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283. BENTHONIC FORAMINIFERA OF THE CHUKCHI SEA¹

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ABSTRACT

A total of 116 samples from the shallow southeastern part of the Chukchi Sea contained an Arctic Fauna dissimilar to Northeast Pacific assemblages. Three ecologic units were differentiated by the percentages of *Eggerella advena*, *Buccella frigida*, and *Elphidium clavatum*. Depth, temperature and salinity restricted a few species but the fauna was affected most by sediment type. A diverse calcareous assemblage was found on coarse sediment and an arenaceous assemblage with few species on fine sediment.

INTRODUCTION

North of the Bering Strait is a shallow shelf sea where conditions usually considered important in the ecology of Foraminifera have only slight variations. This is the southeastern part of the Chukchi Sea, (text fig. 1), where bottom gradients are small, the bottom salinities (away from the coast) do not vary more than 1.0 o/oo and the bottom temperatures remain constant for six to eight months when the area is covered by ice. The range of depths, from 20 to 200 feet, is within the shallowest ecologic unit set by other Arctic foraminiferal ecologists (Phleger, 1960). The object of this paper is to interpret the ecologic factors affecting the distribution of the Foraminifera. This study was financed by Atomic Energy Commission Contract AT-45-1-540, Office of Naval Research Contract Nonr-477(10) Project NR 083 012, and National Science Foundation Grant GP 337. The author wishes to express her gratitude to Joe S. Creager, Department of Oceanography, University of Washington, for suggesting and organizing this problem. Appreciation is also extended to Dean McManus and V. Standish Mallory for their helpful suggestions and criticism. Betty J. Enbysk also gave time to critical analysis of the manuscript and guidance in ecologic interpretations. The author is indebted to Creager and McManus for the use of sedimentary, current and bathymetric data from a manuscript in press. The summer physical and chemical data were taken from a technical report by Fleming and staff (1961) and the winter data from an unpublished report of the Department of Oceanography, University of Washington on the 1960 cruise of the U. S. Coast Guard icebreaker NORTH-WIND. The drawings are by Zella Schultz and Janet Griffin.

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The 116 samples used in this study were collected by the M. V. BROWN BEAR, research vessel of the Department of Oceanography, University of Washington, during the summers of 1959 (1 August - 2 September) and 1960 (26 July - 28 August). Text figure 2 shows the locations of the stations.

PREVIOUS WORK IN THE AREA

Previous foraminiferal studies in this area have been meager. LaFond, Dietz, and Pritchard (1949) presented a list of Foraminifera that was compiled from thirty samples scattered throughout the Bering and Chukchi seas, but no indication was given of distribution or frequencies, except that a single foraminifera was noted as being abundant. Carsola (1953) reported the occurrence of Foraminifera from the Beaufort and northern Chukchi seas. His samples were all taken in water deeper than that in the area discussed here. Scholl and Sainsbury (1959) included a list of Foraminifera identified by Patsy Smith (U. S. Geological Survey), which contained most of the predominant species that are identified in the present report, but covered only five stations in the vicinity of Cape Thompson.

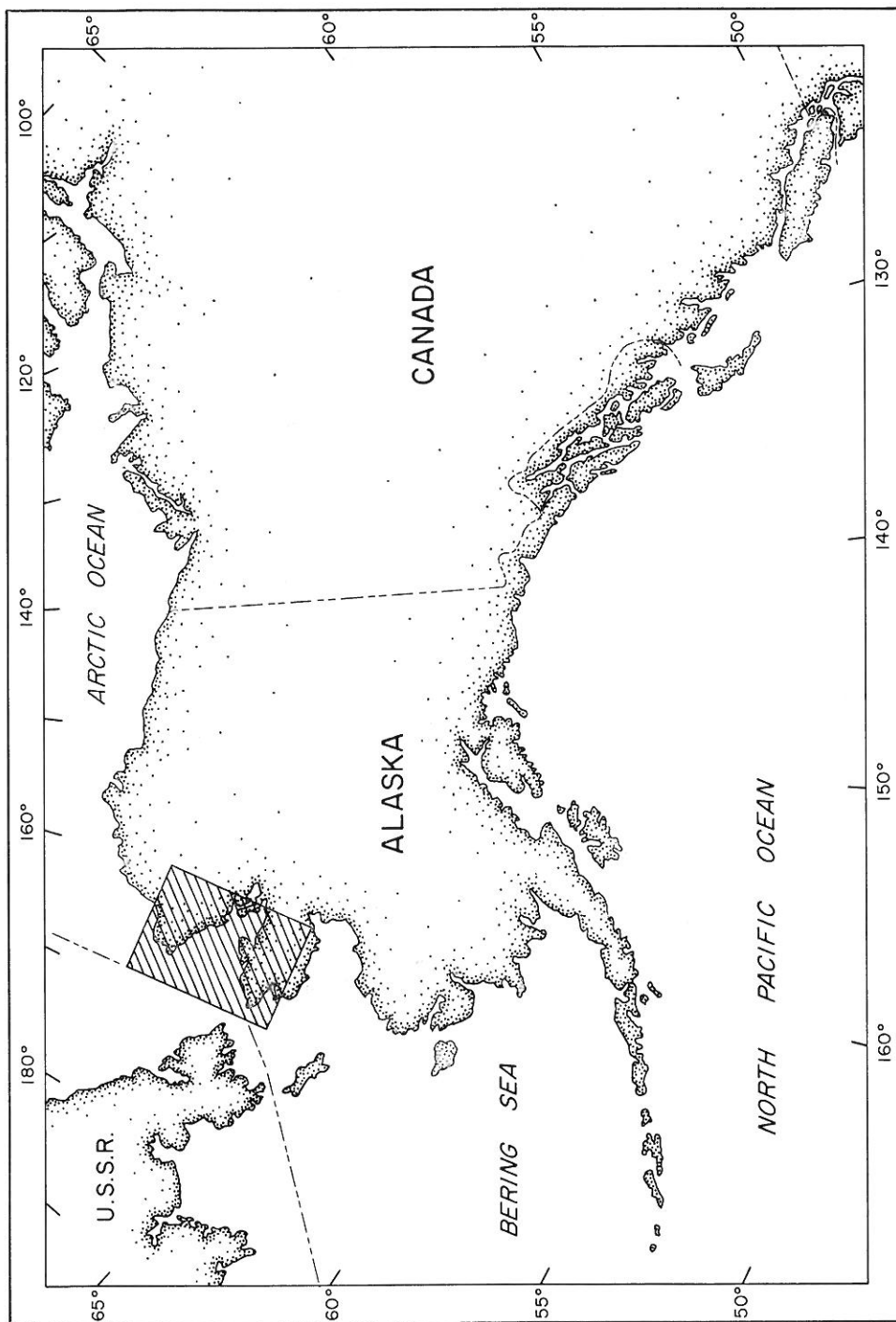
Anderson (1961) had three stations in this area. The assemblages contained the same species in similar percentages as listed in this report. He noted that these stations had unusually high populations in comparison with the northern Chukchi Sea stations.

DESCRIPTION OF THE AREA

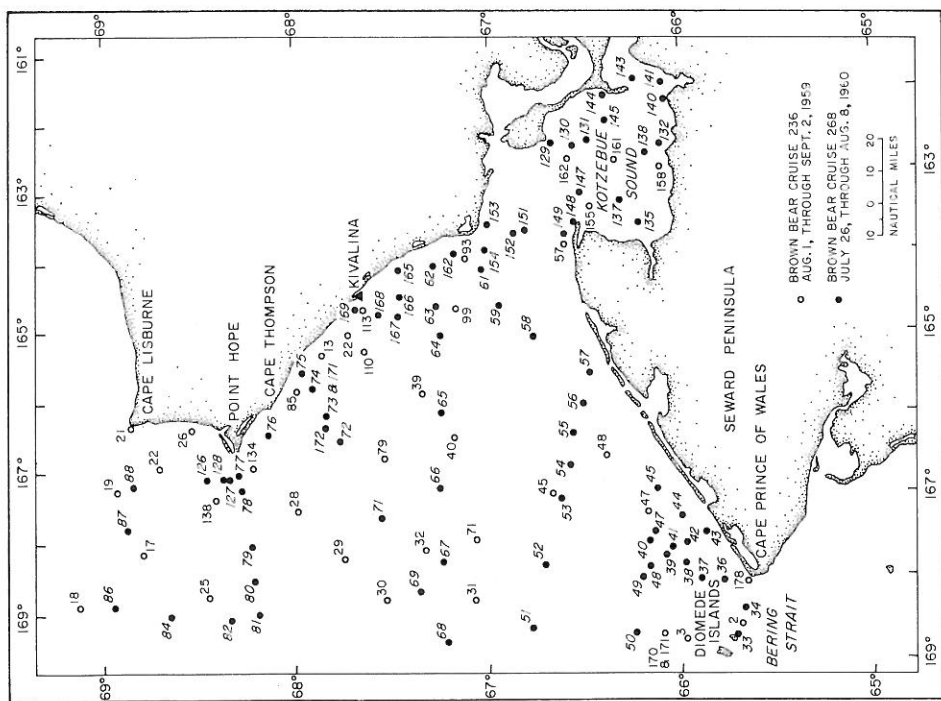
The portion of the Chukchi Sea studied in this paper extends from the Bering Strait (Lat. 65.5°N) to the latitude of Cape Lisburne (69.0°N) and from the Alaskan coast west to 169°W longitude (text fig. 1). It is a large, open embayment with a total area of 20,000 square nautical miles, bounded along most of the eastern perimeter by a low, rolling, poorly drained coastal plain. The southern portion of Kotzebue Sound, the area near Cape Thompson, and most of the coast between Point Hope and Cape Lisburne are bounded by 600 - to 800 - foot shore cliffs.

