Final Report
Research Unit #212

Part 1 of 3

Erosion, Deposition, Faulting, and Instability of Shelf Sediments: Eastern Gulf of Alaska

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INTRODUCTION

The U.S. Geological Survey's Eastern Gulf of Alaska Environmental Hazards Project has been investigating the geological history and environmental hazards of the northeastern Gulf of Alaska since 1974. NOAA/BIM funding and ship time has supported this work, in part, since 1975. As 1981 was the last year of NOAA/BIM funding and no future investigations are anticipated, this report is being prepared to summarize the major findings related to environmental hazards in OCS lease area 55 that were determined during the life of the project. Therefore, the first objective of this final report is to delineate, describe, and illustrate the seafloor geology and geologic hazards in the eastern Gulf of Alaska from west of Yakutat Bay to Cross Sound Sea Valley that must be considered before any offshore petroleum-related development activities are undertaken.

The second object of this study is to describe in detail the geology of the Alsek Sediment Instability Study Area, an area offshore of the mouth of the Alsek River that contains gas pockmarks, craters, and other multiple examples of sediment instability. This area, originally designated as a possible pipeline corridor in BIM's EIS for lease sale 55 (1980), was the primary area of field data acquisition during the last field season of this project, May-June 1980. Lastly, a section is presented on depositional environments interpreted from Ostracod type and abundance by Elisabeth Brewers. Ms. Brewers was funded by NOAA/BIM in the last year of this study to attempt to tie together and interpret previously collected sediment data and micro-paleonotological studies.

An explanation of the oversized plates that accompany this report follows the Ostracod Section.

Reference

U.S. Department of the Interior, Bureau of Land Mamgement, 1980, Final Environmental Impact Statement, Proposed Outer Continental Shelf Oil and Gas Lease Sale, Eastern Gulf of Alaska.

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Section 1

Seafloor Geology and Geologic Hazards in the Eastern Gulf of Alaska

GEOLOGIC SETTING

The eastern Gulf of Alaska is an area of high seismicity and continuing tectonism because of its proximity to the intersection of the Pacific and North American crustal plates. To the north and west of this area, the Pacific plate is being subducted beneath the North American plate along the Aleutian Trench; to the east, a strike-slip motion persists between the two plates. The area of lease sale 55 lies in the transition zone between the two tectonic regimes (Plafker, 1971). The result is a complex series of faulted and folded structures west of Yakutat Sea Valley and simpler structures to the east (Bruns, 1979). Many of the Tertiary units have been truncated by erosion, perhaps during glacially controlled changes of sea level. Both seismic-reflection and sedimentologic evidence point to glaciation of the shelf during the Pleistocene (Carlson and others, 1977b; Molnia and Carlson, 1978) . Glacially derived gravel, sand, and mud presently occur on the middle to outer edge of the shelf, whereas on the inner shelf the till-like materials are covered by a wedge-shaped Holocene-aged unit that grades from sand to clayey silt (Molnia and Carlson, 1980).

Three major sea valleys, incised into the continental shelf approximately perpendicular to shore are, from west to east: Yakutat, Alsek, and Cross Sound Sea Valleys (Fig. 1). Positive-relief features include Pamplona Ridge and Fairweather Ground. Each of these morphologic features has influenced the erosional or depositional processes and the resulting presence or absence of sediment on the continental shelf.

Onshore, the topography consists of a narrow coastal plain backed by the tectonically active glaciated Saint Elias Mountains. The main gaps in these young rugged mountains are valleys carved by seaward-flowing rivers and glaciers. The Alsek River, originating in Canada, annually carries a large load of sediment through the coastal mountains to the Gulf of Alaska. Malaspina Glacier, a massive piedmont glacier, extends to the shoreline and gives rise to numerous meltwater streams that carry significant amounts of suspended matter into the predominantly counterclockwise circulation of the Alaskan Gyre (Reimnitz and Carlson, (1975). Other smaller valley glaciers such as Grand Plateau, Fairweather, and La Perouse Glaciers are the sources of smaller but noteworthy meltwater streams that carry lesser quantities of sediment to the ocean. Two large bays (Icy and Yakutat), which were once the sites of large glaciers (Plafker and Miller, 1958), are incised into the coastline on either side of the Malaspina Glacier. Lituya Bay, 165 km southeast of Yakutat Bay, was also cut by a coalesced glacier that was formed by the glaciers presently discharging melt water and glacial flour at the head of the bay.

Strata, ranging from Paleocene well-indurated argillite and graywacke to Pleistocene semiconsolidated siltstone and conglomeratic mudstone (upper part of the Yakataga Fomation) , crop out in the foothills, on the coastal plain, and on some of the islands and banks of the continental shelf (Plafker, 1967, 1971; Plafker and Addicott, 1976; Molnia and Carlson, 1978). Holocene unconsolidated mud, sand and gravel unconformably overlie the wave-, stream- and glacier-planed surface of Paleocene to Pleistocene rocks on the coastal plain as well as on the continental shelf (Plafker and others, 1975; Carlson and others, 1977b; Molnia and Carlson, 1980).

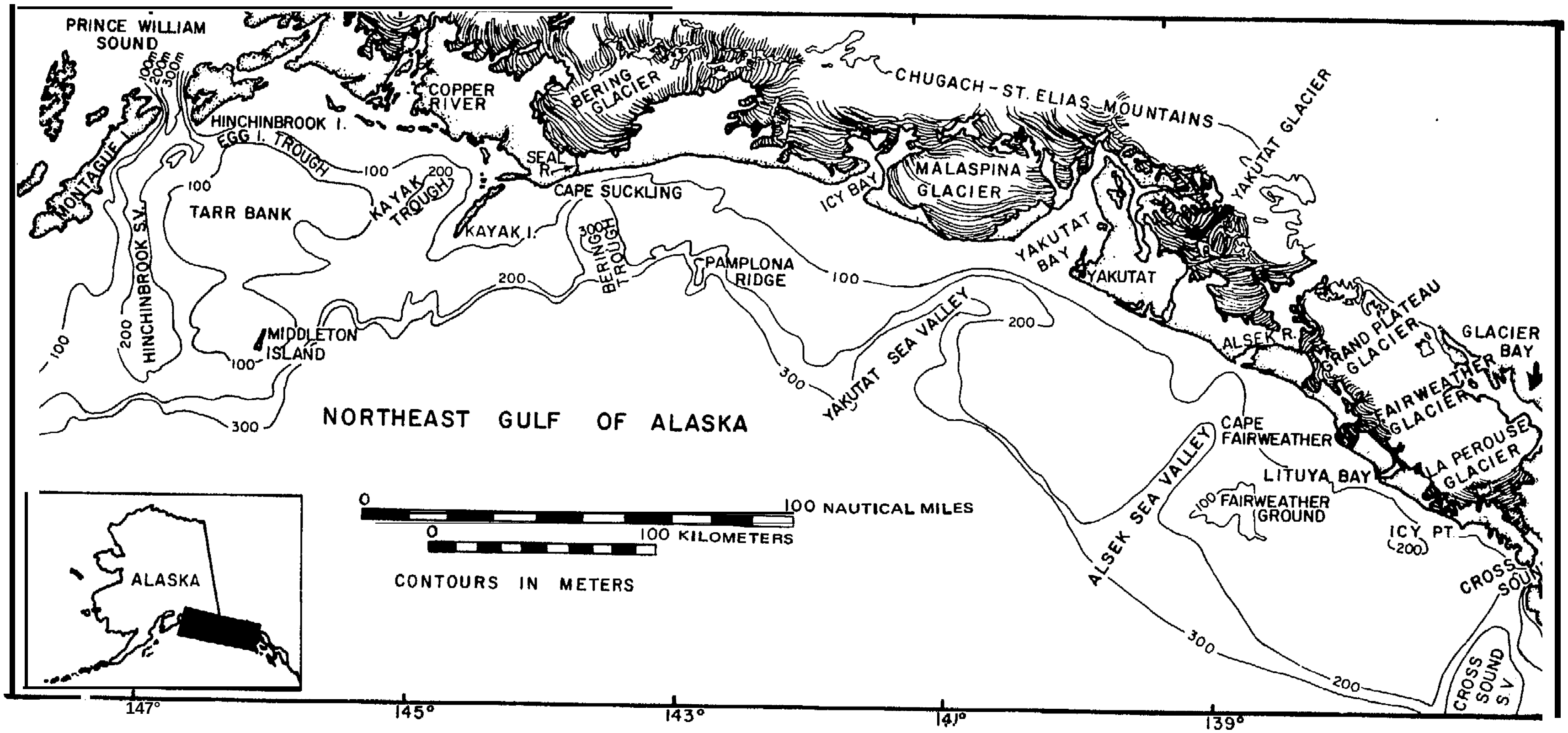

Figure I.-The study area in the northeastern GuM of Alaska and the location of the major geographical features described in the text. .

During the Pleistocene, the continental shelf was repeatedly covered by ice sheets that extended at least to the shelf break (Molnia and Sangrey, 1979). Although no precise date for the last deglaciation of the shelf has been determined, it appears that the outer shelf has been free of a glacial-ice cover for about the past 12,000 years (Molnia, Levy, and Carlson, 1980). Numerous Neoglacial advances of coastal glaciers have covered parts of the inner shelf.

The Alsek River, which drains an area of almost 30,000 km^2, is the largest tributary to the Gulf of Alaska between Yakutat and Cross Sound and appears to be this area's major source of modern sediment. In October 1979, the suspended-sediment load of the Alsek River exceeded 1 g/1.

The coastal area adjacent to the continental shelf is a triangular plain that narrows eastward. North of the plain are glacier-covered mountains that rise to a maximum elevation of about 5,000 m. La Perouse Glacier, approximately 50 km northwest of Cross Sound, is the only glacier in North America whose terminus reaches tidewater in the Pacific Ocean. Other major glaciers in this are are Fairweather Glacier, Grand Plateau Glacier, and Yakutat Glacier. Each of these glacier systems produces large volumes of sediment that is transported by streams, ice rafted, or dumped directly on the continental shelf. Glaciation has been the major sediment-producing process in this region since Miocene time (Molnia and Sangrey, 1979).

Onshore Geology

Onshore, a thick sequence (about 15,000 m) of marine and nonmarine Tertiary and Quaternary sedimentary rocks bound the study area. This sequence crops out in a nearly continuous belt as much as 100 km wide along the south margin of the Chugach and Saint Elias Mountains (Plafker, 1971). The sequence can be divided into a lower, well-indurated, intensely deformed unit made up of Paleocene and Eocene rocks and a varied sequence of middle Tertiary to Quaternary rocks that are less indurated and deformed (Plafker, 1971).

Middle Tertiary rocks are mainly marine mudstone and siltstone with some sandstone. Plafker (1971) described the local occurrence of interbedded tuff, agglomerate, pillow lava, and glauconitic sandstone, as well as alkaline plugs and dikes. Middle Tertiary formations include the Katalla Formation, parts of the Tokun and Poul Creek Formations, Cenotaph Volcanics, and Topsy Formation.

The upper Tertiary and Quaternary section is characterized by a thick sequence (more than 5,000 m) of marine and glacial-marine elastic rocks of Miocene to Holocene age, called the Yakataga Formation. It consists of fossiliferous, thick-bedded mudstone, muddy sandstone, conglomeratic sandy mudstone, and conglomerate (Plafker, 1971).

The Mesozoic Yakutat Group crops out landward of the coastal plain from the Alsek River to Malaspina Glacier and consists of graywacke, argillite, slate, and minor conglomerate (Plafker, 1967). It is mildly to moderately metamorphosed and complexly deformed.

The Chugach-Saint Elias Mountains' crystalline rocks include granitic rocks, schist, gabbro, gneiss, amphibolite, and marble. They are moderately to intensely metamorphosed and complexly deformed.

CLIMATOLOGY AND OCEANOGRAPHY

Weather in the Gulf of Alaska is influenced by two competing pressure systems, the Aleutian Low and the Pacific High (Dodimead and others, 1963; Royer, 1975). Severe westerly storms move through the region during the winter months, when the Aleutian Low predominates. The cyclonic rotation of these storms creates strong easterly winds in the Gulf of Alaska. During the summer the Pacific High becomes dominant, fair weather frequent, and the prevailing winds more southwesterly and more docile. The circulation of shelf waters as a result of wind stress causes strong downwelling during the winter and weak upwelling during the summer (Royer, 1975).

Water circulation in the Gulf of Alaska is forced by the westerly Subarctic Current, that turns north as it nears the North American continent and flows into the Gulf as the Alaskan Gyre. In response, the nearer shore Alaskan Stream flows counterclockwise through the Gulf of Alaska at a speed of 16-20 cm/sec (Dodimead and others, 1963). Large storm waves estimated to be at least 15 m in height (T.C. Royer, University of Alaska, oral commun. , 1977), roll across the shelf throughout the winter. These waves undoubtedly disturb the bottom even at the shelf edge (200 m deep).

Strong bottom currents are believed to be active on highs such as Fairweather Ground and Pamplona Ridge. No current velocity data was obtained during the life of this study.

Tsunamis, generated either by regional or remote earthquakes, are frequent visitors to the Alaskan shelf. These long (400-km wavelength) waves devastate coastal structures (Plafker and others, 1969) and most certainly may have some effect on the surface sediment on the shelf.

DATA COLLECTION

The data incorporated in this report were collected on cruises on USGS and NOAA ships, and also include 4000 km of high-resolution seismic data obtained by Nekton, Inc. on contract to USGS' Conservation Division. The cruises, types of data, number of samples, and kilometers of high-resolution seismic-reflection lines are listed in Table 1. The cruises have utilized various means of navigation, including satellite, Loran A, Loran C, Decca Hi-Fix, Raydist, Motorola Mini-Ranger, and radar. The location accuray ranges from 0.25 to 1.5 km and averages about 0.5 km

Table 1

Cruises in the eastern Gulf of Alaska in study area

Cruise	Date	Type of Data	Amount of Data
NOAA Ship SURVEYOR	4/75 - 5/75	High-resolution seismic	3200 km
NOAA Ship CROMWELL	6/75	Gravity cores and grab samples	125 samples
M/V GREEN (Contract)	6/75 - 8/75	High-resolution seismic	1200 km
NOAA Ship DISCOVERER	10/75	Grab samples	37 samples
R/V SEA SOUNDER	6/76	High-resolution seismic Grab samples	1100 km 59 samples
NOAA Ship DISCOVERER	10/76	Grab samples and cores	25 samples
R/V GROWLER	5/77	High-resolution seismic Cores and grab samples	375 km 12 samples
R/V LEE	6/78	High-resolution seismic	350 km
R/V SEA SOUNDER	6/78 - 7/78	High-resolution seismic Cores and grab samples	1400 km 15 samples
NOAA Ship DISCOVERER	5/79	High-resolution seismic Grab samples	1630 km 47 samples
NEKTON Inc. (Contract)	7/79	High-resolution seismic	4000 km
NOAA Ship DISCOVERER	8/79	High-resolution seismic Cores and grab samples	2000 km 378 samples
R/V SEA SOUNDER	10/79	High-resolution seismic Cores and grab samples	1200 km 36 samples
NOAA Ship MILLER FREEMAN	3/80-4/80	Grab samples	113 samples
NOAA Ship DISCOVERER	5/80 - 6/80	High-resolution seismic Cores and grab samples	800 km 204 samples

TOTAL : 17,255 km of seismic data
1,051 samples

DESCRIPTION OF SURFACE SEDIMENTARY UNITS

Four surface sedimentary units were defined by Molnia and Carlson (1975, 1978) for the continental shelf of the northeastern Gulf of Alaska between Yakutat and Montague Island. The units were defined from their characteristics in seismic profile and from examination of seafloor sediment samples. The units originally defined were: Tertiary and Pleistocene stratified rocks; Quaternary glacial-marine sediment; Holocene end moraines; and Holocene sediment. Additional data and a better understanding of the role of glaciation as the dominant sedimentological process shaping this continental shelf region led Molnia and Sangrey (1979) to revise the definition of the Quaternary and Holocene units.

Their revised units, which are used in extending the mapping of the stratigraphy to the shelf east of Yakutat are: (1) Tertiary and Pleistocene stratified rocks; (2) Quaternary till, outwash, and glacial-marine deposits; (3) Holocene end moraines; and (4) Holocene glacial-marine sediment. Seismic and sedimentologic characteristics of the four units are presented in Table 2.

Table 2. Surface sedimentary units on the continental shelf of the northeastern Gulf of Alaska

Unit	Appearance in Seismic Reflection Profiles	Description
Tertiary and Pleistocene sedimentary rocks	Well-developed reflectors comprising folded, faulted and truncated lithified sedimentary strata	Semi- to well-indurated pebbly and sandy mudstone, siltstone, and sandstone
Quaternary till, outwash, and glacial-marine deposits.	Very irregular, discontinuous contorted and angular reflectors. Stratified in places, but rarely extending more than a few hundred meters.	Olive to gray pebbly mud, sandy pebbly mud, and shelly mud
Holocene end moraines	Highly variable reflectors; some stratified but generally discontinuous, high-angle reflectors. Very irregular surface morphology with relief of as much as 100 m	Olive to gray, unsorted, unstratified, heterogeneous mixture of clay, silt, sand and gravel
Holocene glacial-marine sediment	Relatively horizontal and parallel, continuous reflectors except where disrupted by slumping and other types of sediment failure	Olive to gray, underconsolidated clayey silt and silty clay; fine sand in nearshore nearshore zone, interlayered sand mud units in transition zone

DISTRIBUTION OF THE FOUR SURFACE STRATIGRAPHIC UNITS

Figure 2 presents the distribution of the surface stratigraphic units on the entire northeastern Gulf of Alaska continental shelf from Montague Island to Cross Sound. In this section, however, only the newly mapped Yakutat to Cross Sound segment will be described. A detailed description of the distribution of the surface sedimentary units west of Yakutat can be found in Molnia and Carlson (1978).

Tertiary and Pleistocene Stratified Rocks - Stratified rocks crop out on the north wall of the Alsek Sea Valley, as hogback ridges, and in numerous pinnacles on Fairweather Ground, west of Cape Fairweather, southeast of Lituya Bay, and in a continuous nearshore and coastline belt that extends from west of Icy Point to Cross Sound. The Fairweather Ground is composed of highly folded strata with numerous linear trends on the sea floor. Holocene glacial-marine sediment collects in small basins and among the hogback ridges in the Fairweather Ground area. Nearshore strata from west of Icy Point to Cape Spencer are generally flat to slightly folded and show evidence of glacial erosion. The area of outcrop on the north wall of Alsek Sea Valley consists of glacially eroded stratified rock. The valley wall slopes are 30° or more. The steep slopes may be responsible for the sparse cover of Holocene glacial-marine sediment.

Quaternary Till, Outwash, and Glacial-Marine Deposits - This glacially derived unit covers much of the middle and outer continental shelf from Yakutat to Cross Sound. West of the Alsek River, the unit is exposed 25-35 km from shore. East of the Alsek, the distance from shore is less than 20 m. Between Yakutat and Lituya Bay, Quaternary till is molded into a series of moraines having heights of up to 12 m. A detailed, multi-system geophysical survey of the middle shelf in 1980 showed that moraines are present in an area of more than 2,500 km^2, where water depths range from 120 to 180 m. Post-depositioml modification and sedimentation, and distance between survey lines make correlation of lobes observed on parallel survey lines impossible. Generally, the entire surface of this unit is a pebbly mud. Sandier glacial-fluvial and glacial-lacustrine deposits and coarse areas of sediment winnowing are also present. Sediment thicknesses range from a thin veneer covering older rocks near the shelf edge to more than 150 m (the limit of mini-sparker penetration), where deposits fill glacially scoured bedrock channels. This unit consists of both Pleistocene sediment deposited when the shelf was completely ice-covered and much younger sediment deposited on the inner shelf by Neoglacial advances during the past few years. Samples of this unit generally are overconsolidated and massive. Inner-shelf deposits of this unit are not exposed at the surface. Rather, they have been observed as subcrop on high-resolution seismic profiles.

Holocene End Moraines - Holocene end moraines deposited by Neoglacial advances during the past 1,000 years are present at the mouths of Lituya and Yakutat Bays and at the shoreline in front of Fairweather Glacier. The Lituya Bay and Fairweather Glacier moraines have not been studied in detail. The Yakutat Bay moraine consists of a series of hard, highly reflective ridges, many having more than 150 m of relief. Well-stratified Holocene glacial-marine sediment has accumulated in small basins between ridges. The width of the moraine

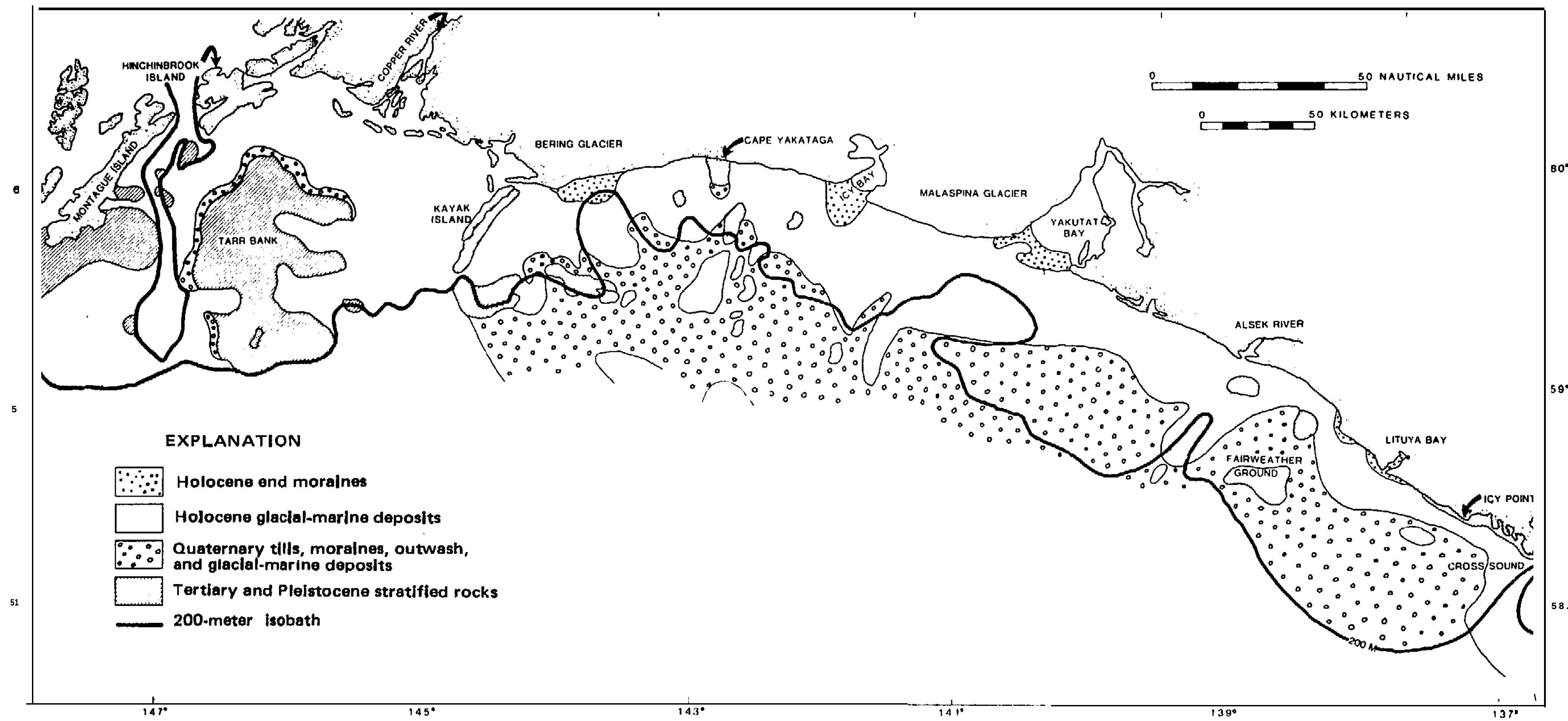

Figure 2.-Distribution of the four continental shelf sedimentary units between Cross Sound and Montague island.

complex at the mouth of Yakutat **Bay** is more than 5 km. The Yakutat moraine was deposited between **A.D.** 900 and 1300 (**Plafker** and Miller, 1978).

Holocene **Glacial-Marine** Sediment - Holocene glacial-marine sediment occurs in a band that extends seaward from the shoreline and ranges in width from about 15 **to** 35 km. Sediment in the band is **coarse-grained** nearshore, and **fine**-grained (clayey silt or **silty** clay) offshore. Two lobes of this unit project down Yakutat and **Alsek** Sea Valleys. Sampling and seismic investigations show that this unit is well stratified and generally underconsolidated.

Thicknesses of this unit exceed 100 m in numerous areas adjacent to the **Fairweather** and Grand Plateau Glaciers and in parts of **Alsek** and Yakutat Sea Valleys. If the last major deglaciation of the shelf was about 12,000 years ago, then maximum Holocene sedimentation rates in this area exceed 10 m per 1,000 years.

SEAFLOOR HAZARDS (Plates I and II)

Four types of seafloor hazard have been mapped in the study area: faults, gas-charged sediment, buried channels, and submarine slides or sediment gravity flows (Fig. 3). These hazards were identified on **high**-resolution seismic-reflection records made with **3.5-kHz,** 400-800-J minisparker or **uniboom** and supplemented with medium resolution sparker (20-80 J) systems. Seafloor samples in the areas of potential hazards were collected with cores (gravity, dart, **vibra)** and grab samplers. These data have provided sediment distribution and stratigraphic relations that are reported in detail by Carlson and others (1977) and **Molnia** and **Carlson** (1978, 1980). **1:250,000** scale maps of these seafloor hazards are presented in Plates I A and B and II A and B.

SURFACE AND NEAR-SURFACE FAULTS

The faults discussed in this paper are those that offset the sea floor or cut strata in the upper few tens of meters of the substrate. The near-surface faults are probably related to development of deeper structures on the continental margin, as shown by **Bruns** (1979), and at least several of these faults appear to relate directly to the northwestward convergence between the Pacific and North American Plates (**Lahr** and **Plafker,** 1980).

Near-surface faults are located in four parts of this eastern Gulf of Alaska region: the **Pamplona** zone, the Fairweather Ground shelf-edge structural high, the shelf edge near **Alsek** Sea Valley, and the seaward extension of the Fairweather fault system that trends southeast from **Palma Bay** (Fig. 3).

The **Pamplona** zone marks the boundary between the structurally simple Yakutat segment of the continental margin and the more complexly folded and faulted **Yakataga** margin to the west (**Bruns,** 1979). This zone extends across the shelf and the slope from Icy Bay **toward** the prominent north-trending **Pamplona** Ridge. **Pamplona** Ridge, a large **horst-like** structure bounded by north-northeast-trending reverse faults, forms part of a zone of structural uplift that has been mapped to the base of the continental slope. North of **Pamplona** Ridge, numerous near-surface faults trend north to northeast,

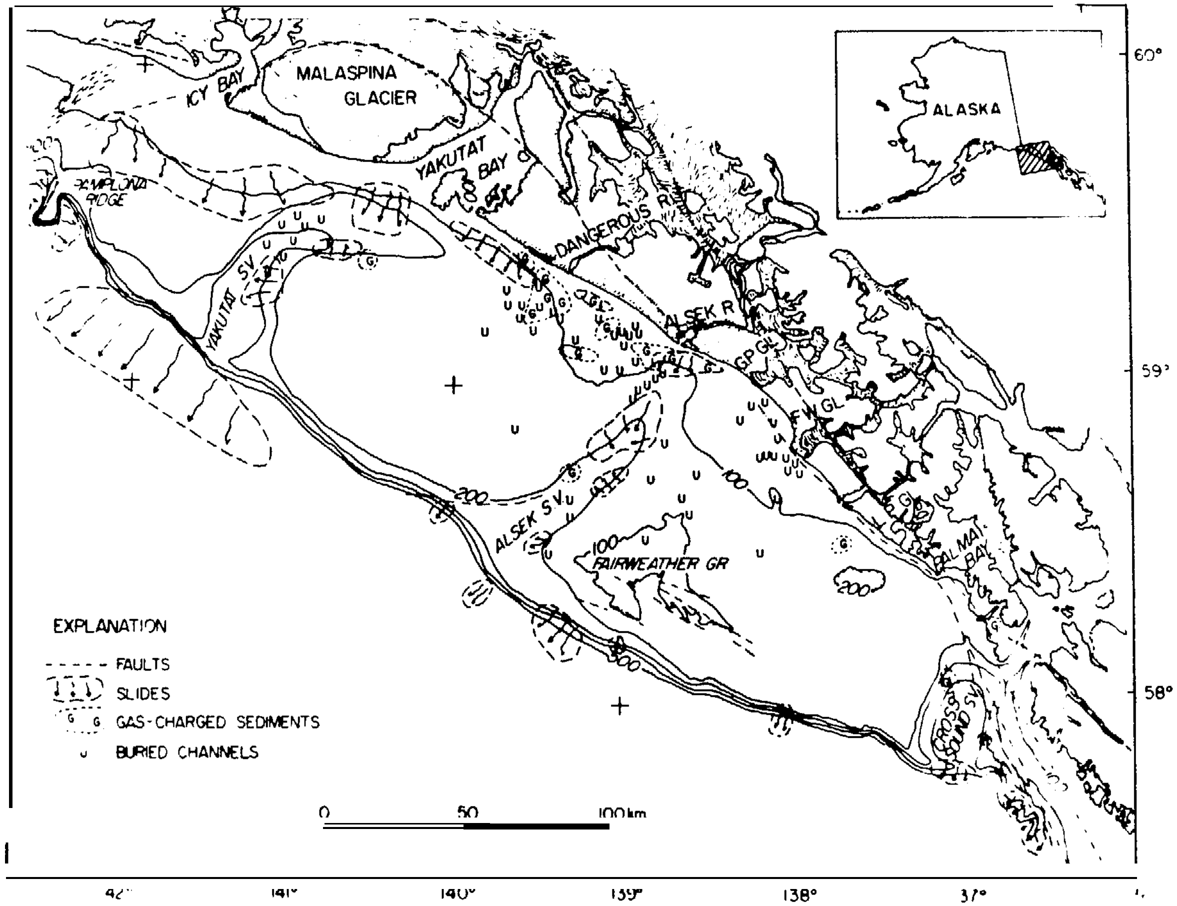

Figure 3. Distribution of the major geohazards of the northeastern Gulf of Alaska between Cross Sound and Pamplona Ridge.

parallel to the major structural trends of the Yakataga shelf that were the targets of recent exploration activities. The longest of these landward dipping reverse faults have been traced for about 30 km (Fig. 3) (Bruns, 1979). Many of these faults are covered by 5 to 10 m of Holocene sediment. However, at least one high-resolution profile shows continuation of a fault upward into the Holocene sediment, but not rupturing the surface. Numerous epicenters of modern earthquakes plot along the Pamplona zone, thus documenting the active nature of these faults (Lahr and others, 1980).

Fairweather Ground is a topographic and structural high about 2100 km^2 in area, located on the outer shelf east of the Alsek Sea Valley (Fig. 1). This high is composed of pre-Tertiary rocks similar to the Yakutat Group on the mainland (Plafker and others, 1978b). Bruns (1979) suggested that steeply dipping seismic reflectors within adjacent rocks of late Yakataga age which flank the high indicate significant uplift during late Cenozoic time of this pre-Tertiary outcrop. Bruns' conclusion is reinforced by the presence of steep scarps with relief of up to 60 m commonly occurring where the rugged pre-Tertiary rocks crop out on the sea floor. These scarps, possibly fault related, trend nearly parallel to the continental slope and have been mapped discontinuously over a total distance of about 60 km (Fig. 3). The alinements of these scarps suggest at least four individual traces along this Fairweather Ground zone. The irregularity of the outcrops and the wide spacing of seismic lines (approximately 10 km) prevent continuous tracing of the possible fault trends.

A solitary fault without surface expression has been mapped at the shelf edge west of Alsek Sea Valley (Fig. 3). No connection is evident between this fault and the multiple traces east of the sea valley. This fault extends in a nearly east-west curvilinear trend for a distance of about 40 km from the upper slope into Alsek Sea Valley. The fault approximatley parallels the northwestern wall of the outer one-third of the valley. Motion on this probable reverse fault is north- or landward-side up. Although the recency of this Alsek Sea Valley fault is not known, indications of active seismicity in this area south of Yakutat Bay can readily be seenby the presence of epicenters for 49 small earthquakes of magnitude 1 - 4.4 which occurred bewtween 1974 and 1978.

The seismically active Fairweather fault borders the northeast part of the study area (Fig. 3). This major right-lateral strike-slip fault which has been mapped onshore from Yakutat Bay to the shoreline of Palma Bay (Plafker, 1967; Plafker and others, 1978a) was first mapped in the offshore in 1975 (Molnia and others, 1978). During the summer of 1978, about 1500 km of seismic lines were collected across the shelf southeast of Palma Bay to trace the offshore extension of the Fairweather fault (Carlson and others, 1979). These seismic lines show eidence for two fault traces (Fig. 3). On lines closest to Palma Bay, the eastern fault trace, which is less well defined than the western, appears to trend directly into the Fairweather fault. The trace west of Palma Bay seems to aline with a fault that has been inferred but never documented, on the bases of structural features along the shore, to lie just offshore along the coastline at least as far north as Grand Plateau Glacier (Plafker, 1967; Bruns, 1979). This inferred location of the northwestward extension of the western trace has been crossed by only two seismic-reflection lines because of its proximity to the coastline. Poor record quality, largely because of the shallow-water multiples, has prevented identification of this inferred fault. An abrupt 25° change of strike occurs between the two fault traces near Palma Bay. The separation between these two subparallel fault traces ranges from 6 km on the seismic line about 1 km from Palma BSy, to about 12 km off southern Chichagof Island. The two traces extend across the shelf in a south-southeasterly direction for about 225 km, where they appear to merge on the upper slope just southwest of Sitka (Carlson and others, 1979) .

The complex fault traces consist of a number of splays or slivers. At several places where a fault bifurcates, the minor trace forms an arc and appears to rejoin the major trace. One exception to this pattern, however, is observed in the Fairweather fault extension about 20 km southeast of Palma Bay, where the Fairweather fault undergoes a major bifurcation in which one branch fault splits off at an angle of about 35°. This branch fault trends toward Lisianski Inlet, where it may connect with the Peril Strait fault (Loney and others, 1975).

The offshore faults vary greatly in appearance on profiles from line to line. Some records show well-defined scarps on the sea floor with reliefs of 25 to 40 m; other crossings of the fault traces exhibit no surface offset, but commonly show broken reflectors or abrupt changes in bedding reflector attitudes that are best explained by faulting. Of the two traces, the western trace is clearly the better defined and is considerably straighter than the eastern. The most unequivocal evidence for Holocene displacement, as manifested by seafloor displacements, is visible in this trace. In most crossings of the fault trace where seafloor offsets are well displayed, the sense of movement is northeast-side down, showing the same sense of vertical displacement as that which occurred along the onshore Fairweather fault during the 1958 Lituya Bay earthquake (Tocher, 1960). The more sinuous eastern trace may be an inactive or relatively less active strand of the fault system; several of the profiles, however, also showed some seafloor offset along this trace.

In addition to the evidence of recent movement along the Fairweather fault system seen on the seismic profiles, the epicenters of two recent large earthquakes coincide very closely with the mapped fault traces. The epicenter of the 1958 Lituya Bay M-7.9 earthquake (Sykes, 1971) plots just south of Palma Bay (Plafker and others, 1978a). The epicenter of the 1972 M-7.3 earthquake (Page, 1973), plots about 2 km west of the outermost fault trace; the focal region of the earthquake virtually coincides with the active trace mapped by Carlson and others (1979), which extends beyond the margin of the study area.

SEAFLOOR INSTABILITY

Three types of potential seafloor hazards involving instability of sediment are present on the continental margin in the eastern Gulf of Alaska: gas-charged sediment, submarine slides and flows, and buried channels. All three hazards are most prevalent in areas seaward of those rivers or streams that carry large quantities of glacially derived sediment to the gulf, or seaward of the glaciers that at one time crossed the shelf.

GAS-CHARGED SEDIMENT

Six areas of gas-charged sediment have been identified in the northeastern Gulf of Alaska between Yakutat Bay and Cross Sound: (1) on the southeast flank of Yakutat Sea Valley, (2) nearshore between Dangerous and Alsek Rivers, (3) on the west flank of Alsek Sea Valley, (4) southeast of Lituya Bay, (5) on the northwest wall of Cross Sound Sea Valley, and (6) southeast of Palma Bay (Fig. 3).

