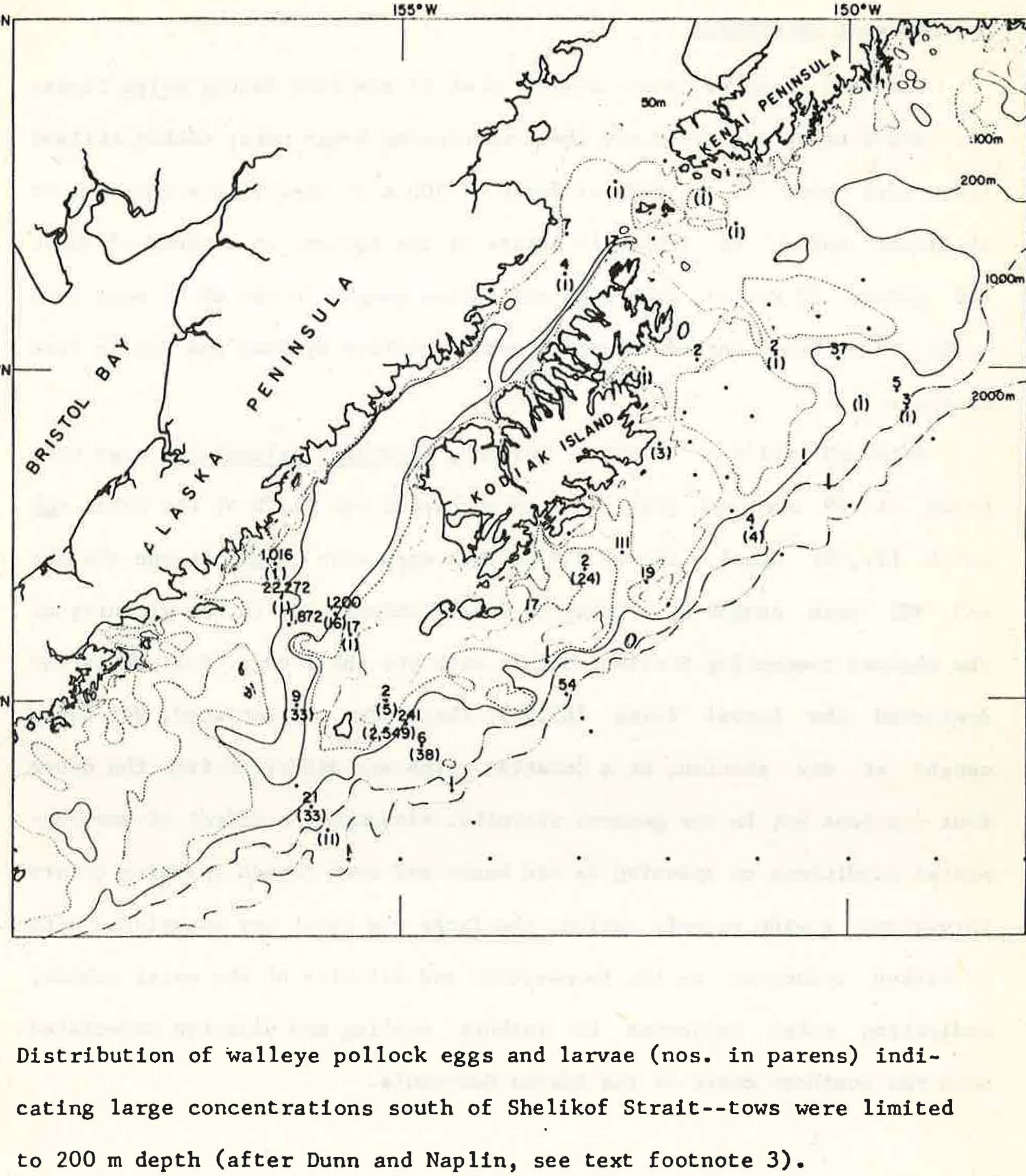


13. Schematic diagram of temperature-salinity relations of bottom conditions: (A) seaward of shelf edge, (B) in the channels between shoals of Portlock and Albatross Banks, (C_1) over the shoals in the vicinity of Portlock Bank, (C_2) over the shoals of Albatross Bank, (D_1) north end of Shelikof Strait, (D_2) south of Shelikof Strait. Cold, dilute conditions at Sta. No. 21 are also indicated.