Bathymetry

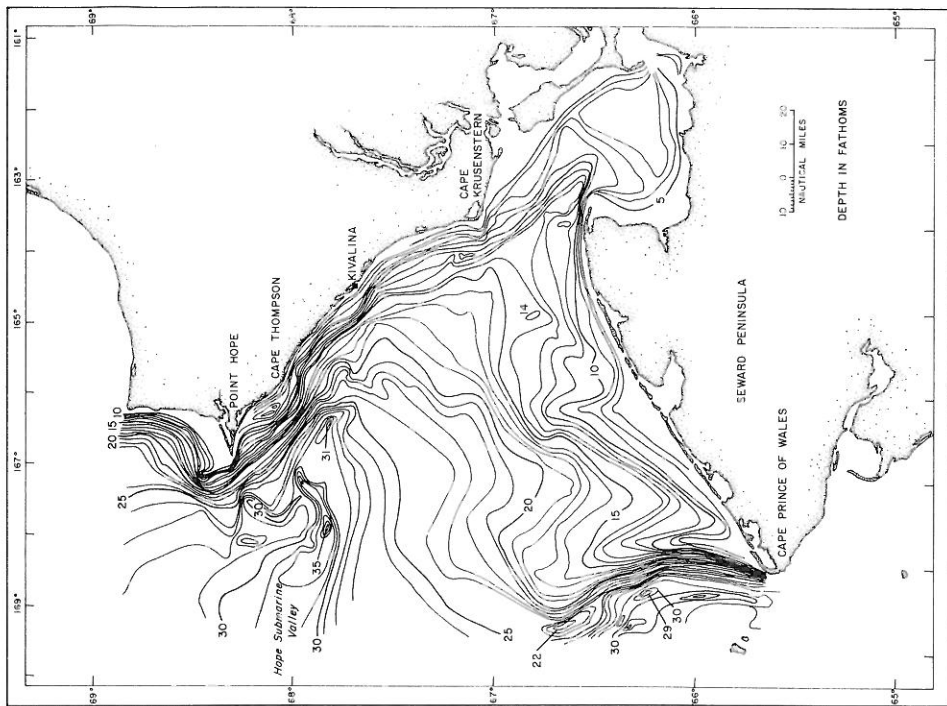
This shelf sea is quite shallow, with depths less than 200 feet, and the bottom is unusually flat (text fig. 3). The gradients in the central area range



TEXT FIGURE 1
Location of study area, the southeast Chukchi Sea.



TEXT FIGURE 2
Location of Stations.



TEXT FIGURE 3
Bathymetry with a contour interval of 1 fathom showing the Hope Submarine Valley and the Prince of Wales Shoal north of Cape Prince of Wales.

from four feet per mile down to tenths of feet per mile. This flat featureless plain is broken only by low relief features such as the shoals at Cape Prince of Wales and Point Hope and the Hope Submarine Valley. Prince of Wales Shoal, which is 80 miles long and 30 miles wide, has maximum gradients of only 31 feet per mile. In general, the depths gradually increase with distance from shore. Kotzebue Sound has depths of less than 40 feet. The shelf is very wide in this Arctic region, 600 miles in many places. Depths are less than 200 feet, 250 to 300 miles seaward of Cape Lisburne.

Currents

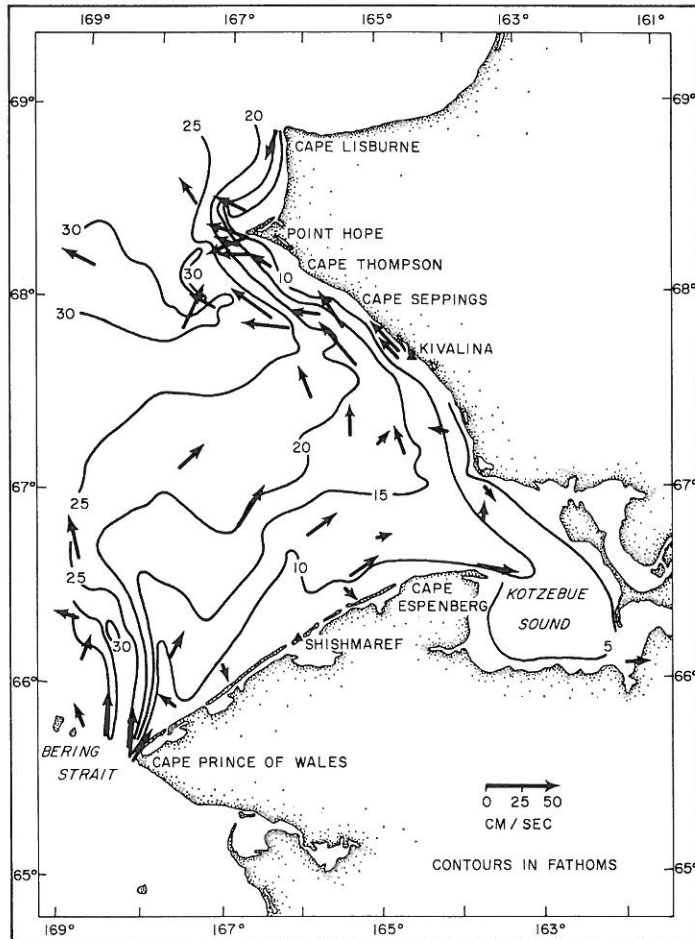
A surface current with an average speed of 15 to 72 cm/sec sets northward through the Bering Strait. This current flows parallel to the isobaths around the north end of Prince of Wales Shoal into the central portion of the embayment and then northwestward along the north side past Point Hope.

In the central portion of the embayment, the average current speeds are reduced to 5 to 25 cm/sec, but along the north side the speeds approach those of the Bering Strait. The currents through the entrance to Kotzebue Sound appear to be tidal (Ozturgut, 1960), flowing in to the south and out to the north with speeds of 4 to 26 cm/sec. Within Kotzebue Sound, the currents are much reduced, with speeds ranging from 8 to 16 cm/sec.

Bottom currents within 20 feet of the bottom reflect the surface currents (text fig. 4). Maximum speeds of 30 to 34 cm/sec were observed in Bering Strait and along the north coast. In the central portion of the embayment, speeds were less than 5 to 25 cm/sec. The average speeds through the entrance to Kotzebue Sound ranged from 4 to 23 cm/sec and within Kotzebue Sound from 8 to 16 cm/sec.

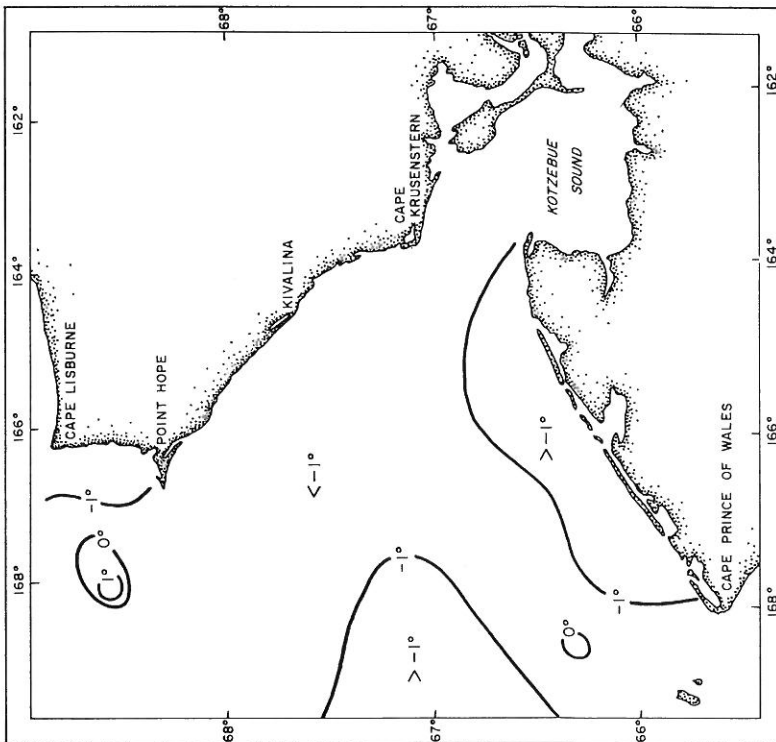
Temperature and Salinity

For seven or eight months, from October or No-



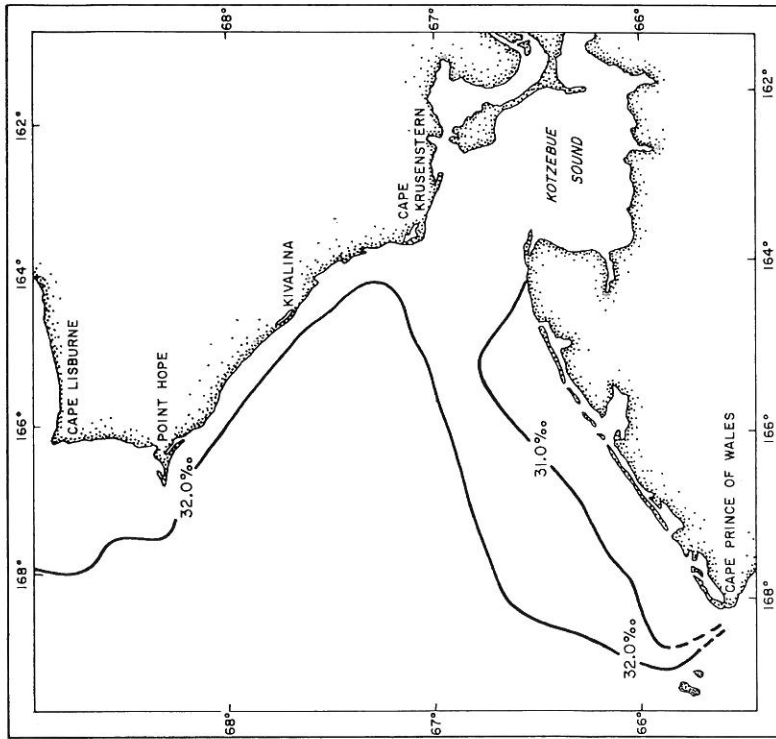
TEXT FIGURE 4

Near bottom currents (within 20 feet of bottom) — after Creager and McManus (in press).



TEXT FIGURE 5

Winter temperatures ($^{\circ}\text{C}$) taken within 5 meters of bottom.



TEXT FIGURE 6

Winter salinities (o/o) taken within 5 meters of bottom.

vember to June, this area is covered with ice. The winter temperatures and salinities taken within five meters of the bottom by the U. S. Coast Guard ice-breaker NORTHWIND in 1960 show very little variation. The temperatures (text fig. 5) vary from -1.8° to $+1.0^{\circ}\text{C}$. The salinities (text fig. 6) are greater than 32 o/oo in the central part of the Chukchi Sea and decrease to 31.0 o/oo along the coasts.

The summer temperatures and salinities (text figs. 7, 8), taken within five meters of the bottom, show more variation. A warm, relatively dilute, coastal water is formed which overrides the cold, more saline, offshore water. In Kotzebue Sound, warm water was found in different places in the two different years so the isotherms were not extended. Two isolated occurrences of cold (0°C), saline (32.5 o/oo) water have been found which were residual from the previous winter (Ozturgut, 1960). Near the river mouths in Kotzebue Sound the salinities are less than 29.0 o/oo.

Oxygen and phosphate values have been examined but no correlation with the fauna could be determined. The oxygen values range from .865 to .539 mg/atoms/liter and phosphates from 2.00 to .72 μ -atoms/liter.