Five of the 6 gas-charged areas are small, covering 10 km^2 or less. The single exception is a nearshore area between the Dangerous area and the area east of the Alsek River, encompassing over 200 km^2. This is the only one of the 6 areas with a surface manifestation of gas. There, thousands of seafloor pockmarks and craters, ranging in diameter from smaller than 2 m to as large as 400 m, are present. These pockmarks and craters are actively forming today (Molnia, 1979) and often are the site of gas seepage to the water column. The eastern part of this region is the site of the Alsek River Sediment Instability Study Area (Section 2).

Seismic profiles of the 6 gas-charged areas show combinations of displaced reflectors (pull-ups and pull-downs), wiPeouts and acoustic transparency in the top 50 m of sediment and occasional gas plumes in the water column. Gas analyzed from sediment cores collected in these gas-charged areas, and in gas-charged areas to the west, is predominantly biogenic methane (Molnia and others, 1978). The maximum gas concentration measured in 1979 from a core collected in the nearshore between the Dangerous and Alsek Rivers was 3 x 10^7 nl of methane per liter of wet sediment, a gas concentration 3 to 4 orders of magnitude greater than background. Similar high concentrations were measured in gas-charged sediment west of the study area (Molnia and others, 1978).

In each of the 6 areas, gas-charged sediment is present in the upper part of a thick Holocene sedimentary section. No evidence of leakage from deeper pre-Holocene sources is visible on the high-resolution profiles. This observation, as well as the biogenic nature of the gas, suggests that bacterial breakdown of organic material deposited in the rapidly accumulating Holocene sediment may be the source of the gas.

Gas-charged sediment has reduced strength and bearing capacity. As the gas concentration increases, sediment stability decreases until failure occurs. Such failure poses a potential hazard to seafloor exploitation because drilling into gas-charged sediment, cyclic loading, seismicity, or spontaneous over-pressurization may cause a sudden and catastrophic release of gas and pore water, and could lead to failure of pipelines and platforms in the imediate area.

Pockmarks and craters on seismic profiles from the nearshore area between the Dangerous and Alsek Rivers closely resemble these in other disturbed areas where sediment sliding is active. Only through site specific side-scan sonar surveys and sediment coring has the relation between the gas-charged sediment and the seafloor pockmarks and craters been established. This relation suggests that in other areas where sediment sliding is active, gas in the sediment may be a major cause for this sediment instability.

SUBMARINE SLIDES

Submarine slides and sediment gravity flows have been found in three general areas in this section of the Gulf of Alaska: in nearshore zones, especially off the mouths of rivers, on the walls of sea valleys, and along the continental slope (Fig.3).

The largest slide (1080 km^2) on the shelf in the study area is located seaward of Icy Bay and the Malaspina Glacier. Here a process of progressive slumping of underconsolidated Holocene clayey silt is taking place in water depths of 70 to 160 m on a slope of less than 0.5°. The slump structures are about 0.5 km long and have relief of 2 to 5 m. The slip surfaces extend to a depth beneath the sea floor of 15 to 40 m, and so the volume of the entire Icy Bay-Malaspina slump is about 32 km^3. This active landward-growing slump may be triggered by prolonged ground shaking resulting from the frequent earthquakes in the nearby Pamplona Ridge zone (Carlson, 1978).

Four other, smaller areas of mass transport have been mapped in the nearshore zone (Fig. 3) all in water shallower than 100 m. The combined area of all four is less than that of the Icy Bay-Malaspina slump. One slide southwest of Yakutat Bay begins on the north wall of Yakutat Sea Valley and extends across most of the valley floor. Ths slide, which covers an area of about 350 km^2 and incorporates the upper few meters of clayey silt, appears to fit into Varnes' (1978) classification as a mudflow that failed due to lateral spreading. A second slide, which begins 4 km seaward of the coastline between Yakutat Bay and Dangerous River, is elongate, about 40 km long, and about 260 km^2 in area. The gradient of the upper part of the slide is about 1° and decreases to about 0.5° at the seaward edge of the slide. High-resolution profiles across the middle of this slide mass are characterized by a series of steplike surfaces with a tread length of about 100 m and a riser height of 3 to 4 m. Apparent backward rotation of these blocks indicates a true rotational slump movement. The effective depth of the rupture surfaces of these slump blocks is about 10 m, so the volume of slumped material is nearly 3 km^3. The third and smallest of the slide masses (60 km^2 in area), located southeast of the Dangerous River, begins about 2 km offshore in water shallower than 20 m. This area of seafloor instability and also the fourth nearshore-slide area seaward of the Alsek River are both associated with gas-charged sediment. It is likely that the gas in the sediment has resulted in high pore pressures, thus contributing to the low strength of the sediment that may fail when agitated by the pounding of storm waves, or from ground shaking during earthquakes. The 150-km^2 area of mass transport just seaward of the mouth of the Alsek River begins in sand and sandy mud less than 2 km offshore in about 25 m of water. This debris flow that has moved down the headwall (approximately 1° slope) to the floor of Alsek Sea Valley has affected the sediment to a depth of 10 to 20 m.

In addition to the slides and flows in the nearshore zone that have entered the upper ends of Alsek and Yakutat Sea Valleys, six other slides have been mapped within the three sea valleys. Numerous areas of sliding and slumping have also been mapped on the continental slope adjacent to the mouths of these sea valleys (Fig. 3). The slides that have been found on the walls of the sea valleys all appear to be mud or debris flow types of mass transport affecting the upper 10 to 20 m of seafloor sediment similar to the debirs flow at the head of Alsek Sea Valley.

Although most of the slides observed on the continental slope in the study area are immediately seaward of the sea valleys, sliding appears to be a widespread mechanism for transporting sediment down the continental slope in the entire Gulf of Alaska (Hampton and others, 1978). More than 80 percent of the U.S. Geological Survey's single-channel seismic lines along 1000km of continental slope in the eastern Gulf of Alaska show evidence of some type of sliding or slumping (Carlson, 1979). Many of these slides are longer than 5 km and occur on slopes with gradients of 3° to 6°. The slides can range from discrete mudflows thinner than 50 m to complex zones of mass transport several hundred meters thick consisting of multiple slides, such as in the area southeast of Cross Sound Sea Valley. The large zone of submarine slides seaward of the mouth of Yakutat Sea Valley encompasses 3000 km^2 (Fig. 3). Profiles across this slide area show evidence of mass transport ranging from hummocky surface morphology and broken or disrupted internal reflectors, to downslope displacement of large blocks. The types of sediment contained in these slides, flows, and slumps are probably of two kinds and two sources. The sediment on the outer shelf is primarily pebbly mud deposited by glaciers that covered the shelf during parts of the Pleistocene. This sediment comprises many of the debris flows, slumps, and glide blocks. The clayey silt comprising the mudflows predominates in the middle shelf and fine sand predominates on the innermost shelf. Cores taken in the sea valleys contain fine sand and silt layers, displaced shallow-water organisms, and some land-derived plant debris indicating the movement of turbidity currents through the sea valleys. These turbidity currents probably carried some of the fne sand and mud onto the slope and contributed to the thick sedimentary sections.

BURIED CHANNELS

A more subtle form of gelogic hazard than gas-charged sediment or submarine slides is the buried channel. The presence of a buried channel often means facies variations between the channel fill and adjacent sediment creating conditions for differential settling and, if self-sorted sand and gravel are present in the fill, pathways for fluid migraton. These features which are considered hazards in the North Sea (Fannin, 1979) should also be considered in the Gulf of Alaska.

Buried channels have been identified in the area between Yakutat Sea Valley and Lituya Bay (Fig. 3). Most of these buried channels are concentrated in three nearshore locations, off the Dangerous and Alsek Rivers and seaward of the Fairweather Glacier. Other buried channels have been identified in Yakutat and Alsek Sea Valleys and on the middle shelf seaward of Fairweather Glacier. No attempt has been made to trace or connect the channels, but the buried channels within Yakutat Sea Valley evidently are connected, as are those in the upper part of Alsek Sea Valley. These buried channels range in size from less than 0.5 km wide and 25 m deep to more than 2 km wide and over 100 m deep and most appear to have been cut into Pleistocene and older glacial sediment. As the glaciers retreated, a large number of meltwater streams flowed across the shelf. Some buried channels show evidence of scour and fill, and several larger channels have small channels nested within them.

In addition to the buried channels marked on Figure 3, the three sea valleys are presently being filled with Holocene sediment (Carlson and others, 1977a; Molnia and Carlson, 1980). This sea valley fill also could create differential settlement problems and must be carefully analyzed bewfore any seafloor structures such as pipelines are built across the fill.

CONCLUSIONS

Seafloor hazards identified within and around OCS lease-sale area 55 include faults, gas-charged sediment, submarine slides and buried channels. These hazards must be carefully delineated and understood before drilling and other seafloor operations related to exploration and production, such as pipeline emplacement, can be carried out safely. Surface and nearsurface faults showing various degrees of activity occur in the Pamplona Ridge-Icy Bay zone, on the shelf-edge structural high on both sides of the Alsek Sea Valley, and along the seaward extension of the Fairweather Fault system southeast from Palma Bay. The nearshore zone between Yakutat Bay and Fairweather Glacier contains three types of hazards that result in seafloor instability: gas-charged sediment, buried channels, and submarine slides. Slides and slumps also are prevalent along the edges of the sea valleys and appear to be virtually everywhere on the continental slope in the eastern Gulf of Alaska. Because of the highly unstable nature of the slope deposits, especially in the tectonically active eastern Gulf of Alaska, this-slope area constitutes the greatest challenge to successful resource development.

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Section 2

Geology of the Alsek Sediment Instability Study Area

INTRODUCTION

In May and June 1980, a 20-km^2 seafloor area offshore of the mouth of the Alsek River that had been previously identified as containing pockmarks, slumps, and other related sediment-failure features (Molnia and others, 1978; Molnia, 1979) was mosaicked as part of a detailed multisystem investigation of the northeastern Gulf of Alaska continental shelf (Fig. 1 and Plate 4). The multisystem survey of the area was run at a 100-m line spacing utilizing Mini-Ranger for navigation, 3.5- and 12-kHz echo sounders, 400 to BOO-J minisparker, and 5- to 25-in^3 airgun acoustic systems. In addition, a digital-recording and processing side-scan sonar system with slant-range correction was used to compile the 100-percent-overlap seafloor mosaic of the area. Sediment samples were collected by Van Veen grab samplers and small corers from within the study area. Uniboom seismic profiles were made between the study area and the coastline.

Description of the area.- A complete picture of the sea floor in the 10 x 2 km mosaicked area was made by assembling 21 speed-corrected, digitally processed, side-scan sonar lines (Plate 4). Analysis of this mosaic and related bathymetric and seismic data has delineated four seafloor zones: (1) a northwest zone of minimal sediment disturbance characterized by isolated pockmarks and fields of ripple marks or featureless mud; (2) a northcentral zone of medium-density slumping with small slumps and pockmarks; (3) a southcentral zone of intensive and massive sediment disturbance characterized by blocky failures, pockmarks, areas of chaotic multiple scarps, large slumps, accumulation debris, and numerous flow lobes; and (4) an eastern area characterized by north-south sediment funneling channels. Figure 2 is a schematic drawing of the area.

Zone 1 - The northwestern “undisturbed zone” is characterized by the presence of either broad expanses of sand covered by ripples with wavelengths of 1 - 5 m, or large featureless areas where the surface sediment is a cohesive mud. Isolated slumps and pockmarks are present but cover less than 10 percent of the zone. Ripple orientation suggests onshore/offshore sediment movement.

Sediment instability is characterized by in-situ collapse features without much evidence of translational motion. Isolated pocks and collapse depressions are generally less than 50 m in maximum dimension, with many being 10 m or less in size. Figures 3, 4, and 5 show typical characteristics of the “undisturbed” zone.

Zone 2 - The northcentral zone of small-sized, medium density slmping is characterized by many small slumps, slides, small collapse features, and a variety of types of flows. Most examples of sediment instability have well-defined boundaries and are not layered or superimposed, one slide or slump on top of another. Many areas are covered by an irregular, blocky surface, suggestive of differential in situ sediment volume reduction.

The largest features present are closed collapse depressions up to 300 m in maximum dimension, and elongate flows, also up to 300 m long. Most features, however, are much smaller, with maximum dimensions less than 50 m.

In the northwestern part of Zone 2 the relationship between sediment-failure features and the sand and mud blanket of Zone 1 is not clear. It

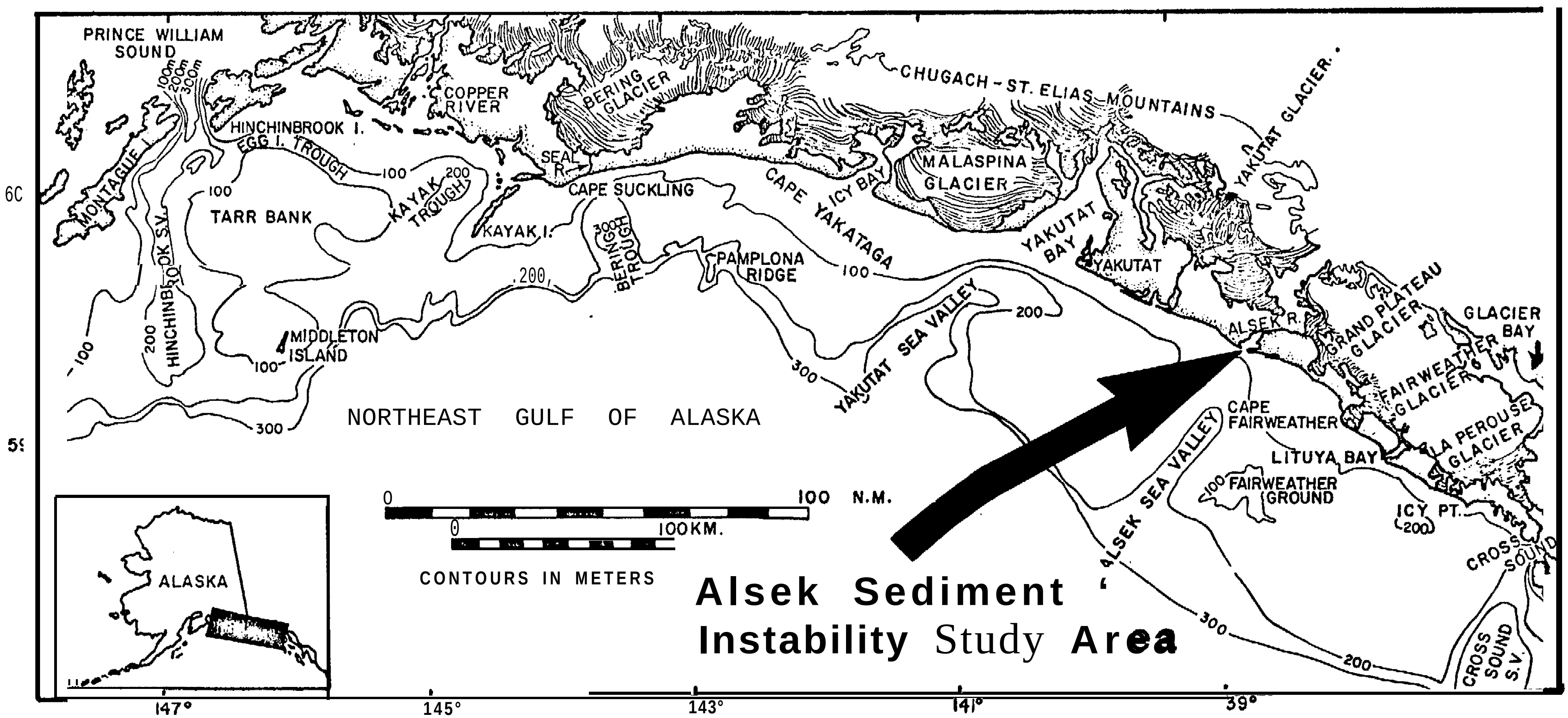


Figure 1. Location of the Alsek Sediment Instability Study Area in the northeaster Gulf of Alaska.

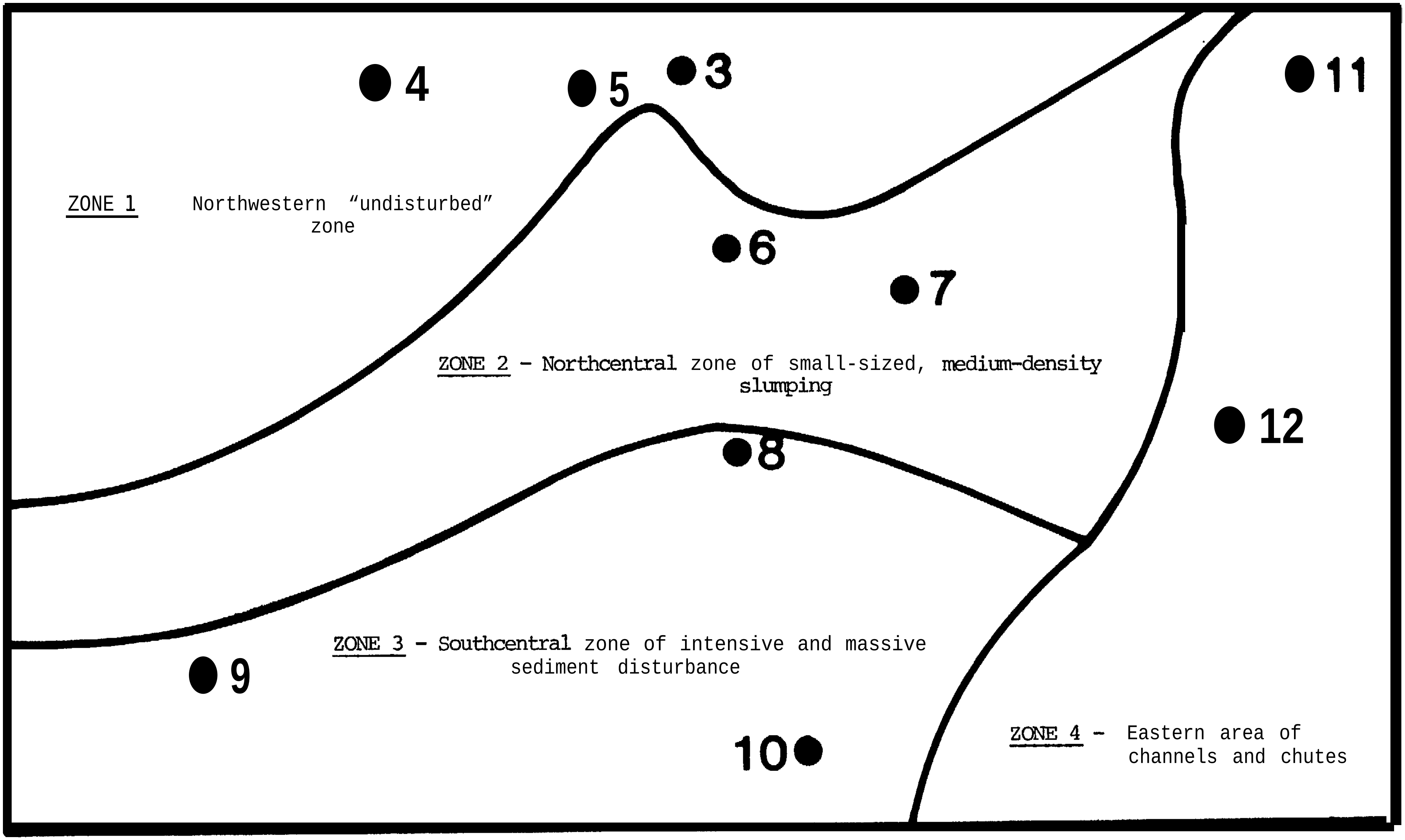


Figure 2. Schematic drawing of the Alsek Sediment Instability Study Area showing the four zones, each characterized by a different style of sediment instability. Numbers correspond to the locations of Figures in this section.

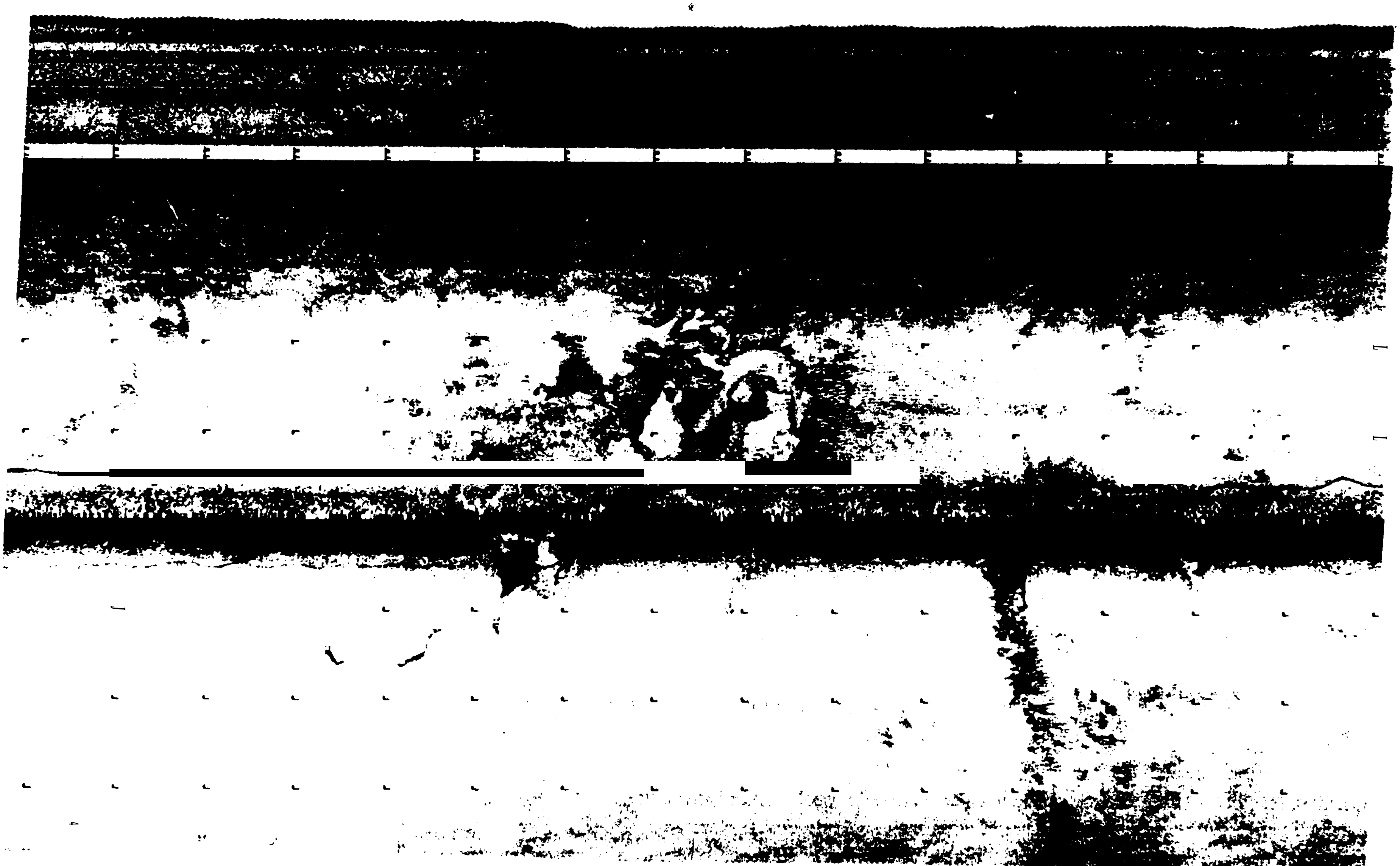
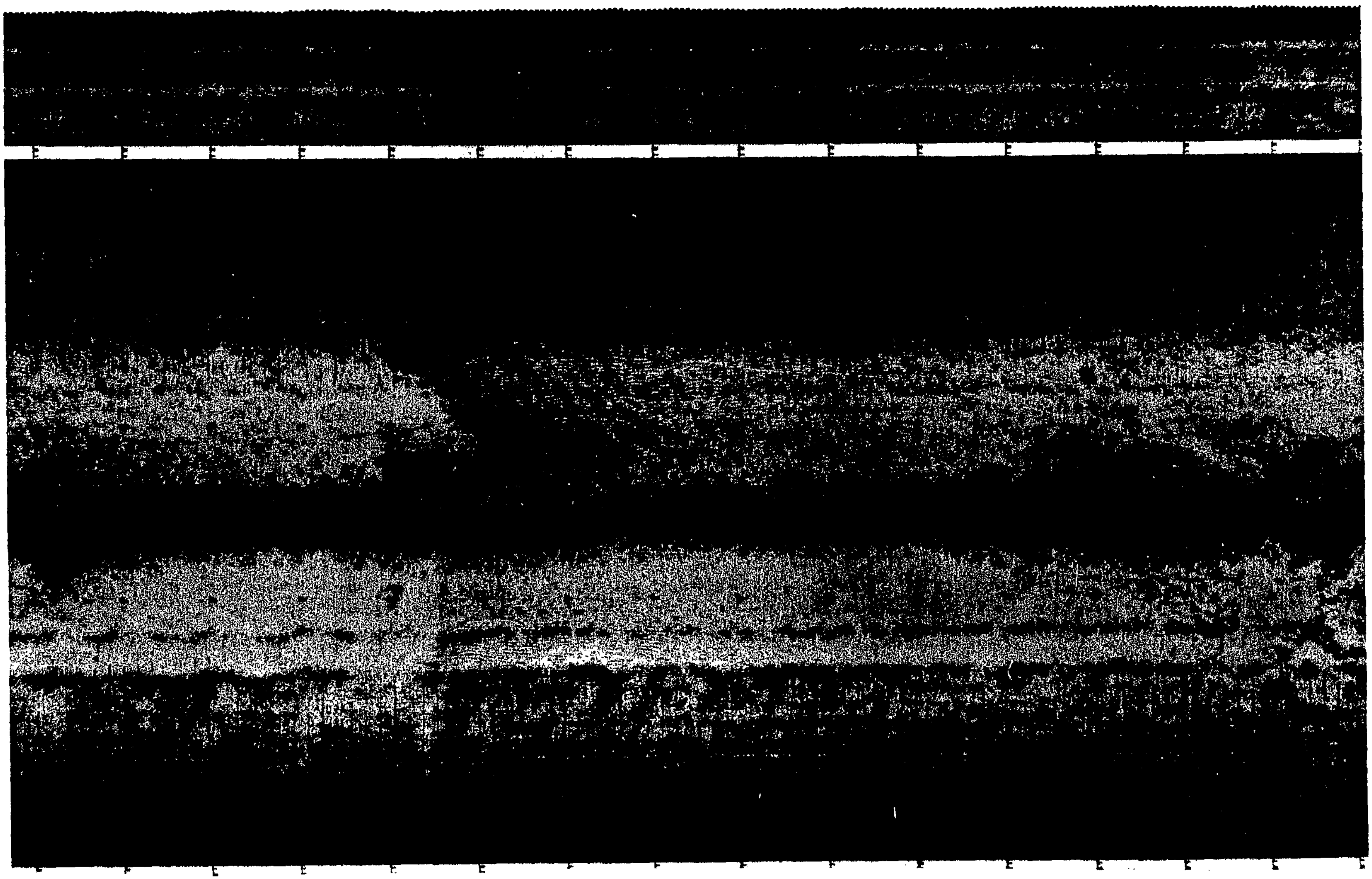


Figure 3. SONAGRAPH example of rippled-sand surface of the northwestern "undisturbed" zone. Note the few isolated collapse features. The upper profile shows mid-line bathymetry. The distance between tick-marks is 25 m.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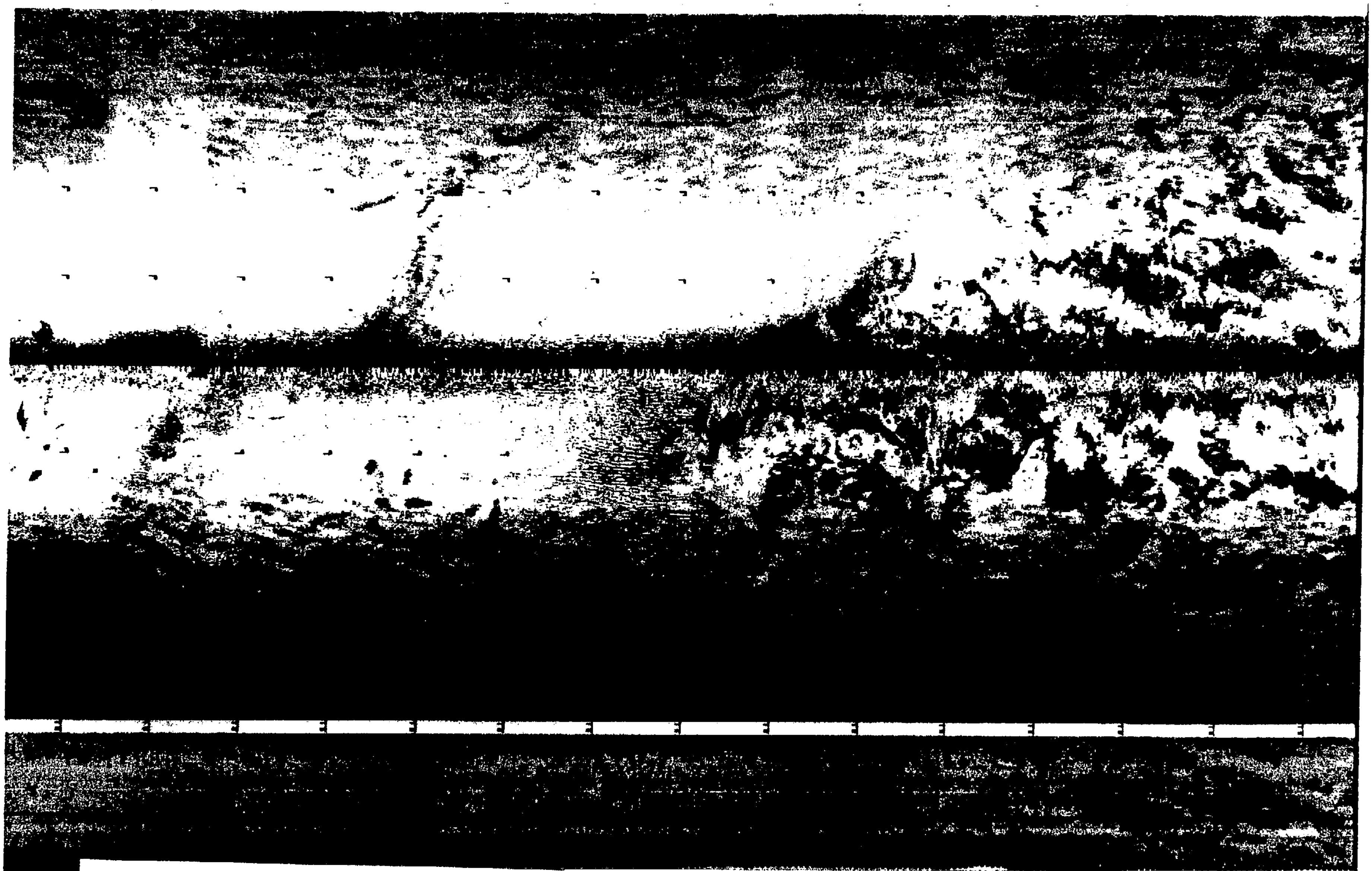


Figure 5. SONARGRAPH of ripples, sand bodies and featureless mud in the northwest "undisturbed" zone.

cannot be clearly determined whether Zone 2 features are expanding northward into Zone 1 or whether the mobile sediment blanket of Zone 1 is burying older craters, pockmarks, and collapse features of northern Zone 2. Examples of Zone 2 features are shown in Figures 6 and 7.

Zone 3 - The largest of the four zones, Zone 3 (the southcentral zone of intensive and massive sediment disturbance) is characterized by multiple generations of slides, slumps, flows, collapse features and other varieties of sediment instability. Features are extremely complex with multiple flow lobes coming from a variety of directions. The size of flows appears to increase at the southern limit of the area. Topography is complex with many areas of flows bounded by channels with well developed sand waves. Examples of Zone 3 features are shown in Figures 8, 9, and 10.

Zone 4 - The eastern area of channels and chutes occupies about 15 percent of the entire mosaic area. Here, generally north-south oriented, well-developed linear troughs, channels and chutes 3-6 m deep, up to 300-400 m wide, and as much as 1.5-1.8 km long, occupy more than half the area. The chutes serve as active channelways for the funneling of currents and probably sediment. Many sets of trowel marks approach the chutes, disappear within the channel, and then continue on the far side of the chute.

Inter-channel areas are generally devoid of slides, slumps and other types of sediment-failure features. They do, however, have much higher surface reflectivity than channels and chutes. Examples of Zone 4 features are shown in Figures 11 and 12.

GEOTECHNICAL STUDIES IN THE AREA

In-Situ Tests.- In-situ cone penetration and vane shear tests were conducted with the Multi-purpose In-Situ Test System (MITS) leased from Woodward-Clyde Consultants. Two stations were occupied; one in the undisturbed rippled sand (Zone 1) and the other in an area of disturbance (Zone 3). Cone penetration tests in the rippled sand area indicate a layer of dense sand with a friction angle of about 38 degrees and a relative density of near 100 percent, extending from 1-3 m below the sea floor. This material is overlain by a 1-m-thick layer of weak material; generally loose sand or clayey silt. From 3-5 m below the surface a stratified zone exists that is apparently interbedded silts and sands. The sands have a relative density of about 80 percent and a friction angle of about 34 degrees. The silts are relatively dense and have a strength to overburden pressure ratio of around 1.

Vane and cone tests in the area of disturbance (Zone 3)indicate a relatively weak material, probably silt, that is interbedded with sands. The sands comprise 30-40 percent of the 6-m subbottom section that was tested and occur in beds ranging in thickness from 10-70 cm. The sand is apparently in a relatively loose state. The occurrence of sand decreases with depth with the lower 3 m being predominately silt. The silt appears normally- to slightly underconsolidated and has a strength to overburden pressure ratio of 0.5.

Index Property Tests.- Twelve gravity cores from the area of disturbance were tested for vane shearing strength, water content and Atterberg limits. The material tested was almost exclusively silt. Vane shear strengths ranged from 3-19 kPa with a slight tendency toward lower strength in the eastern part of

Figure 6. SONARGRAPH example of **small collapse features,** slides, and linear flows in the northcentral zone of **small-**sized, medium density slumping.

Figure 7. Sonargraph example of multiple collapse depressions, small slides, slumps and flows in the north-central zone of small sized, medium-density slumping.