POLLOCK EGGS AND LARVAE

Plankton samples were collected at 67 stations during _Kelez_ Cruise No. K72-2 using paired 60 and 20-cm nonclosing Bongo nets; double oblique tows were made to a nominal depth of 200 m at oceanic stations or, in shallower water, to within 15 meters of the bottom, at a speed of about 100 cm/sec (2 knots). Fish eggs and larvae caught in the 60 cm nets (505 mesh) have been sorted, counted, and identified by Dunn and Naplin (see Footnote 3).

Although walleye (Alaska) pollock, _Theragra chalcogramma_, eggs were found at 29 stations (Fig. 14) and accounted for 97.2% of the total egg catch (27,721 eggs), 83% of the pollock eggs were caught at one station and 98% were caught at a total of four stations--all in the vicinity of the channel connecting Shelikof Strait with the shelf edge. Pollock larvae dominated the larval forms (62.3%). These were concentrated, 94% being caught at one station, at a location which was different from the above four stations but in the general vicinity. Although the effect of environmental conditions on spawning is not known and even though spawning occurs throughout a wide oceanic region, the large egg catch was associated with a marked reduction in the temperature and salinity of the water column, indicating water subjected to inshore cooling and dilution associated with the southern coast of the Alaska Peninsula.



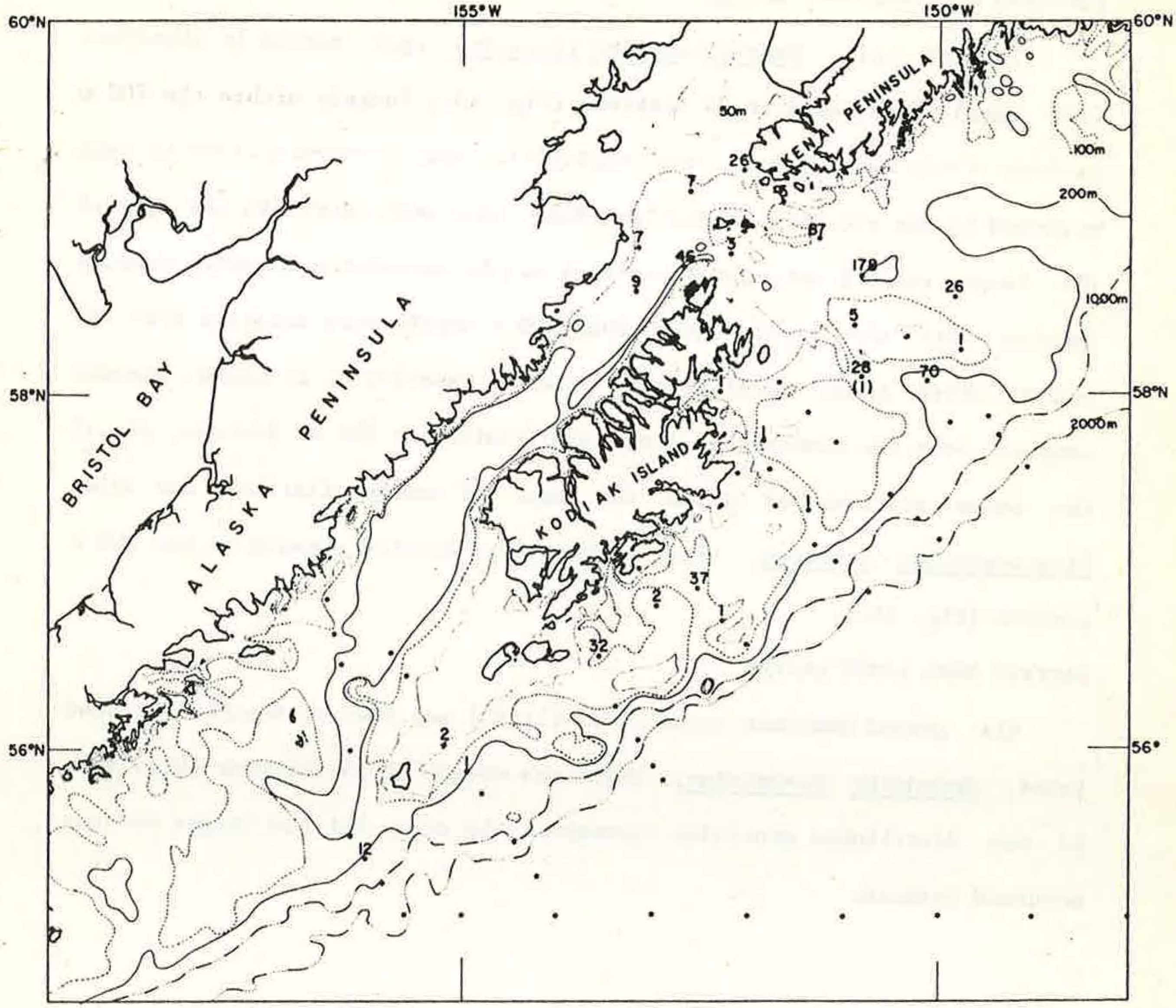
14. Distribution of walleye pollock eggs and larvae (nos. in parens) indicating large concentrations south of Shelikof Strait--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).