Sediments

The sediment distribution shown in text figure 9 is based on mean particle diameter using phi-notation: $\phi = \log_2 d$ where d = grain diameter in millimeters (Krumbein, 1934, p. 76). The classic picture of the coarse sediment nearshore grading to finer sediment offshore occurs off the northeast coast between Kivalina and Point Hope. But in the area around Bering Strait, the gradation is reversed. There the sediments are gravel in the deeper water of the Strait and grade to coarse silts near Cape Prince of Wales. The finest sediment, clayey silt (three end-member classification of Shepard, 1954), occurs along the northwestern margin in the central portion of the area and in Kotzebue Sound. Gravel is found along the coast between Kivalina and Point Hope and in Bering Strait. The rest of the area is covered by sands.

The sorting is poor in the entire area but the best sorted sediment is found along the Seward Peninsula. Most of Kotzebue Sound has poorly to very poorly sorted silts indicating that this is an area of quiet water deposition. Several deposits of coarse, poorly sorted sediments near the coast of Kotzebue Sound have their source in local cliffs.

The current flowing through Bering Strait decreases in speed after leaving the narrow part of the Strait, diminishing its capacity and producing the deposits of the Prince of Wales Shoal. North of the Strait the sediment size decreases from -2ϕ to the silt sizes of the central area, and the sorting is improved.

PROCEDURE

The 116 samples were collected with a van Veen grab sampler, which penetrates to a maximum depth of 9 inches. The samples were frozen immediately and thawed just prior to analysis. They were split to about 30 grams, a quantity assumed to be representative of the entire sample. They were then dried, weighed and graded into whole phi sizes, according to the Wentworth classification, using the phi transformation. The samples were examined for Foraminifera: the larger phi sizes were picked completely and the 3 and 4 ϕ sizes were split with the Otto Microsplit (Otto, 1933), weighed and a representative fraction examined. Because the samples were previously dried for sediment analysis, it was not possible to stain them with rose bengal to get living-dead ratios. The ratio of Foraminifera per gram was computed from the dry sample weight to give a rough comparison of the abundance of organisms. The identifications were made and the total populations and percentages were computed.

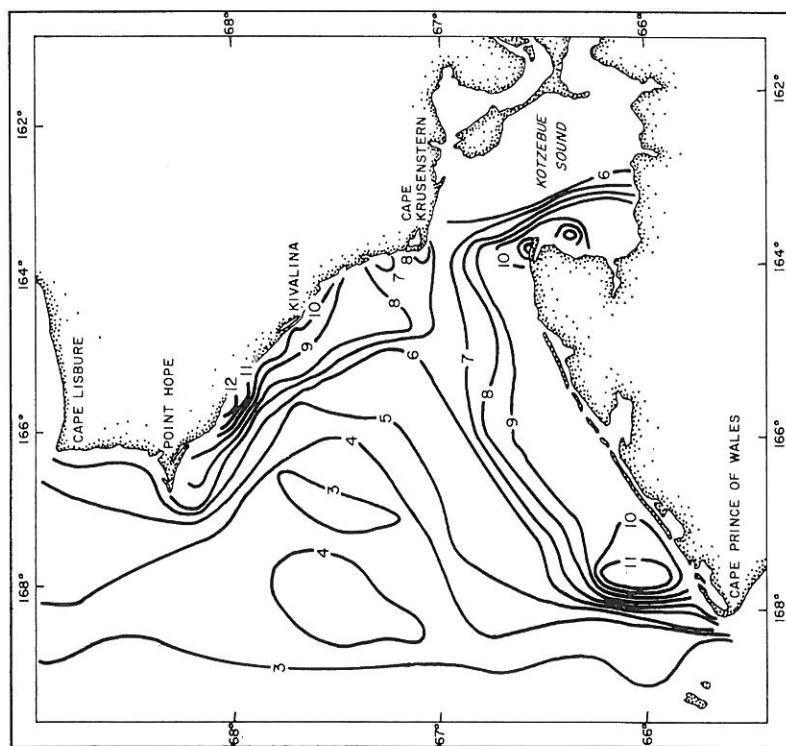
FAUNA

The Chukchi Sea fauna varied from sparse, predominantly arenaceous assemblages to rich calcareous assemblages. The arenaceous Foraminifera were represented by few species but comprised large percentages of some populations. Where the calcareous Foraminifera dominated the populations, many different species occurred. The imperforate calcareous Miliolidae were found rarely.

The number of species was small, even for the Arctic region, but the number of individuals (0-368 tests/gram) was about the same as in the Northeast Pacific (Enbysk, 1960), and in the Bering Sea (Anderson, 1961). The size of the populations varied in different areas. Two stations, 236-162 in Kotzebue Sound and 268-81 west of Point Hope, had no Foraminifera, but nearby stations contained 30-70 tests/gram. Several stations had very high populations, as high as 300 tests/gram, but surrounding stations did not have a corresponding abundance of forms. Foraminifera, like other organisms, may have patchy distributions even under the apparently same ecologic conditions.

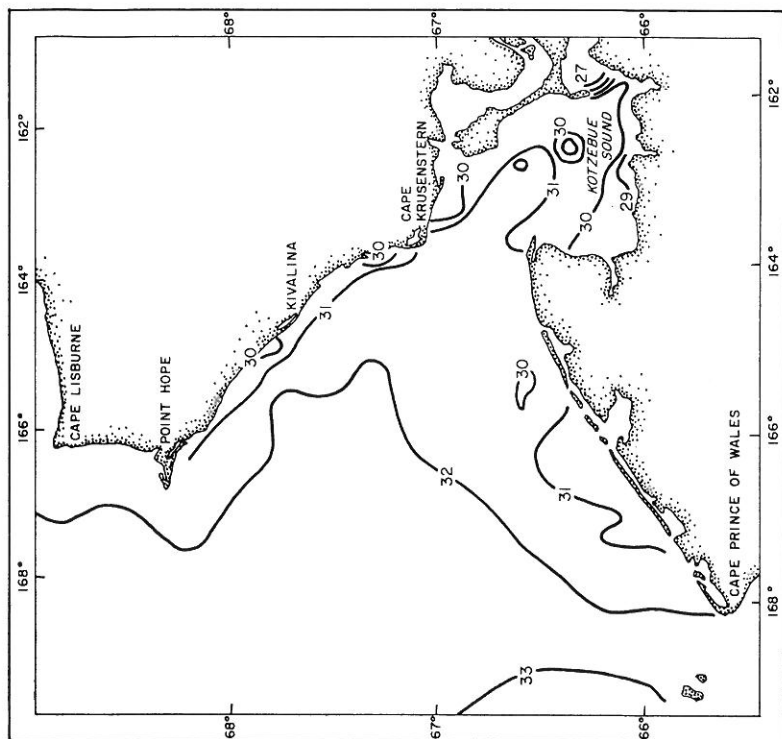
In Bering Strait two stations, 268-48 and 49 (text fig. 2) had unusually high populations, over 230 tests/gram. These stations were surrounded by areas where the populations were about 100 tests/gram. Many juvenile forms were present in the populations and few broken or worn specimens were found which indicate that this probably was an area of high productivity.

The specimens were the same size as those found in the Northeast Pacific (Enbysk, 1960). The only abnormality recorded was bent specimens of *Eggerella advena*. There were several occurrences of *Buccella frigida* attached at right angles while



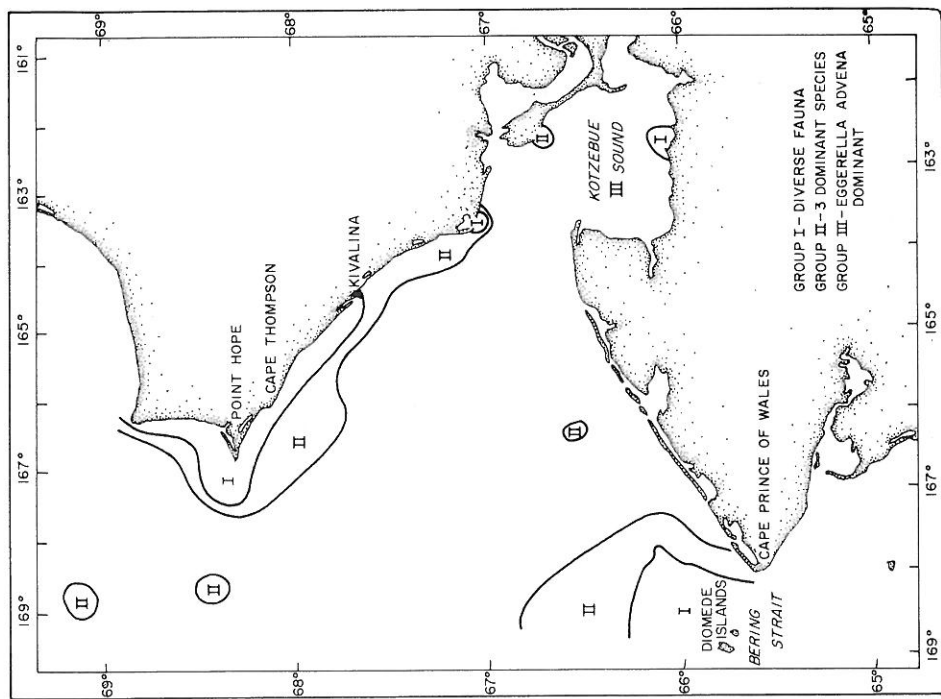
TEXT FIGURE 7

Summer temperatures (°C) taken within 5 meters of bottom. The contours are not extended into Kotzebue Sound as the warmer water was found in different places in two summers.

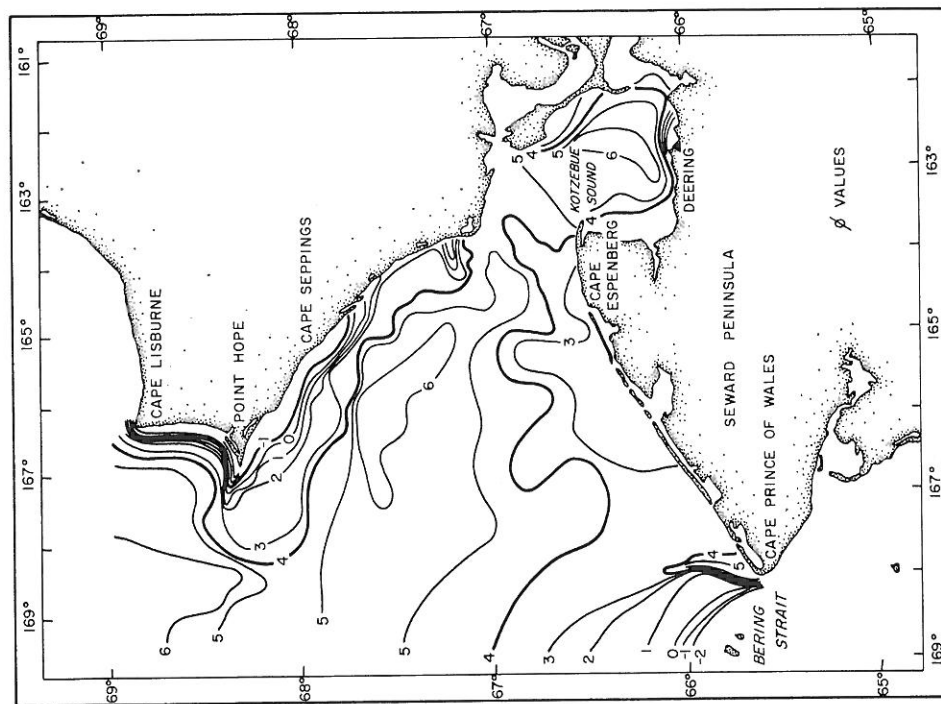


TEXT FIGURE 8

Summer salinities (o/oo) taken within 5 meters of bottom.