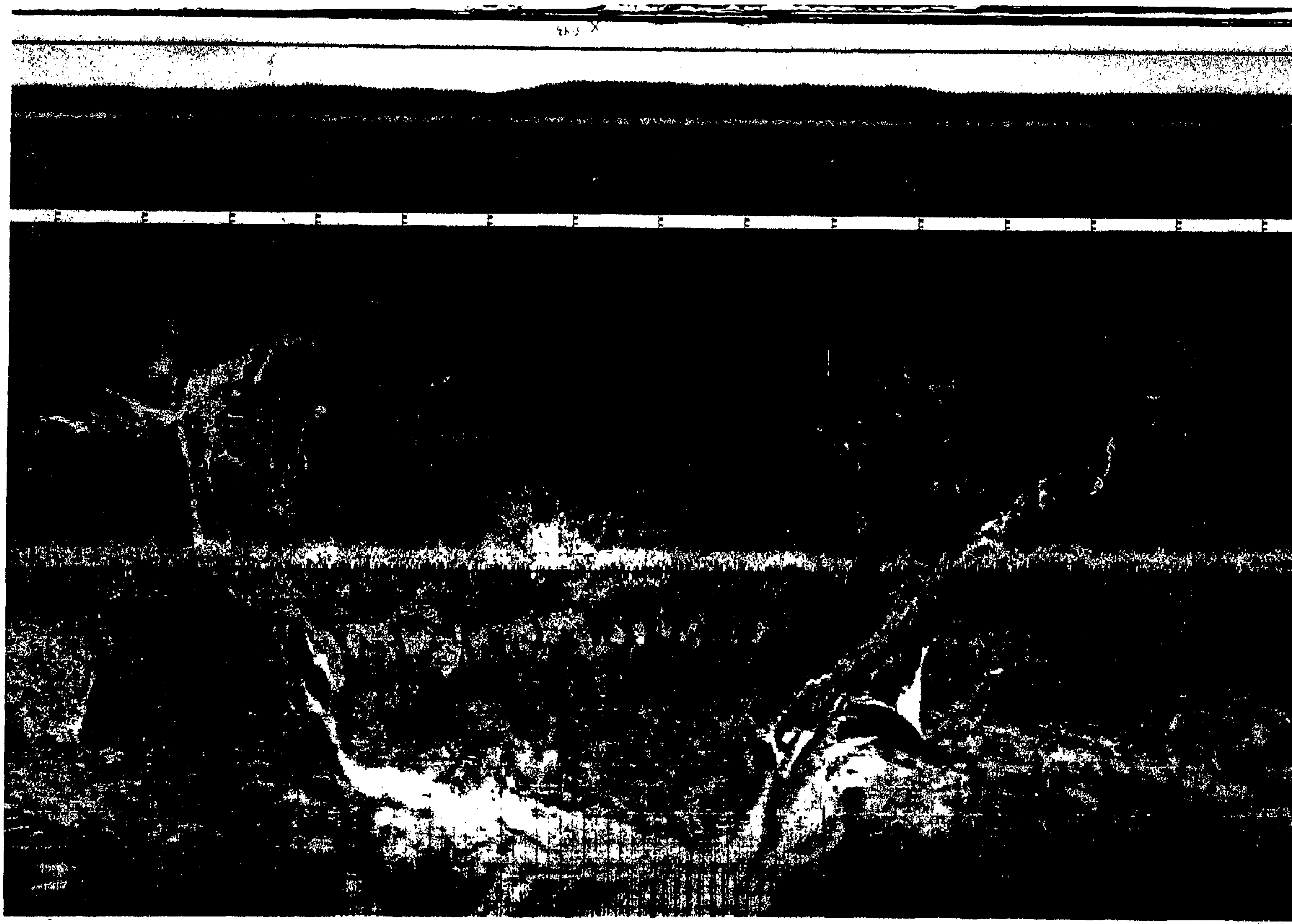


Figure 8. Example of surface features at the north end of the south-central zone of intensive and massive sediment disturbance.

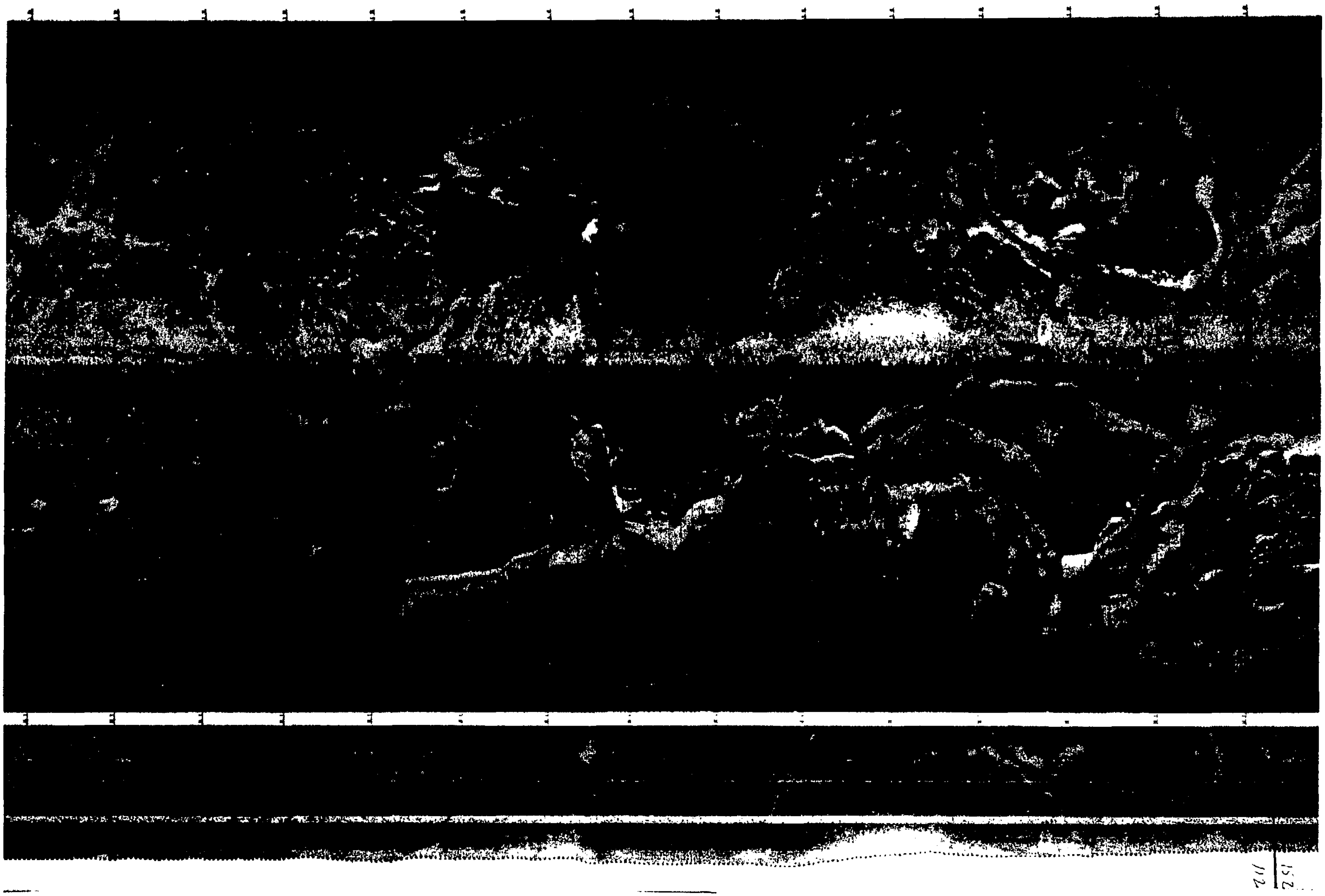
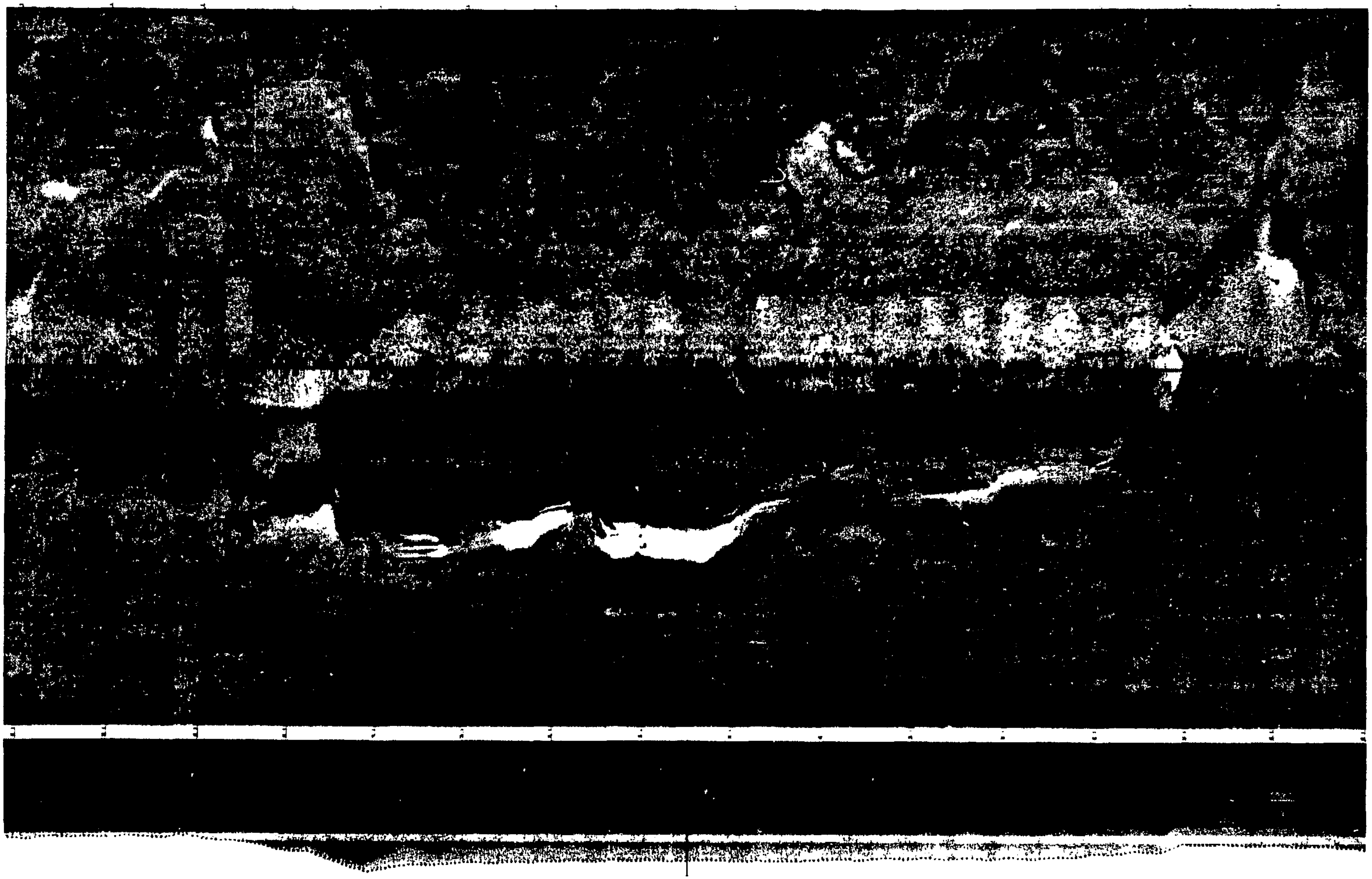


Figure 9. **Multiple flows, slumps, and** slides in the south-central zone of intensive and massive sediment disturbance.



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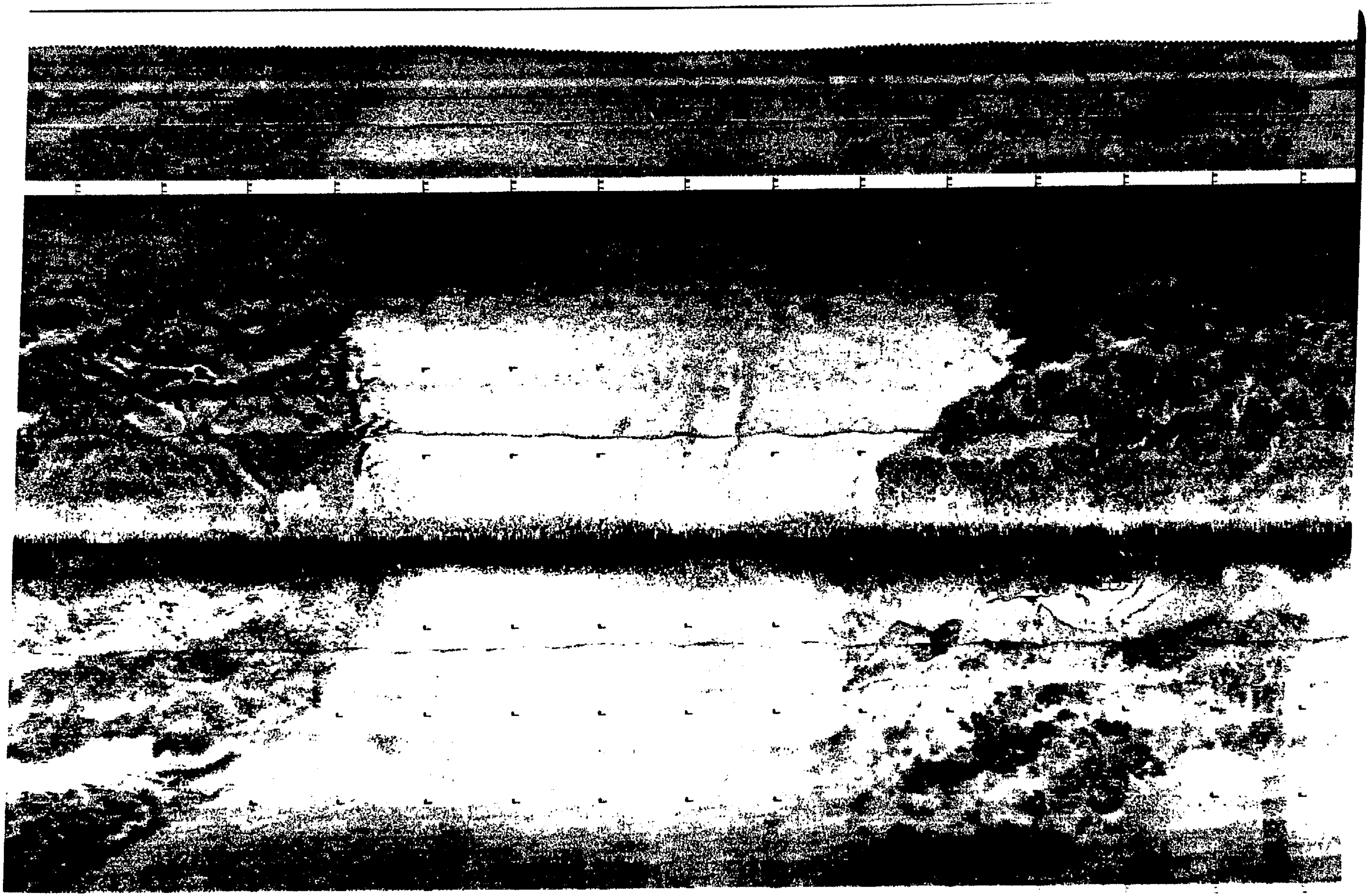

Figure 11. Example of a 150-m-wide channel with **wall** relief of about 1 m. Features like this are common in the **eastern** area of channels.

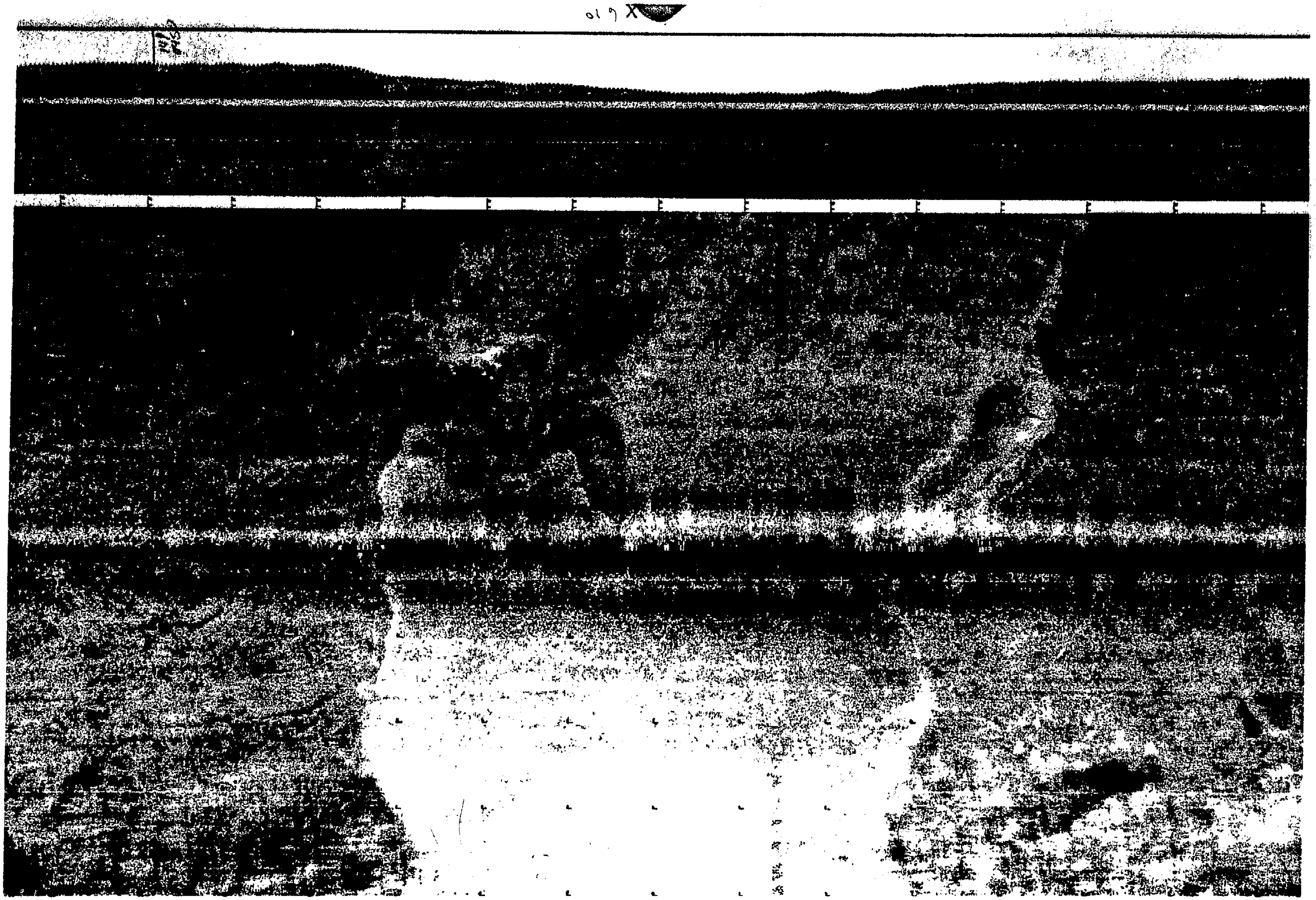

Figure 12. North-south oriented channel in the eastern area of channels and chutes.

the mosaic area. Water contents ranged from 27-50 percent dry weight with the higher values occurring in the eastern section. The liquid limit ranged from 2-41 percent and was typically near the natural water content. Such a condition *is* generally indicative of a very sensitive material.

Triaxial Testing.- Four gravity cores from the area of distrubance were subjected to static and cyclic triaxial tests. The ratio of strength to overburden pressure for the material in a normally consolidated state was determined to be 0.7. This value can be used to determine the consolidation state of the silts tested in place. The cyclic tests showed a strength degradation of 70 percent during 10 cycles of loading. This is significantly greater than the 30-40 percent strength degradation usually found with nearshore silts and clays and indicates the material could easily lose most of its strength during earthquake or wave loading.

Origin of Sediment **Instability.-** The upper few meters of sediment are failing as a result of dewatering and degassing induced by the action of one or more of the following processes, all of which are active in this area: cyclic waveloading, earthquake ground shaking, rapid sedimentation, or saturation of the sediment by biogenic methane gas. Additional factors that may contribute to the sediment instability include high pore-water content and the possible presence of a slip surface between the present-day Alsek River sediment and an underlying, dewatered, older silty-sand and clayey-silt layer. The pockmarks, slumps, and other sediment-failure features occur on slopes as gentle as 0.4 degrees and in water 35-80 m deep. Sedimentological evidence from the cores and grab samples suggests that the regional stratigraphy in the mosaic area consists of a veneer of sand less than 1 m thick overlying a 2-4 m thickness of underconsolidated clayey silt with a high water content. The silt, which contains thin sand lenses, overlies a much thicker dewatered clayey silt. Minisparker and airgun seismic data indicate that the total thickness of Holocene sediment in the mosaic area, and in the area adjacent to the mosaic, ranges from 40-120 m and unconformably overlies an older lithified unit. The boundary between the two units is characterized by rounded, glacially-eroded features and by many small U-shaped channels.

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Section 3

The Taxonomy, Ecology and Zoogeography of the Holocene and Pleistocene Ostracode Fauna of the Gulf of Alaska

THE TAXONOMY, ECOLOGY AND ZOOGEOGRAPHY OF THE HOLOCENE AND PLEISTOCENE OSTRACODE FAUNA OF THE GULF OF ALASKA

ELISABETH M. BROUWERS

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1. SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

The northeastern Gulf of Alaska, from Montague Island to Cross Sound (148° to 137° W. longitude), was studied to determine the areas and processes of significant environmental concern to resource development. My specific objective in this project was to provide pertinent information of the age, environment, and sediment transport of continental shelf sediments in the eastern Gulf of Alaska based on the contained ostracode assemblages. An intensive examination was conducted of selected bottom grab samples, assessing the faunal and floral organisms present in each sample. Very detailed studies were made of the ostracode assemblages in the samples.

The Gulf of Alaska forms part of the Aleutian Zoogeographic Province, with a cold temperate (boreal) marine climate. The ostracode species distribution patterns establish the provincial boundaries - south at Dixon Entrance and north at the Aleutian Islands. The provincial boundaries are marked by the termination of some species ranges and by the overlap of species from adjacent faunal provinces. The ostracode assemblages enable a definition and characterization of the Aleutian Province to be made.

Five distinct ostracode assemblages have been defined by means of Principal Coordinate Analysis (PCOORD). Four of these assemblages correspond to physical and chemical parameters that change with depth, primarily water temperature and salinity; to a lesser extent, oxygen content, turbidity, substrate, nutrient supply, and wave and storm activity. These depth assemblages are also reflected in the associated faunal and floral elements. The fifth assemblage is composed of ostracode species that correspond to environments no longer existing in the Gulf of Alaska. Species that presently live either in colder or warmer waters than are present today and/or species that require less turbid waters with lower sediment influx comprise the fossil assemblage. The smaller sediment influx that existed for the fossil ostracode species can also be seen in the associated presence of large numbers of filter feeding organisms.

Ostracode species presently living in the Gulf of Alaska were evaluated to determine and characterize distinct biofacies. Individual species distributions were correlated to the distribution of major controlling environmental variables. Specific regions were recognized containing mixtures of modern and Pleistocene species. The exposed offshore Pleistocene deposits were defined and characterized. Careful examination of modern species enabled the recognition of undescribed fossil species in these sediments. The accurate interpretation of either the modern environments or the Pleistocene deposits hinges on recognizing and deciphering these mixtures.

Detailed counts of adult versus juvenile specimens of a species allows the determination of a life assemblage (biocoenosis) versus a death assemblage (thanatocoenosis, composed of fossil, transported, or reworked specimens). The adult: juvenile-ratio provides some measure of sediment transport, both downslope transport and current movement. Recognition of the preferred depth habitat of a species enables an assessment to be made of the origin of the transported sediment, as well as the size range involved.

Establishment of this modern datum of the environmental factors that significantly control or contribute to the distributional patterns of modern ostracode species occurring on the Alaskan continental shelf enables geological applications to be made. This information forms a vital part of the interpretive aspects of Neogene and Quaternary stratigraphic and paleoenvironmental studies in this region. The defined depth assemblages permit reconstruction of paleobathymetry.

Ostracodes have been shown to be sensitive to oil spills in climatically similar environments. Characterization of the present assemblages in terms of species diversity and abundance provides an environmental datum. Any adverse effects caused by an oil spill can be monitored by a re-examination of the assemblage composition and comparison to the established datum.

II. INTRODUCTION

A. GENERAL NATURE AND SCOPE OF STUDY

The primary goal of this study has been to provide pertinent information on the age, environment, and sediment transport of continental shelf sediments of the northeast Gulf of Alaska based on the ostracode assemblages. In addition, these studies provide information tabulating the ostracode species present as well as associated faunal and floral elements. These data on the patterns of distribution and abundance of benthic organisms provide a baseline prior to the development of oil and gas leases on the continental shelf of the Gulf of Alaska.

B. SPECIFIC OBJECTIVES

My specific objective in this study has been to document the distribution and relative abundances of the ostracode species occurring in the Gulf of Alaska and to correlate the distributional patterns to environmental parameters that significantly control or contribute to these patterns. In addition, all associated fauna and flora were identified and documented. The ostracode assemblages examined permit the definition and characterization of a major zoogeographic province in this region. Detailed analyses of the ostracode species enabled recognition of distinct biofacies associations.

This report provides data on the counts of adult versus juvenile specimens, which adds to the documentation of sediment transport patterns on the continental shelf. Finally, the recognition and characterization of offshore, outcropping fossil sediments has been accomplished.

C* TAXONOMIC PLACEMENT AND CHARACTERIZATION OF OSTRACODES

The Ostracoda are *a class* of the Crustacea, and are characterized by: a) having a bivalved carapace that is hinged along the dorsal margin (with the carapace usually being calcified); b) possessing *a* bisegmented body with an undifferentiated head; and c) the presence of four pairs of cephalic 'appendages (antennules, antennae, mandibles", and maxillae). Most species are microscopic (0.4-1.5 mm), although some freshwater forms are larger (up *to* 8 mm), and macroscopic pelagic forms can be up to 30 mm long (Moore, 1961).

The short, laterally-compressed body is suspended from the dorsal region as an elongate chitinous-pouch. The outer epidermal cells of the chitinous body wall secretes a calcareous layer over all of its surface. The five to seven paired appendages are greatly diversified according to function; these differences are used in part to define the extant orders, *suborders,* and superfamilies (minor differences in the appendages are also used to define families, genera, and species).

Most ostracodes reproduce sexually, and the differences between the sexes is often reflected in the calcareous valves in the form of dimorphic shell shapes" at the posterior end of the valves. Growth of ostracodes is by ecdysis (molting), with chitinous and calcareous layers periodically shed and replaced by larger carapaces (Moore, 1961; Van Morkhoven, 1962, 1979). Each molt involves an approximate doubling in body volume, new appendages are added, and the valves become progressively thicker. Ostracodes molt eight times, with each stage (instar) contributing two valves to the sediment.

Each podocopid ostracode provides 18 valves to the sediment. Ideal preservation of the living population structure in which all ostracodes grew to the adult stage would provide an adult:juvenile ratio of 1:8. In nature, effects of predation and destruction of the very early instars causes the actual adult:juvenile ratio to be about 1:3 to as high as 1:5; the laboratory processing also eliminates the early instars by sieving. The adult to juvenile structure provides an important means of determining a life assemblage. In addition, the population structure has important ramifications in determining whether a fossil assemblage has been transported or is in place. Various juvenile valves and the adult valves are frequently selectively sorted by size according to the water energy, providing a means of determining sediment size fractions moved and water energies involved. The ontogenetic development of an ostracode seems to be restricted to one biotope (Elofson, 1941), so that juveniles and adults occur in the same environment. This means that determinations of a species habitat applies to the adults and juveniles. The adult:juvenile structure provides a key to interpreting ostracode sedimentation patterns and various degrees of valve transportation.

Ostracodes occur in nearly all types and depths of aquatic environments. In the marine world, they occur from abyssal depths to marginal marine inner littoral habitats. Ostracodes are very sensitive to the ambient environment. The species are adapted to particular ranges of the scenopoetic parameters of their environment, so that individual species and communities of species can be used to reconstruct detailed paleoenvironments. The provincial nature of ostracodes further provides that distinctions can be made between northern Japanese and southern Alaskan assemblages from the same climatic zone. The restricted geographic distribution and well-defined biotopes of ostracodes makes them ideal organisms for defining and characterizing particular zoogeographic province.

III. CURRENT STATE OF KNOWLEDGE

The only previous study of ostracodes from the Gulf of Alaska is an unpublished Masters thesis by Painter (1965), done at the University of Kansas. Painter examined 35 samples from the northeast Pacific and Gulf of Alaska, finding 12 species.

Swain and Gilby (1974) described and illustrated 80 species of Holocene ostracodes from the Pacific Ocean along the coastlines of the United States, Mexico, Nicarugua. They found no ostracodes in their samples off of Washington state, nor did they examine any samples further north.

A monographic study of the Holocene ostracodes from the western United States (Baja California to Puget Sound, 21° N to 48* N latitude) by Valentine (1976) treated 341 species in 255 samples from the continental shelf. Valentine recognized four major faunal provinces based on ostracodes; this study suggests that the Gulf of Alaska falls within the cold temperate Aleutian Province.

A series of papers treating ostracode species that live in the warmer temperate waters of Washington, Oregon, and California are useful in Identifying species that range to the southeast Pacific as well as warmer water species that are now locally extinct. These papers include Juday [1907), LeRoy (1943a, 1943b, 1945), Skogsberg (1928, 1950), Triebel (1957), Hazel (1962), Crouch (1949), Lucas (1931), Smith (1952), and Watling (1970). Hanai (1957a, 1957b, 1957c, 1959a, 1959b, 1961, 1970) has published on Japanese species that occur in the same climatic province, as has Ishizaki (1966, 1968, 1969, 1971). Ohmert (1968) has studied Chilean ostracodes from the mild temperate climatic zone.

A series of papers have aided in the identification and determination of the northern geographical limits of the colder water species include Swain (1963), Schmidt (1963, 1967), Schmidt and Sellman {1966), Neale and Howe (1973, 1975), Neale and Schmidt (1967), Schornikov (1974, 1975), Neale (1959, 1973a, 1973b, 1974), Hazel (1967, 1970), and Lev (1969).

IV.

This report is based on 368 samples collected during three cruises to the Gulf of Alaska, from 1975 to 1980. All of the samples are from the continental shelf, from depths ranging from one meter to 200 meters. Cruise EGAL-75-KC (F.R.S. Townsend Cromwell, 1975) included 228 samples taken between Montague Island and Yakutat Bay (140°-148″ W longitude). Thirty-one samples were examined from cruise DC1-79-EG (R/V Discoverer, 1979), with localities between Dry Bay and Cross Sound (136°-138′ W longitude). Cruise DC2-80-EG (R/V Discoverer, 1980) included 109 samples taken between Icy Bay and Dry Bay

(138°-1420 W longitude).

V. SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

A. FIELD METHODS

Most of the sediment samples taken in the field were large volume, bottom grabs (Van Veen, Shipek, and Box Core}. These samples were analyzed for lithology, grain size, bulk mineralogy, water content, clay mineralogy, and carbon content. These samples proved ideal for a reconnaissance of the benthic organisms present in the Gulf of Alaska. The large volume of sediment enabled large residues to be examined, so that, as much as possible, the total ostracode assemblages present were represented. Samples smaller in size, such as those obtained from core tops, provide information only on the most abundant species; the more rare species living at a site are not represented. Sample locations were selected to reflect the wide range in depth, bathymet ric structures, and sediment types occurring in the eastern Gulf .

B. LABORATORY METHODS

The micropaleontological subsamples taken were not standardized, and ranged in size from 200 grams to over one kilogram (wet weight], depending on the initial amount of sample available. The bulk grab samples that were subsampled had not been kept refrigerated, so that many had dried out. In terms of preservation of ostracode soft parts, these storage conditions were better than being kept cold.

All samples were washed on a 200-mesh sieve (75 micrometer opening). The washed sediment was sorted using a set of nested sieves and examined to a sieve size of 180 micrometers. The tabulation of fauna and flora, therefore, does not include any organisms smaller than 180 micrometers in size.

All samples were completely stripped of ostracode valves. All of the ostracode adult and juvenile specimens found in each sample were identified and counted. The percentage each species constitutes of the entire ostracode assemblage was calculated. The counts refer to the total number of valves or recognizable fragments of a species; a carapace is counted as two valves. Any specimens containing preserved chitinous soft parts were noted; these individuals were probably living when collected.

All other organisms present in the washed sediment were identified and tabulated. No attempt was made to assess the relative abundances of these associated fauna and flora.

VI. ZOOGEOGRAPHY

A. INTRODUCTION

A faunal province may be defined as a region in-which communities maintain characteristic taxonomic compositions (Valentine, 1973). Temperature is the underlying factor controlling the distribution of organisms, and the distribution of kinds of organisms determines the nature and extent of the different provinces (Hazel, 1970). The boundaries between provinces forms the basis for climatic zone boundaries (from north to south, the northern hemisphere climatic zones are: frigid, subfrigid, cold temperate, mild temperate, warm temperate, subtropical, and tropical). Provincial boundaries are recognized where shelf assemblages, diagnostic over a broad area, alter their composition because of the termination of species ranges and the appearance of forms ranging in from neighboring provinces. These boundaries mark distributional discontinuities which are controlled by environmental factors (Valentine, 1976).

Marine invertebrates cannot control their body temperature, with the rates of their physiological processes being directly influenced by the ambient water temperature. Water temperature is considered the fundamental factor limiting species distribution (Gunter, 1957; Kinne, 1963; Valentine, 1973). This can be seen at many provincial boundaries where a steep temperature gradient occurs over a short geographic distance. Such a steep gradient may act as a survival barrier if a species lethal temperature is present, or it may act as a repopulation barrier for reproduction or larval development temperature requirements (Hutchins, 1947).

A faunal province is unique; climatic changes, faunal migrations, and evolutionary events mitigates against the duplication of "successive provinces through time. Even if only the climate is altered, species will be found in new associations and constitute different provinces (Valentine, 1976). Hazel (1970) showed that modern amphiatlantic ostracode species form different species associations because marine climates differ on opposite sides of the same ocean basin.

The faunal pattern fits the hydrographic pattern closely. Whenever the hydrographic regime changes or is modified, certain species cannot overcome the barrier. Where a hydrographic regime is monotonous, the fauna is similarly so. In all cases, provincial boundaries are marked by marine climatic changes, usually localized by topographic irregularities (Valentine, 1973). Southern boundaries can generally be correlated with summer (August) differences and those in the north correlated with winter differences.

B. FAUNAL PROVINCES OF THE NORTHEAST PACIFIC BASIN

Valentine (1966, 1973) identified six provinces based on molluscan distributions along the west coast of North America. These are: (a) the Bering Province, extending from Point Barrow to the Aleutian Island arc area; (b) the Aleutian Province, extending south to Dixon Entrance; (c) the Oregonian Province, extending south to Point Conception; (d) the Californian Province, extending south to Punts Eugenia-Cedro Island; (e) the Surian Province, extending south to Cabo San Lucas; and (f) the Panamanian Province, extending south to the equator.

The environmental basis for this provincial pattern is clear for most of the boundaries. To the south, the Surian/Panamanian boundary {22° N latitude} marks the subtropical/tropical marine climates. Two large areas of upwelling to the south of Cabo San Lazaro and Punta Eugenia provide a formidable thermal barrier for the northward expanding tropical species. The Californian/Surian boundary (27° N latitude) marks the warm temperate/subtropical marine climates. This break correlates with the change from Pacific equatorial water to the transitional water of the California Current in the summer. The Oregonian/Californian boundary (34° N latitude) marks the mild temperate/warm temperate marine climates. This boundary is at Point Conception, where a sharp thermal gradient is localized by the semipermanent gyre south of Point Conception. The Aleutian/Oregonian boundary (54° N latitude) indicates the cold temperate/mild temperate marine climates. This boundary correlates to the change from the California Current water to the Alaska Current system. The Bering/Aleutian boundary (about 62° N latitude) marks the subfrigid/cold temperate marine climates. This boundary is more subtle, probably corresponding to the change in water masses from the Alaska Current to the Bering Sea water mass.