FLATHEAD SOLE EGGS AND LARVAE

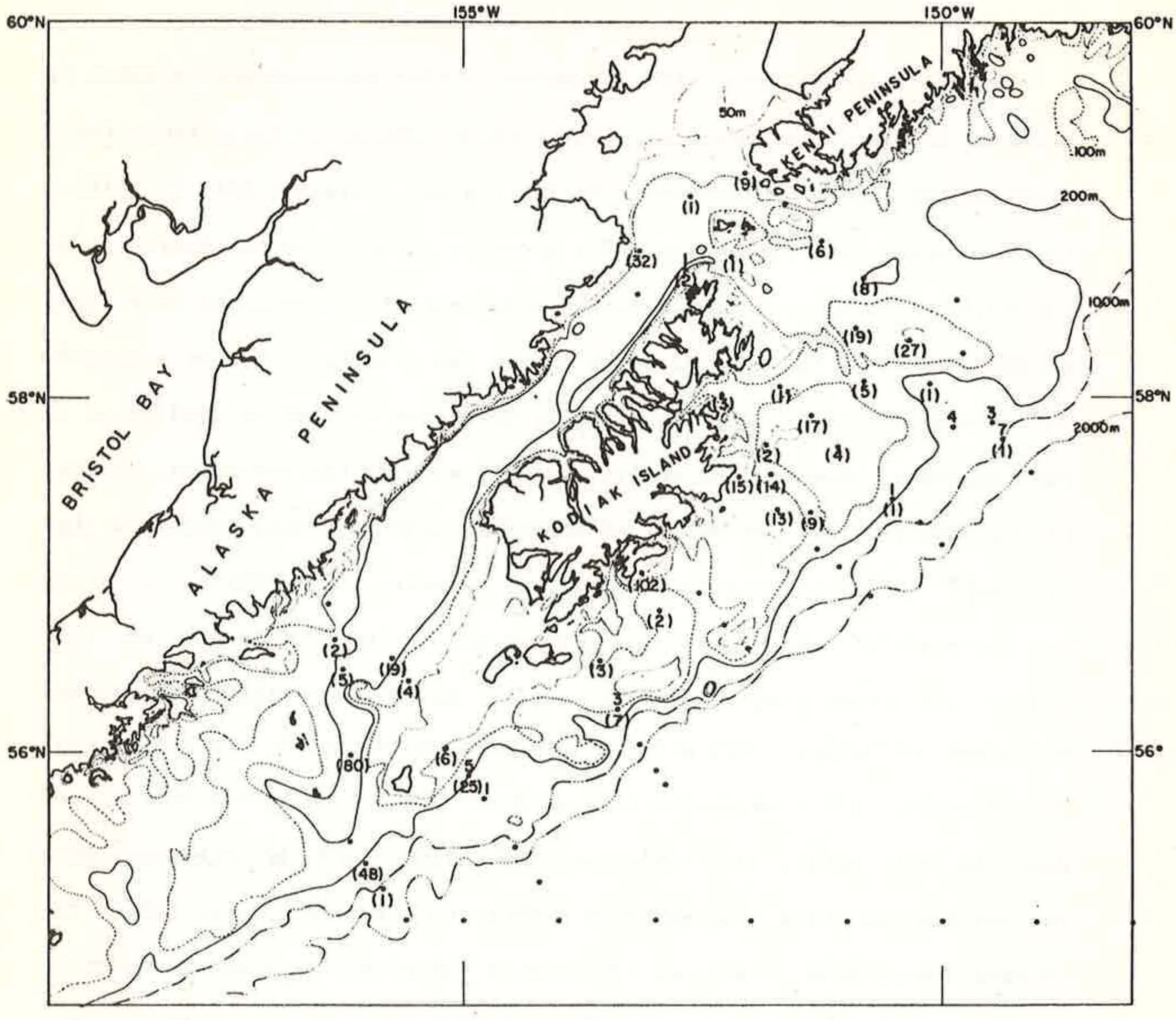
Flathead sole, Hippoglossoides elassodon, eggs, second in abundance (558 eggs), were found at 24 stations (Fig. 15), largely within the 200 m isobath (only one larvae was reported). Main concentrations of eggs occurred in the vicinity of Portlock Bank; none were caught in the area of the large pollock catches. These data may be somewhat misleading because samples over the shelf (less than 200 m depth) were obtained near the bottom where these demersal eggs could be expected to be found, whereas samples over the continental slope were limited to 200 m. However, six of the seven stations at which the eggs of another flatfish, Rex sole, Glyptocephalus zachirus, were caught were located seaward of the 200 m isobath (Fig. 16.).

PACIFIC SAND LANCE LARVAE

The second dominant larval form (11.4%) was that of the Pacific sand lance, Ammodytes hexapterus, which was caught at 34 stations (Fig. 16). It was distributed generally throughout the area, but the larger catches occurred inshore.



15. Distribution of eggs and larvae of flathead sole (nos. of larvae in parens) indicating concentrations in the warm water north and east of Afognak Island. Few were caught in the area southwest of Kodiak Island--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).



16. Distribution of eggs of Rex sole and larvae of Pacific sand lance (nos. in parens)--tows were limited to 200 m depth (after Dunn and Naplin, see text footnote 3).

CONCLUSIONS

Everyone associated with offshore marine environmental studies is aware of the fact that there is a limit to the amount of interdisciplinary research that can be accommodated during a given cruise as well as a limit to the scope and intensity of a specific study. This was basically an exploratory cruise, and STD lowerings were made at 127 stations in a short period of time in an area where only a few observations were available. In retrospect, more attention should have been focused on conditions in the channels between the shoals, as well as over the individual shoals. It is obvious that the number of stations could have been increased significantly with increasingly rewarding results. In addition, although the numbers of eggs and larvae were disappointingly small when one considers the productivity of this area, better sampling devices and different techniques may provide more informative numbers in the future. For example, all tows should have extended very close to the bottom, not only on the shelf, but also on the slope, and it might have been informative to have sampled three strata: (1) the mixed layer (above the temperature-minimum stratum); (2) between the mixed-layer and the bottom, or the level of the sigma-t surface of 26.7 (whichever occurred first); and (3) between the sigma-t surface of 26.7 and the bottom.