TEXT FIGURE 10
Faunal Zones.



TEXT FIGURE 9
Mean particle diameter (ϕ values) — after Creager and McManus (in press).

others had their dorsal sides cemented together, probably in plastogomy.

Faunal Assemblages

Three faunal assemblages were distinguished: (1) a diverse assemblage, (2) an assemblage that was dominated by *Eggerella advena*, *Buccella frigida* and *Elphidium clavatum* and (3) a widespread assemblage that was dominated by arenaceous forms, usually *Eggerella advena*. The areal distribution of each group is shown in text Figure 10. Three species: *Eggerella advena*, *Elphidium clavatum*, and *Buccella frigida* are dominant in the whole area and the degree of dominance is the basis for the differentiation of the assemblages. The characteristic faunal assemblages are listed in Table 1.

Group I is found where the sediment is coarser than 2.0 ϕ : through Bering Strait, along the northeast coast between Kivalina and Point Hope, and at one station near the coast in Kotzebue Sound (text fig. 10). The assemblages are dominated by calcareous forms with as many as 25 species at one

station. The populations may be low, as on very coarse sediment, or unusually high, like the stations north of the Strait, but the characteristic diverse calcareous assemblage is retained. The three dominant species of the entire area are usually present but in small percentages at some stations. *Cibicides lobatulus*, which is usually associated with coarse sediment, *Trochammina squamata*, and *Fissurina marginata* occur only in this group. The *Elphidium* are numerous and varied. Many intergradations exist between the end member forms of *Elphidium* species.

Group II is found where the sediments have a mean size of about 3.0 ϕ , on Prince of Wales Shoal, and seaward of the first group (text fig. 10). This assemblage is characterized by a large percentage of the three main species. *Eggerella advena*, *Buccella frigida*, and *Elphidium clavatum* comprise about 70 percent of the population. *Eggerella advena* makes up 33 to 66 percent and *Elphidium clavatum* and *Buccella frigida* the remainder. The rest of the species are mainly calcareous. Other

TABLE 1
FAUNAL ASSEMBLAGES

GROUP I	GROUP II	GROUP III
<i>Eggerella advena</i>	<i>Eggerella advena</i>	<i>Eggerella advena</i>
<i>Buccella frigida</i>	<i>Buccella frigida</i>	<i>Buccella frigida</i>
<i>Elphidium clavatum</i>	<i>Elphidium clavatum</i>	<i>Elphidium clavatum</i>
<i>Elphidium bartletti</i>	<i>Elphidium bartletti</i>	<i>Elphidium bartletti</i>
<i>Elphidium orbiculare</i>	<i>Elphidium orbiculare</i>	<i>Elphidium orbiculare</i>
<i>Elphidium subarcticum</i>	<i>Elphidium variants</i>	<i>Textularia torquata</i>
<i>Elphidium frigidum</i>		<i>Reophax arctica</i>
<i>Elphidium variants</i>		<i>Ammotium cassis</i>
<i>Trochammina squamata</i>		<i>Spiroplectammina biformis</i>
<i>Rosalina wrightii</i>		
COSMOPOLITAN SPECIES	SPECIES NOT OCCURRING IN CENTRAL AREA	
<i>Pseudopolymorphina novangliae</i>	<i>Quinqueloculina agglutinata</i>	
<i>Cassidulina islandica</i>	<i>Trochammina lobata</i>	
<i>Nonionella auricula</i>	<i>Rosalina wrightii</i>	
	<i>Asterellina pulchella</i>	
	<i>Cibicides lobatulus</i>	
	RARE SPECIES	
<i>Proteonia atlantica</i>	* <i>Lagena semilineata</i>	
<i>Proteonia fusiformis</i>	* <i>Oolina costata</i>	
<i>Reophax curtus</i>	<i>Oolina globosa</i>	
<i>Reophax nodulosa</i>	* <i>Oolina lineata</i>	
* <i>Reophax scotti</i>	<i>Oolina melo</i>	
<i>Reophax sp.</i>	<i>Fissurina marginata</i>	
* <i>Protoschista findens</i>	<i>Fissurina ventricosa</i>	
<i>Recurvoides turbinatus</i>	* <i>Sigmomorphina gallowayi</i>	
<i>Textularia earlandi</i>	<i>Globulina glacialis</i>	
<i>Quinqueloculina arctica</i>	* <i>Laryngosigma hyalascida</i>	
<i>Quinqueloculina seminula</i>	* <i>Guttulina problema</i>	
<i>Quinqueloculina sp.</i>	<i>Buliminella elegantissima</i>	
* <i>Pateoris hauerinoides</i>	<i>Elphidiella arctica</i>	
<i>Trochammina rotaliformis</i>	<i>Elphidiella groenlandica</i>	
<i>Dentalina sp.</i>	<i>Elphidiella sp.</i>	
<i>Lagena apiopleura</i>	* <i>Bolivina pseudopunctata</i>	
<i>Lagena gracillima</i>	* <i>Cornuspira carinata</i>	
<i>Lagena mollis</i>	<i>Patellina corrugata</i>	
<i>Lagena cf. L. striata</i>	* <i>Buccella inusitata</i>	

* restricted to Group I

arenaceous forms are not uncommon, but do not comprise over 10 percent of the population. Scattered localized occurrences of Group II are found in Kotzebue Sound, the central area and in the extreme northwest region.

Group III is found in the broad central area and Kotzebue Sound, where the mean size of sediment is in the silt range (text fig. 10). Few species, chiefly arenaceous forms, characterize this assemblage. *Eggerella advena* comprises 50 to 97 percent of the total population. At many stations the populations are very low, whereas at others *Eggerella advena* occurs in such abundance that the populations are quite large for this region. Usually several *Elphidium bartletti* or *Elphidium orbiculare* are found in the 1 and 2 ϕ sizes, while the finer fractions contain many arenaceous forms. *Ammobaculites cassis*, *Spiroplectammina biformis* and *Reophax arctica* are the common arenaceous Foraminifera besides *Eggerella advena*. In a few stations in the northwest region and in Kotzebue Sound, these species occur in such numbers that *Eggerella advena* comprises less than 50 percent of the population. The assemblages are still characteristically dominated by arenaceous forms and have few species; thus they are included in this group.

Table 1 lists the species characteristic of each faunal assemblage, restricted species, and species that occur throughout the whole area. *Pseudopolymorphina novangliae*, *Cassidulina islandica*, and *Nonionella auricula* are found in small percentages at scattered stations over the entire area. *Quinqueloculina agglutinata*, *Rosalina wrighti*, *Trochammina lobata* and *Asterellina pulchella* are found

near the coasts and in Kotzebue Sound in a wide range of depths, but never occur in the broad central area. *Trochammina lobata* is found only where the salinity is less than 31.5 o/oo. The species listed under "Rare" occur at a few scattered locations in frequencies of about 1 percent. Those marked with an asterisk (*) are restricted to Group I.

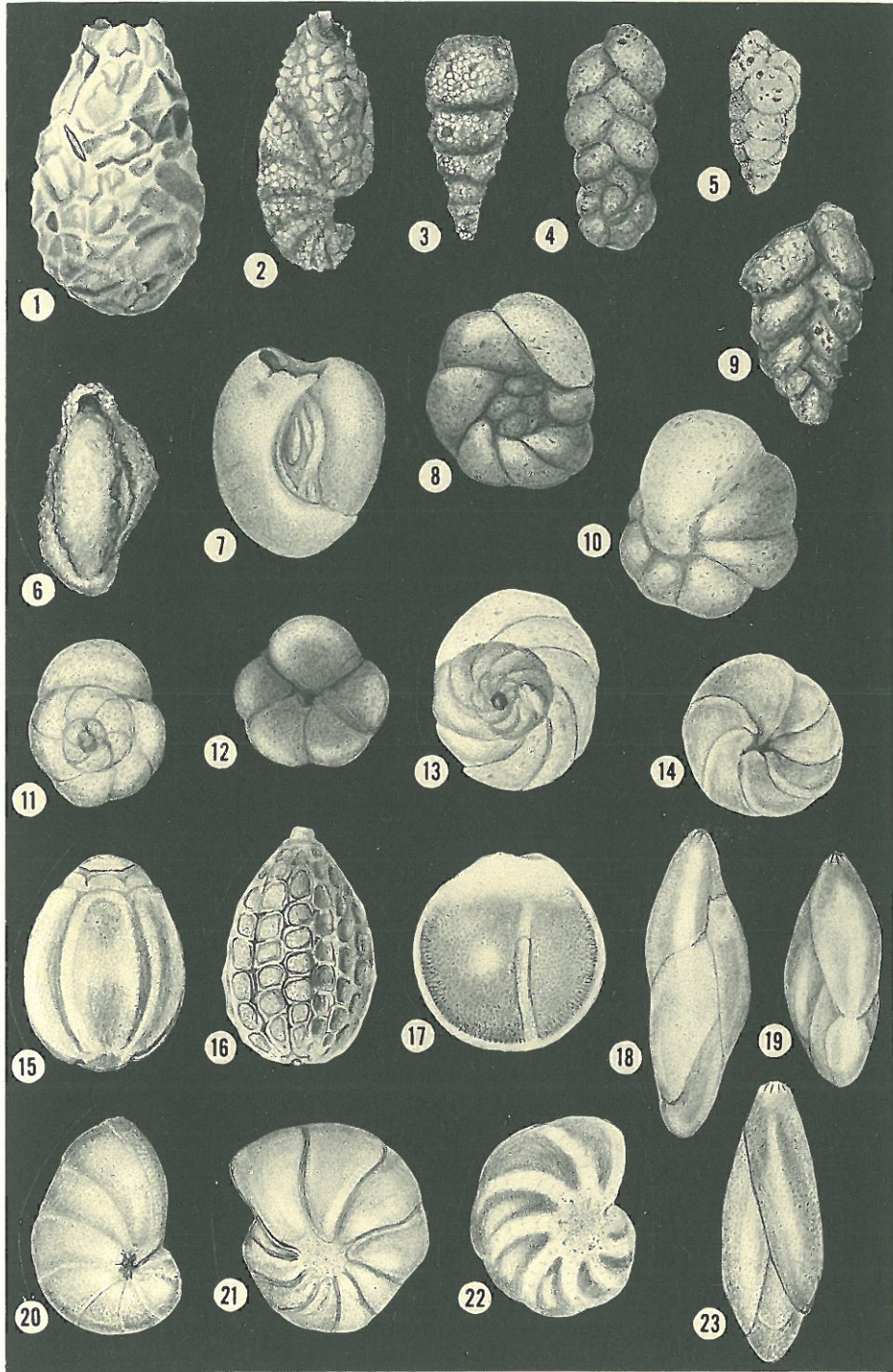
Prince of Wales Shoal and Kotzebue Sound. There are two areas in the Chukchi Sea, Kotzebue Sound and Prince of Wales Shoal, which show that sediment size is an important factor in foraminiferal distribution. In Kotzebue Sound, the depths are less than 40 feet and tides and currents are weak. The salinity is less than 31.5 o/oo and drops to 23.0-26.0 o/oo where rivers flow into the Sound. The temperatures fluctuate seasonally as much as 12°C. It is not known whether the pockets of cold, saline water which have been reported, persist through several seasons. Ozturgut (1960) suggests that the tides and currents do not flush Kotzebue Sound. The assemblage at one station within this anomalous water had a higher number of species than nearby stations, but was still dominated by arenaceous forms, while another was barren. Near the coast in Kotzebue Sound where the salinity is less than 30.0 o/oo, *Buccella frigida* is not found but it occurs in areas of low salinity in the Chukchi Sea.