C. THE ALEUTIAN PROVINCE

Figure 1 shows the proposed boundary positions for the Aleutian Province based on twelve different studies, primarily based on mollusk distributions. Note that the southern extent has varied from 48° to 55° N latitude (Puget Sound to Dixon Entrance) and the northern border from 56° to 62° N latitude (Dixon' Entrance to southern Norton Sound) (Valentine, 1966)

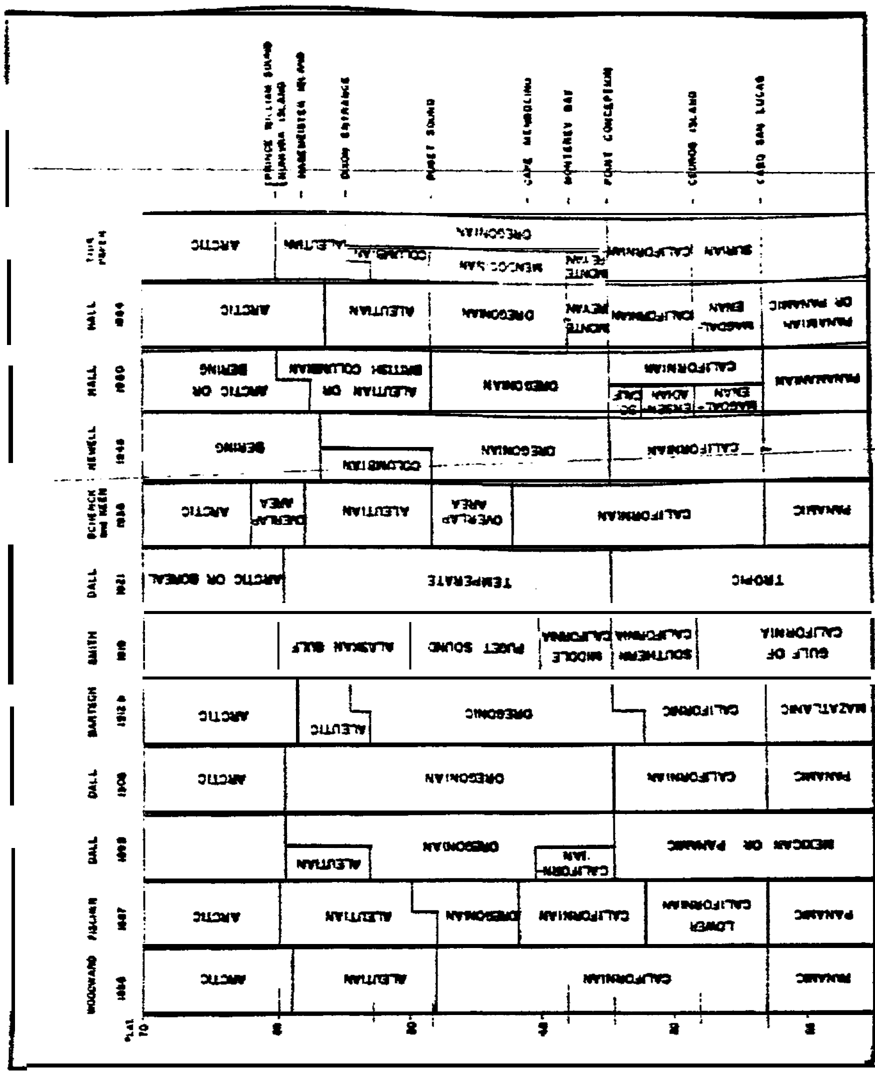
Based on the ostracode assemblages examined from the Gulf of Alaska, these waters fall into a cold temperate marine climate. Genera commonly found in the mild temperate Oregonian Province such as Ambostracon, "Aurila", "Hemicythere", Radimella, and Coquimba do not presently live in the Gulf. Species of Ambostracon and Coquimba have been found in Pleistocene lag deposits, suggesting a warming interval during the time of deposition. Some genera from the mild temperate zone do extend to the Gulf of Alaska, including Cytheropteron, Loxoconcha, Pontocythere, Cythere, Munseyella, Pectocythere, and Hemicythere. These are genera that commonly have species existing in the mild temperate through subfrigid marine climates in other regions of the northern hemisphere. Other genera seem to be restricted to this area, including Buntonia, Elofsonia, "Leguminocythereis", Eucytherura, Sclerochilus, and Bythocythere.

Sampling did not extend farther south than Cross Sound, so that an exact

FIGURE 1

TWELVE PROVINCIAL SYSTEMS PROPOSED FOR THE NORTHEASTERN PACIFIC SHELF, BASED ON MOLLUSKS
(FROM VALENTINE , 1966)

FIGURE 1



Some of the provincial systems proposed for Mollusca of the northeastern Pacific shelf.

southern boundary for the Aleutian Province could not be determined based on ostracodes. However, based on scattered studies of ostracodes from Vancouver Island (Lucas, 1931; Smith, 1952), combined with the general trend of shallow water ostracode faunas to have similar faunal boundaries as mollusks, the southern boundary at Dixon Entrance proposed by Valentine (1966) is estimated to correspond to the ostracode faunal boundary.

The northern boundary of the Aleutian Province is located to the north of the Aleutian Islands. A series of samples examined from the north Aleutian shelf (between Port Heiden and Port Muller) as well as selected samples from the Pribilof Islands have a markedly arctic influence. The only cold temperate genera present are Cytheropteron, Loxoconcha, Semicytherura, "Leguminocythereis", Sclerochilus, and Pectocythere. The frigid to subfrigid forms present in the south Bering Sea include Finmarchinella, Normanicythere, Elofsonella, Eucytheridea, Paracyprideis, and Schizocythere. The cold temperate species are kept out of the Bering Sea by a combination of two factors: a) the change in water mass from the Alaska Current to the northwest Pacific and Bering Sea waters, and b) by the colder summer temperatures and slightly cooler winter temperatures present on the Aleutian shelf.

VII. PRINCIPAL COORDINATE ANALYSIS

A. INTRODUCTION OF TECHNIQUE

The data analyzed in this study were very large, consisting of 368 samples containing 150 ostracode species. This information is great enough to cause conclusions to be based on only part of the available data base. Multivariate techniques were used to provide a consistent way to search for patterns in the large data matrix.

Principal coordinates analysis (PCOORD) is a method of relating the objects in an analysis to major axes (eigenvectors), to reduce the multidimensional nature of the problem (Hazel, 1977). The eigenvectors and eigenvalues are extracted from a Q-mode matrix of coefficients, in which the various samples are compared to one another on the basis of the species they contain (Hazel, 1970b). The output of the PCOORD is scatter plots of the samples in reduced dimensions. The eigenvalues of the samples for the first three coordinate axes were plotted as the first versus second Principal Coordinate Axes and as the first versus third Coordinate Axes. Principal Coordinates Analysis provides accurate between-group relationships; however, within-group relationships become distorted in reduced space. Hazel (1977) notes that PCOORD is practically unlimited as to the number of species, and that PCOORD is particularly advantageous when there is some structure to the data but when the groups are not compact.

B. PRINCIPAL COORDINATES ANALYSIS A

Appendix X shows the principal coordinates analysis of selected bottom grab samples from cruises EGAL-75-KC, DC1-79-EG, and DC2-80-EG (Table 1). Five different ostracode assemblages were recognized from the PCOORD analysis: Assemblages I,II,III,IV, and V. The assemblages are gradational in nature due to two factors: a) the environments represented by the assemblages are gradational, and b) the samples are not standardized in size, and all species and samples were included in the analysis, resulting in a considerable amount of "noise"

Assemblage I represents the inner neritic depth zone, and is characterized by shallow water species of Cytheromorpha, Bairdia, Argilloecia. Pectocythere, Aurila, Cythere, Elofsonia, Buntonia, Hemicythere, "Leguminocythereis", Eucythere, Pontocythere, and Loxoconcha (Table 4). In addition, occasional non-marine species of Candona, Cyclocypris and Cyprinotus are present.

Assemblage II can be correlated with the middle neritic depth zone. It is characterized by the presence of "Acanthocythereis" dunelmensis, Argilloecia, Buntonia, Cluthia, Cytheromorpha, certain species of Cytheropteron, Eucythere, Eucytherura, "Leguminocythereis", Loxoconcha, Palmanella limicola, Paracypris, Pectocythere, *and* Robertsonites tuberculata.

Assemblage III corresponds to the outer neritic depth zone. It can be characterized by the presence of "Acanthocythereis" dunelmensis, Cluthia, certain species of Cytheropteron, Cytherura, Eucytherura, Loxoconcha, Macrocypris, Munseyella, Palmanella limicola, Robertsonites tuberculata, Xestoleberis, Hemicytherura, and Bythocythere.

Assemblage IV represents the upper bathyal depth zone. Species that typify this environment include "Acanthocythereis" duenlmensis, Loxoconcha, Cluthia, certain species-of Cytheropteron, Eucytherura, Krithe, and Bythocythere.

Assemblage V does not correspond to a depth zone. This group of samples contains large numbers of species that are no longer endemic to the Gulf of Alaska, and are interpreted to represent fossil species. These species include Ambostracon, Baffinicythere emarginata, Bythocytheromorpha, Coquimba, certain Cytheropteron species, selected Cytherura species, Finmarchinella, "Leguminocythereis" sp. D, several Loxoconcha species, Normanicythere, many of the Paradoxostoma species, Patagonacythere, certain Pectocythere species, many of the Sclerochilus species, "Radimella", several of the Semicytherura species, Xestoleberis, and Xiphichilus.

Each sample was assigned to one of the five major ostracode assemblages. Samples that occurred on the boundary of two depth assemblages and which could not clearly be assigned to one were termed a mixture of the two assemblages. Most of the samples containing fossil species also contained modern species living on top of the exposed, unconsolidated fossil deposits. Depending on the water depth at which the fossil deposit occurred, these samples were termed a mixture of Assemblage V and the appropriate modern depth assemblage.

Examination of the plot of Principal Coordinate Axes One and Two shows that Assemblages I and II form distinct groups with very few mixtures. Assemblage 111 represents most of the samples examined in this analysis, and shows a considerable amount of scatter. Assemblage IV falls within the scatter of Assemblage III, mainly because more species of IV are in common with 111 than are different. Assemblage V occupies the northwest quadrant, forming a fairly compact grouping, but with no clear differentiation of the different modern mixtures.

Examination of the plot of Principal Coordinate Axes One and Three provides additional information that more clearly separates the five assemblages and the mixtures. Assemblage I again clearly exists as a distinct group of samples. Assemblage II becomes better segregated from Assemblage I. Further, the mixtures of Assemblages 11 and V cluster together with the samples from pure Assemblage II. Assemblage 111 remains a large grouping of scattered samples; the mixture of Assemblages III and V do not cluster together with III, but they do form a discrete group isolated from the other fossil mixtures. Assemblage IV shows a more coherent, separated group in this plot .

C. PRINCIPAL COORDINATES ANALYSIS B

Appendix IX shows the Principal Coordinates Analysis of selected bottom grab samples from cruise EGAL-75-KC (Table 2). This analysis was run after PCOORD A had defined the five major ostracode assemblages.

Examination of the plot of Principal Coordinate Axes One and Two corroborates the distinct grouping of samples forming Assemblage I. Assemblage II shows a very large amount of scatter, extending over three quadrants. The mixture of Assemblages II and V forms a more coherent group in the southeast quadrant. Assemblage III consists of far fewer samples which were collected in relatively close geographic proximity; note that these samples form a very discrete cluster.

The plot of Principal Coordinate Axes One and Three again provides a better picture of the sample grouping. Samples from Assemblage I remain a distinct group, although the third axis reveals more vertical scatter than PCOORD A showed. Assemblage II remains a scattered, amorphous plot of samples, Comparison of Assemblage II samples to their geographic locations shows three different environments can be correlated to the PCOORD scatter. Samples of Assemblage II plotting in the southeast quadrant correspond to middle neritic environments off of the Copper River delta. Samples of Assemblage II plotting in the northeast quadrant can be correlated to middle neritic depths of Icy Bay. Samples of Assemblage II plotting in the northwest quadrant correspond to middle neritic depths of Tarr Bank.

Assemblage IV forms a scattered group of samples in the northwest quadrant. Mixtures of Assemblages V and I and of V and III tend to cluster near the groups of Assemblages I and 111, respectively. Note that mixtures of

Assemblages V and II form three groups that cluster with the three different environments of pure Assemblage II.

VIII. AREAL DISTRIBUTION OF THE FIVE MAJOR OSTRACODE ASSEMBLAGES

A. YAKUTAT To CRoss SOUND

Each sample containing ostracodes was assigned to a major ostracode assemblage or mixture of assemblages based on the Principal Coordinates Analyses and based on the species composition of the sample. The areal distribution of the assemblages was then determined by plotting these samples on maps of the Gulf of Alaska.

The map covering the area between Yakutat and Cross Sound (Appendix IX) has the smallest sample coverage. The sample series taken from Palms Bay out to 200 meters depth shows a gradual change in assemblage type as the different depth zones are crossed. Two regions contain exposed fossil deposits: a) Fairweather Ground, and b) eastern Palms Bay. The Palms Bay exposure covers a malatively small area. The Fairweather Ground exposures, in contrast, form a flat bank between 100 and 200 meters water depth, and extend from the Alsek Sea Valley to the Cross Sound Sea Valley.

B. BERING GLACIER TO YAKUTAT BAY

Appendix XII illustrates the five major ostracode assemblages and mixtures of assemblages between the Bering Glacier and Yakutat Bay. Assemblage I is poorly represented in this region, consisting of some small boat collections between Yakutat and Icy Bay and a few samples collected west of Icy Bay.

One of the three Assemblage II environments separated by PCOORD B is represented in the group of samples taken at the mouth of Icy Bay. This environment consists of a steep-sided fiord with cold water and a very high sediment influx from Guyot, Yahtse, and Tyndall Glaciers.

The transitional nature of assemblages proceeding from one depth zone to the next is clearly shown in the transect taken off of the Malaspina Glacier. Three small regions of outcropping fossil sediments are indicated: a) just southeast of Ocean Cape, b) at the mouth of Icy Bay, and c) just seaward of Cape Yakataga.

c. MONTAGUE ISLAND TO KAYAK ISLAND

The most thorough sampling was conducted between Montague Island and Kayak Island (Appendix XIII), during cruise EGAL-75-KC. Assemblage I is well represented as a series of nearshore samples taken between Cape Suckling and Hinchinbrook Island. As documented in PCOORD B, two different environments of Assemblage II occur in this area: a) middle neritic depths east of the Copper River, primarily around Kayak Island, and b) middle neritic depths west of the Copper River, primarily around Tarr Bank. These different environments may reflect the differences in sediment influx of these two regions, with a higher sedimentation rate around Kayak Island and a lower sedimentation rate due to bypassing by currents around Tarr Bank.

Assemblage III is best represented in the samples from this region, showing comparable species composition over the entire depth zone.

Large regions of outcropping fossil deposits exist in this region, consisting of large banks as well as outcroppings around several of the islands. Both mixtures of fossil and modern species as well as wholly fossil samples are present. The largest exposure of Pleistocene sediments is Tarr Bank, defined by the 100 meter isobath, and cropping out between Montague Island and offshore of the Copper River delta. Exposures of fossil sediments also occur around the southern and western part of Kayak Island, west of Wingham Island, around Middleton Island, and along the southeastern side of Montague Island. Regions containing primarily modern species with transported, eroded fossil species can be seen along the southern end of Tarr Bank, especially to the north and south, and along the southern end of Kayak Island. Samples consisting entirely of fossil species occur in the middle of Tarr Bank, near Seal Rocks, and east of Middleton Island.

IX. CORRELATION OF OSTRACODE ASSEMBLAGES TO ENVIRONMENTAL PARAMETERS

Of the five assemblages defined by means of Principal Coordinate Analysis combined with species composition, four of these can be correlated to depth zones. Assemblage I corresponds to the inner neritic zone, extending from shoreline to about 50-60 meters. Assemblage II comprises the middle neritic zone, extending from 50 to 110 meters. Assemblage III corresponds to the outer neritic zone, from 100 to 200 meters. Assemblage V forms the upper bathyal zone, extending from 200-350 meters.

The break between Assemblages I and II occurs at 50-60 meters. The faunal transition between the inner and middle neritic zones correlates closely with the change in sediment type from sand and silty sand of the inner shelf to the clayey silt of the middle and outer shelf (fig. 2). The deeper limit of inner shelf sand reflects the deeper limit of intermittent turbulence caused by storm waves and storm-induced currents. The 50-60 meter mark is

FIGURE 2

DISTRIBUTION OF SEDIMENT TYPES AND VERTICAL PROFILES OF THE ANNUAL RANGE OF TEMPERATURE , SALINITY , AND OXYGEN FROM THE CONTINENTAL SHELF , GULF OF ALASKA

(FROM ARMENTROUT, 1980)

FIGURE 2

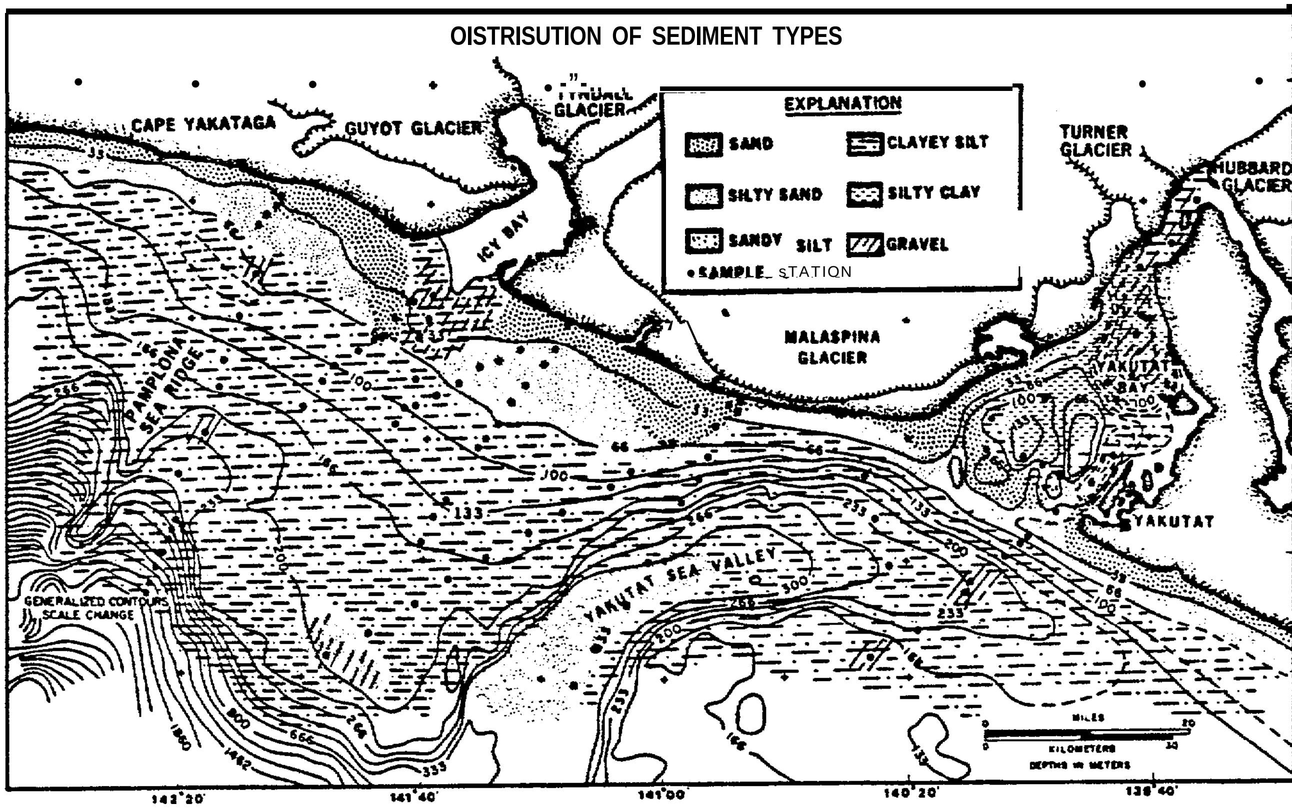


FIGURE 2. Distribution of sediment types based on grain-size (after Armentrout, 1980).

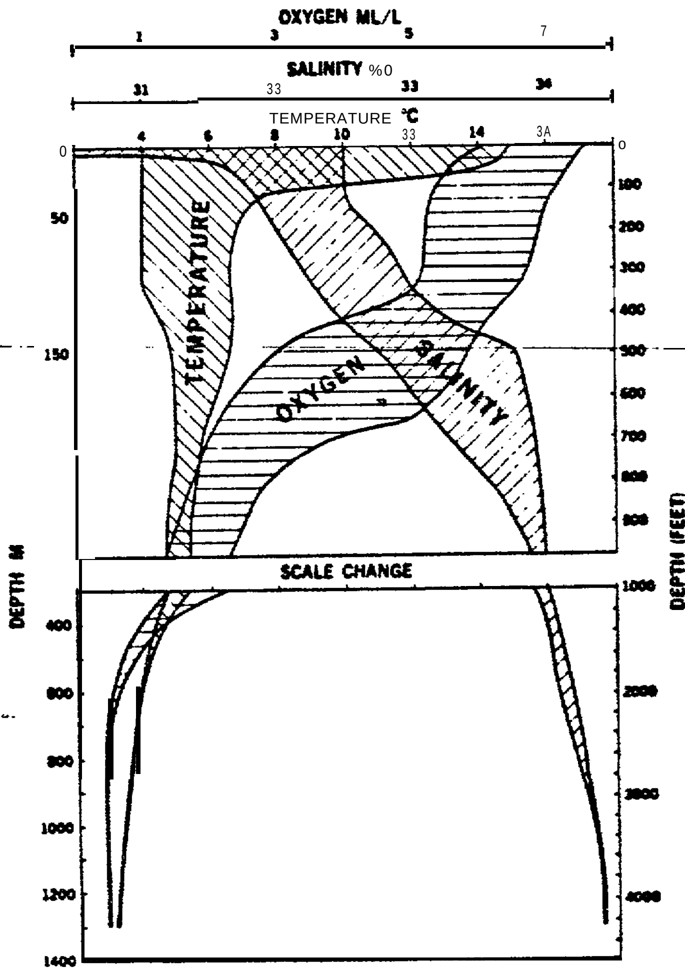


FIGURE 3. Variability of temperature, salinity, and oxygen with depth in coastal waters of study area. Data from Royer (1972).

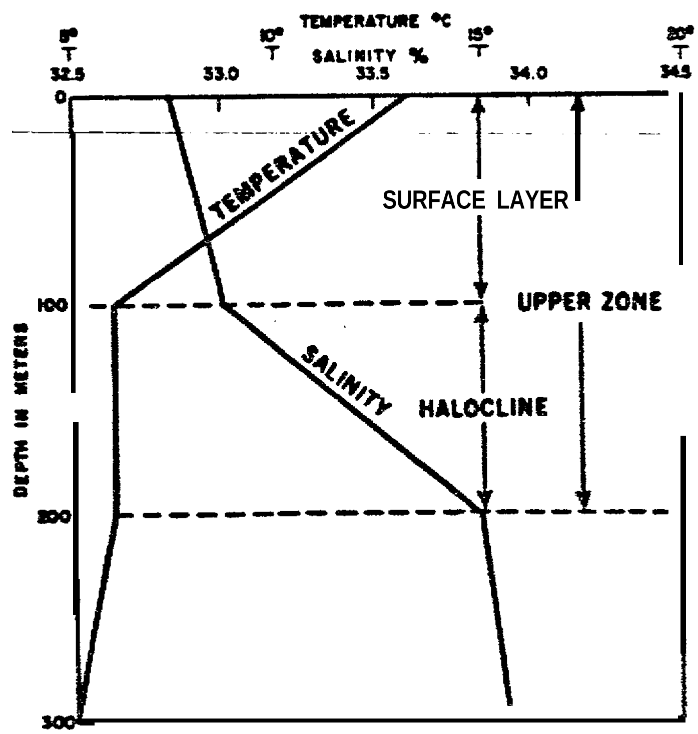


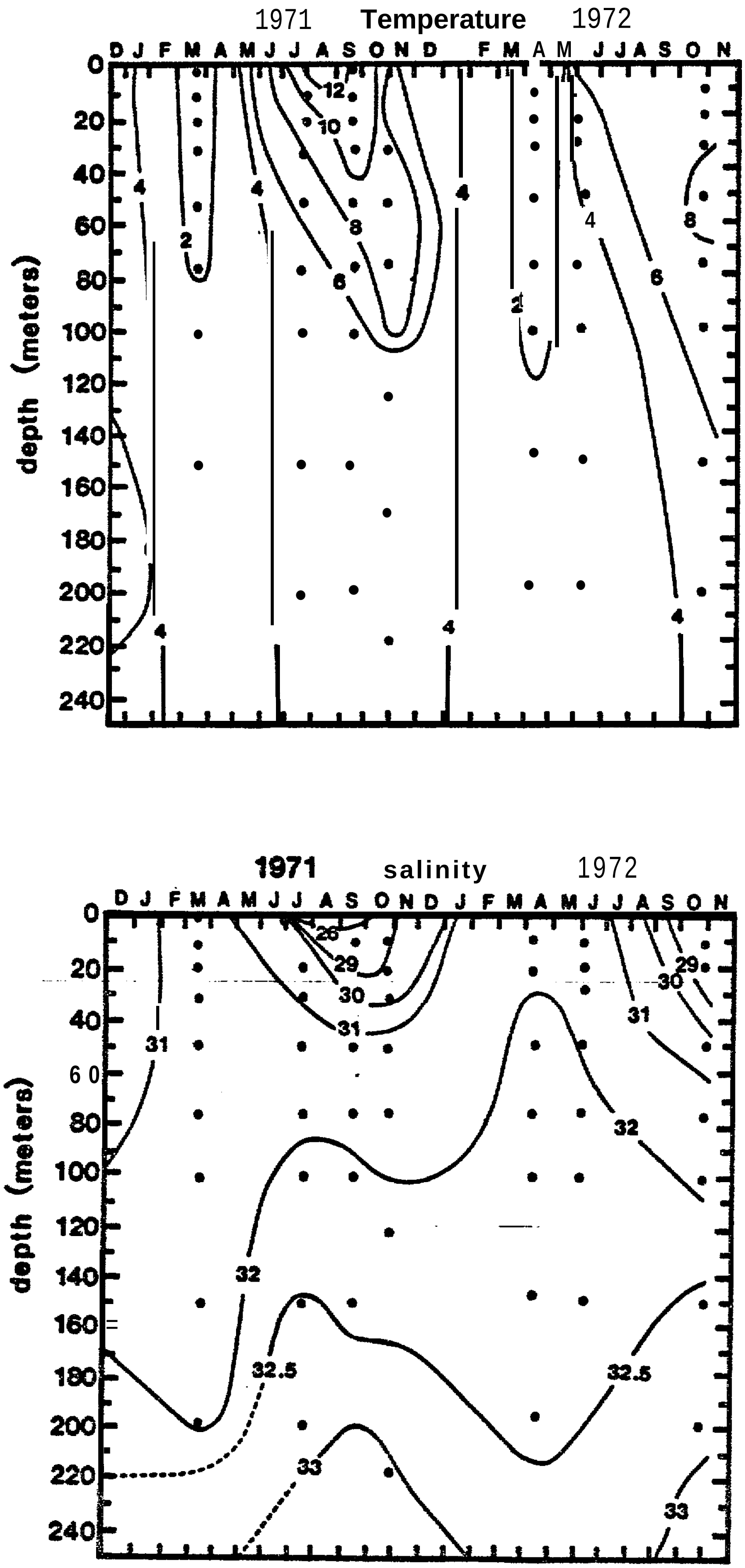
FIGURE 4. Schematic temperature and salinity distributions showing structure of the upper zone in the subartic Pacific Ocean (after Fleming, 1958).

FIGURE 3

TIME SERIES OF TEMPERATURE AND SALINITY TAKEN BETWEEN DECEMBER 1970 AND OCTOBER 1972, GULF OF ALASKA

(FROM ROYER, 1975)

FIGURE 3


1971 Temperature 1972
D J F M A M J J A S O N D F M A M J J A S O N
depth (meters)
0
20
40
60
80
100
120
140
160
180
200
220
240
12
10
8
6
4
2
1971 salinity 1972
D J F M A M J J A S O N D J F M A M J J A S O N
26
29
30
31
32
32.5
33

consistent with extremely severe winter storm conditions. The inner neritic zone marks the area with the largest salinity and temperature fluctuations, on an annual basis (figs. 2 and 3). Salinity varies from 26-29 o/oo from June to October up to 31 o/oo from January to April. Temperature can vary from 0° to 15° c. The ostracodes that characterize Assemblage I consist of species that can tolerate wide fluctuations in their physical-chemical environment. These species include "Acanthocythereis" dunelmensis, Argilloecia sp. A, Aurila sp. A, Bairdia sp. A, Buntonia sp. A, Cytherois sp. A, Cytheromorpha sp. B, sp. D and sp. E, Cytheropteron aff. C. nodosoalatum, Elofsonia, Eucythere, Hemicythere, "Leguminocythereis", Loxoconcha, and Pectocythere.

The middle neritic zone is characterized by some temperature and salinity variations, although on a markedly reduced scale. salinity can vary from 32-33 0/00; temperature varies from 3.5 to 12° C. Bottom sediments are primarily clayey silt. Species characteristic of this zone include "Acanthocythereis" dunelmensis, Argilloecia sp. A, Buntonia, Cluthia, Cytheromorpha, Cytheropteron sp. A and sp. D, Eucythere, Eucytherura, "Leguminocythereis", Loxoconcha sp. A and sp. B, Palmanella limicola, Paracypris, Paradoxostoma sp. I, Pectocythere, and Robertsonites tuberculata.

The boundary between Assemblages II and III marks the middle/outer neritic depth zones, and occurs at 100-110 meters. At this point, bottom temperature begins to stabilize at 5 to 5.5° C and no longer undergoes wide seasonal fluctuations. Oxygen content begins to decrease at 100 meters, changing from 7 ml/l at 100 meters and decreasing to 3 ml/l at 200 meters. Empirical observations shipboard document a reduction in turbidity and suspended particulate.

A small break occurs at 150-170 meters, which does not correspond to a major environmental change, but a noticeable faunal change. At this point,

FIGURE 4

DISTRIBUTION OF DEPTH ZONES DEFINED BY ASSOCIATIONS OF BENTHIC FORAMINIFERS (FROM ARMENTROUT, 1980)

FIGURE 4

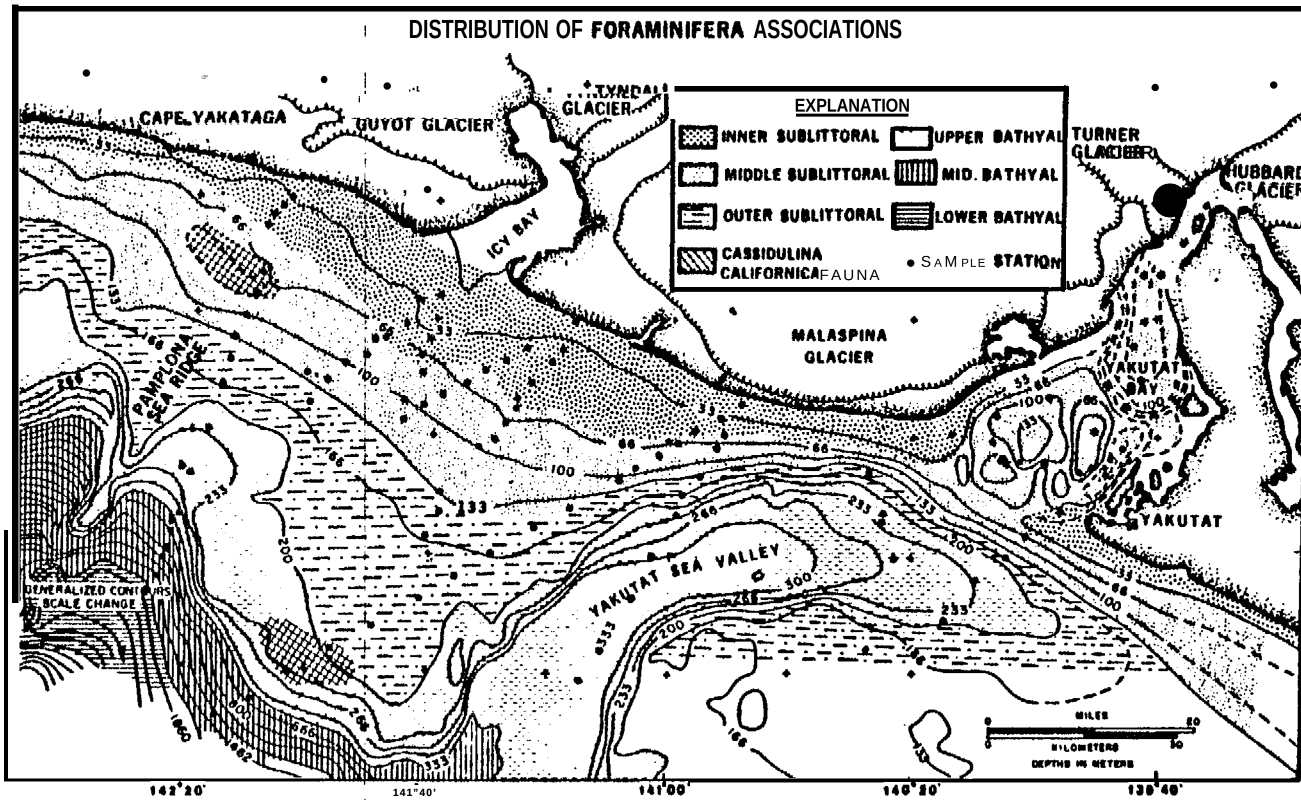


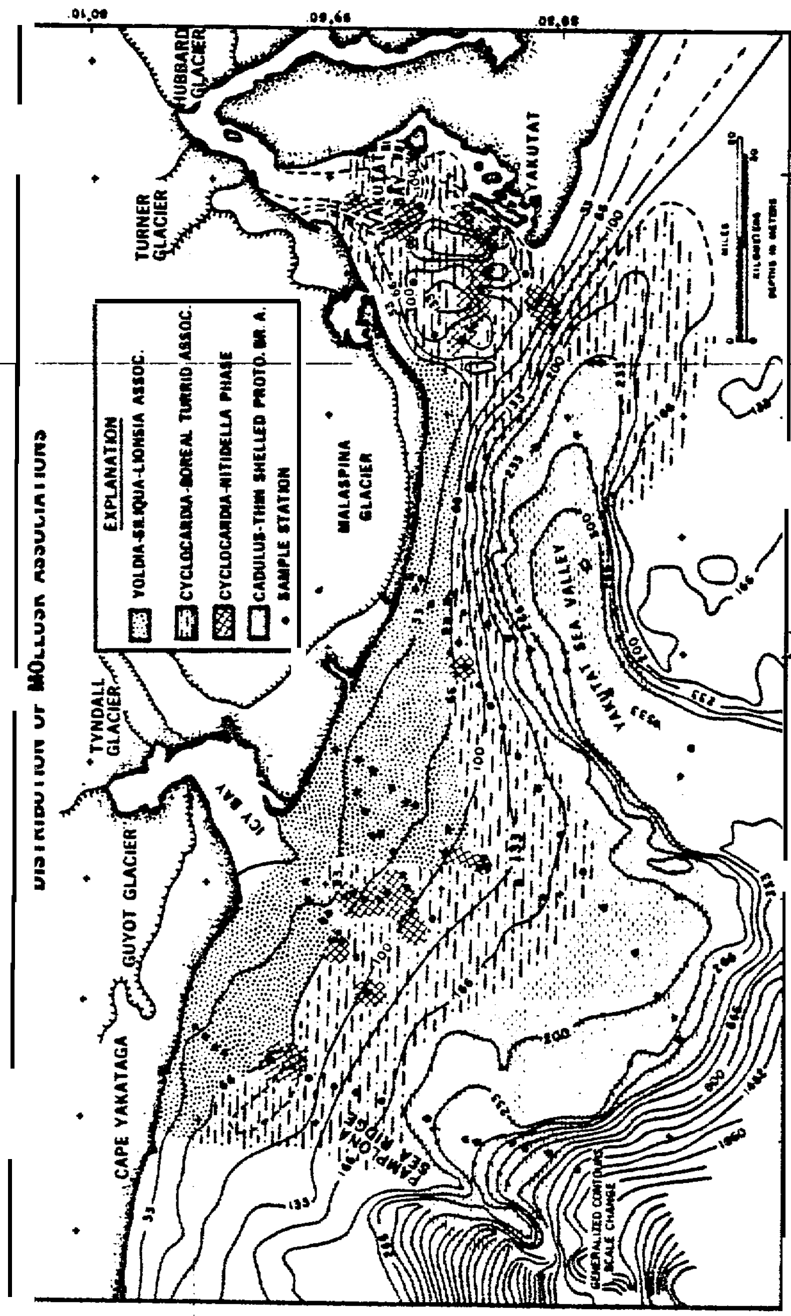
FIGURE 12. Map distribution of depth zones defined by associations of **benthic foraminifera** species.

FIGURE 5

DISTRIBUTION OF MOLLUSK ASSOCIATIONS IN TEE GULF OF ALASKA

(FROM ARMENTROUT, 1980)

FIGURE 5



Distribution of mollusk associations. Based on data provided by Hickman (M.S., 1976).

Pectocythere aff. *P. parkerae. Cytherois* sp. A, *Munseyella* sp. A, *Robertsonites tuberculata, Aurila* sp. A, *Pectocythere* aff. *P. quadrangulata,* and *Cytheropteron* aff. *C. latissimum* drop out. It is around this depth that most of the suspended sediments settle out. No other major environmental parameter can be correlated with this break in fauna.

The boundary between Assemblages III and IV marks the outer neritic/upper bathyal depth zones, occurring at 190-200 meters. Oxygen content is still declining at this point, but at a much slower rate (dropping from 4 ml/1 at 200 meters and stabilizing at 1 ml/1 at 600 meters). The species diversity drops considerably from Assemblage 111 to Assemblage IV, as does the relative abundance. The salinity halocline ends at 200 meters, with a salinity value of 33.8 o/oo; salinity slowly increases with greater water depth. Bottom temperatures show no seasonal fluctuations, ranging from 4* to6° C.