Environmental conditions in this area are complex and variable. However, there is apparently considerable continuity of some features and a great deal of information was obtained that should be of use in planning future oceanographic and fishing cruises.

1. Southwestward volume transport (referred to 1500 db) out of the Gulf of Alaska (seaward of the shelf) was 12.5 sv, and 71% of this flow occurred within 50 km of the shelf edge. Southwestward geostrophic velocities of 50 cm/sec (referred to 1000 db) occurred in a narrow band (approximately 20 km wide) along the shelf edge, and a velocity of 98 cm/sec (referred to 1500 db) occurred between two stations 10 km apart.

2. Northeastward flows were detected inshore and offshore of this boundary flow and disturbances in the water column, in phase with inshore tidal heights, were also apparent.

3. Geopotential topography over the shelf indicated the presence of a large cyclonic eddy with speeds of only a few cm/sec, separating the southwest flow at the shelf edge and the southwest flow along the east side of Afognak and Kodiak Islands. Bottom flow in the inshore area as implied by seabed drifter recoveries indicated a general onshore flow with speeds of 0.5 cm/sec.

4. Temperatures of 4–5°C, about 2C° higher than at the sea surface, occurred at the bottom at or seaward of the shelf (200–400 m), and onshore intrusions of warm water (>3°C) were apparent in channels between the offshore shoals associated with Portlock and Albatross Banks. Extensive vertical mixing was evident over these shoals where bottom temperatures were in excess of 3°C northeast of Afognak Island, in excess of 2°C east of Kodiak Island, and near 1°C south of Kodiak Island.

5. Onshore flow along the bottom may be critical to early life stages of various organisms (e.g., shrimp and king crab, Paralithodes camtschatica), and it is apparent that such flow occurs in the channels between the shoals. Kaguyak Bay, an area of high abundance of king crab, lies at the shoreward terminus of one of these channels where winter turnover and coastal conditions result in bottom temperatures near 1°C. Two instances of high abundance of eggs and larvae of walleye pollock occurred in two of these channels.

6. Eggs of flathead sole occurred throughout the area near Portlock Bank where bottom temperatures were above 3°C and none occurred south of Kodiak Island where bottom temperatures were about 1°C. The presence of eggs in the Portlock Bank area may be attributed to an onshore component of general westerly flow across the northern Gulf of Alaska, whereas the shoal south of Kodiak Island is isolated from the continuation of this flow southwesterly along the shelf edge. The absence of eggs in the channel south of Kodiak Island may be due to the 200 m sill depth at the shelf edge which restricts flow into the channel.

7. Large numbers of ichthyoplankton, particularly eggs of walleye pollock, may be concentrated in small areas in this part of the Gulf of Alaska.

8. In addition to marked salinity gradients at the sea surface, increased stirring and mixing and other boundary processes certainly occur in the shear zone along the edge of the continental shelf. If capable of being detected by salmon, Oncorhynchus spp., this zone could influence not only seaward and shoreward, but also oceanic, migration paths.

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FOOTNOTES

1/ Naplin, N. A., J. R. Dunn, and K. Niggol. 1973. Fish eggs, larvae and juveniles collected from the northeast Pacific Ocean, October-November, 1971. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash., NWFC MARMAP Survey I, Rep. 10, 39 p. + 121 tables. (Processed.)

2/ Portlock's chart shows approximate position; 58°01'N, 149°15'W, see Fig. 1 for vessel track.

3/ Dunn, J. R., and N. A. Naplin. 1974. Fish eggs and larvae collected from waters adjacent to Kodiak Island, Alaska, during April and May 1972. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash., NWFC MARMAP Survey I, Rep. 12, 61 p. (Processed.)

4/ 1 Sverdrup equals a flow of 10^6 m^3 sec.

5/ Dr. S. Tabata, Environment Canada, Marine Sciences Branch, Victoria, B. C., Pers. commun., Nov. 1974.