Most of the Sound contains fine (3.5 to 6.0 ϕ) sediment; however, at one location near the coast there is a coarse sediment with a mean size of 0.9 ϕ . The assemblage which occurs at this station contains only five percent arenaceous Foraminifera,

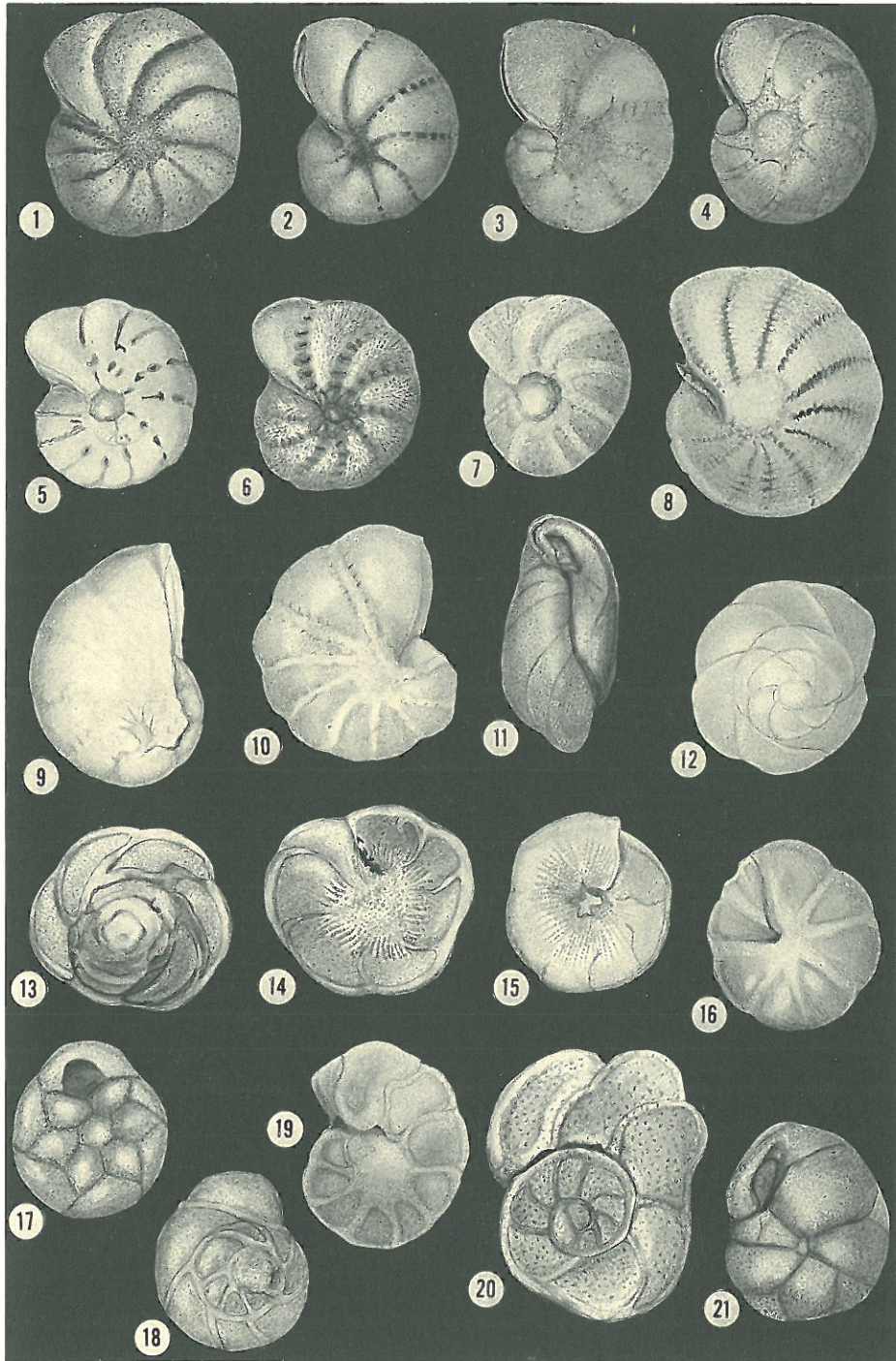
EXPLANATION OF PLATE 5

(Size of hypotypes after each specific name, in parentheses)

FIGS.	PAGE
1. <i>Proteonia atlantica</i> Cushman. (1.78 mm) \times 29	92
2. <i>Ammotium cassis</i> (Parker). (0.70 mm) \times 67	92
3. <i>Reophax arctica</i> Brady. (0.24 mm) \times 153	92
4. <i>Spiroplectammina biformis</i> (Parker and Jones). (0.31 mm) \times 131	92
5. <i>Eggerella advena</i> (Cushman). (0.34 mm) \times 88	94
6. <i>Quinqueloculina agglutinata</i> Cushman. (0.45 mm) \times 85	94
7. <i>Pateoris hauerinoides</i> (Rhumbler). (0.45 mm) \times 85	94
8. <i>Trochammina lobata</i> Cushman. (0.4 mm) \times 86	94
9. <i>Textularia torquata</i> F. Parker. (0.28 mm) \times 142	94
10. <i>Trochammina lobata</i> Cushman. (0.4 mm) \times 94	94
11. <i>Trochammina rotaliformis</i> Wright. (0.18 mm) \times 166	94
12. <i>Trochammina rotaliformis</i> Wright. (0.13 mm) \times 207	94
13. <i>Trochammina squamata</i> Parker and Jones. (0.4 mm) \times 90	94
14. <i>Trochammina squamata</i> Parker and Jones. (0.18 mm) \times 162	94
15. <i>Lagena apiopleura</i> Loeblich and Tappan. (0.24 mm) \times 162	94
16. <i>Oolina melo</i> d'Orbigny. (0.44 mm) \times 97	94
17. <i>Fissurina marginata</i> (Montagu). (0.33 mm) \times 109	94
18. <i>Pseudopolymorphina novangliae</i> (Cushman). (0.82 mm) \times 68	95
19. <i>Pseudopolymorphina novangliae</i> (Cushman). (0.61 mm) \times 69	95
20. <i>Nonionella auricula</i> Heron-Allen and Earland. (0.54 mm) \times 72	95
21. <i>Elphidium orbiculare</i> (Brady). (0.54 mm) \times 69	95
22. <i>Elphidium subarcticum</i> Cushman. (0.84 mm) \times 43	95
23. <i>Pyrulina gutta</i> (d'Orbigny). (0.37 mm) \times 137	94



Cooper: Foraminifera of the Chukchi Sea



Cooper: Foraminifera of the Chukchi Sea

while nearby stations contain 50 to 80 percent arenaceous forms.

In general, the faunal assemblages are in Group III, with the exception of the station on coarse sediment, which is in Group I. Arenaceous forms dominate but a wider variety of species is found than in the broad central area.

Four species, *Pyrulina gutta*, *Asterellina pulchella*, *Textularia torquata* and *Ammotium cassis* occurred often with frequencies up to 10 percent. One arenaceous species, *Spiroplectammina biformis*, which was present at stations deeper than 100 feet in the northwest and central region, was not found in the sound. *Elphidiella groenlandica* occurred only in Kotzebue Sound except for one station south of Kivalina near the coast.

The temperatures vary so much that all the species which occur probably are able to withstand a wide seasonal range. Salinity variations affect the

assemblages slightly, but a change in sediment type completely alters the fauna.

Although the Prince of Wales Shoal is one of the most prominent topographic features of the Chukchi Sea, it has a very low gradient: 31 feet per mile on the current slope and 10 feet per mile on the eastern slope. Text figure 11 shows the sedimentary environments delineated by McManus and Creager. The sediments in the strait are gravel and sand, while those on the current slope are fine sands and silts. The shoal crest has fine sand and on the sheltered eastern slope a moderately sorted very fine sand is found. The changing percentages of *Elgerella advena* and *Buccella frigida* in these areas are shown in Table 2.