Some of the ostracode species are restricted to one depth assemblage, while others range through several depth zones (Table 4). The major ostracode assemblages are defined by the total assemblage species composition and relative abundance of the various species.

The four depth assemblages based on ostracodes correlates well with the "--' distributions of foraminifers and mollusks determined for this area (Armentrout, 1980; Echols and Armentrout, 1980; figs. 4, 5). Similar environmental parameters restrict these organisms distributions.

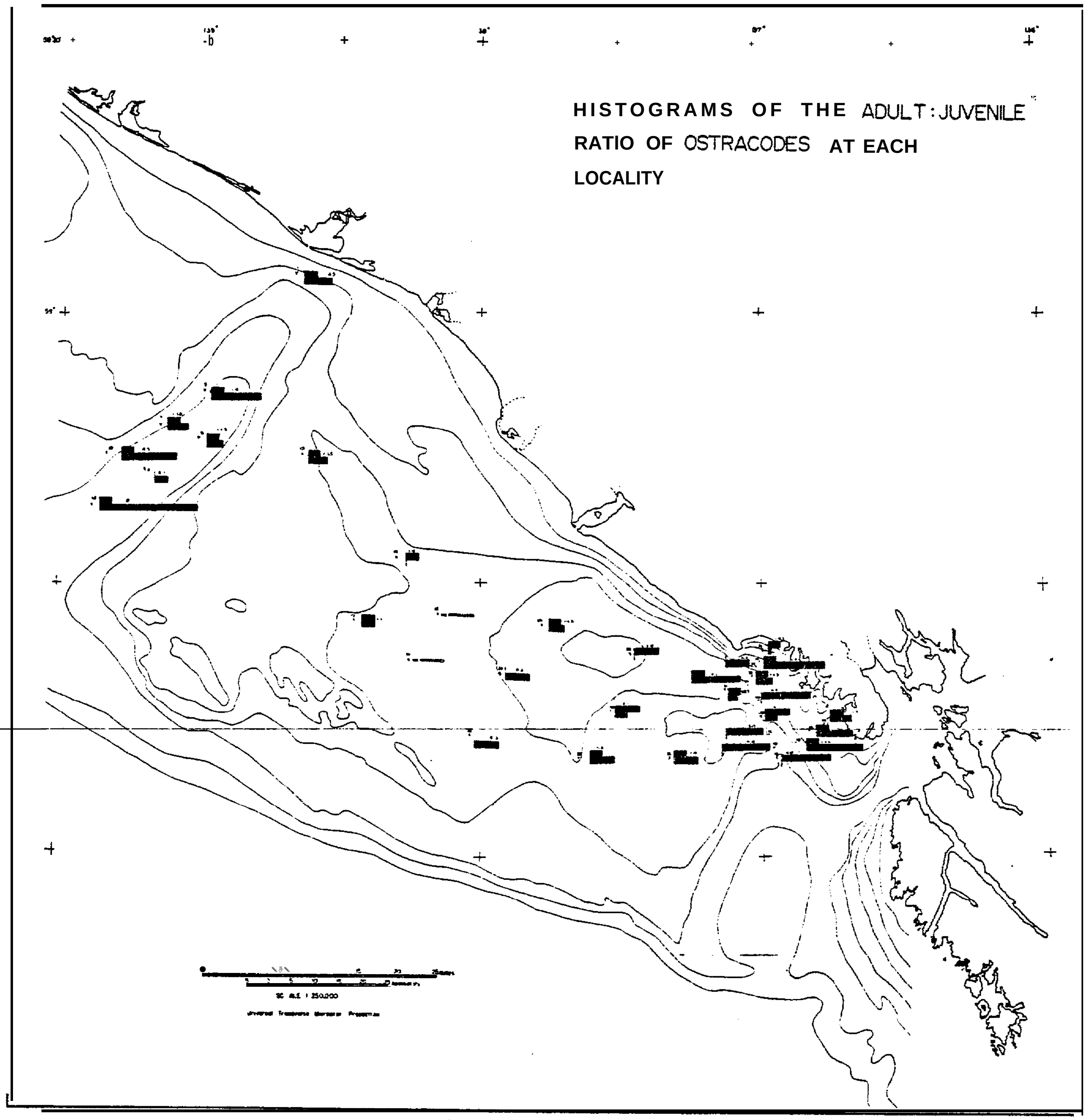
X. SEDIMENT TRANSPORT PATTERNS

Each ostracode adult has undergone eight molts; adding in the adult, an individual has the potential of leaving 18 valves in the sediment. The adult to juvenile ratio is ideally 1:8. However, the delicate nature of the early

FIGURE 6

HISTOGRAM OF THE ADULT: JUVENILE RATIO OF OSTRACODES FROM SAMPLES OF CRUISE DC1-79-EG, BETWEEN DRY BAY AND CROSS SOUND

FIGURE 6


HISTOGRAMS OF THE ADULT:JUVENILE RATIO OF OSTRACODES AT EACH LOCALITY

instars, combined with sample preparation techniques reduces this ratio to about 1:3 to 1:4. Examination of the adult to juvenile structure provides a measure of whether the ostracode assemblage is a life assemblage or death assemblage.

Figure 6 illustrates histograms of the adult:juvenile ratio of ostracodes at each locality of cruise DC1-79-EG, between Dry Bay and Cross Sound. The species diversity drops faster where there are steep gradients, as off of Dry Bay. In areas containing broad gentle slopes, such as southwest of Dry Bay, the species diversity and number of individuals progressively decreases seaward In a regular, linear pattern. These latter patterns suggest various degrees of ostracode valve transportation from the onshore areas where ostracodes are diverse and common to deeper water where living ostracodes are less common and apparently less diverse. The deeper water facies are therefore a sum of transported shallow water species and deeper water species. This distribution of ostracodes is readily seen when the ostracode adult:juvenile ratios are examined. The juvenile stages are more easily transported than the adults, and when the adult:juvenile ratios are plotted for the Alsek Sea Valley and Cross Sound Sea Valley, a consistent pattern of decreasing adult:juvenile ratios emerges. These ostracode sedimentation patterns also correspond to an increase in siliceous organisms (sponges and diatoms) in offshore samples. The fact that the distributional patterns of ostracodes have a sedimentological component as well as an ecologic component, is one of the more interesting results of this study.

A series of plots were made of selected species showing abundance *versus* water depth. Appendix XIV illustrates the 33 most abundant ostracode species found in the Gulf of Alaska. The relative abundance of the species clearly indicates the preferred depth habitats. All of the species illustrated reveal a long "tail" of rare occurrences in deeper waters. These "tails" demonstrate the active downslope transport that is occurring with the shelf sediments, moving fine-grained sediments of the littoral zone into slope deposits.

Figures 7 to 26 illustrate 20 species showing absolute numbers of valves versus water depth. The number of valves is high in the depth zones a species lives in. At both the shallow end and the deep end of a species range, the abundance drops. All of the species illustrated show the effects of downslope transport as a 'tail" of rare occurrences in deeper water.

XI. OSTRACODES AS MONITORS OF OIL SPILL EFFECTS AND BENTHIC RECOVERY

A recent detailed study of the macro- and meiofauna from a cold temperate to subfrigid marine climatic zone was conducted by Ankar and Elmgren (1976) at Asko, Sweden, along the northern Baltic coastline. Minimum water temperatures of the Asko study area are somewhat lower than in the Gulf of Alaska (reaching 0° C), but many similarities exist between the two regions. The geographic location of the southern Baltic is at about 54"-60" N latitude, with similar incoming solar radiation as southern Alaska. Many of the macrobenthic and microbenthic species are the same or have closely related counterparts.

Examination of the abundance, wet weight biomass, and species diversity of macro- and meiofauna was conducted at various Asko stations with different bottom lithologies. The deeper muddy substrates were found to contain the richest meiofauna and the lowest biomass. Ostracodes formed 41% of this meiofauna biomass, being more than 'twice as large as the nematode biomass (17%). Many of the colder water ostracodes were found to have a long life cycle (2 years).

In 1977 the Soviet tanker Tsesis struck a rock in the Asko region and

FIGURE 7

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE INNER-MIDDLE NERITIC SPECIES

"LEGUMINOCYTHEREIS SP. A

FIGURE 7

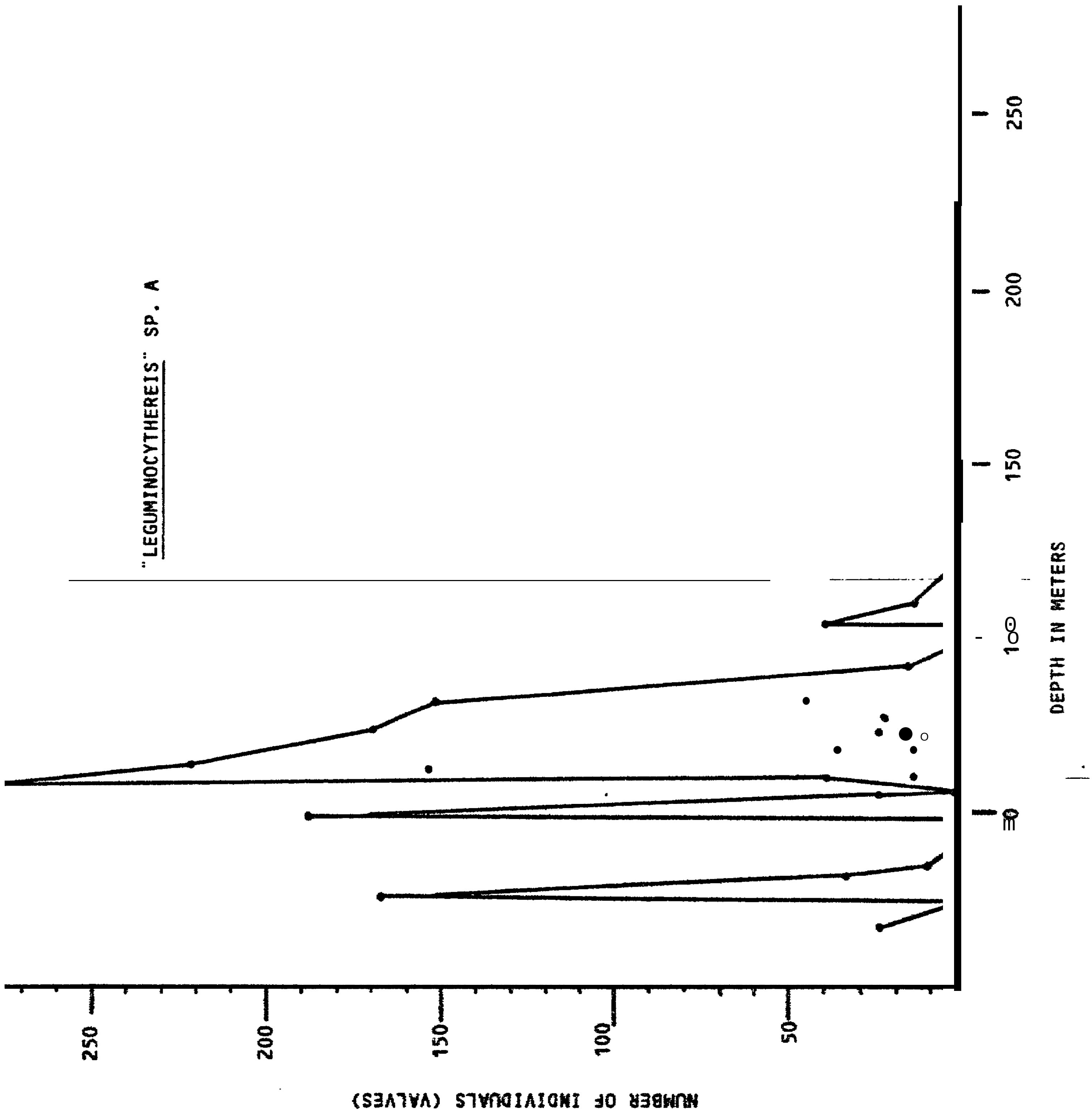

"LEGUMINOCYTHEREIS" SP. A
DEPTH IN METERS
50
100
150
200
250
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200
250

FIGURE 8

ABSOLUTE ABUNDANCE VS. WATER DEPTH OPTHE INNER-MIDDLE NERITIC SPECIES LOXOCONCHA SP. A

FIGURE 8

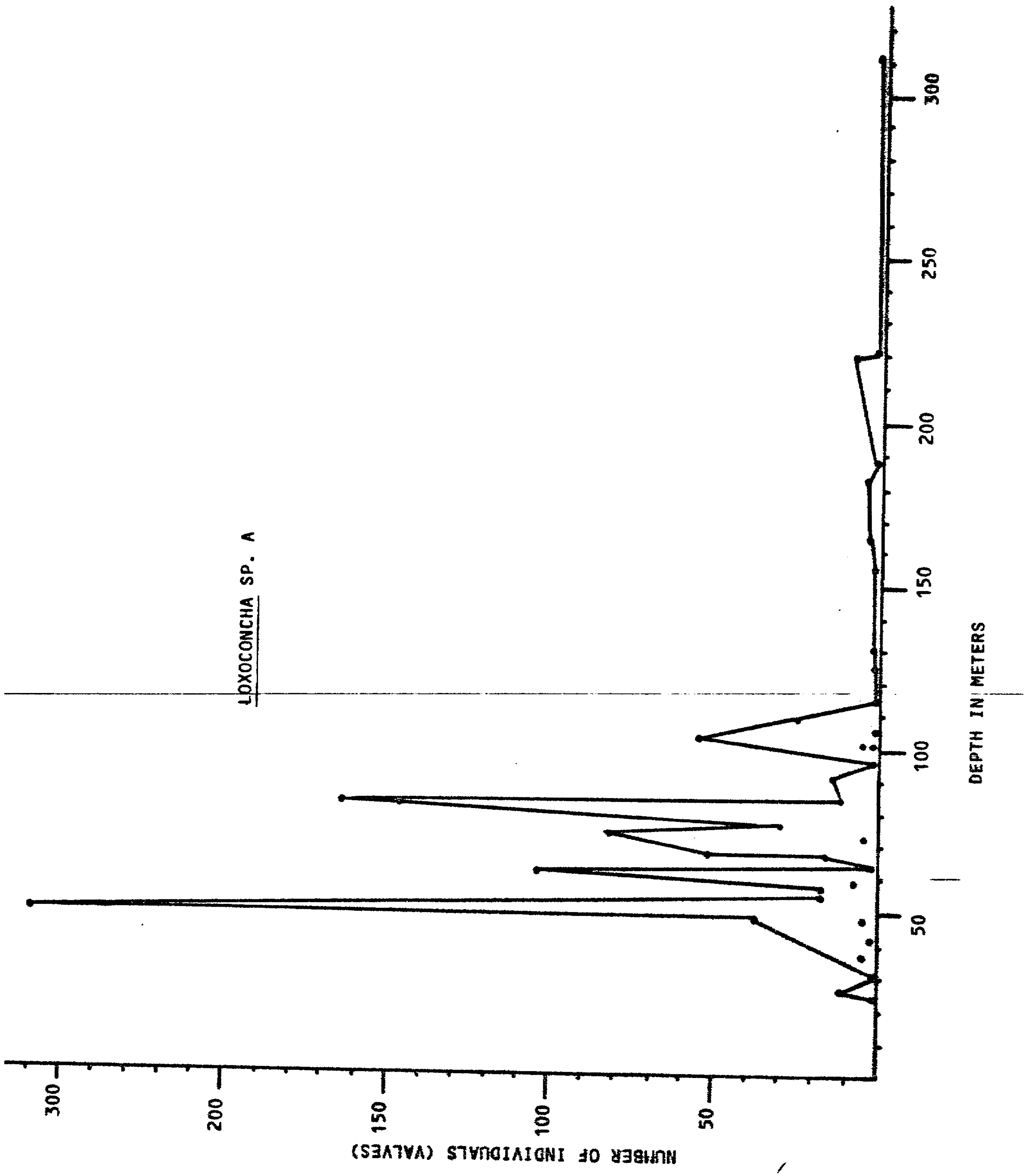
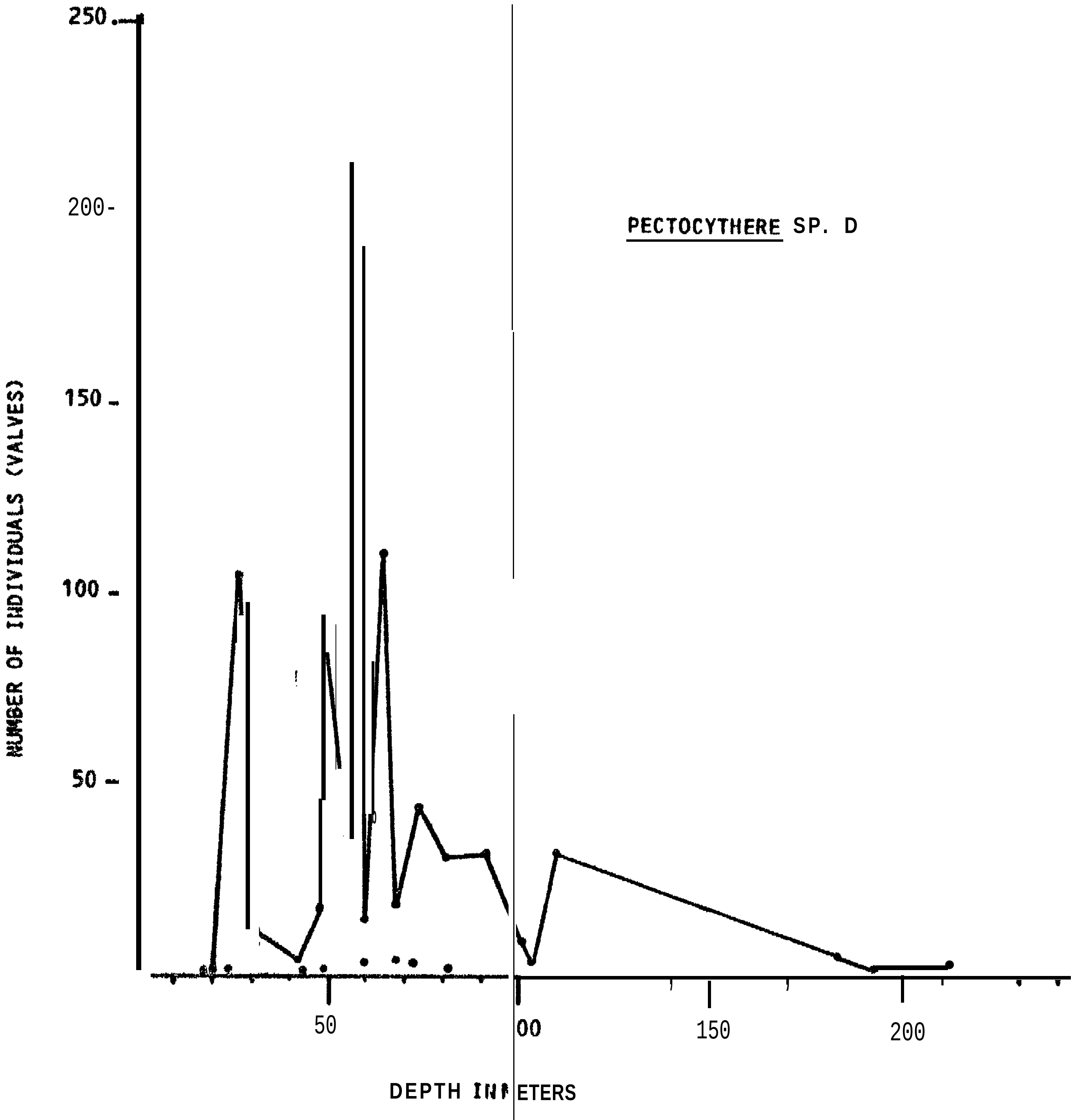

LOXOCONCHA SP. A
DEPTH IN METERS
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200
250
300

FIGURE 9

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF TEE INNER-MIDDLE NERITIC SPECIES _PECTOCYTHERE_ SP. D



PECTOCYTHERE SP. D
250
200
150
100
50
NUMBER OF INDIVIDUALS (VALVES)
50
00
150
200
DEPTH IN METERS

FIGURE 9

FIGURE 10

ABSOLUTE ABUNDANCE **VS.** WATER DEPTH OF THE **INNER-OUTER NERITIC** SPECIES **PALMANELLA LIMICOLA**

FIGURE 10

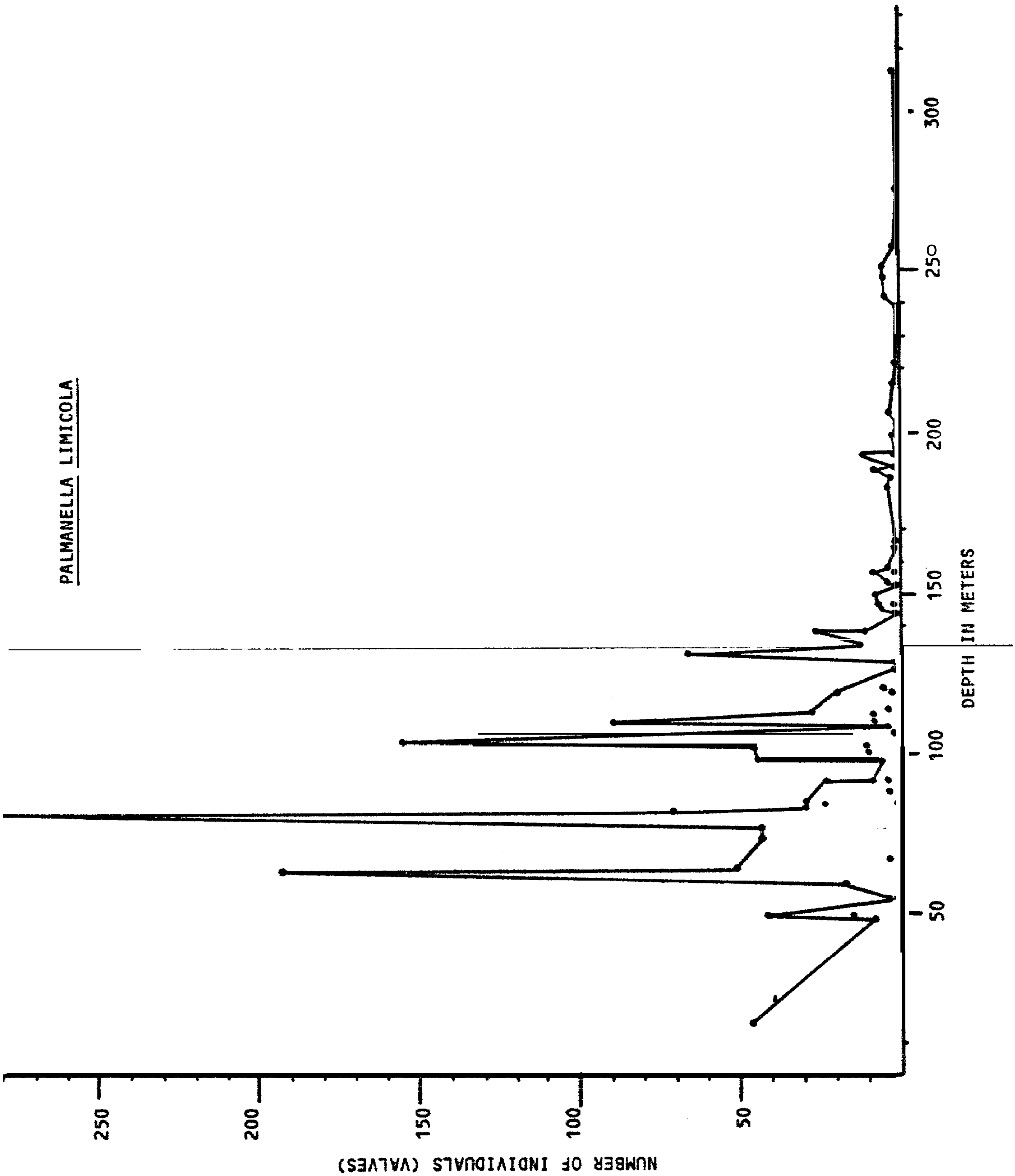
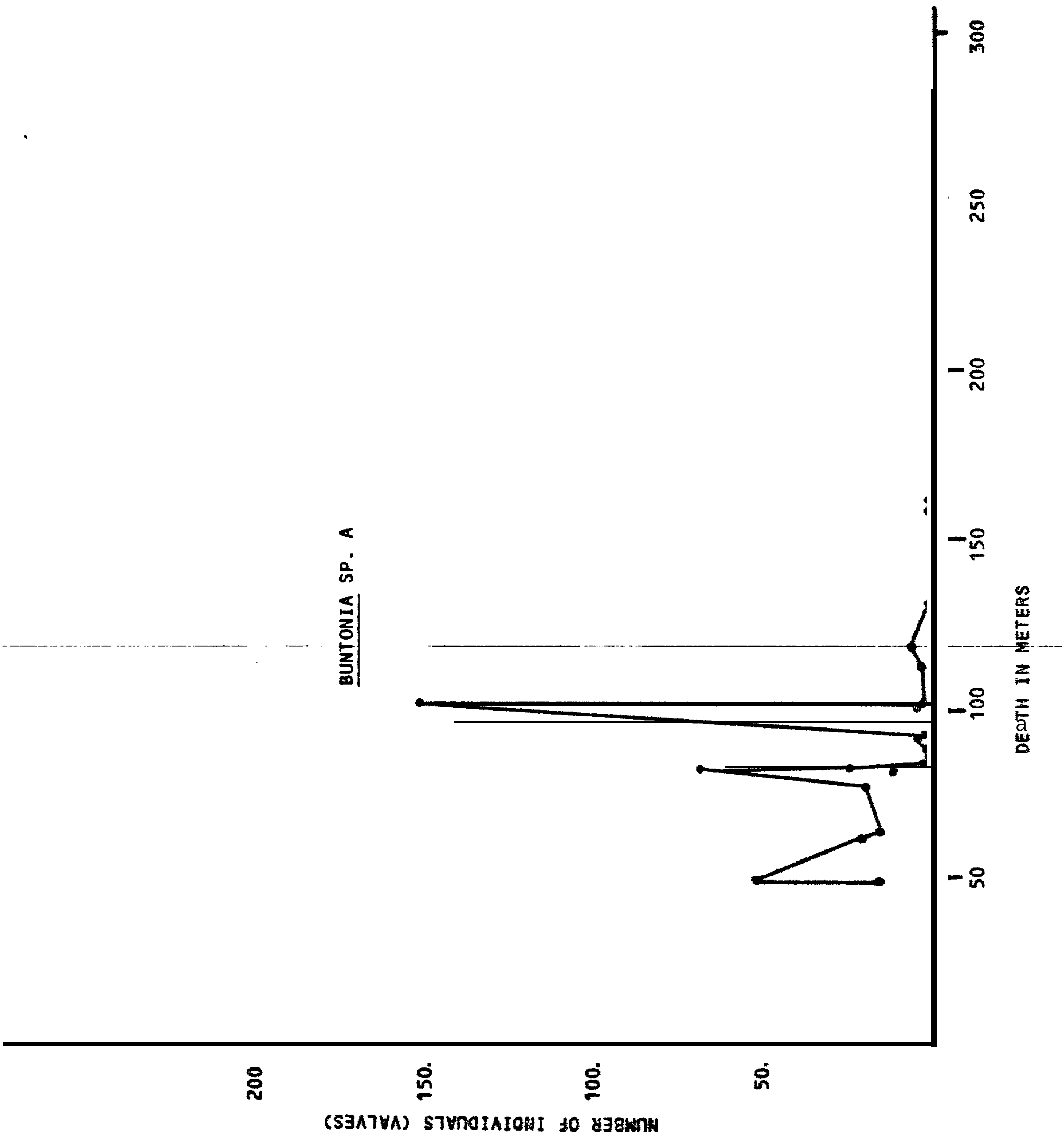

PALMANELLA LIMICOLA
DEPTH IN METERS
50
100
150
200
250
300
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200
250

FIGURE 11

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE NERITIC SPECIES BUNTONIA SP. A

FIGURE 11



BUNTONIA SP. A
DEPTH IN METERS
50
100
150
200
250
300
NUMBER OF INDIVIDUALS (VALVES)
50.
100.
150.
200

FIGURE 12

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE NERITIC SPECIES *CYTHEROPTERON* SP. A

FIGURE 12

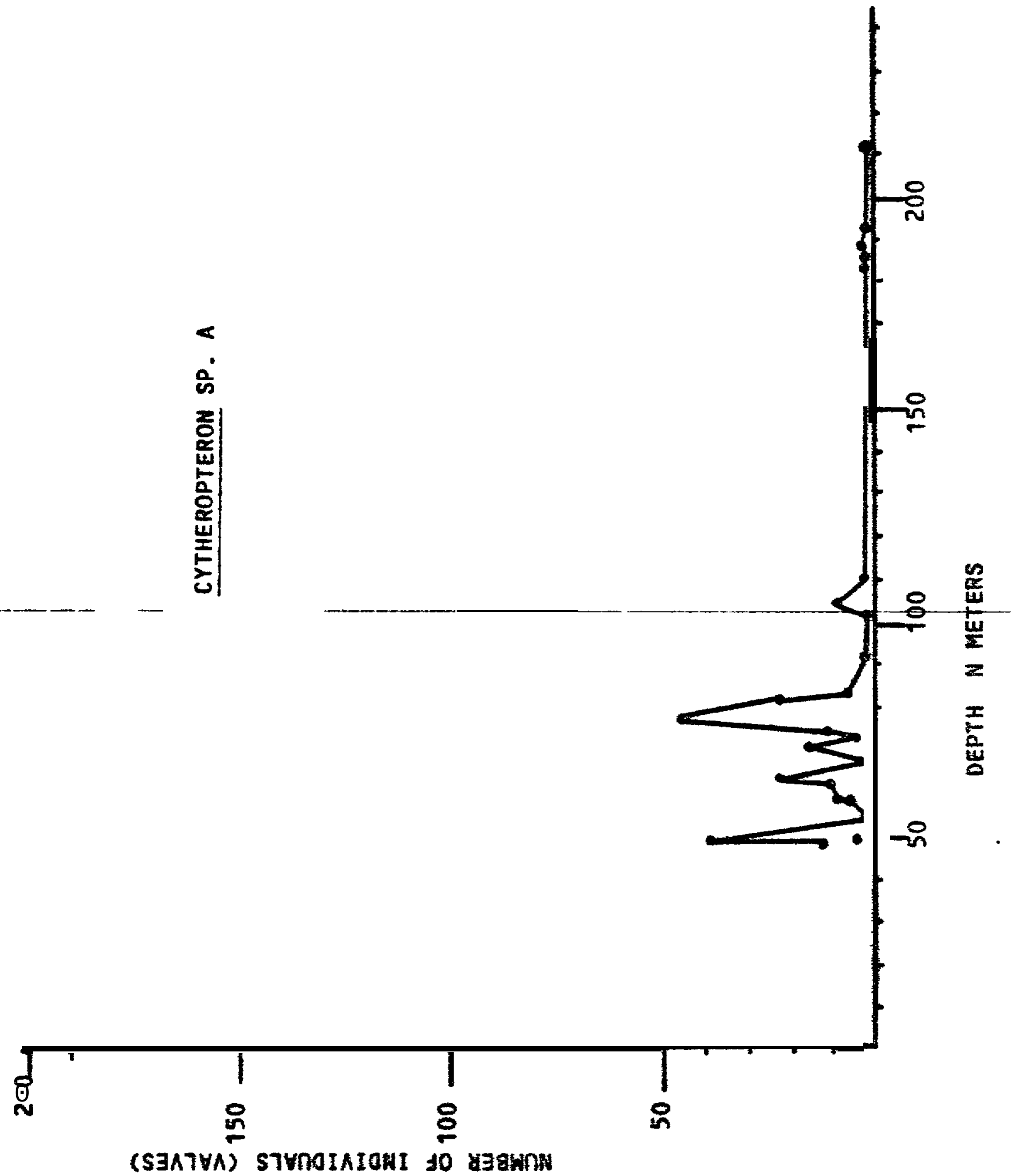
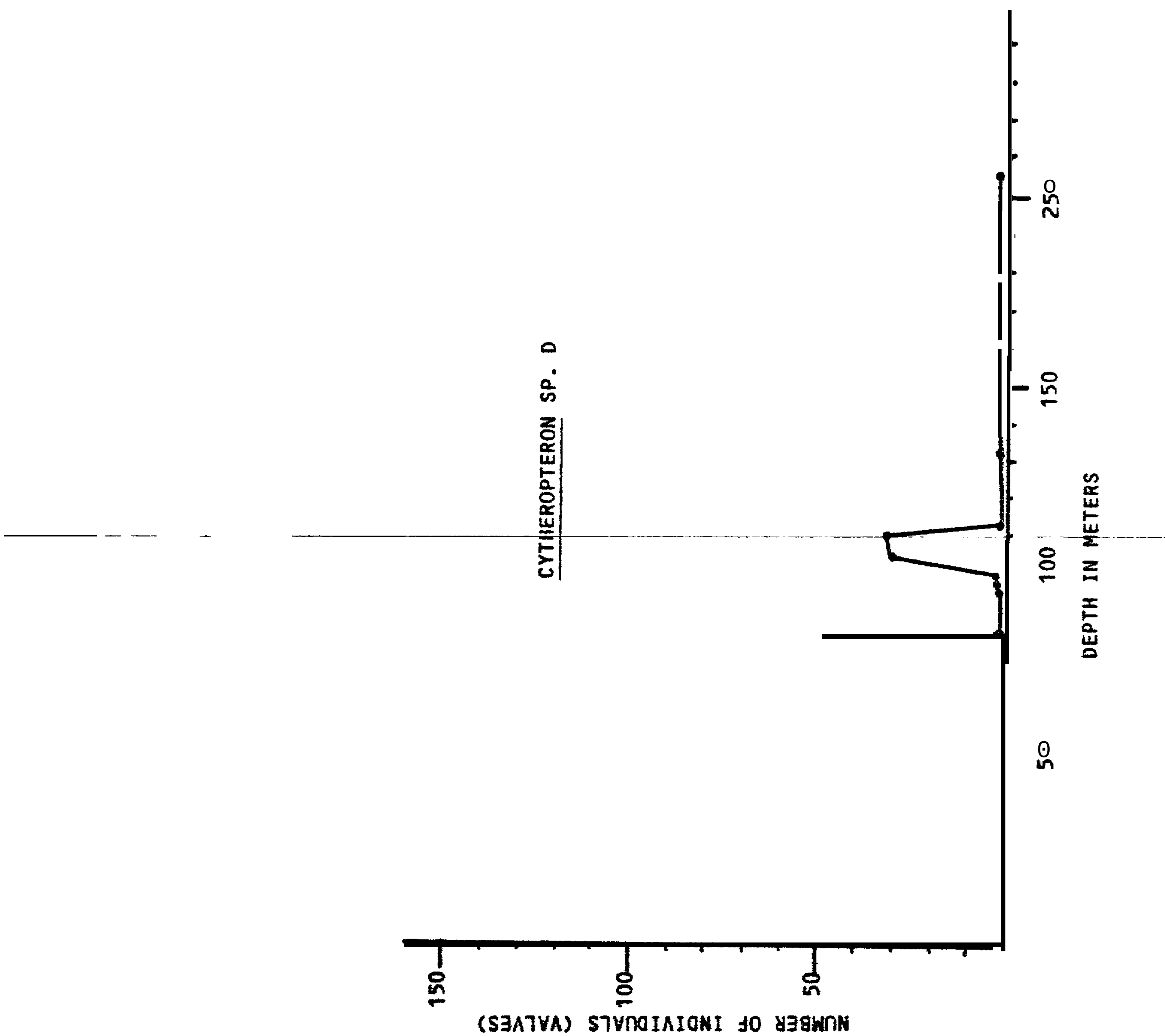

CYTHEROPTERON SP. A
DEPTH N METERS
50
100
150
200
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200

FIGURE 13

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE NERITIC SPECIES *CYTHEROPTERON* SP. D

FIGURE 13



CYTHEROPTERON SP. D
DEPTH IN METERS
50
100
150
250
NUMBER OF INDIVIDUALS (VALVES)
150
100
50

FIGURE 14

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE NERITIC SPECIES *PECTOCYTHERE* AFF. *P. PARKERAE*

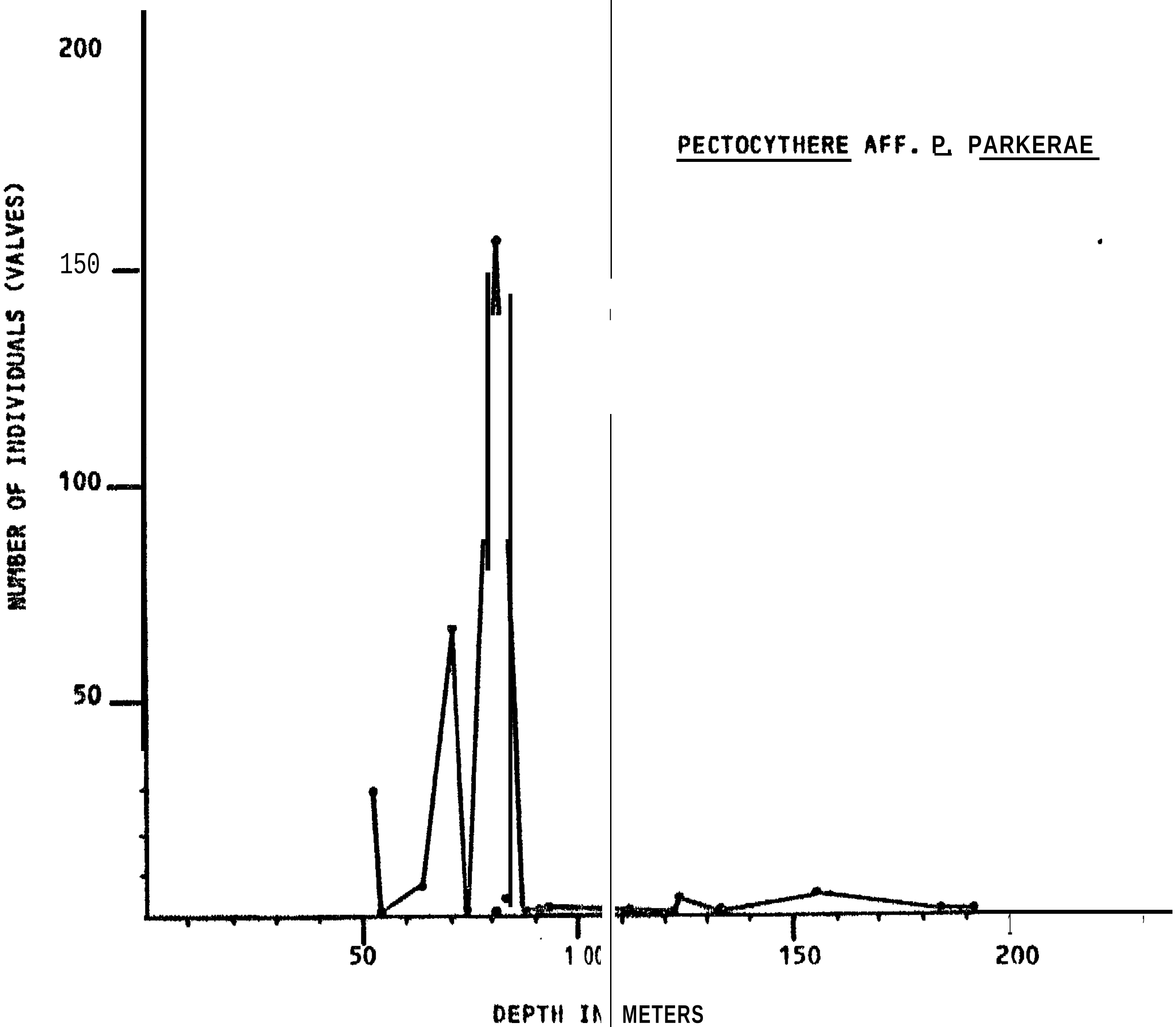


FIGURE 14

3-56

FIGURE 15

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES "ACANTHOCYTHEREIS" DUNELMENSIS

FIGURE 15

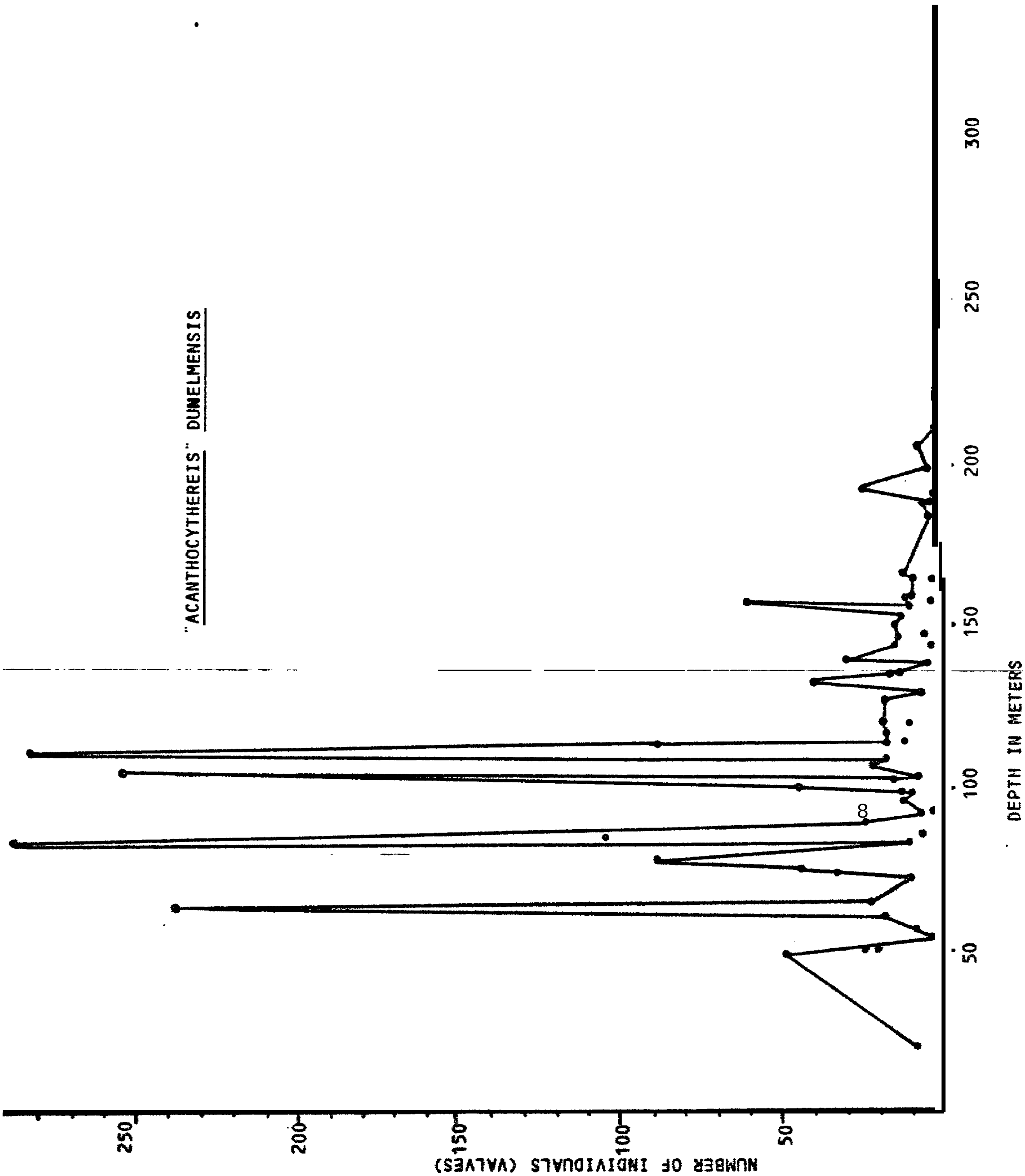

"ACANTHOCYTHEREIS" DUNELMENSIS
DEPTH IN METERS
50
100
150
200
250
300
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200
250

FIGURE 16

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES *AURILA* SP. A

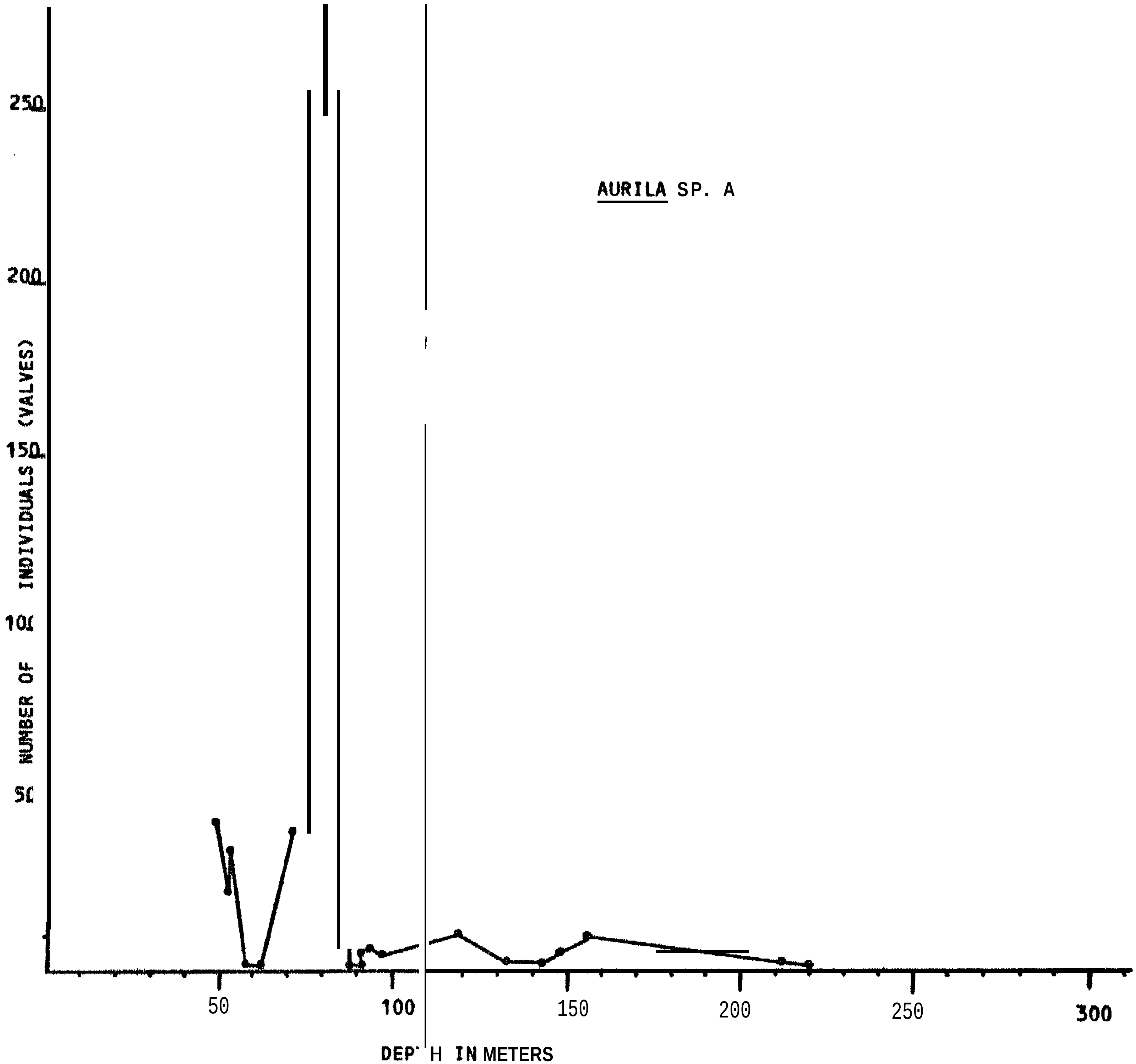

AURILA SP. A
NUMBER OF INDIVIDUALS (VALVES)
250
200
150
100
50
50
100
150
200
250
300
DEPTH IN METERS

FIGURE 16

FIGURE 17

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES CLUTHIA SP. A

FIGURE 17

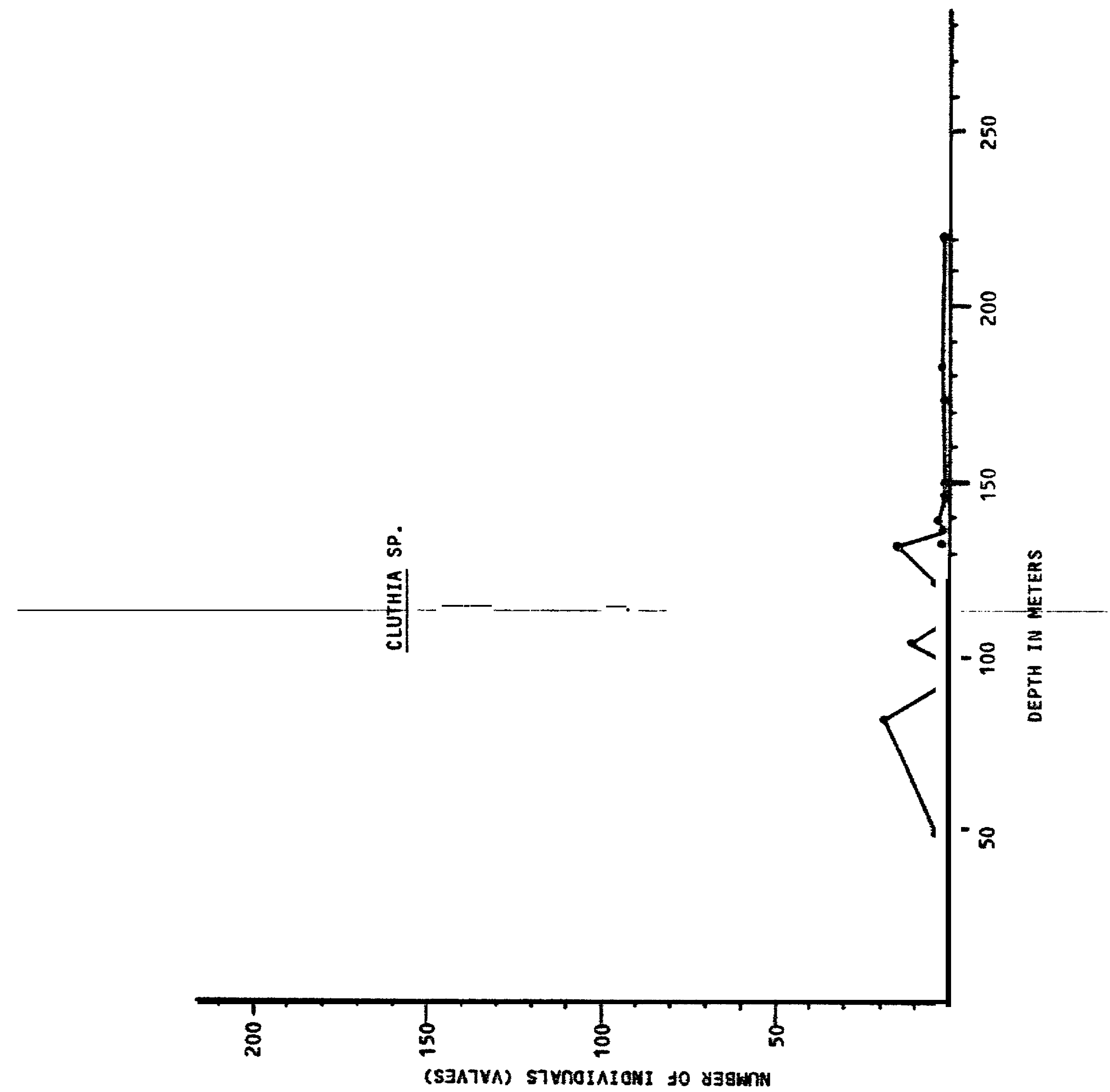

CLUTHIA SP.
DEPTH IN METERS
50
100
150
200
250
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200

FIGURE 18

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES *CYTHEROPTERON* AFF. *C. LATISSIMUM*

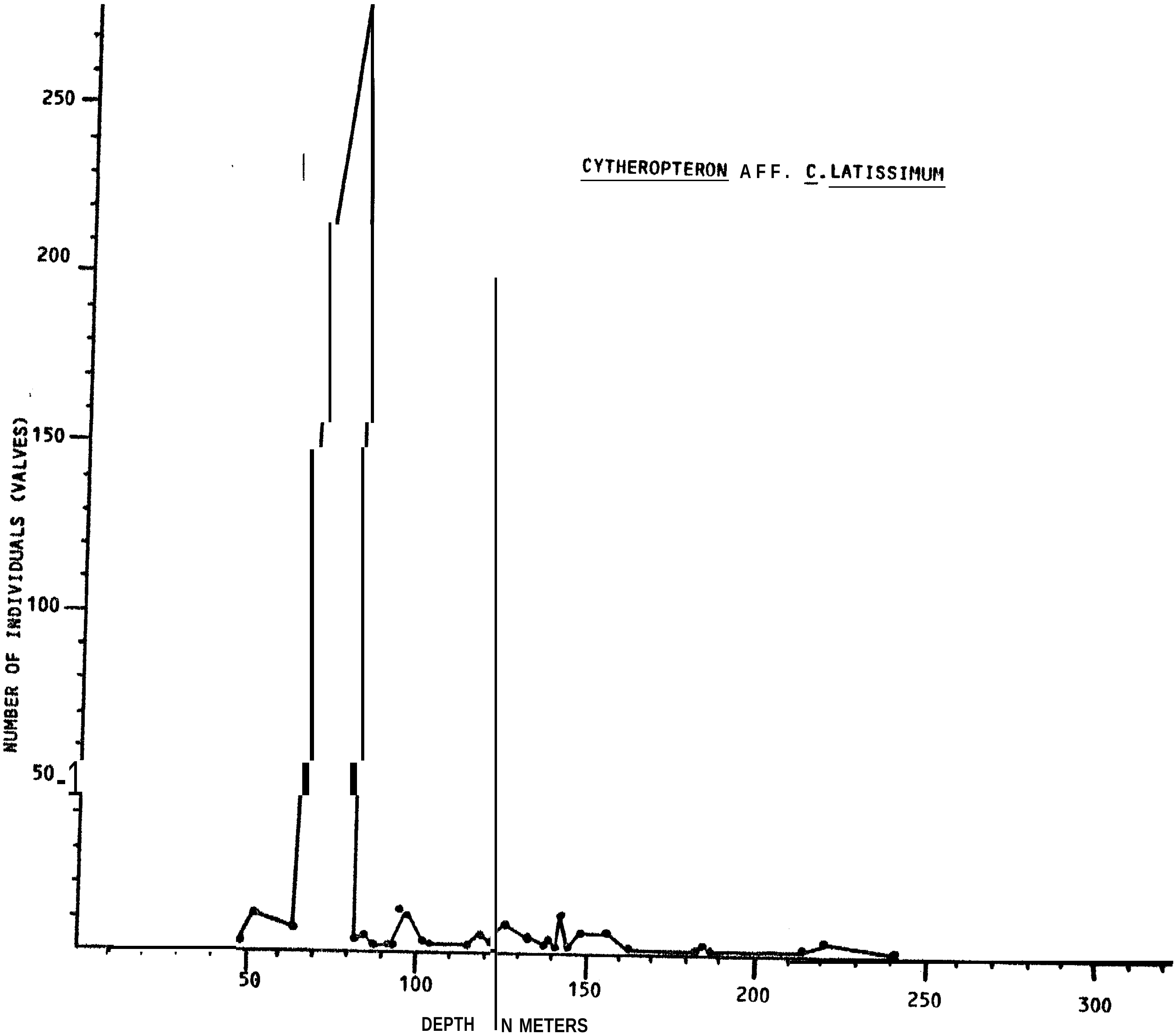

CYTHEROPTERON AFF. C. LATISSIMUM
NUMBER OF INDIVIDUALS (VALVES)
250
200
150
100
50
50
100
150
200
250
300
DEPTH IN METERS

FIGURE 18

FIGURE 19

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES CYTHEROIS SP. A

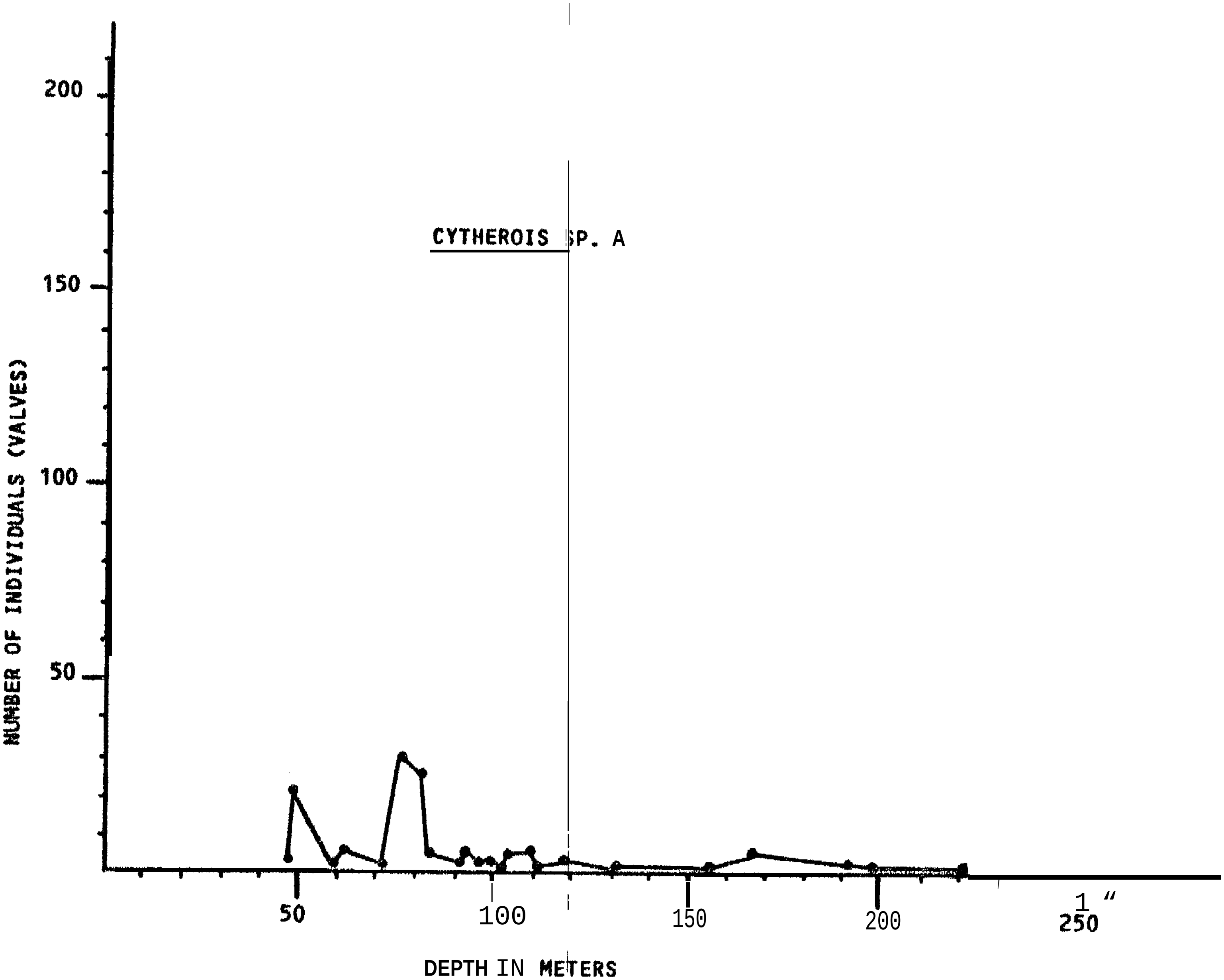

CYTHEROIS SP. A
NUMBER OF INDIVIDUALS (VALVES)
200
150
100
50
50
100
150
200
250
DEPTH IN METERS

FIGURE 19

FIGURE 20

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES *CYTHEROPTERON* SP. B

FIGURE 20

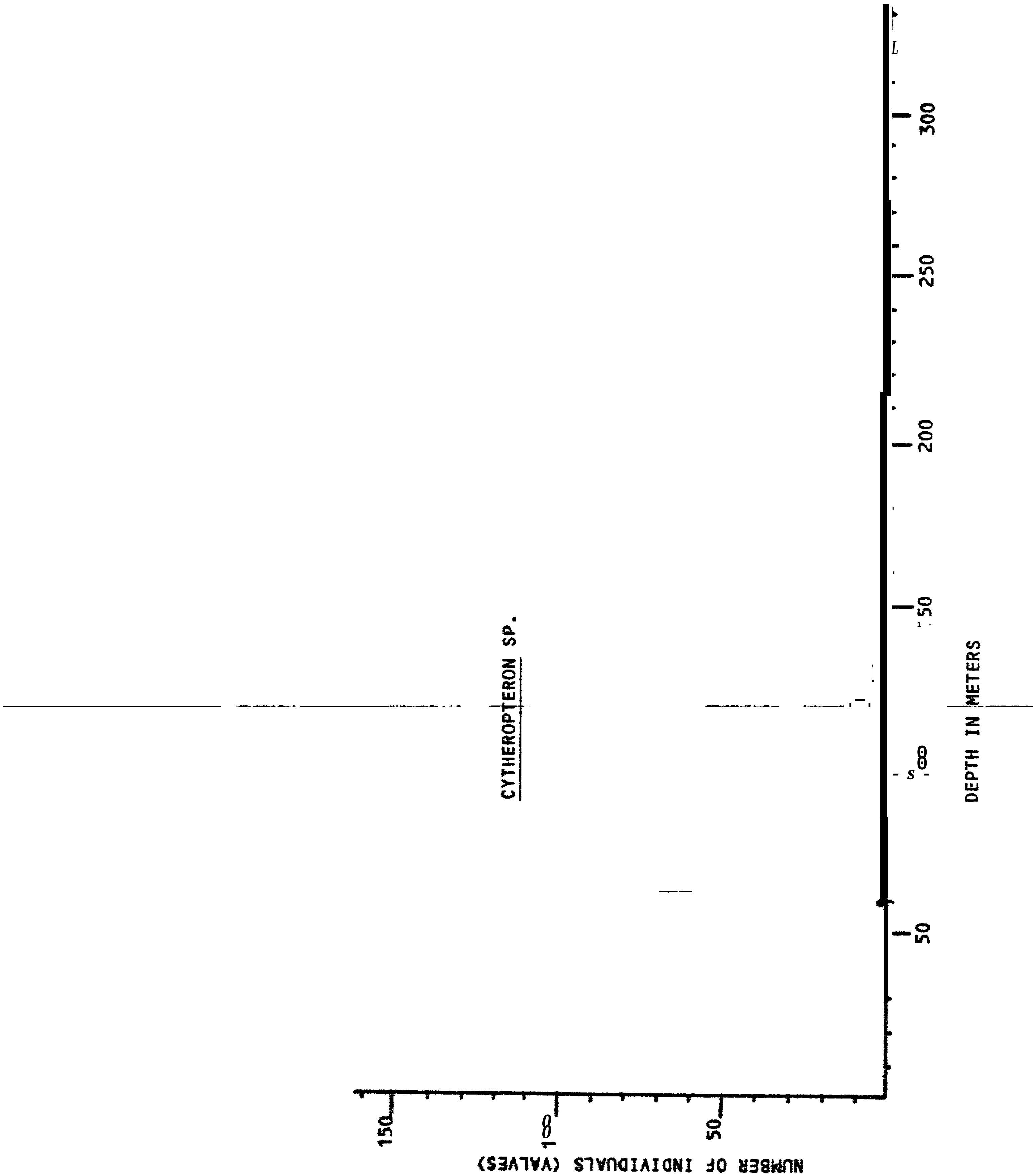

CYTHEROPTERON SP.
DEPTH IN METERS
NUMBER OF INDIVIDUALS (VALVES)
150
50
50
150
200
250
300

FIGURE 21

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES LOXOCONCHA SP. B

FIGURE 21

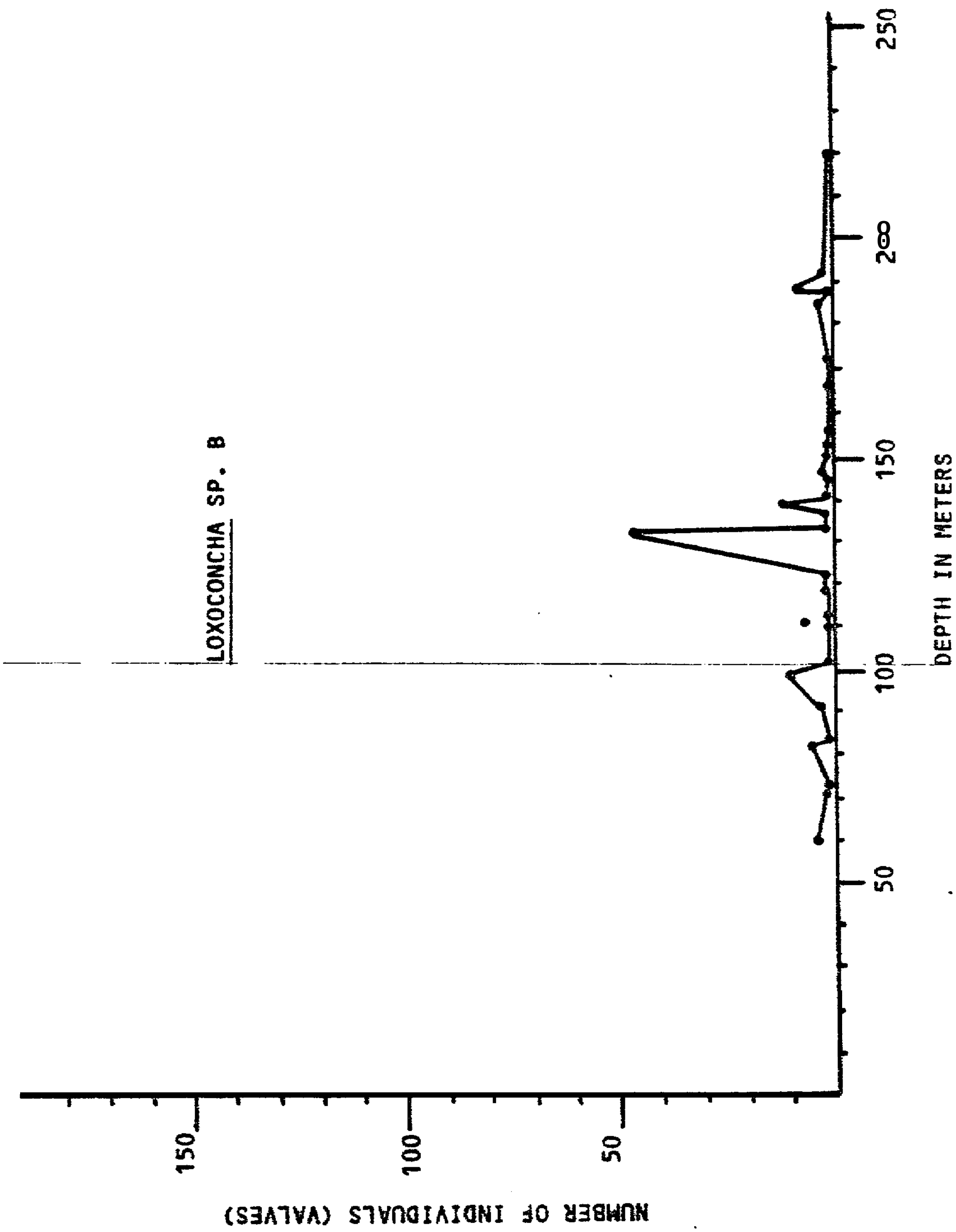

LOXOCONCHA SP. B
DEPTH IN METERS
50
100
150
200
250
NUMBER OF INDIVIDUALS (VALVES)
50
100
150

FIGURE 22

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES *PECTOCYTHERE* AFF. *P. QUADRANGULATA*

FIGURE 22

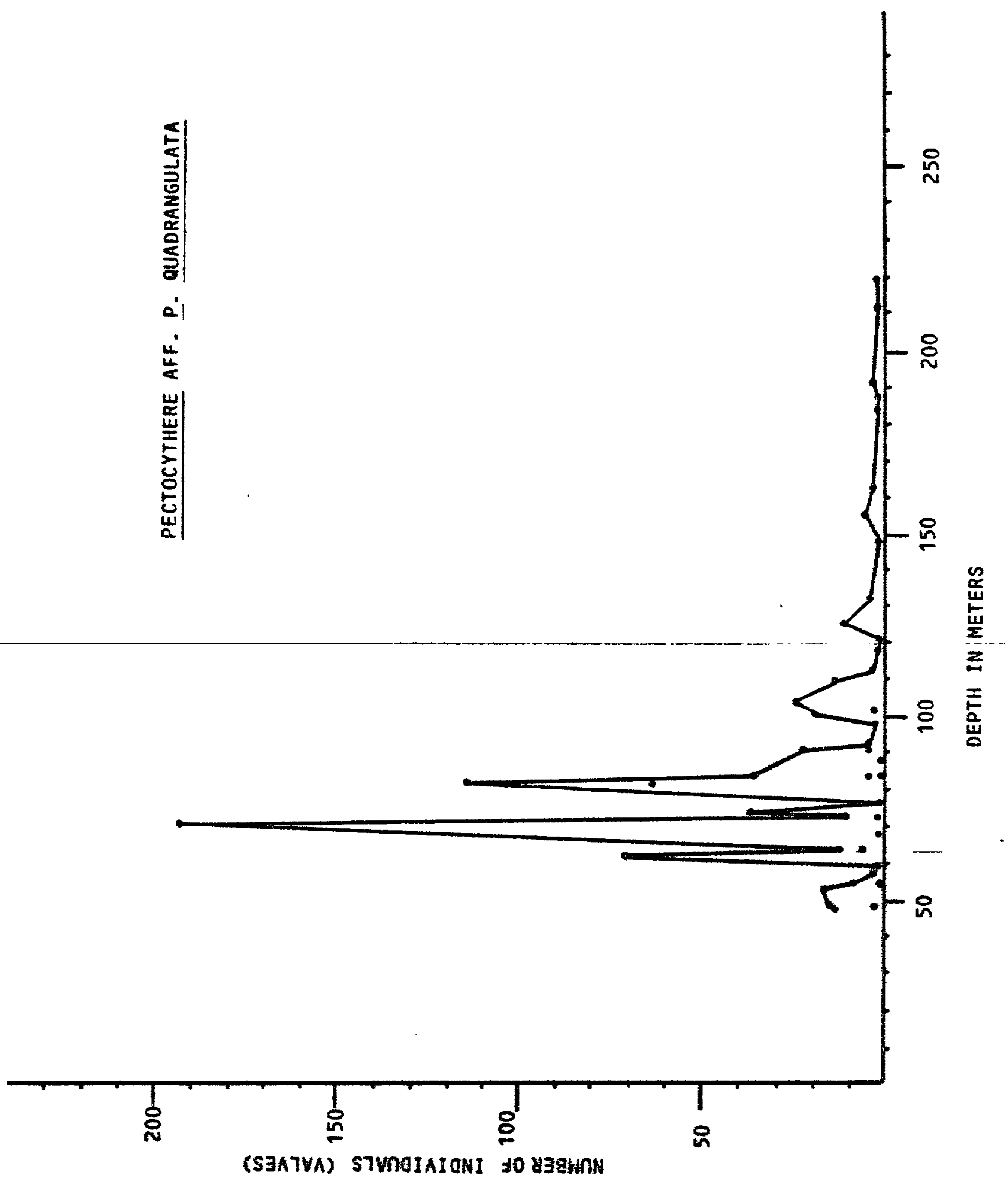

PECTOCYTHERE AFF. P. QUADRANGULATA
DEPTH IN METERS
50
100
150
200
250
NUMBER OF INDIVIDUALS (VALVES)
50
100
150
200

FIGURE 23

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES ROBERTSONITES TUBERCULATA