The percentages of *Buccella frigida* and *Elgerella advena* vary from the strait to the eastern slope with the greatest change occurring between the strait and the current slope where there is the most

TABLE 2
Percentages of *Buccella frigida* and *Elgerella advena* across shoal

STRAIT			CURRENT SLOPE			SHOAL CREST			EASTERN SLOPE		
STA.	PERCENT B	E	STA.	PERCENT B	E	STA.	PERCENT B	E	STA.	PERCENT B	E
236-2	19	8	268-36	2	51	268-39	19	24	236-47	2	98
3	20	1	38	10	63	42	0	49	268-40	10	55
170	17	0	48	0	75	43	2	91	41	11	51
268-33	18	11							44	16	77
34	19	9							45	2	84
37	24	9							47	5	60
49	35	13									
50	15	28									
RANGE	15-38	0-28		0-10	51-75		0-19	24-91		2-16	51-98
AVG.	20	10		4	63		7	55		8	71

EXPLANATION OF PLATE 6

(Size of hypotypes after each specific name, in parentheses)

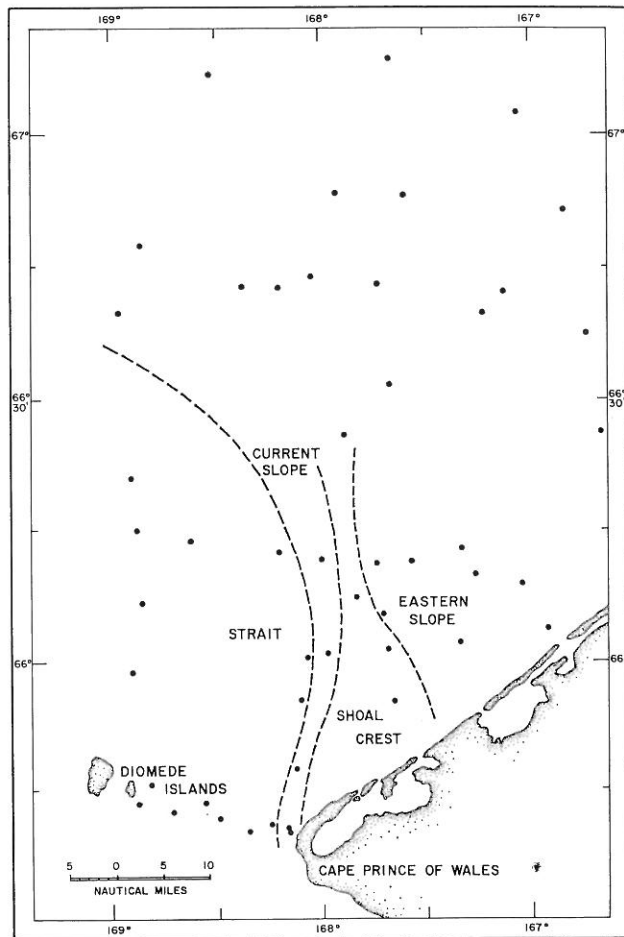
FIGS.		PAGE
1.	<i>Elphidium bartletti</i> Cushman. (0.58 mm) × 68	95
2.	<i>Elphidium bartletti</i> Cushman. (0.45 mm) × 82	95
3.	<i>Elphidium frigidum</i> Cushman. (0.42 mm) × 91	95
4.	<i>Elphidium frigidum</i> Cushman. (0.22 mm) × 170	95
5.	<i>Elphidium clavatum</i> (Cushman). (0.44 mm) × 77	95
6.	<i>Elphidium clavatum</i> (Cushman). (0.38 mm) × 89	95
7.	<i>Elphidium clavatum</i> (Cushman). (0.21 mm) × 150	95
8.	<i>Elphidiella groenlandica</i> (Cushman). (0.78 mm) × 57	95
9.	<i>Elphidiella</i> sp. (0.83 mm) × 51	102
10.	<i>Elphidiella arctica</i> (Parker and Jones). (1.05 mm) × 40	95
11.	<i>Buliminella elegantissima</i> (d'Orbigny). (0.26 mm) × 164	95
12.	<i>Buccella frigida</i> (Cushman). (0.47 mm) × 91	102
13.	<i>Rosalina wrightii</i> (Brady). (0.66 mm) × 56	102
14.	<i>Rosalina wrightii</i> (Brady). (0.74 mm) × 50	102
15.	<i>Rosalina wrightii</i> (Brady). (0.39 mm) × 75	102
16.	<i>Buccella frigida</i> (Cushman). (0.47 mm) × 91	102
17, 18.	<i>Asterellina pulchella</i> (Parker). (0.12 mm) × 256	102
19.	<i>Cibicides lobatulus</i> (Walker and Jacob). (0.33 mm) × 111	102
20.	<i>Cibicides lobatulus</i> (Walker and Jacob). (0.68 mm) × 72	102
21.	<i>Cassidulina islandica</i> Nørvang. (0.47 mm) × 141	102

marked sediment size change. Two factors, depth and water mass properties, have been considered but are not responsible for the faunal shift. The average depth in the strait is 166 feet, on the current slope, 104 feet and on the shoal crest, 57 feet. The depth change between each two adjacent areas is about the same. This does not rule out the possibility that depth is important, but the calcareous fauna in the deep water of the strait is more like the fauna along the northwest coast (Group I) than the other areas over 150 feet, where an arenaceous fauna (Group III) is found. The coastal water mass, with high summer temperatures and low salinities, extends to the western side of the current slope. The abrupt change in faunal assemblage might be linked to this, but the assemblages of the shoal crest and the eastern slope are similar to the assemblages in the broad central area (Group III),

not to the other coastal areas where this warm, dilute water is present (Group I).

COMPARISON WITH OTHER SHALLOW COLD WATER FAUNAS

The fauna of the Chukchi Sea has many of the same species as the faunas found along the eastern continental shelf of North America by Parker (1948, 1952), Phleger (1952 a & b), and Athearn (1954). However, there are fewer species in the Chukchi Sea than any of the eastern faunas except off the Labrador coast, where Athearn reported only six species as abundant. Phleger (1952a) found a correlation between sediment type and Foraminifera in the Gulf of Maine, but as depth and sediment type varied together and the restricted Foraminifera were found nearby on different types of sediment, he concluded that the distribution was



TEXT FIGURE 11

Enlarged view of Prince of Wales Shoal showing sedimentary environments (after McManus and Creager, in press).

affected more by depth and other ecologic factors than by sediment type.

Phleger (1952b) reported a fauna from the Canadian and Greenland Arctic that contained only a few species which were not found in the Chukchi Sea. *Cassidulina norcrossi* was found in large percentages. *Haplophragmoides glomeratum* and *Protonina atlantica* also occurred frequently in the shallow samples, but they are found rarely in the Chukchi Sea.

Loeblich and Tappan (1953) reported a faunal change with a change in sediment type off Point Barrow, Alaska. This took place in shallow water, less than 50 meters, or the same depths as the Chukchi Sea. They found a diverse fauna on very coarse sediment and a meager fauna associated with mud.

Samples taken off the southwest coast of Japan (Uchio, 1959) contained a shallow water fauna that has a remarkable resemblance to the Chukchi Sea assemblages. The depth zonations at 20 meters and 50 meters were marked by shifts in frequency of *Pseudonion japonicum*, *Buccella frigida*, *Elphidium clavatum*, and *Eggerella advena*. The described area had three currents, two warm and one cold, which fluctuated over the area. Seasonal variations of temperature and salinity were also recorded and affected the fauna to a depth of 50 meters. No correlation of the assemblages with sediment type was attempted but it was noted that lower populations occurred with an increase in pumice grains in the sediment.

Saidova (1960) recognized 21 different assemblages in the Okhotsk Sea based on depth, temperature, salinity, oxygen, sediment type and locality. *Buccella frigida* was cosmopolitan and *Elphidium clavatum* had a broad range. In general, the species found in the shallow areas are common to the Chukchi Sea. However, the calcareous forms were dominant in most of the shallow areas with one exception, and the arenaceous species of that sample were not found in the Chukchi Sea.

In the western part of the Bering Sea, Beljaeva (1960) also found a predominance of calcareous forms in five shelf faunas. These faunas include species found in the Chukchi, but there were also many other calcareous forms.

Both Saidova and Beljaeva found mainly calcareous forms in shallow water. No shallow arenaceous assemblage was described that was similar to those of the Chukchi Sea. The same species were identified, but there were fewer arenaceous forms in actual numbers and in comparison with the calcareous populations. Reported total populations varied from 20 to 600 forms for 50 grams of sediment. This appears to be low in comparison with the 0.4-368 tests/gram found in the Chukchi Sea,

but the method of sampling was different. The method described by Saidova (1956) is to take 50 grams of sediment from the grab sampler and wash it through a 20 x 15 cm sack of Miller's gauze No. 61 which retains particles larger than 0.1 mm (3.33 ϕ). Since the sediment is weighed wet and only sediment coarser than 0.1 mm is picked, the total population cannot be compared with populations in this report which are calculated from a dry weight and are picked from sediment coarser than .062 mm (4.0 ϕ). Many *Reophax arctica* and *Eggerella advena* were found in the fraction finer than 3 ϕ .

In the Northeast Pacific, Enbysk (1960) did not find *Rosalina wrightii*, *Asterellina pulchella* or *Textularia torquata*, and found only a few *Reophax arctica*. However, many Foraminifera of the Pacific fauna are not found in the Chukchi Sea. Only one species each of *Bulimina*, *Cassidulina* and *Nonionella* were found and there were no *Bolivina*, *Uvigerina*, *Angulogerina*, or *Robulus*. All these forms were numerous in the shallow water of the Gulf of Alaska. *Globulimina auriculata*, which was found both in the Pacific and near Point Barrow (Loeblich and Tappan, 1953) does not occur in this area. Calcareous forms were dominant in the majority of shelf stations (less than 100 fathoms) along the coasts of Alaska, Vancouver Island and Washington.

Anderson (1961) found that the inner shelf assemblage in the Bering Sea was similar to the fauna of the Chukchi Sea. He also recorded few species, and arenaceous forms dominate at most stations. The assemblages which occurred north of Cape Lisburne contained the same species as those listed in this report. *Spiroplectammina biformis* was abundant only in the Chukchi Sea. In restricted brackish environments, *Elphidium clavatum* dominated the samples but stations just outside the bay or inlet were dominated by *Eggerella advena*. Salinity was recorded as the major factor affecting distribution. Sediment size analyses were not run for any open ocean stations, but the percentages of *Elphidium clavatum* and sand seemed to vary together in Elson Lagoon and Newak Lake.

DISCUSSION

The fauna of the Chukchi Sea contains species that are circumpolar. These species have joint occurrences in the shallow areas of the Okhotsk, Bering and Chukchi seas as well as the Canadian and Greenland Arctic. The paucity of arenaceous forms in Russian faunas may be due to differences in sampling methods. However, shallow stations along the Aleutian Islands, Alaska, Vancouver Island and Washington were dominated by calcareous forms, very different from the Arctic species. The Aleutian Islands may be an effective block but the similarity of the Japanese and Arctic faunas is an interesting factor. More study is needed to determine if similar

rigorous conditions produced the Japanese fauna or if there are real connections.

In the Chukchi Sea, which is shallower than the depth boundaries of Stschedrina (1953), Carsola (1953), and Phleger (1960), definite faunal variations were noted. Where temperature, salinity, and other conditions have large seasonal fluctuations, it is likely that factors other than depth become important for the distribution of Foraminifera, such as sediment size.

Phleger (1960) has included *Eggerella advena*, *Buccella frigida*, *Elphidium subarcticum*, *Trochammina lobata* and *T. squamata* in the list of species that are common to more than one environment. He suggested that they are primarily adapted to inner continental shelf water, and thus are able to withstand variable conditions. It is particularly significant that these species make up most of the fauna of the southeastern Chukchi Sea, bearing out Phleger's conclusions. *Eggerella advena* seems to thrive in different shelf conditions throughout the world. In this area it dominates many of the populations and sometimes occurs in numbers as high as 100 tests/gram.