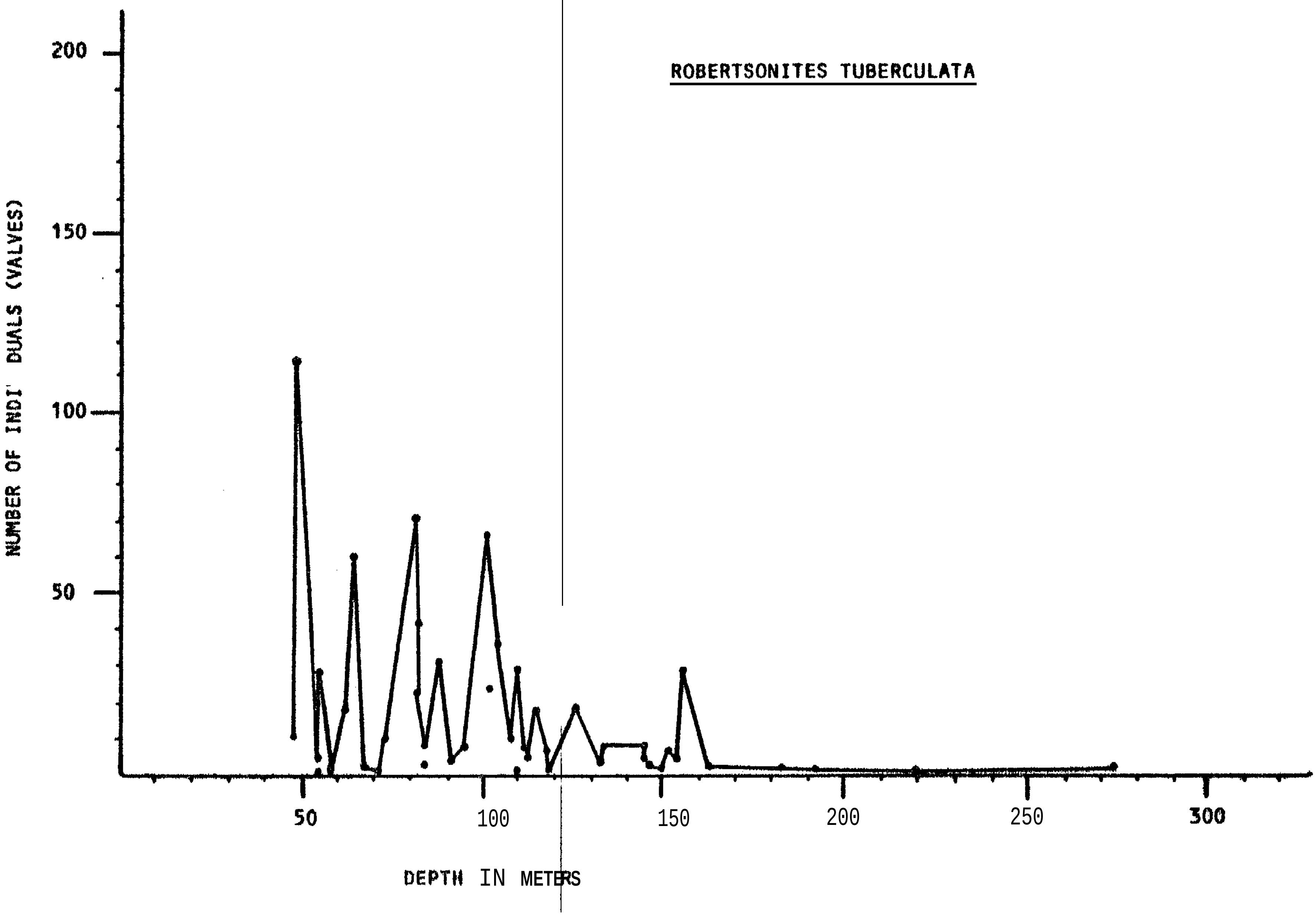

ROBERTSONITES TUBERCULATA
NUMBER OF INDI' DUALS (VALVES)
200
150
100
50
50
100
150
200
250
300
DEPTH IN METERS

FIGURE 23

FIGURE 24

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC SPECIES MUNSEYELLA SP. A

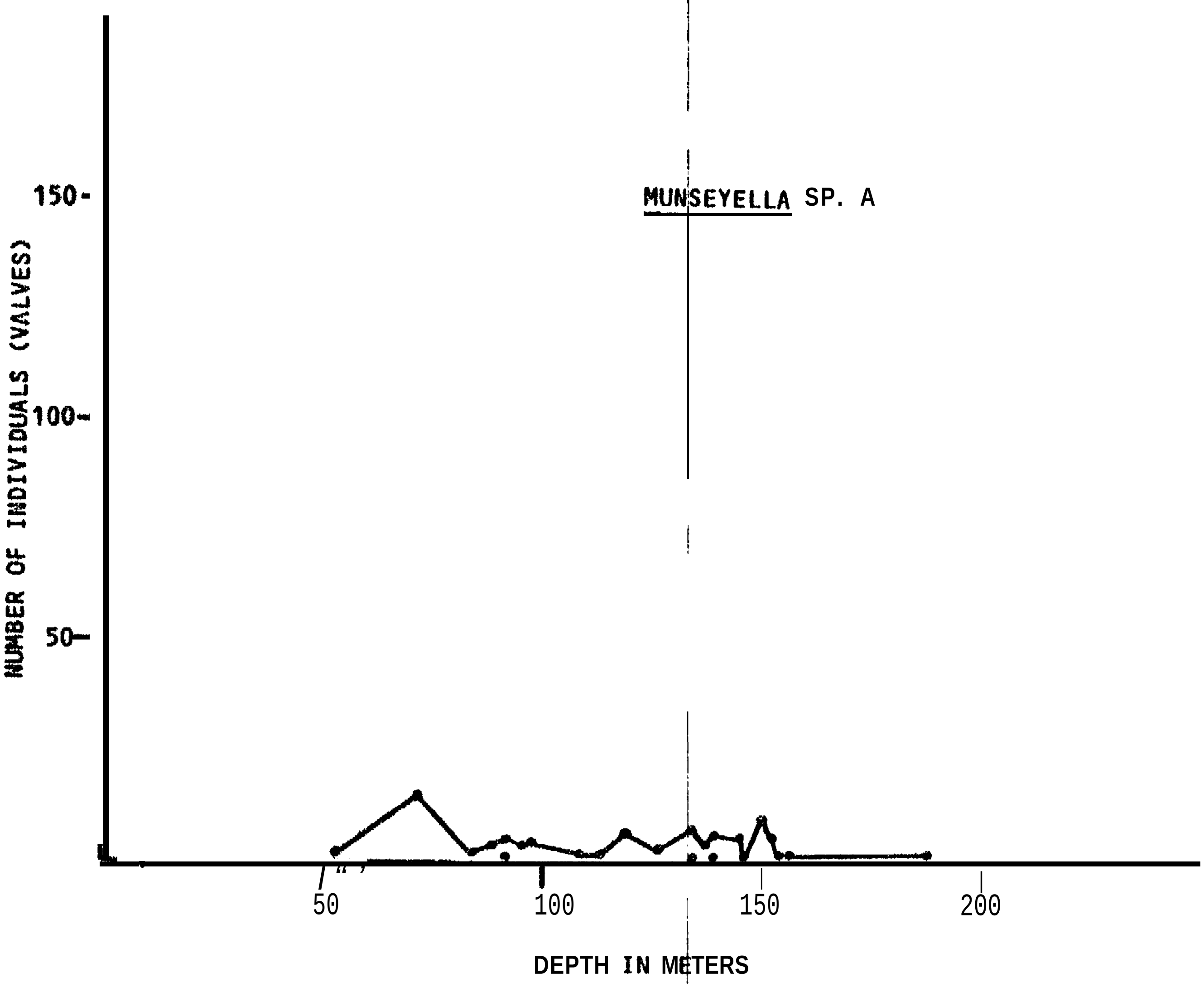


FIGURE 24

3-76

FIGURE 25

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF THE MIDDLE-OUTER NERITIC , UPPER BATHYAL SPECIES EUCYTHERURA SP . A

FIGURE 25

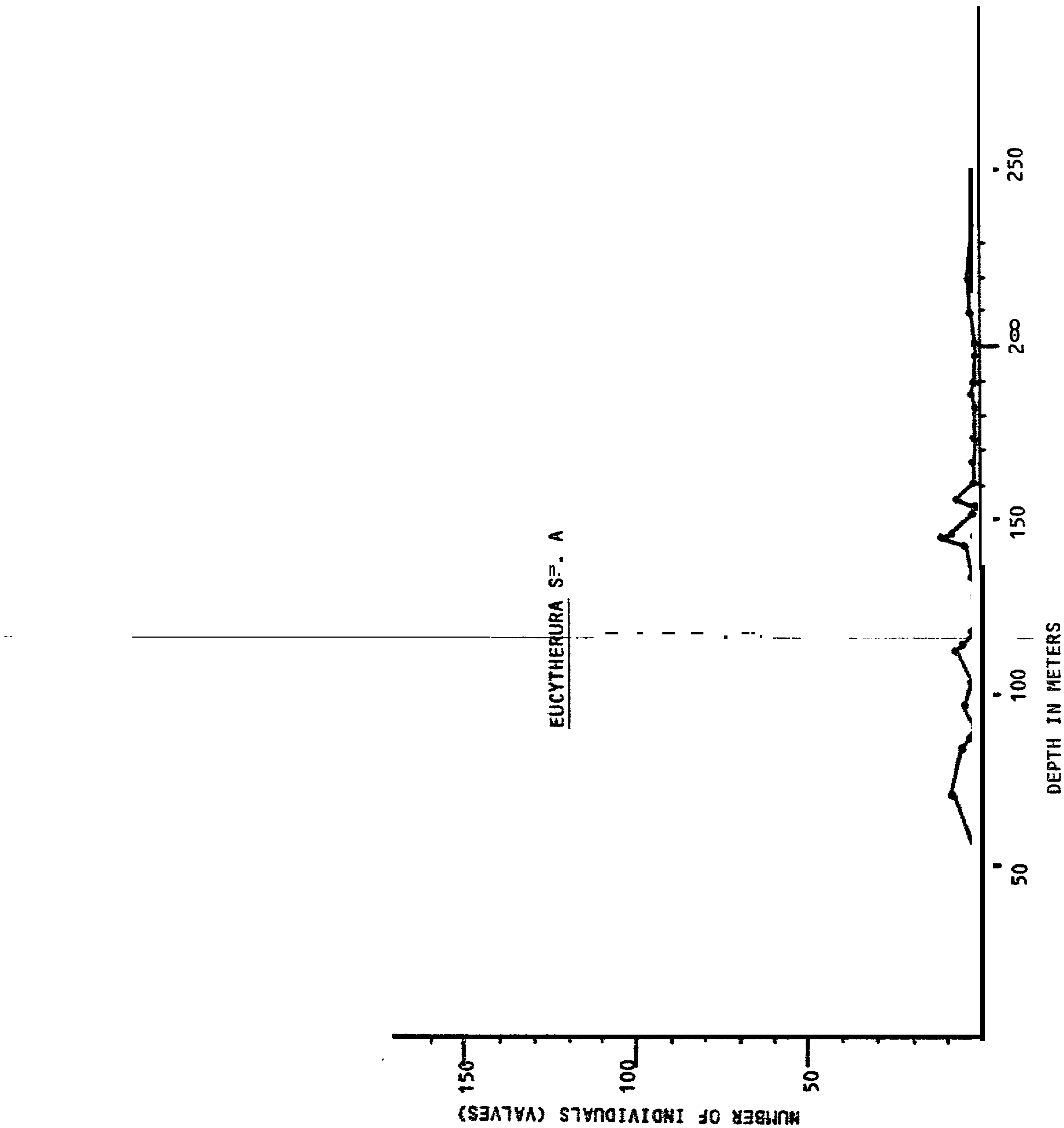
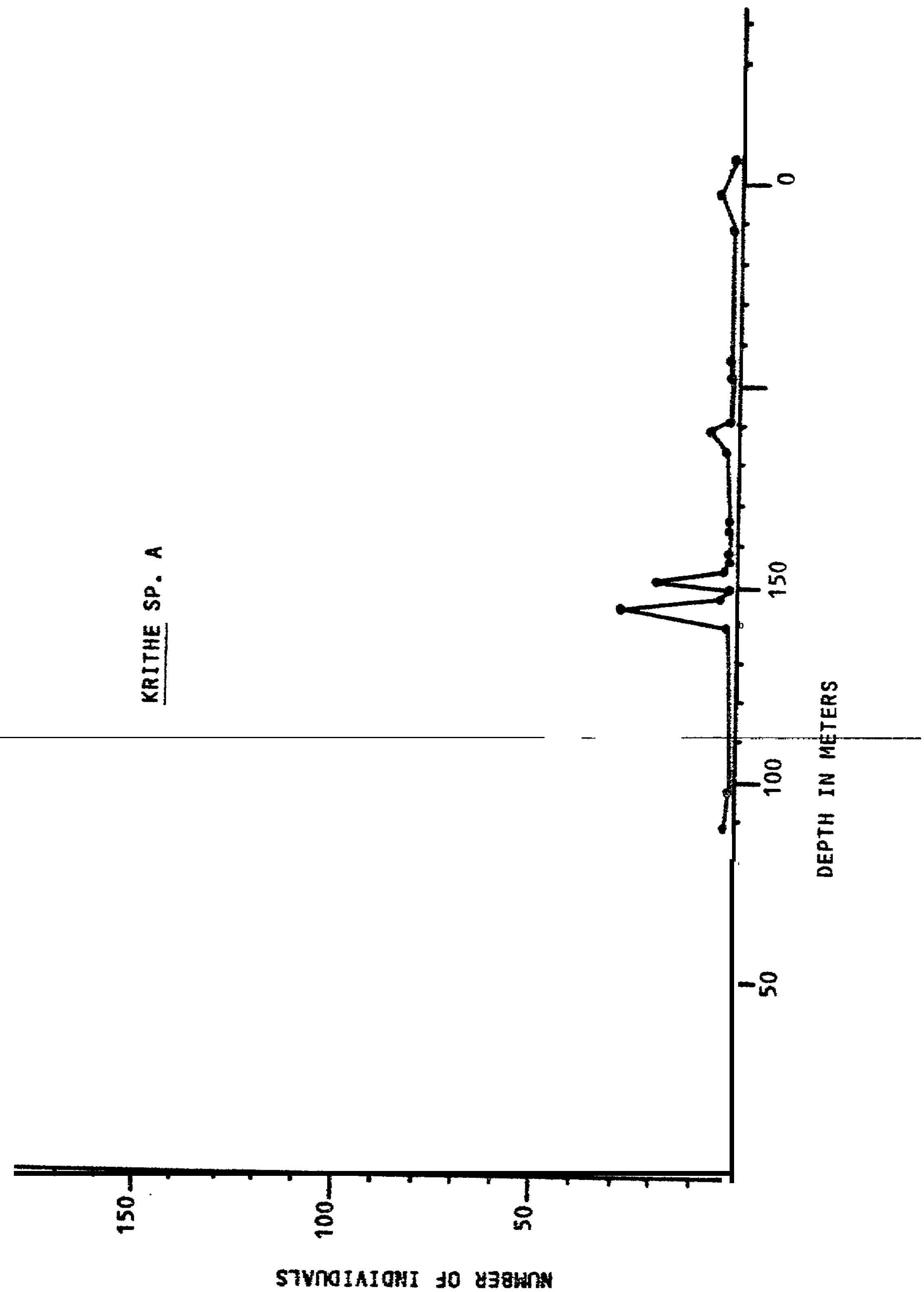

EUCYTHERURA SP. A
DEPTH IN METERS
50
100
150
200
250
NUMBER OF INDIVIDUALS (VALVES)
50
100
150

FIGURE 26

ABSOLUTE ABUNDANCE VS. WATER DEPTH OF TEE OUTER NERITIC ,
UPPER BATHYAL SPECIES _KRITHE_ SP. A

FIGURE 26


KRITHE SP. A
DEPTH IN METERS
0
150
100
50
NUMBER OF INDIVIDUALS
150
100
50

spilled a large amount of oil. Comparison of the post-spill meiofauna with the 1976 baseline provided an excellent monitor of the effects on the benthos (Kineman et. al., 1976). The ostracodes showed a particular sensitivity to the oil, with a dramatic drop in abundance that can be correlated directly to the oil spill (figs. 27-29). Ostracodes are primarily benthic in nature, capable of clumsy movement in the form of short, non-sustained, "'"swimming" motions and slow crawling through the sediment. As such, they cannot rapidly escape from an environmental catastrophe such as an oil spill as can more mobile crustaceans (amphipods, for example).

Continued sampling of the Asko bottom sediments up to 10 months following the spill showed selected recovery among the macrofauna and meiofauna. The ostracodes, however, continued showing low abundance throughout this interval, revealing no evidence of recovery. Because of the long life cycle (up to 2 years) and non-migrating behaviour of the cold water ostracodss, the effects of the Tsesis oil spill on the soft bottoms remained for at least two years.

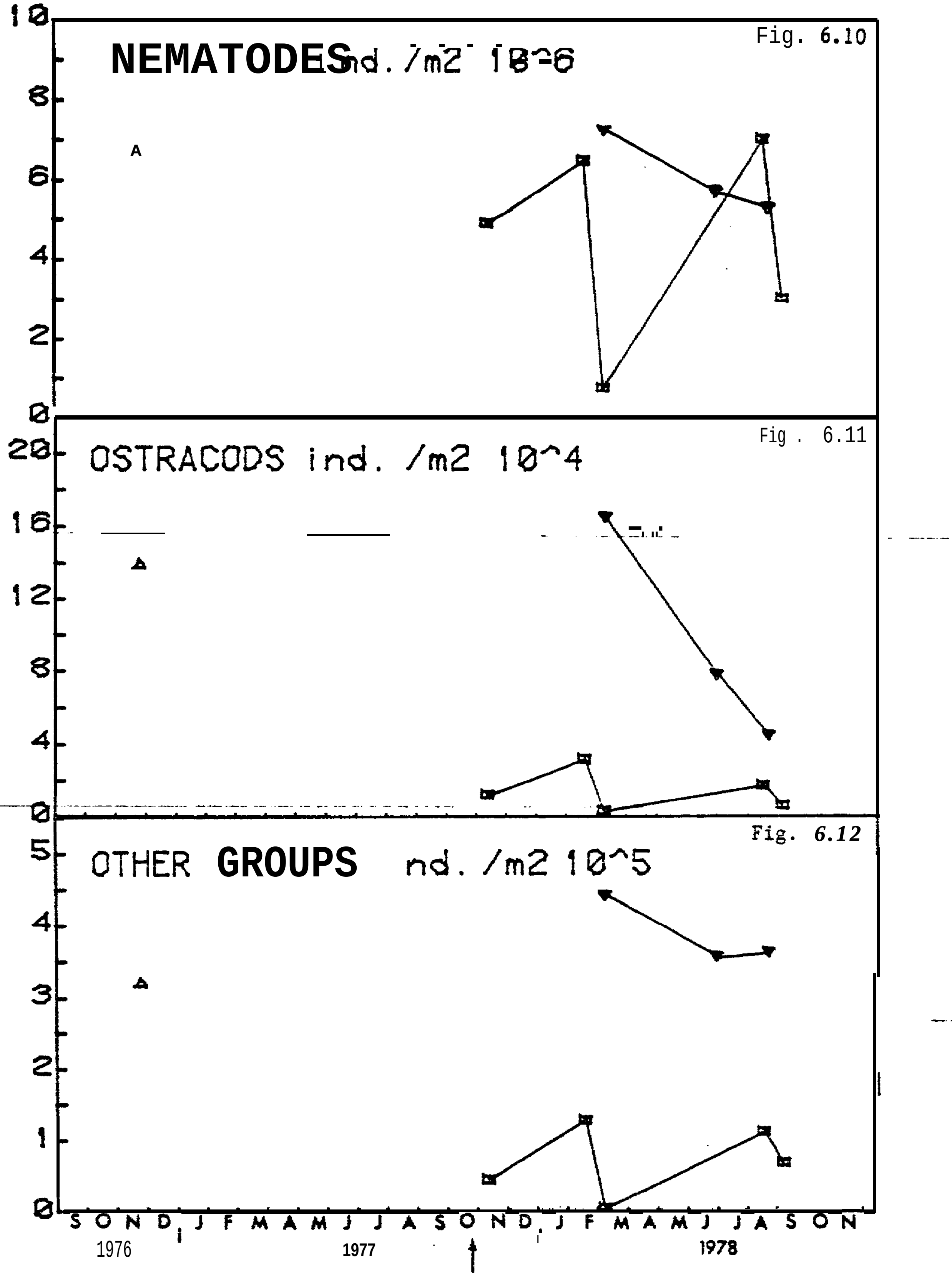
In the Gulf of Alaska, active longshore currents, storm- and wind-driven waves, and tidal activity would cause rapid dispersal of any oil spill in water depths of less than 50 meters. However, in water greater than 50 meters, the substrate is formed of fine-grained silt and clayey silt, with a large meiofauna present. Oil to reach these environments would cause a similar devastating effect on the ostracode populations such as occurred as Asko, especially to the species that are more environmentally restricted (table 3).

The baseline datum that has been established for the Gulf of Alaska ostracodes includes species diversity and relative abundance, as well as detailed geographic distributions of the species. Any oil spill that affects the bottom sediments will profoundly affect the ostracode populations, 'as

FIGURE 27

ABUNDANCE OF NEMATODES, OSTRACODES AND OTHER GROUPS AT STATION 15, ASKO, SHOWING THE DROP IN ABUNDANCE WITH THE TSESIS OIL SPILL (FROM KINEMAN, ET. AL., 1976)

FIGURE 27

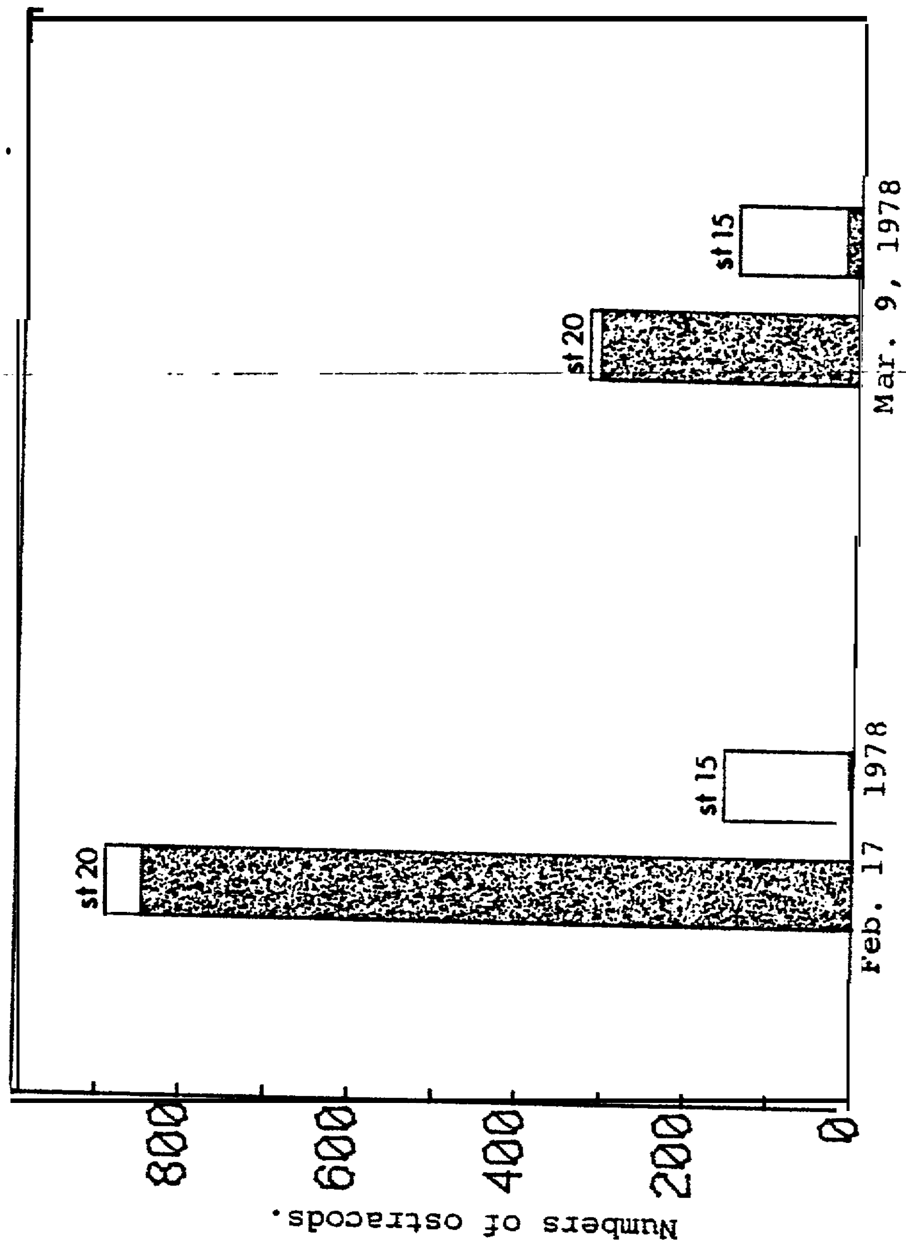


Abundance of nematodes, ostracods and other **groups** (excluding nematodes and **ostracods**) at station **20** (□) **and station** 15 (▼). Data in 1976 **from station** 21 (A). Arrows indicate grounding **of** Tsesis.

FIGURE 28

NUMBER OF LIVE VS. DEAD OSTRACODES BEFORE (FEB. 17) AND AFTER (MARCH 9) THE TSESIS OIL SPILL (FROM KI NEMAN, ET. AL., 1976)

FIGURE 28

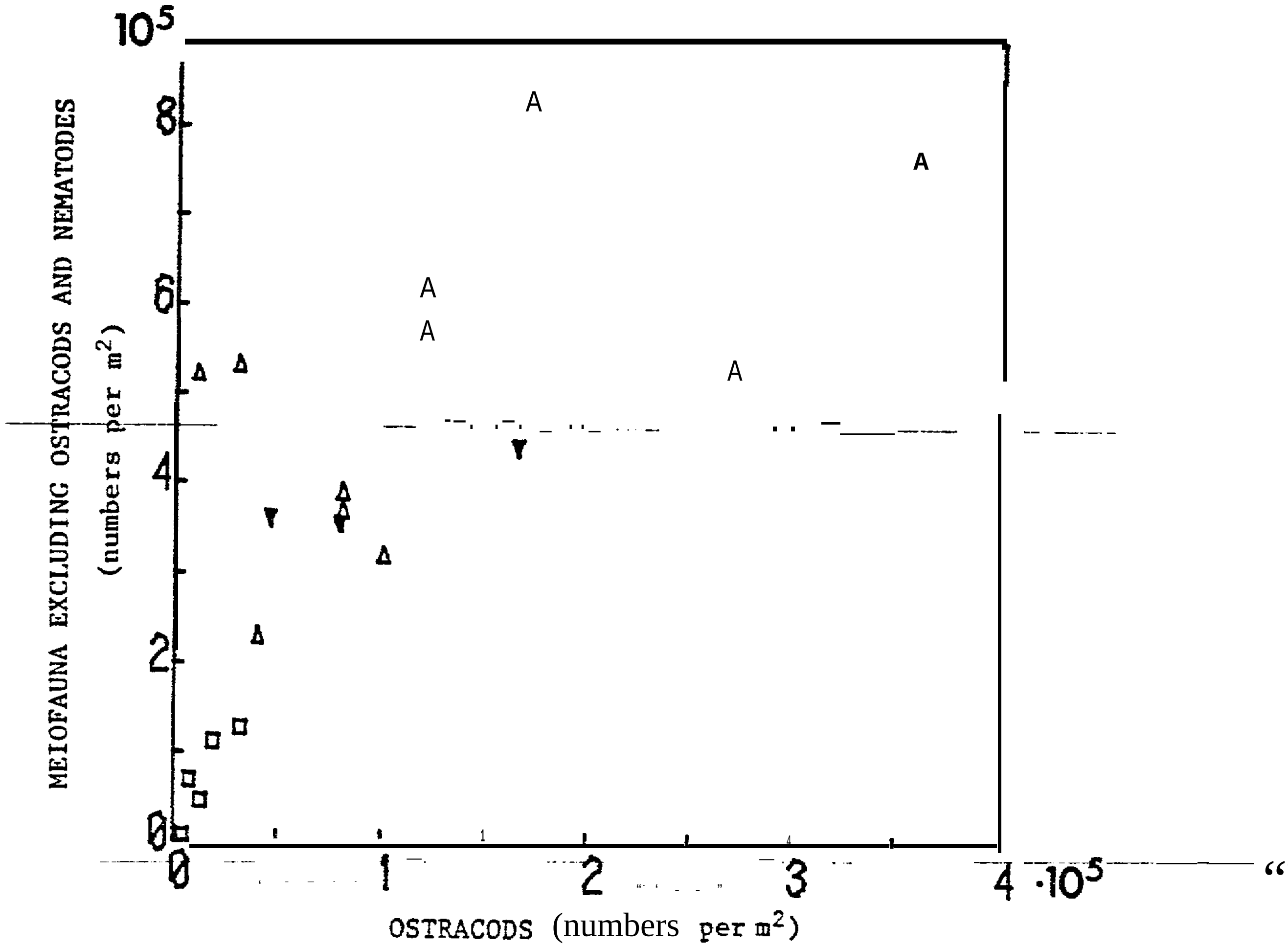


Live (white) and dead (stained) ostracods in dredges (mesh size 450 µm) from station 20 and station 15, February 17 and March 9, 1978.

FIGURE 29

ABUNDANCE OF OSTRACODES VS. ABUNDANCE OF OTHER MEIOFAUNA GROUPS
(FROM KINEMAN, ET. AL., 1976)

FIGURE 29



Abundance of ostracods versus abundance of other meiofauna groups (excluding nematodes and ostracods) in the Askö - Landsort area. (□) Data from station 20 (mean of three cores) . (▼) Data from station 15 (mean of three cores) . (▲) Data from the Askö - Landsort area. Data from single cores taken at randomly selected stations in the depth range 25 to 45 m.

shown by Kineman et. al. (1976). The ostracode species composition and relative abundances of the species will provide a sensitive monitor for adverse oil spill effects on the benthic environment, as well as providing a guide to the total re-establishment of the pre-spill benthic community structure.

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TABLE 1
LIST OF THE SAMPLES ANALYZED IN PRINCIPLE COORDINATE ANALYSIS A

CRUISE EGAL-75-KC

BC-4	VV-90	VV-259	S-420
BC-5	W-92	w-2 60	S-421
BC-6	VV-107	S-263	s-426
BC-11	W-1 08	W-282	S-430
BC-16	S-170A	VV-283	s-434
Vv-17	S-171	W-285	
w-18	S-173	VV-286	
S-19	S-176	W-288	
W-20	S-179A	S-289	
s-22	S-180	S-290	
VV-24	S-183	S-296	
VV-26	W-1 84	w-2 97	
W-27	S-202	VV-308	
S-32	w-2 04	w-3 12	
w-39	VV-205	VV-313	
VV-41	S-208	w-3 14	
W-46	S-209	VV-316	
W-52A	S-210	w-3 17	
W-53	S-211	VV-319	
VV-54	S-212	W-320	
w-55	S-213	VV-324	
VV-58	s-2 14	W-325	
W-59A	S-215	S-328	
VV-59B	S-216	VV-330	
VV-63B	VV-217	VV-332	
S-65B	S-224	W-333	
s-66	S-226	VV-336	
VV-70	S-246	W-338	
W-71	W-247	VV-339	
VV-83	s-2 51	VV-341	
W-84	S-256	s-344	
VV-86	VV-257	s-347	

TABLE 2
LIST OF TEE SAMPLES ANALYZED IN PRINCIPLE COORDINATE ANALYSIS B

CRUISE **EGAL-75-KC**

s-68	**S-120**	S-166	S-427
VV-69	S-122A	S-167	S-428
W-72	**S-123**	**BC-170B**	S-429
VV-73	BC-124B	S-174	S-431
VV-74	**BC-124A**	S-175	S-432
VV-75	**VV-125**	**S-181**	s-433
VV-76	**BC-127**	VV-219	
VV-77	**BC-128**	S-221	
W-78	**S-129**	**BC-223**	
W-80	s-1 30	s-225	
W-87	**S-132**	s-227	
s-88	s-1 33	W-2 29	
S-89	S-134	VV-231	
VV-91	S-1 38	W-232	
VV-94	**VV-141**	**VV-233**	
VV-95	w-1 44U	W-237	
VV-96	**S-145**	W-23 9	
VV-97	S-1 46	w-2 49	
W-98	**S-147**	**VV-258**	
VV-99	s-1 49	S-264	
S-103	**VV-1** 50	S-265	
S-1 04	**VV-1** 53	S-266	
BC-105	**VV-154**	S-268	
VV-1 06	W-155	W-2 84	
VV-109	**VV-157**	s-294	
S-no	W-158	W-306	
S-111	**S-159**	W-307	
w-l 12	**VV-1 61**	W-326	
S-113	W-162	**VV-331**	
S-115	**VV-163**	S-406	
S-117	**VV-164B**	S-422	
S-118	S-165	s-625	

CRUISE DC1-79-EG

S-1
S-5
S-6
S-7
S-9
S-10
S-12
S-13
S-17
S-19
S-23
S-24
S-25
S-28
S-29
S-30B
S-31B
S-32B
S-35
S-36
S-37
S-38 -"-"
S-39
S-40
S-41
S-42
S-43
S-44
S-45
S-46
S-47

CRUISE DC2-80-EG

W-14
W-16
W-18
W-24
W-27
W-41
W-48
W-60
W-62
W-63
W-67
W-70
W-73
W-82
W-86
W-89
W-91
W-94
W-97
W-99
W-155
W-167
W-168
W-169
W-170
W-174
W-177
W-180
W-183
W-186
W-189
W-192
W-195

TABLE 3
LIST OF SELECTED SPECIES FROM THE NORTHEAST GULF OF ALASKA, SHOWING THE DEPTH ASSEMBLAGES THEY OCCUR IN AND THEIR MODERN DEPTH RANGE

[Note that an asterisk (*) indicates that some of the specimens of this species have been found with soft parts in this depth zone]

SPECIES	DEPTH ASSEMBLAGE					MODERN DEPTH RANGE
"Acanthocythereis" dunelmensis	I*	II*	III	IV		Neritic, bathyal
Acuminocythere sp. A			III		V	Outer neritic
Ambostracon sp. A					V	Fossil
Argilloecia sp. A	I*	II*	III			Neritic
Argilloecia sp. B		II*	III	IV	V	Middle-outer neritic, bathyal
Aurila sp. A	I*	II	III		V	Neritic
"Australicythere" sp. A		II*	III		V	Middle-outer neritic
Baffinicythere emarginata					V	Fossil
Bairdia sp. A	I*	II*			V	Inner-middle neritic
Buntonia sp. A	I*	II*	III*			Neritic
Bythocythere sp. A		II			V	Middle neritic
Bythocythere sp. B		II	III	IV	V	Middle-outer neritic, bathyal
Bythocythere sp. C			III			Outer neritic
Bythocytherormopha sp. A					V	Fossil
Bythocytheromorpha sp. B					V	Fossil
Bythocytheromorpha sp. C					V	Fossil
Cluthia cluthae		II			V	Middle neritic
Cluthia sp. A		II*	III*	IV*		Middle-outer neritic, bathyal
Coquimba sp. A					V	Fossil
Cythere aff. C. alveolivalva	I	II			V	Inner-middle neritic
Cythere sp. A		II	III		V	Middle-outer neritic
Cytherois sp. A	I*	II	III			Neritic

SPECIES	DEPTH ASSEMBLAGE	MODERN DEPTH RANGE
Cytherois sp. B	II	Middle neritic
Cytheromorpha sp. A	I II III V	Neritic
Cytheromorpha sp. B	II* III*	Middle-outer neritic
Cytheromorpha sp. C	II	Middle neritic
Cytheromorpha sp. D	II* III	Middle-outer neritic
Cytheromorpha sp. E	II* III*	Middle-outer neritic
Cytheropteron aff. C. latissimum	II III IV V	Middle-outer neritic, bathyal
Cytheropteron aff. C. nodosoalatum	I* II III V	Neritic
Cytheropteron sp. A	II* III* IV V	Middle-outer neritic, bathyal
Cytheropteron sp. B	II III IV	Middle-outer neritic, bathyal
Cytheropteron sp. C	III IV V	Outer neritic, bathyal
Cytheropteron sp. D	II* III IV	Middle-outer neritic, bathyal
Cytheropteron sp. E	II III V	Middle-outer neritic
Cytheropteron sp. F	II III V	Middle-outer neritic
Cytheropteron sp. G	II III IV V	Middle-outer neritic, bathyal
Cytheropteron sp. H	II III IV V	Middle-outer neritic, bathyal
Cytheropteron sp. I	II V	Middle neritic
Cytheropteron sp. J	II	Middle neritic
Cytheropteron sp. K	III	Outer neritic
Cytheropteron sp. L	II III IV	Middle-outer neritic, bathyal