The small number of species compared to other Arctic areas suggests conditions which are conducive only to hardy Foraminifera. During the winter months when the area is covered by ice, bottom temperatures remain very cold. This might be one of the reasons for the small number of species, but other shallow Arctic areas, except the Bering Sea and Labrador coast, contain at least 15 species in each sample, while many stations in this area have only 5 or 6 species.

The salinity does not vary seasonally more than 1.0 o/oo except in Kotzebue Sound, which contains all but three of the significant species. Several Foraminifera are affected by depth and salinity, but in this area the assemblages are more reasonably correlated with change in sediment type. On coarse sediment a diverse calcareous assemblage is present and on the fine sediment an arenaceous assemblage with few species occurs.

SUMMARY

1) The Chukchi Sea fauna is a meager Arctic fauna that is predominately arenaceous.

2) In this area ecologic units can be differentiated by the percentages of *Eggerella advena*, *Buccella frigida* and *Elphidium clavatum*.

3) Depth, temperature and salinity changes restrict a few species but have only slight effects on faunal assemblages.

4) In this shallow Arctic Sea where the conditions vary from the wide changes in Kotzebue Sound to the small gradations of the central area, the hardy fauna is affected most by change in sediment type.

DISTRIBUTION OF SPECIES

Proteonia atlantica CUSHMAN, 1944, Special Publication 12, Cushman Laboratory Foraminiferal Research, p. 5, pl. 1, fig. 4.

This species was found at ten stations, five in Kotzebue Sound, two near Bering Strait and three others deeper than 160 feet, associated with a variety of sediment types, temperatures and salinities.

Proteonia fusiformis WILLIAMSON, 1858, Recent Foraminifera of Great Britain, Ray Soc., London, England, p. 1, pl. 1, fig. 1.

This form was present in small percentages at several stations that had predominately arenaceous Foraminifera but a wide range of depths and summer temperatures and salinities. The mean size of sediment ranged from 2.0 to 4.0 ϕ .

Reophax arctica BRADY, 1881, Ann. Magazine Natural History, ser. 5, vol. 8, no. 48, p. 405, pl. 21, figs 2a, b.

This species occurred at forty stations throughout the whole area, but had its greatest concentration at deeper stations with sediment in the silt range, summer temperatures between 2.5°C and 5.0°C and salinities greater than 31.5 o/oo. In these arenaceous dominated assemblages, five stations, (268-66, 68, 71, 82, and 84), *Reophax arctica* constituted over 20 percent of the population, probably replacing *Eggerella advena* which drops from 60-70 percent in surrounding stations, to as low as 33 percent.

Ammotium cassis (PARKER) = *Lituola cassis* PARKER, 1870, in Dawson, Can. Nat. n. ser., vol. 5, pp. 177, 180, fig. 3.

Ammotium cassis was found at twenty-one stations, nine of which were in Kotzebue Sound. Although it occurred at stations with a wide range of depth (32-180 feet), sediment size (1.5-6.00 ϕ), summer temperature (-.06 to 10.40°C), and salinity (30.3-32.7 o/oo) it was found most frequently in percentages over 1.0 percent in Kotzebue Sound.

Spiroplectammina biformis (PARKER and JONES) = *Textularia agglutinans* D'ORBIGNY var. *biformis*. Parker and Jones, 1865, Phil. Trans. Roy. Soc. London, vol. 155, p. 370, pl. 15, figs. 23, 24.

This species occurred at eleven stations, all deeper than 100 feet. Six of these stations were in the northwest region, north of 68°N. latitude (text fig. 12). The summer temperatures and salinities had small ranges from 1.4 to 4.3°C and 31.9 to 32.9 o/oo, whereas the sediment size varied from 2.0 to 6.4 ϕ . Although the small variations of temperatures and salinities are associated with the deeper water of the central and northwest region, this species did not occur at the deeper stations in Bering Strait or near Point Hope.

Textularia earlandi F. PARKER, 1952, Harvard Coll., Museum Comp. Zool. Bull., vol. 106, (1951-1952), no. 10, p. 458, = *Textularia tenuissima*

imens were found at each station. This species was reported by Brady in 2300 fathoms in the North Pacific (Barker, 1960), and by Jarke (1960) in 220 and 380 meters in the Barents Sea.

Pseudopolymorphina novangliae (CUSHMAN) = *Polymorphina lactea* (WALKER and JACOB) var. *novangliae* CUSHMAN, 1923, Bull. 104, U. S. Nat. Mus., pt. 4, p. 146, pl. 39, figs. 6-8.

This species occurred at ten stations throughout the whole area and did not appear to be limited by region or conditions. Several smaller, more rounded forms were found but they probably were young specimens.

Buliminella elegantissima (D'ORBIGNY) = *Bulimina elegantissima* D'ORBIGNY, 1839, Voyage dans l'Amerique Meridionale, Foraminiferes, vol. 5, pt. 5, p. 51, pl. 7, figs. 13, 14.

This species occurs at four stations, three on Prince of Wales Shoal and one near Point Hope, in percentages less than 1 percent. Phleger (1960) listed this as an open ocean species and all the stations where it occurred had salinities greater than 31.5 o/oo.

Nonionella auricula HERON-ALLEN and EARLAND, 1930, Journal Royal Micro. Soc. ser. 3, vol. 50, p. 192, pl. 5, figs. 68-70.

This species was widespread and occurred in percentages up to 12.2 percent. Most of the twenty-two stations were northwest of Point Hope and near Cape Thompson, but a few were scattered through the central area and in Bering Strait. No preference for sediment type was shown. The summer temperatures were around 2.5°C and the summer salinities above 31.0 o/oo except for a few shallow stations. This species occurred in significant numbers in different conditions.

Elphidium bartletti CUSHMAN, 1933, Smithsonian Inst. Misc. Coll., vol. 89, no. 9, p. 4, pl. 1, fig. 9.

This *Elphidium* species occurred commonly in the entire area, but had its highest percentages along the northeast coast, and to the north of Bering Strait and on Prince of Wales Shoal. In Group III assemblages, it occurred in frequencies of less than 7 percent. Plate 6, figures 1 and 2 illustrate the variations which occurred. In smaller forms, it was difficult to distinguish from *E. subarcticum*, *E. frigidum*, and occasionally *E. orbiculare*. The *Elphidium* genus is notorious for intergradations between species and this area is no exception. Complete suites of specimens could be laid out, grading from every *Elphidium* species to another.

Elphidium clavatum (CUSHMAN) = *Elphidium incertum* var. *clavatum* CUSHMAN, 1930, U. S. Nat. Mus. Bull. 104, pt. 7, p. 20, pl. 7, fig. 10.

One of the three dominant species of the area, *E. clavatum* varied from a translucent yellow pinnate

texture to a porcellaneous one, occasionally on different chambers of the same specimen. The elaborate umbilical boss and retral processes made this form distinctive. It occurred at almost all stations, but had its highest frequencies on Prince of Wales Shoal and near Point Hope. There were several scattered stations in Kotzebue Sound, the central area and north of Point Hope, with frequencies over 30 percent.

Elphidium frigidum CUSHMAN, 1933, Smithsonian Misc. Coll., vol. 89, no. 9, p. 5, pl. 1, fig. 8.

This species was found where the calcareous forms were dominant; near the Bering Strait, and two stations off Point Hope and at two stations near Kivalina, and did not occur in any other areas.

It graded into *E. subarcticum* and *E. bartletti*. A smaller form without the striae similar to the small holotype of Loeblich and Tappan (1953), pl. 18, fig. 10 is figured on plate 6, fig. 4.

Elphidium orbiculare (BRADY) = *Nonionina orbicularis* BRADY, 1881, Ann. Mag. Nat. Hist., ser. 5, vol. 8, no. 48, p. 415, pl. 21, fig. 5a, b.

This robust form was present at many stations throughout the entire area. In Group III assemblages, a few large specimens of *E. orbiculare* and *E. bartletti* often were the only forms present besides the three dominant species. The highest percentages occurred along the northeast coast from Kivalina to Cape Lisburne and north of Bering Strait.

Elphidium subarcticum CUSHMAN, 1944, Cushman Lab. Foram. Res., Spec. Publ. 12, p. 27, pl. 3, figs. 34, 35.

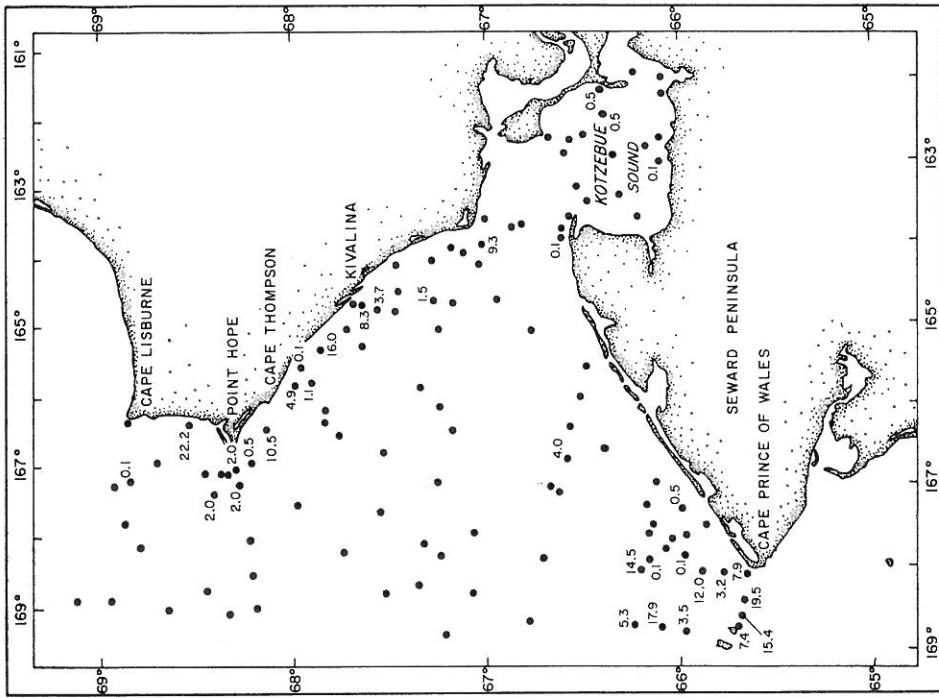
This species is found in Group I assemblages, along the northwest coast and in Bering Strait where there are many other *Elphidium* species. The wide band along the sutures is present in the larger forms but the smaller specimens grade into *E. frigidum*.

Elphidiella arctica (PARKER and JONES) = *Polystomella arctica*, PARKER and JONES, 1864, in H. B. Brady, Trans. Linn. Soc. London, Zool., vol. 24, pt. 3, p. 471, pl. 48, fig. 18.