SPECIES	DEPTH ASSEMBLAGE				MODERN DEPTH RANGE	
Cytheropteron sp. M		II	III		V	Middle-outer neritic
Cytheropteron sp. N		II	III		V	Middle-outer neritic
Cytheropteron sp. O		11			V	Middle neritic
Cytheropteron 8p* P		II	III		V	Middle-outer neritic
Cytheropteron sp. Q		II	III	IV		Middle-outer neritic
Cytheropteron sp. R	I	11	111		V	Neritic
Cytheropteron sp. S					V	Fossil
Cytheropteron sp. T		II			V	Middle neritic
Cytheropteron sp. U		II			V	Middle neritic
Cytheropteron sp. V					V	Fossil
Cytheropteron sp. W		II	III		V	Middle-outer neritic
Cytheropteron sp. X				IV		Bathyal
Cytheropteron sp. Y					V	Fossil
Cytheropteron sp. Z					V	Fossil
Cytheropteron sp. AA			111			Middle neritic
Cytherura sp. C		II	III		V	Middle-outer neritic
Cytherura sp. D	I	II			V	Inner-middle neritic
Cytherura sp. E					V	Fossil
Cytherura sp. F		II			V	Middle neritic
Cytherura sp. G					V	Fossil
Cytherura sp. H					V	Fossil
Cytherura sp. I			III		V	Outer neritic
Cytherura sp. J					V	Fossil
Elofsonia sp. A	I*	II				Inner-middle neritic
Eucythere sp. A	I*	II*				Inner-middle neritic

SPECIES	DEPTH ASSEMBLAGE	MODERN DEPTH RANGE
Eucytherura sp. A	II III IV	Middle-outer neritic, bathyal
Eucytherura sp. B	II	Middle neritic
Eucytherura sp. C	111	Outer neritic
Finmarchinella (Barentsovia) angulata	V	Fossil
Finmarchinella (Barentsovia) barentsovoensis	V	Fossil
Finmarchinella (Barentsovia) sp. A	V	Fossil
Finmarchinella (Barentsovia) finmarchinella	V	Fossil
Hemicythere aff. H. quadrinodosa	I* II III	Neritic
Hemicytherura sp. A	II III V	Middle-outer neritic
Hemicytherura sp. B	II III	Middle-outer neritic
Hemicytherura sp. C	II V	Middle neritic
Krithe sp. A	III* IV* V	Outer neritic, bathyal
"Leguminocythereis" sp. A	I* II* III	Neritic
"Leguminocythereis" sp. B	I* II*	Inner-middle neritic
"Leguminocythereis" sp. C	III	Outer neritic
"Leguminocythereis" sp. D	V	Fossil
Loxoconcha sp. A	I* II* III* IV*	Middle-outer neritic, bathyal
Loxoconcha sp. B	II* III* IV*	Middle-outer neritic, bathyal
Loxoconcha sp. D	V	Fossil
Loxoconcha sp. E	V	Fossil
Loxoconcha sp. F	II V	Middle neritic
Macrocypris sp. A	III*	Outer neritic

SPECIES	DEPTH ASSEMBLAGE				MODERN DEPTH RANGE
Munseyella sp. A		II	III*		Middle-outer neritic
Munseyella sp. B		11	III		Middle-outer neritic
Normanicythere sp.				v	Fossil
Palmanella limicola		II*	III* IV		Middle-outer neritic
Paracypris sp. A		II*			Middle neritic
Paracypris sp. B		II			Middle neritic
Paracytheridea sp. A				v	Fossil
Paradoxostoma aff. P. brunneatum				v	Fossil
Paradoxostoma aff. P. flaccidum				v	Fossil
Paradoxostoma aff. P. honssuensis				v	Fossil
Paradoxostoma aff. P. japonicum				v	Fossil
Paradoxostoma sp. A				V	Fossil
Paradoxostoma sp. B			III	V	Outer neritic
Paradoxostoma sp. C			111	v	Outer neritic
Paradoxostoma sp. D				v	Fossil
Paradoxostoma sp. G		II		v	Inner neritic
Paradoxostoma sp. H		II		V	Inner neritic
Paradoxostoma sp. I		II		v	Inner neritic
Paradoxostoma sp. J				v	Fossil
Patagonacythere sp. A				V	Fossil
Pectocythere aff. P. parkerae	I*	II*	III	v	Neritic
Pectocythere aff. P. quadrangulata	I*	II*	III	v	Neritic
Pectocythere sp. C				v	Fossil
Pectocythere sp. D	I*	II*			Inner-middle neritic
Pectocythere sp. E				v	Fossil
Pectocythere sp. F				v	Fossil
Pectocythere sp. G				v	Fossil
Pontocypris sp. A				v	Fossil

SPECIES	ASSEMBLAGE ZONES					MODERN DEPTH RANGE
Pontocythere sp. A	I*				V	Inner neritic
Pseudocythere sp. A		II	III		V	Middle-outer neritic
Pseudocythere sp. B			111			Outer neritic
"Radimella" jollaensis					V	Fossil
Robertsonites tuberculata	I*	II*	III*	IV	V	Neritic, bathyal
Schizocythere sp. A					V'	Fossil
Sclerochilus sp. B			III			Outer neritic
Sclerochilus sp. C		II	III		V	Middle-outer neritic
Sclerochilus sp. D			III		V	Outer neritic
Sclerochilus sp. F					V	Fossil
Sclerochilus sp. G					V	Fossil
Semicytherura aff. S. undata					V	Fossil
Semicytherura sp. D			111		V	Outer neritic
Semicytherura sp. E		II			V	Middle neritic
Semicytherura sp. F					V	Fossil
Xestoleberis sp. A					V	Fossil
Xestoleberis sp. B		II	III		V	Middle-outer neritic
Xiphichilus sp. A					V	Fossil
Xiphichilus Sp. B					V	Fossil

TABLE 4

TABULATION OF THE OSTRACODE SPECIES OCCURRING IN EACH MAJOR OSTRACODE ASSEMBLAGE , IN ALPHABETICAL ORDER.

[An asterisk indicates that some of the specimens of that species contained soft parts, which is interpreted to indicate that those specimens were living in situ when collected. Note that in Assemblage V many of the fossil species are presently living in the depth assemblage noted after the species binomen.]

OSTRACODE ASSEMBLAGE I

"Acanthocythereis" dunelmensis	*	Candona sp.
Argilloecia sp. A	*	Cyclocypris sp.
Aurila sp. A	*	Cyprinotus sp.
Bairdia sp. A	*	
Buntonia sp. A	*	
Cytherois sp. A	*	
Cythere aff. C. alveolivalva		
Cytheromorpha sp. A		
Cytheromorpha sp. B	*	
Cytheromorpha sp. C		
Cytheromorpha sp. D	*	
Cytheromorpha sp. E	*	
Cytheropteron aff. C. nodosoalatum	*	
Cytheropteron sp. R		
Cytherura sp. D		
Elofsonia sp. A	*	
Eucythere sp. A	*	
Hemicythere aff. H quadrinodosa	*	
"Leguminocythereis" sp. A	*	
"Leguminocythereis" sp. B	*	
Loxoconcha sp. A	*	
Pectocythere aff. P. parkerae	*	
Pectocythere aff. P. quadrangulata	*	
Pectocythere sp. D	*	
Pontocythere sp. A	*	
Robertsonites tuberculata	*	

OSTRACODE ASSEMBLAGE II

"Acanthocythereis" dunelmensis	*
Argilloecia sp. A	*
Argilloecia sp. B	
Aurila sp. A	
"Australicythere" sp. A	*
Bairdia sp. A	*
Buntonia sp. A	*
Bythocythere sp. B	
Cluthia cluthae	
Cluthia sp. A	*
Cythere aff. C. alveolivalva	
Cythere sp. A	
Cytherois sp. A	
Cytherois sp. B	
Cytheromorpha sp. A	
Cytheromorpha sp. B	*
Cytheromorpha sp. D	
Cytheromorpha sp. E	*
Cytheropteron aff. C. latissimum	
Cytheropteron aff. C. nodosoalatum	
Cytheropteron sp. A	*
Cytheropteron sp. B	
Cytheropteron sp. D	*
Cytheropteron sp. E	
Cytheropteron sp. F	
Cytheropteron sp. G	
Cytheropteron sp. H	
Cytheropteron sp. I	
Cytheropteron sp. J	
Cytheropteron sp. L	
Cytheropteron sp. M	
Cytheropteron sp. N	
Cytheropteron sp. O	
Cytheropteron sp. P	

Cytheropteron sp. Q
Cytheropteron sp. R
Cytheropteron sp. T
Cytheropteron sp. W
Cytherura sp. C
Cytherura sp. D
Cytherura sp. F
Eucythere sp. A *
Elofsonia sp. A
Eucytherura sp. A
Eucytherura sp. B
Eucytherura sp. C *
Hemicythere aff. H. quadrinodosa
Hemicytherura sp. A
Hemicytherura sp. B
"Leguminocythereis" sp. A *
"Leguminocythereis: sp. B *
Loxoconcha sp. A *
Loxoconcha sp. B *
Loxoconcha sp. F
Munseyella sp. A
Munseyella sp. B
Palmanella limicola *
Paracypris sp. A *
Paracypris sp. B
Paradoxostoma sp. G
Paradoxostoma sp. H
Paradoxostoma sp. I *
Pectocythere aff. P. parkerae *
Pectocythere aff. P. quadrangulata *
Pseudocythere sp. A
Pectocythere sp. D *
Robertsonites tuberculata *
Sclerochilus sp. C

OSTRACODE ASSEMBLAGE 111

"Acanthocythereis: dunelmensis
Acuminocythere sp. A
Argilloecia sp. A
Argilloecia sp. B
Aurila sp. A
"Australicythere" sp. A
Buntonia sp. A *
Bythocythere sp. B
Bythocythere sp. C
Cluthia cluthae
Cluthia sp. A *
Cythere sp. A
Cytherois sp. A
Cytheromorpha sp. A
Cytheropteron aff. C. latissimum
Cytheropteron aff. C. nodosoalatum
Cytheropteron sp. A *
Cytheropteron sp. B
Cytheropteron sp. C
Cytheropteron sp. D
Cytheropteron sp. E
Cytheropteron sp. F
Cytheropteron sp. G
Cytheropteron sp. K
Cytheropteron sp. L
Cytheropteron sp. M
Cytheropteron sp. N
Cytheropteron sp. Q
Cytheropteron sp. R
Cytheropteron sp. W
Cytheropteron sp. X
Cytheropteron sp. AA
Cytherura sp. C
Cytherura sp. I

Eucytherura sp. A

Eucytherura sp. C

Hemicythere aff. H. quadrinodosa

Hemicytherura sp. A

Hemicytherura sp. B

Krithe sp. A *

"Leguminocythereis" sp. A

"Leguminocythereis" sp. c

Loxoconcha sp. A *

Loxoconcha sp. B *

Macrocypris sp. A *

Munseyella sp. A *

Munseyella sp. 3

Palmanella limicola *

Paradoxostoma sp. B

Paradoxostoma sp. C

Pectocythere aff. P. parkerae

Pectocythere aff. P. quadrangulata

Pseudocythere sp. B

Robertsonites tuberculata *

Sclerochilus sp. B

Sclerochilus sp. C

Sclerochilus sp. D

Semicytherura sp. D

Xestoleberis sp. B

OSTRACODE ASSEMBLAGE IV

"Acanthocythereis" dunelmensis *

Argilloecia sp. B

Bythocythere sp. B

Cluthia sp. A *

Cytheropteron aff. C. latissimum

Cytheropteron sp. A

Cytheropteron sp. B

Cytheropteron sp. C

Cytheropteron sp. G

Cytheropteron sp. H

Cytheropteron sp. L

Cytheropteron sp. Q

Cytheropteron sp. X

Eucytherura sp. A

Krithe sp. A *

Loxoconcha sp. B *

Palmanella limicola

Robertsonites tuberculata

OSTRACODE ASSEMBLAGE V

Acuminocythere sp. A

Ambostracon sp. A

Argilloecia sp. B /III

Aurila sp. A /II

"Australicythere" sp. A

Baffinicythere emarginata

Bairdia sp. A

Bythocythere sp. A /II

Bythocythere sp. B

Bvthocvtheromorpha sp. A

Bythocytheromorpha sp. B

Bythocytheromorpha sp. c

Cluthia cluthae

Coquimba sp. A

Cythere aff. C. alveolivalva /II

Cythere sp. A

Cytheromorpha sp. A

Cytheropteron aff. C. latissimum

Cytheropteron aff. C.nodosoalatum /II

Cytheropteron sp. A

Cytheropteron sp. C /III

Cytheropteron sp. E	/III
Cytheropteron sp. G	?III
Cytheropteron sp. G	/II
Cytheropteron sp. H	/II,III
Cytheropteron sp. I	
Cytheropteron sp. M	/III
Cytheropteron sp. N	/11
Cytheropteron sp. O	/II
Cytheropteron sp. P	/11,111
Cytheropteron sp. R	
Cytheropteron sp. S	
Cytheropteron sp. T	/11
Cytheropteron sp. U	/II
Cytheropteron sp. V	/II
Cytheropteron sp. W	/111
Cytheropteron sp. Y	/III
Cytheropteron sp. Z	/11
Cytherura sp. A	
Cytherura sp. B	
Cytherura sp. C	
Cytherura sp. D	/S1
Cytherura sp. E	/II
Cytherura sp. F	/II
Cytherura sp. G	
Cytherura sp. H	/II
Cytherura sp. I	/III
Cytherura sp. J	/II
Finmarchinella (Barentsovia) barentzovoensis	
Finmarchinella (Barentsovia) angulata	
Finmarchinella)Barentsovia) sp. A	
Finmarchinella (Finmarchinella) finmarchica	
Hemicytherura sp. A	
Hemicytherura sp. C	/II
Krithe sp. A	
"Leguminocythereis" sp. D	
Loxoconcha sp. D	

Loxoconcha Sp. E

Loxoconcha sp. F

Normanicythere sp.

Paracytheridea sp. A

Paradoxostoma aff. P. brunneatum

Paradoxostoma aff. P. flaccidum

Paradoxostoma aff. P. honssuensis

Paradoxostoma aff. P. japonicum

Paradoxostoma sp. A

Paradoxostoma sp. B

Paradoxostoma sp. C

Paradoxostoma sp. D

Paradoxostoma sp. G /II

Paradoxostoma sp. H

Paradoxostoma sp. I /11

Paradoxostoma sp. J

Patagonacythere sp. A

Pectocythere aff. P. parkerae

Pectocythere aff. P. quadrangulata

Pectocythere sp. C

Pectocythere sp. E

Pectocythere sp. F

Pectocythere sp. G

Pontocypris sp.

Pontocythere sp. A

Pseudocythere sp. A /11,111

"Radimella" jollaensis

Robertsonites tuberculata /II

Schizocythere sp.

Sclerochilus sp. C /II

Sclerochilus sp. D

Sclerochilus sp. F

Sclerochilus sp. G

Semicytherura aff. S. undata

Semicytherura sp. D

Semicytherura sp. E /II

Semicytherura sp. F

Xestoleberis sp. A

Xestoleberis sp. B /II

Xiphichilus sp. A

Xiphichilus Sp. B

LIST OF THE LOCATION, WATER DEPTH, AND OSTRACODE ASSEMBLAGE TYPE OF TEE SAMPLES EXAMINED FROM THE GULF OF ALASKA

CRUISE EGAL-75-KC

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
BC-4	59° 39.3′ N	147° 40.1′ w	Unknown	V/III
BC-5	59° 36.5′ N	147″ 32.8′ W	Unknown	III
BC-6	59″ 32.3′ N	147″ 21.1' w	143 meters	III
BC-11	59″ 55.9′ N	147° 25.4′ W	49 meters	V/11
VV-16	59° 45.9′ N	146° 49.4′ W	91 meters	III
VV-17	59* 38.1′ N	146° 43.5′ W	97 meters	V/11
VV-18	59° 33.5′ N	146° 42.4′ W	113 meters	III
S-19	59° 31.8′ N	146° 51.0' W	113 meters	III
VV-20	59° 28.5′ N	146° 41.8′ W	88 meters	V/11
s-22	59° 27.2′ N	146′ 41.1' W	106 meters	II
VV-24	60° 01.2′ N	147° 15.0′ W	143 meters	III
VV-26	59° 56.6′ N	147° 06.1' W	205 meters	Iv
VV-27	59″ 53.8′ N	146° 59.2′ W	163 meters	III
S-32	59° 28.7′ N	146° 29.1′ W	53 meters	V/II
VV-39	59° 28.0′ N	145° 59.7′ w	148 meters	V
VV-41	60°09.05' N	147° 07.2' W	212 meters	v
VV-46	60° 00.0' N	146° 45.5′ W	126 meters	V/III
VV-52A	59° 59.0' N	146° 27.5′ W	71 meters	V/II
VV-53	60″ 07.7' N	146° 52.8' W	156 meters	V/III
VV-54	60° 06.1' N	146° 49.4' W	112 meters	III
VV-55	60° 14.5' N	146° 50.6' W	220 meters	V
VV-58	60° 13.8' N	146° 44.25′ W	221 meters	I
VV-59A	60° 12.1' N	146° 41.2' W	192 meters	V
VV-59B	60° 11.8' N	146° 41.5′ W	183 meters	III
VV-63B	60″ 01.8′ N	146° 14.6' W	64 meters	V/II
S-65B	59* 49.4' N	146″ 14.9' W	53 meters	V/I
s-66	59° 46.6′ N	146° 15.9' W	75 meters	v
s-68A	59° 42.6′ N	146° 15.0' W	81 meters	V/II

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
VV-69	59° 42.6′ N	146° 14.6' W	49 meters	V/II
VV-70	60″ 12.6′ N	146° 15.3′ W	108 meters	III
VV-71	60° 10.1′ N	146° 15.0' W	84 meters	II
VV-72	60″ 15.3' N	146° 00.8′ W	90 meters	11
VV-73	60° 10.45' N	146° 01.35' W	95 meters	II
VV-74	60° 09.2′ N	146° 01.5' W	90 meters	II
VV-75	60° 07.4′ N	146° 02.3' W	84 meters	II
VV-76	60° 02.0' N	146° 00.5′ W	77 meters	V/II
VV-77	59″ 56′ N	146° 1.5' W	86 meters	V/II
VV-78	59° 51.6' N	146° 00.9′ W	101 meters	III
VV-80	59° 46.7' N	145° 59.5′ w	91 meters	II
VV-83	59° 39.0′ N	145° 59*5′ w	91 meters	II
VV-84	59° 32.2′ N	145° 59.5' w	157 meters	III
VV-86	60° 14.0′ N	145° 34.5′ W	48 meters	II
VV-87	60″ 06.9′ N	145° 34.4' w	126 meters	III
S-88	59″ 59.2′ N	145° 34*O′ w	88 meters	11
S-89	59° 58.5′ N	145° 34.2′ W	84 meters	v
VV-90	59° 52.6' N	145° 34.5′ w	88 meters	V/II
VV-91	59° 50.5' N	145° 39.6′ W	97 meters	III
VV-92	59° 45.9' N	145° 34*5′ w	119 meters	III
VV-94	60″ 07.7′ N	145° 21.0′ W	97 meters	II/III
VV- 95	60° 03. 3- ' N	145° "19'.8" W	132 meter-s	III
VV-96	59° 59.2' N	145° 19.3' w	119 meters	111
VV-97	59° 55.7' N	145 19*5′ W	101 meters	111
VV-98	59° 52.5′ N	145° 19.8′ W	101 meters	III
VV-99	59° 50.4' N	145° 20.6' W	110 meters	III
S-1 03	60° 09.4' N	144° 58.2' W	35 meters	_ .1
S-104	60° 08.1′ N	144° 54.9′ w	53 meters	XI
BC-105	59° 57.1′ N	144° 55.4′ w	183 meters	III
VV-106	59° 57.0' N	144° 57.4′ w	192 meters	III
Vv-107	59° 46.5' N	145° 03.2' w	185 meters	III
VV-108	59° 44.2' N	144° 56.2′ W	192 meters	V/III
VV-109	59° 43.4' N	144° 52.7' W	102 meters	II/III

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DE PTH	ASSEMBLAGE TYPE
S-no	59° 41.5' N	144° 4'7.2' W	97 meters	II
S-111	59° 38.9' N	144" 41.0' w	148 meters	111
VV-112	59° 37.6' N	144° 37*0' w	145 meters	III
S-113	59° 34.9' N	144° 30.0' w	139 meters	V/III
S-115	59° 46.0' N	144° 47.7' w	64 meters	v/xi
S-117	59° 43.0' N	144° 38.1' W	119 meters	II/III
S-118	59° 40.7' N	144° 33.3' w	137 meters	II/III
S-120	59° 48.8' N	144" 41.0' w	66 meters	11
S-122A	59° 55.6' N	144° 31.4' w	55 meters	V/II
s-123	59° 56.7' N	144° 40.2' W	210 meters	IV
BC-124B	59" 57*5' N	144° 43.2' W	234 meters	IV
BC-124A	59° 57.5' N	144° 43.2' W	234 meters	IV
VV-125	59" 59.8' N	144° 44*0' w	232 meters	II/III
BC-127	60° 02.8' N	144" 43.5' W	210 meters	IV
BC-128	60" 00.6' N	144" 40.0' w	227 meters	V/II
s-129	60° 04.9' N	144° 40.4' w	146 meters	I
S-130	60° 07.8' N	144° 39*5' w	31 meters	I/III
s-132	60° 07.1' N	144" 31.2' W	20 meters	I
S-133	60° 03.8' N	144° 26.2' W	17 meters	I
S-134	59" 59.0' N	144° 24.0' W	20 meters	v/I
S-138	59° 38s2' N	145° 50.4' W	168 meters	III
VV-141	60° 06.8' W	146° 14.5' W	71 meters	V/11
VV-144U	59° 57*3' N	146° 19.6' W	64 meters	V/II
S-145	59" 37.4' N	146° 09.0' W	101 meters	III
S-146	59° 35.6' N	145° 54.8' w	143 meters	III
S-147	59° 34.2' N	145° 45.7' W	165 meters	III
S-149	60" 03.2' N	145° 34.5' w	104 meters	III
VV-150	60° 10.4' N	145° 34.5' w	104 meters	II/III
VV-153	60° 12.5' N	146" 27.0' W	137 meters	V/III
VV-154	59° 51.4' N	145° 28.5' w	95 meters	III
VV-155	59" 55.2' N	145° 42.0' W	82 meters	II
VV-157	60° 01.4' N	146° 08.5' W	73 meters	V/II
VV-158	60° 06.0' N	146° 40.5' W	117 meters	III

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
S-159	60″ 10.2′ N	146° 52.1′ W	165 meters	V/III
VV-161	60° 17.4′ N	146° 23.7′ W	22 meters	I
VV-162	60° 19.2′ N	146° 13.2′ W	24 meters	I
VV-163	60° 19.5′ N	146° 07.0′ W	22 meters	I
VV-164B	60″ 19.5′ N	146* 00.0′ W	22 meters	I
S-165	60° 18.3′ N	145° 53.5′ w	33 meters	I
S-166	60° 17.7′ N	145° 45.6′ W	20 meters	I
S-167	60° 16.4′ N	145° 38.4′ W	26 meters	I
S-170A	60° 16.9′ N	145° 42.0′ W	20 meters	I
BC-170B	60° 16.9′ N	145° 42.0′ W	20 meters	I
S-171	60° 14.25′ N	145° 28.0′ W	24 meters	I
S-173	60° 10.4′ N	145° 13.6′ W	24 meters	I
S-174	60° 09.6′ N	145° 06.4′ W	35 meters	I
S-175	60° 09.4′ N	145° 00.0′ w	33 meters	I
S-176	60° 10.0′ N	144° 48.0′ w	31 meters	I
S-179A	60° 14.75′ N	145° 27.1′ W	18 meters	I
S-180	60° 09.1′ N	144° 44.7′ w	26 meters	I
S-181	60° 01.0′ N	144° 24.0′ W	33 meters	v/I
S-183	59° 55.5′ N	144° 34.6′ W	91 meters	III
VV-184	59° 54.8′ N	144° 54.6′ W	188 meters	III
S-202	59° 31.4′ N	144° 36.6′ W	187 meters	? /III
VV-204	59° 34.8′ N	144° 35.8′ W	141 meters	V/III
VV-205	59° 3700′ N	144° 35.3′ W	145 meters	III
S-208	59° 33.25′ N	144° 31.3′ w	156 meters	V/III
S-209	59° 35.1′ N	144° 31.7′ W	139 meters	V/III
S-210	59″ 36.9′ N	144° 30.5′ W	146 meters	III
S-211	59° 40.1′ N	144″ 28.4′ W	146 meters	III
S-212	59° 46.1′ N	144° 33.1′ w	91 meters	II
S-213	55″ 44.7′ N	144° 30.2′ W	113 meters	III
S-214	59° 43.7′ N	144° 28.6′ W	55 meters	II
S-215	59° 42.9′ N	144° 27.0′ W	134 meters	III
S-216	59° 42.1′ N	144° 23.0′ W	152 meters	III
VV-217	59° 39.8′ N	144° 21.2′ w	154 meters	III

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
VV-219	59° 36.3′ N	144° 17.4′ W	475 meters	Iv
S-221	59° 50.1′ N	144″ 27.4′ W	29 meters	V/I
BC-223	59° 52.4′ N	144° 18.7′ W	51 meters	1/11
S-224	59° 50.0′ N	144° 16.0′ W	64 meters	II
S-225	59° 46.2′ N	144° 11.5′ W	101 meters	III
S-226	59° 43.0′ N	144° 07.25′ W	128 meters	III
S-227	59″ 39.4′ N	144° 04.9′ W	161 meters	V/111
VV-229	59° 34.0′ N	144° 01.2′ W	1189 meters	IV
VV-231	59° 56.9′ N	144° 09.7′ W	33 meters	I
VV-232	59° 57.25′ N	144° 09.9′ W	49 meters	I
VV-233	59° 51.6′ N	143° 53.25′ W	106 meters	II/III
VV-237	59° 51.7′ N	143° 42.5′ W	225 meters	Iv
VV-239	59° 55.6′ N	143° 32.4′ W	252 meters	IV
S-246	59° 41.9′ N	142° 55.8′ W	198 meters	III
VV-247	59″ 52.2′ N	143° 20.5′ W	214 meters	IV
VV-249	59° 58.4′ N	143° 23.0′ W	152 meters	111
S-251	59° 44.5′ N	142° 54.0′ W	188 meters	III
S-256	59° 48.2′ N	142° 46.2′ W	190 meters	III
VV-257	59° 57.3′ N	142° 46.5′ W	119 meters	III
VV-258	59° 57.5′ N	142° 41.0′ W	108 meters	II/III
V.V-239	~~59° 58.1′ N~~	~~142° 38.2′ W~~	~~91 meters~~	III
VV-260	60° 00.0′ N	142° 43.0′ W	88 meters	III
S-263	59° 50.8′ N	142° 31.0′ W	95 meters	V/III
S-264	59° 49.5′ N	142° 30.0′ W	134 meters	III
S-265	59° 46.2′ N	142° 29.9′ W	181 meters	III
S-266	59° 42.5′ N	142″ 34.0′ W	262 meters	IV
S-268	′59° 40.7′ N	142° 21.6′ W	174 meters	III
VV-282	59″ 54.5′ N	142° 20.0′ W	$2 meters	II
VV-283	59° 51.0′ N	142″ 14.5′ W	84 meters	II
VV-284	59° 50.0′ N	142° 14.2′ W	86 meters	II
VV-285	59° 47.4′ N	142° 14.2′ W	115 meters	III
VV-286	59° 43.0′ N	142° 13.1′ W	157 meters	III
VV-288	59° 36.0′ N	142° 13.7′ W	238 meters	IV

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
S-289	59° 53.1′ N	142° 03.8' w	55 meters	II
S-290	59° 54.6′ N	141″ 52.3′ W	31 meters	I
S-294	59° 48.7' N	141° 25.0' W	29 meters	I
S-296	59° 45.5′ N	141° 43*5′ w	49 meters	11
VV-297	59° 32.9′ N	141° 46.7′ W	165 meters	III
VV-306	59° 30.4¹ N	141° 30.0' W	161 meters	III
VV-307	59° 28.9′ N	141° 27.8′ W	165 meters	III
VV-308	59° 25.8' N	141° 21.1' w	201 meters	IV
VV-312	59° 31.7′ N	141° 14.3′ u	156 meters	III
VV-313	59° 29.5′ N	141″ 11.0′ w	256 meters	IV
VV-314	59° 28.5' N	141″ 06.3′ W	311 meters	″ Iv
VV-316	59° 22.8′ N	140° 51.7' w	163 meters	III
VV-317	59° 27.2′ N	140° 49.4′ w	274 meters	Iv
VV-319	59° 33.8′ N	140° 50.5′ w	247 meters	IV
VV-320	59″ 36.4′ N	140° 50.5′ w	163 meters	III
VV-324	59° 32.3′ N	140° 14.0′ w	192 meters	III
VV-325	50″ 29.0′ N	140° 14.1' w	241 meters	IV
VV-326	59° 24.6′ N	140° 14.5′ w	183 meters	III
S-328	59° 43.2′ N	144″ 33.6′ W	134 meters	III
VV-330	59″ 58.2′ N	144″ 02.8′ W	24 meters	I
~~VV-331~~	~~59° 56.1' N~~	~~143° 53.4' W~~	~~66 meters~~	~~V/II~~
VV-332	59° 54.3′ N	143″ 53.2' W	73 meters	II
VV-333	59° 47.1' N	143° 51.5′ w	128 meters	III
VV-336	59° 48.4′ N	144° 38.0' W	274 meters	IV
VV-338	60° 01.0′ N	143° 09.3' w	101 meters	II
VV-339	60° 00.8'	142° 56.6′ W	102 meters	II
VV-341	59° 57.7′ N	143° 04.7′ w	137 *meters*	III
s-344	59° 39.2′ N	142″ 22.2′ W	210 meters	IV
s-347	59″ 41.0' N	142° 39.7′ W	333 meters	Iv
VV-360	59° 39.7′ N	140° 31.1' W	48 meters	1
S-406	59° 53.0′ N	141° 36.5′ W	26 meters	II
S-420	59° 55.1′ N	141° 32.9′ W	64 *meters*	II
S-421	59° 55.2' N	141° 34.4 w	59 meters	II

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
S-422	59° 55.8' N	141° 35.6' W	68 meters	V/11
S-425	59°56.7' N	141° 35.1' W	59 meters	II
S-426	59° 56.1' N	141° 33.5' w	71 meters	II
S-427	59° 55.45' N	141° 32.7' W	71 meters	II
S-428	59° 54.7' N	141° 30.1' w	49 meters	V/11
S-429	59° 55.5' N	141° 30.6' W	60 meters	v
S-430	59° 56.0' N	141° 31.6' W	59 meters	II
S-431	59° 56.5' N	141° 33.3' w	59 meters	II
S-432	59° 57.2' N	141° 31.6' W	68 meters	II
s-433	59° 57.5' N	141° 30.8' W	68 meters	II
s-434	59° 57.1' N	141° 29.6' W	68 meters	II

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s-1	59° 05.0' N	138″ 39.9' W	77 meters	I
s-5	58° 52.1' N	138″ 58.6' W	205 meters	III
S-6	58″ 46.8' N	138° 59.7' W	220 meters	IV
s-7	58° 48.2' N	139° 07.9' w	188 meters	III
s-9	58″ 43.1' N	139° 10.3' w	240 meters	IV
s-lo	58* 44.9' N	139° 19.1' w	183 meters	III
S-12	58° 39.0' N	139° 22.3; W	251 meters	IV
S-13	58° 45.2' N	138° 38.4' W	108 meters	V/III
S-17	58° 26.4' N	138° 26.4' W	123 meters	V/III
S-19	58″ 33.6' N	138° 17.5' W	122 meters	V/III
S-23	58° 26.0' N	137° 48.3' W	167 meters	III
s-24	58° 20.7' N	137° 55.7' w	156 meters	III
S-25	58° 13.9' N	138° 01.9' W	138 meters	V/III
S-28	58° 11.2' N	137° 39.1' w	161 meters	III
S-29	58° 16.4' N	137° 32.5' W	154 meters	III
S-30B	58° 23.0' N	137° 27.9' W	196 meters	III
S-31B	58° 18.6' N	137° 08.2' W	154 meters	III
S-32B	58° 10.9' N	137″ 19.8' W	121 meters	V/III
s-35	58° 22.7' N	136° 59.9' w	70 meters	I

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
S-36	58° 21.7' N	137° 00.7′ W	111 meters	II
s-37	58″ 21.0' N	137° 01.5' W	137 meters	III
S-38	58″ 20.2′ N	137″ 02.3' W	159 meters	III
s-39	58° 19.2' N	137° 03.1′ w	173 meters	III
S-40	58° 17.2′ N	137° 01.8' W	186 meters	III
S-41	58° 15.7' N	137° 00.4′ w	187 meters	III
S-42	58° 13.6′ N	136° 58.9′ W	174 meters	III
s-43	58° 12.1' N	136° 57.9′ W	185 meters	III
s-44	58° 11.0' N	136° 57.3′ W	111 meters	III
s-45	58″ 14.6′ N	136° 47.8′ W	119 meters	V/111
S-46	58° 50.1' N	136° 50.1' W	93 meters	V/III
s-47	58° 12.6' N	136° 53.2′ W	133 meters	III
		CRUISE DC2-80-EG		
VV-14	59° 19′ 10″ N	139° 19' 50″ w	<20 meters	I
VV-16	59° 18.81' N	139° 18.6′ w	35 meters	I
VV-18	59° 06.99' N	138° 48.28′ W	44 meters	I
VV-24	59″ 06.99' N	138° 44.02′ W	42 meters	I
VV-27	59° 06.99 N	138° 43.97′ W	43 meters	I
VV-41	59° 06.89′ N	138° 42.96′ w	40 meters	I
VV-48	59° 06.92′ N	138° 42.59′ W	37 meters	I
VV-60	59° 28.46' N	139° 47.99' W	58 meters	I
VV-62	59° 28.50′ N	139° 48.35′ W	64 meters	I
VV-63	59° 28.16' N	139° 48.90′ W	62 meters	II
VV-67	59° 28.01' N	139° 49.29′ W	82 meters	II
VV-70	59° 28.89′ N	139° 49.81' W	98 meters	II
VV-73	59° 27.73′ N	139″ 50.20' W	104 meters	II
VV-82	59° 28.18' N	139° 48.38' W	74 meters	II
VV-86	59° 27.48′ N	139° 50.48′ W	110 meters	II
VV-89	59° 28.64′ N	139° 48.16' W	55 meters	II
VV-91	59° 00.16′ N	139″ 54.01′ w	128 meters	V/III
VV-94	59° 36.6′ N	141° 23.3′ W	99 meters	II/III

SAMPLE NUMBER	LATITUDE	LONGITUDE	WATER DEPTH	ASSEMBLAGE TYPE
VV-97	59″ 41.8' N	141″ 20.1′ w	60 meters	11
VV-99	59° 41.0′ N	141° 20.7' W	60 meters	II
VV-155	59° 26.05′ N	140° 47.35′ W	<20 meters	I
VV-167	59° 40.1' N	141° 21.6' W	68 meters	II
VV-168	59″ 40.1′ N	141° 21.6′ W	68 meters	II
VV-169	59″ 39.2′ N	141° 22.1' w	73 meters	II
VV-170	59″ 38.1′ N	141° 22.5' W	84 meters	II
VV-174	59° 37.2′ N	141° 23.1′ W	91 meters	II
VV-177	59° 36.1′ N	141° 23.5′ W	102 meters	III
VV-180	59″ 35.2′ N	141° 24.5′ W	111 meters	III
VV-183	59° 34.4′ N′	141° 25.1' W ·	121 meters	III
VV-186	59″ 33.3′ N	141° 25.3′ W	132 meters	111
VV-189	59° 32.5′ N	141° 26.4′ W	139 meters	III
VV-192	59° 31.2' N	141° 26.8′ W	150 meters	III
VV-195	59° 36.5′ N	140° 19.2′ W	82 meters	V/II