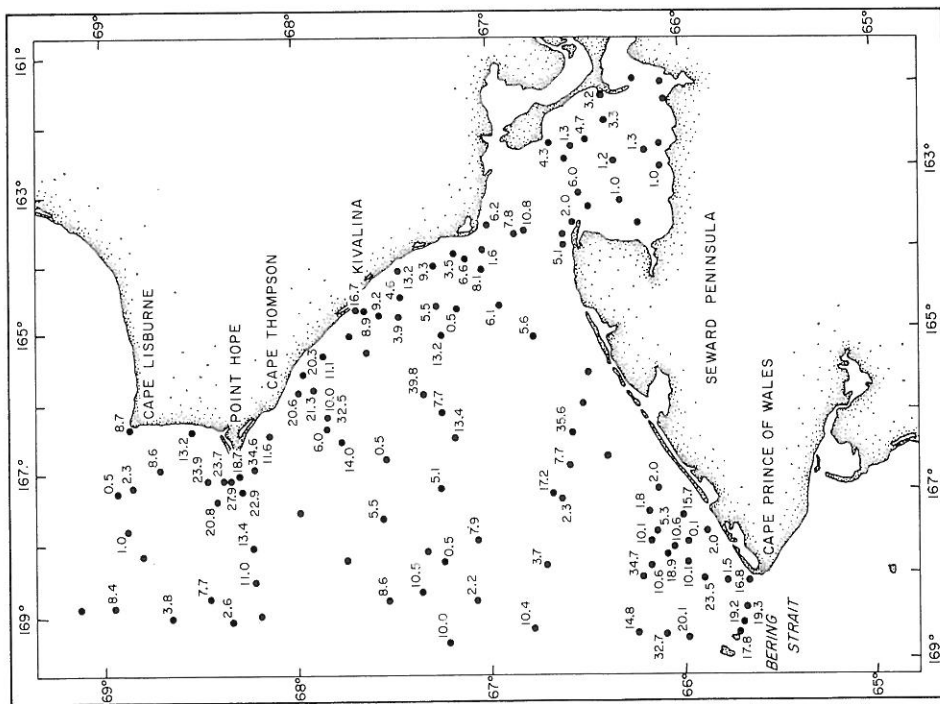
This species was found at eight stations on coarse sediments, seven near Bering Strait and one off Point Hope. Most of the assemblages were in Group I, and all of them were at depths greater than 120 feet, salinities greater than 32.4 o/oo and temperatures less than 3.5°C.

Elphidiella groenlandica (CUSHMAN) = *Elphidium groenlandicum* CUSHMAN 1933, Smithsonian Inst. Misc. Coll., vol. 89, no. 9, p. 4, pl. 1, fig. 10.

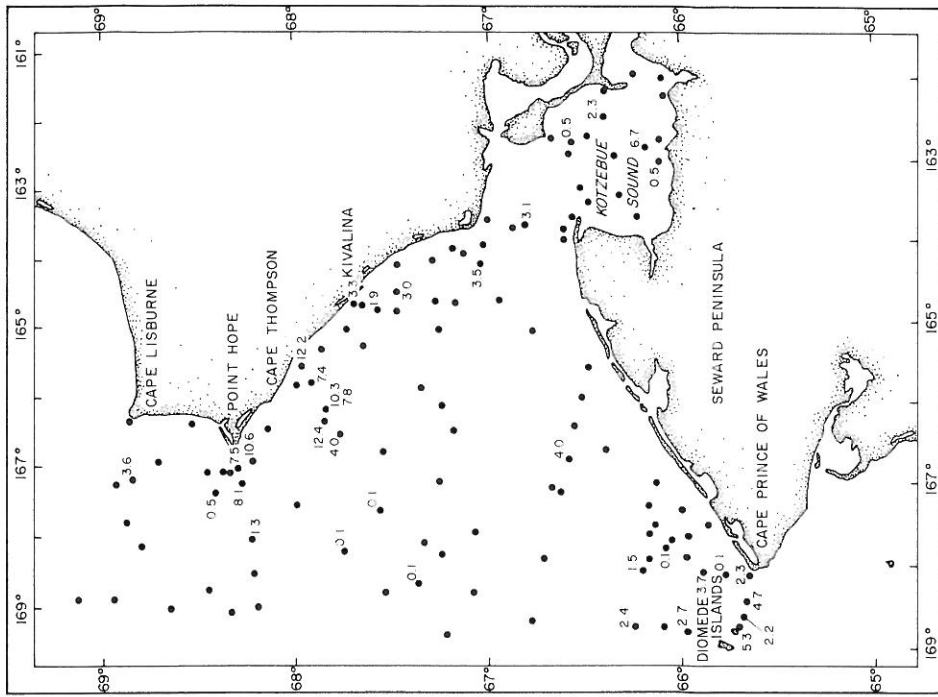
This distinctive form was found only in Kotzebue Sound and at one station south of Kivalina. The depths were less than 60 feet, and the temperatures and salinities had wide annual fluctuations. The



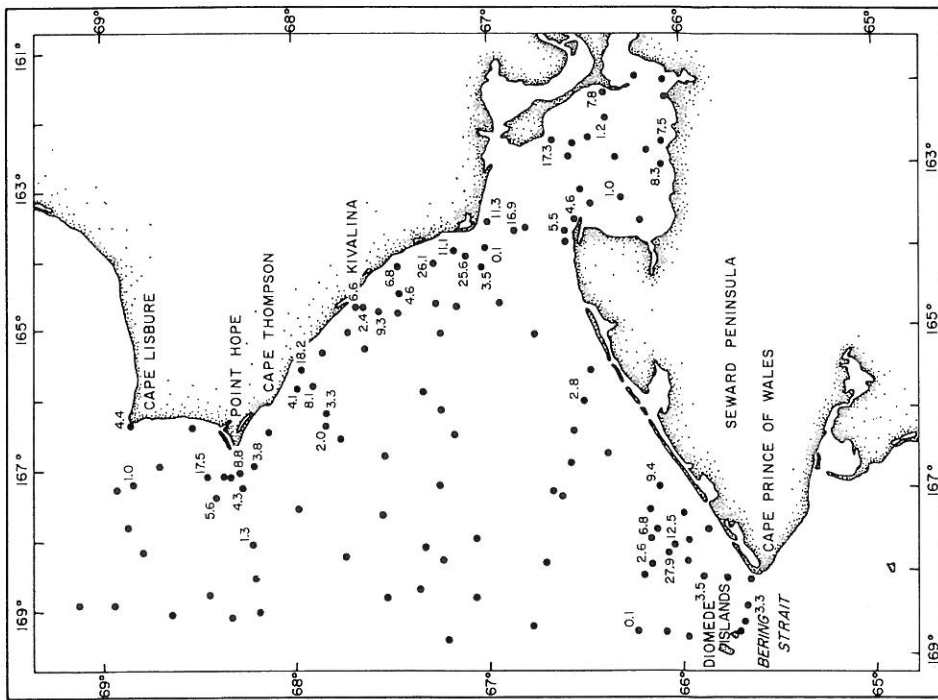
TEXT FIGURE 15
Distribution of *Rosalina wrighthii* (Brady)
in percent of total population.



TEXT FIGURE 14
Distribution of *Buccella frigida* (Cushman)
in percent of total population.



TEXT FIGURE 17
Distribution of *Cassidulina islandica* (Nørvang)
in percent of total population.



TEXT FIGURE 16
Distribution of *Asterellina pulchella* (F. Parker)
in percent of total population.

mean sediment sizes were finer than 3.3 ϕ . Loeblich and Tappan noted that this species may be a fossil from Pleistocene sediments but in this region every station where a worn specimen was found there were several fresh specimens.

Elphidiella sp.

This form appeared at stations 236-3, 170, 268-33, 34 and 49. The porcellaneous texture, heavy test and flat sides with the final chamber covering the umbilical region distinguished this species from *E. arctica*. In many cases the sutural pores were indistinct. The specimen illustrated in Plate 6, figure 9 shows the striations at the base of the last chamber which occurred in some forms.

Buccella frigida (CUSHMAN) = *Pulvinulina frigida* CUSHMAN, 1922, Contr. Can. Biol. no. 9 (1921), p. 12, (144).

This widespread species was found in the greatest percentages in Bering Strait, on Prince of Wales Shoal and along the northeast coast (text fig. 14). However, two stations, 236-39 and 268-39, in the central area had unusually high frequencies, over 35 percent. Many stations in Kotzebue Sound did not contain *B. frigida* and three stations on the Seward Peninsula also were barren. The large seasonal fluctuations may affect this species but it has been reported from shallow, low salinity stations in other regions.

Buccella inusitata ANDERSON, 1952, Journ. Washington Acad. Sci., vol. 42, no. 5, p. 148, figs. 10a-11c.

This species occurred in Bering Strait, on Prince of Wales Shoal and along the northeast coast where the sediment is coarse and the populations are predominantly calcareous.

Rosalina wrightii (Brady) = *Discorbina wrightii* Brady, 1881, Ann. Mag. Nat. Hist., London, Ser. 5, vol. 8, no. 48, p. 413.

This species comprised as high as 22 percent in Bering Strait and along the northeast coast but did not occur in the central area (text fig. 15). It was found associated with a variety of sediment types, depths, salinities and temperatures. The factors affecting the distributions of this species are not known. Plate 6, fig. 15 shows a younger specimen with very little ornamentation and fig. 14 shows a mature specimen with the umbilical region almost filled.

Asterellina pulchella (PARKER) = *Pninaella* (?) *pulchella* PARKER, 1952, Harvard Coll., Mus. Comp. Zool. Bull., vol. 106 (1951-1952), no. 9, p. 420, pl. 6, figs. 18-20.

This species under several different generic names, has been recorded from the Gulf of Maine, Long Island Sound, Bering Sea and from late Pleistocene sediments on Sado Island on the west coast of

Japan. It occurred in this area at thirty-two stations, on the Prince of Wales Shoal, along the northeast coast and in Kotzebue Sound (text fig. 16). It was found at a wide range of depths, sediment sizes, temperatures and salinities.

Cassidulina islandica NØRVANG, 1945, Foraminifera, Zoology of Iceland, vol. 2, pt. 2, p. 41, text figs. 7, 8d-f.

This species was found over the entire area but had its highest percentages near Bering Strait, Point Hope and Kivalina (text fig. 17). Associated with a range of conditions, it did not comprise over 12.5 percent of the populations but was found at thirty-two stations.

Cibicides lobatulus (WALKER and JACOB) = *Nautilus lobatulus* WALKER and JACOB, 1798, Adams Essays, Kannmacher's ed. (ed. II), p. 642, pl. 14, fig. 36.

This species occurred at fourteen stations, associated mainly with coarse sediment on stations deeper than 80 feet. The salinities varied from 31.1 to 33.0 o/oo and the temperatures from 2.5 to 8.1°C. *Cibicides lobatulus* had variations in size (Plate 6, figs. 19, 20) but they occurred at the same stations and it was assumed they were the same species.

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