

Walter R. Hale. APPLICATION OF A REGRESSION MODEL IN THE DETERMINATION OF POST-MORTEM TRANSPORT OF FORAMINIFERAL TESTS. (Under the direction of Dr. Scott W. Snyder) East Carolina University, Department of Geology, December 1985.

Continental shelf surface sediments from Tillamook Head (northern Oregon) to Juan de Fuca Canyon (Washington) yielded 106 benthic foraminiferal species. Planktonic species are too rare to be considered important. Most specimens identified are agglutinated species, with calcareous species occurring primarily on the outer shelf. Species diversity generally increases with water depth, but low diversity values extend seaward near major submarine canyons. Eggerella advena is the most ubiquitous and abundant species.

Cluster analysis of between-station faunal similarity reveals five major biofacies: 1) the inner shelf, where E. advena predominates with abundances of greater than 60% in all samples; 2) the middle shelf north of the Columbia River, predominated by E. advena (40-60%) and Spiroplectammina biformis (20-45%); 3) the middle shelf south of the Columbia River, where Recurvoides turbinatus, S. biformis and E. advena each compose 20-40% of the assemblage; 4) the middle to outer shelf, containing a more diverse assemblage including E. advena (20-40%), Adercotryma glomerata (5-20%), S. biformis (0-15%), Haplophragmoides bradyi (0-10%), Textularia earlandi (3-8%), and Uvigerina juncea (5-20%); and 5) isolated patches on the outermost shelf, where U. juncea (20-35%) and Trifarina angulosa, A. glomerata and H. bradyi (each 5-15%) are the most abundant species. These major faunal associations are distributed

parallel to isobaths and coincide closely with sediment-size patterns and accumulation-rate patterns for the region.

A linear regression equation provided by Kontrovitz et al. was used to estimate traction velocity (Y) for each of the 31 most commonly occurring species. Values range from 4.1 to 13.3 cm/sec. Using Scheffé's method of multiple comparisons, species were separated into three groups. The species within each group are moved by velocities from the same statistical population. Nearly equidimensional forms are most easily transported (Y = 4.0 to 6.5 cm/sec); flattened-discoidal and elongate-compressed forms are most difficult to transport (Y > 10 cm/sec); forms of intermediate shape have intermediate traction velocities (Y = 6.5 to 10 cm/sec). Current-sorted assemblages would be expected to contain species with similar traction velocities, while unsorted assemblages should show a wide range of values.

Each major biofacies identified contains common species with a broad range of Y values. This implies a lack of sorting and is consistent with data on bottom-current velocities in the study area. Sustained currents rarely exceed 10 cm/sec (usually during winter storms), and current direction is variable.

The value of the regression method employed in this study is as a tool to be used in assessing post-mortem transport of foraminiferal tests, which could affect the reliability of paleoenvironmental interpretations.

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APPLICATION OF A REGRESSION MODEL
IN THE DETERMINATION OF POST-MORTEM
TRANSPORT OF FORAMINIFERAL TESTS

A Thesis

Presented to

the Faculty of the Department of Geology

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Geology

by

Walter R. Hale

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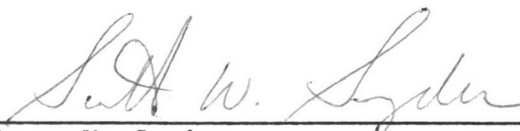
APPLICATION OF A REGRESSION MODEL
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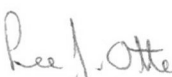
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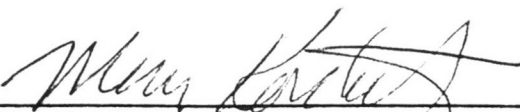
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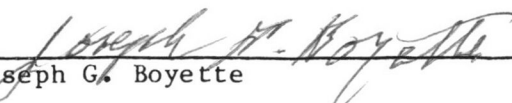
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INTRODUCTION

Benthic foraminifera are used more extensively as paleoenvironmental indicators than any other microfossil group because 1) they are widespread geographically and geologically, 2) the ease of collecting large numbers of them allows the use of statistical correlation techniques and 3) modern forms are acutely responsive to their environments (Ellison, 1951; Schafer and Young, 1977). However, it is becoming increasingly apparent that the effects of transport must be assessed when interpreting paleoecology based on microfossil assemblages. As early as 1958, D. J. Jones recognized that microfossils were particularly susceptible to displacement because of their small size. He also suggested that environmental mixing was fairly common, and should be expected near ancient shorelines where wave-induced bottom currents were active. To understand how foraminiferal assemblages accumulate, one must understand bottom-current movements and how foraminiferal tests respond to such movements.

Equations derived experimentally (Kontrovitz et al., 1978; Kontrovitz et al., 1979) can be used to estimate the traction velocities of foraminiferal tests. Current-sorted assemblages should comprise species with similar traction velocities. The intent of this thesis is to evaluate the applicability of these equations in reflecting known current patterns within a modern large-scale natural system.

The Washington State continental shelf is an appropriate area to study the effect of bottom currents effects on sediment particle transport for two main reasons: 1) the existence of extensive physical

oceanographic and geologic data on the region and 2) the availability of a large sample base from the area. Input of a large supply of low-level radioactive waste to the Columbia River by the Hanford reactors from January, 1943 to January, 1971 (Pruter and Alverson, 1972; Foster, 1972) stimulated interest in potential environmental effects. The presence of radionuclides has facilitated study because they act as "tags" that can be traced through the river and out onto the shelf. The result has been that oceanographers, encouraged by support from the Atomic Energy Commission, Energy Research and Development Agency and National Science Foundation, have produced a large volume of data on current patterns and sedimentary processes on this shelf. These data have proven to be invaluable to this study, which was funded by a grant from the National Science Foundation (S.W. Snyder, principal investigator). A total of 90 box-core samples were obtained through C.A. Nittrouer and R.W. Sternberg from previous NSF-funded sedimentological studies. This broad sample coverage has allowed benthic foraminiferal distribution patterns to be realistically compared to very general, large-scale bottom-current patterns.

REGIONAL SETTING

Geographic Setting

The study area lies off the northwest coast of the United States, extending from Tillamook Head, Oregon in the south to the submarine Juan de Fuca Canyon in the north (Figs. 1 & 2). The southernmost samples were taken at approximately $45^{\circ} 55' \text{ N}$, and the northernmost samples at $48^{\circ} 00' \text{ N}$. Because of the west-northwest trend of the coastline and shelf isobaths, the study area extends farthest west in the north (to $125^{\circ} 07' \text{ W}$) and the easternmost samples are in the southern part of the area (at $124^{\circ} 03' \text{ W}$). The nearest sample to shore (WA-30), from a depth of 31 meters, is about seven kilometers from the spit enclosing the northern part of Grays Harbor (Figs. 2 & 3). The farthest offshore sample (WA-29B), from a depth of 172 meters, is about 54 kilometers from the same point on shore.

Geologic Setting

The continental shelf in this area has an average width of about 40 kilometers. It is a relatively steep, narrow, and deep shelf (Nittrouer et al., 1979b) that is a generally smooth, uniformly-sloping surface, but is incised by at least six submarine canyons (including the Juan de Fuca Canyon at the northern boundary of the study area). The shelf varies considerably in width as a result of the submarine canyons. It is narrowest near the mouth of the Columbia River, where it is only about 19 kilometers from the shore to the head of Astoria Canyon (McManus, 1972).

The shoreline in the north can be characterized as rocky, with prominent headlands and narrow beaches. Sediment is supplied by fairly

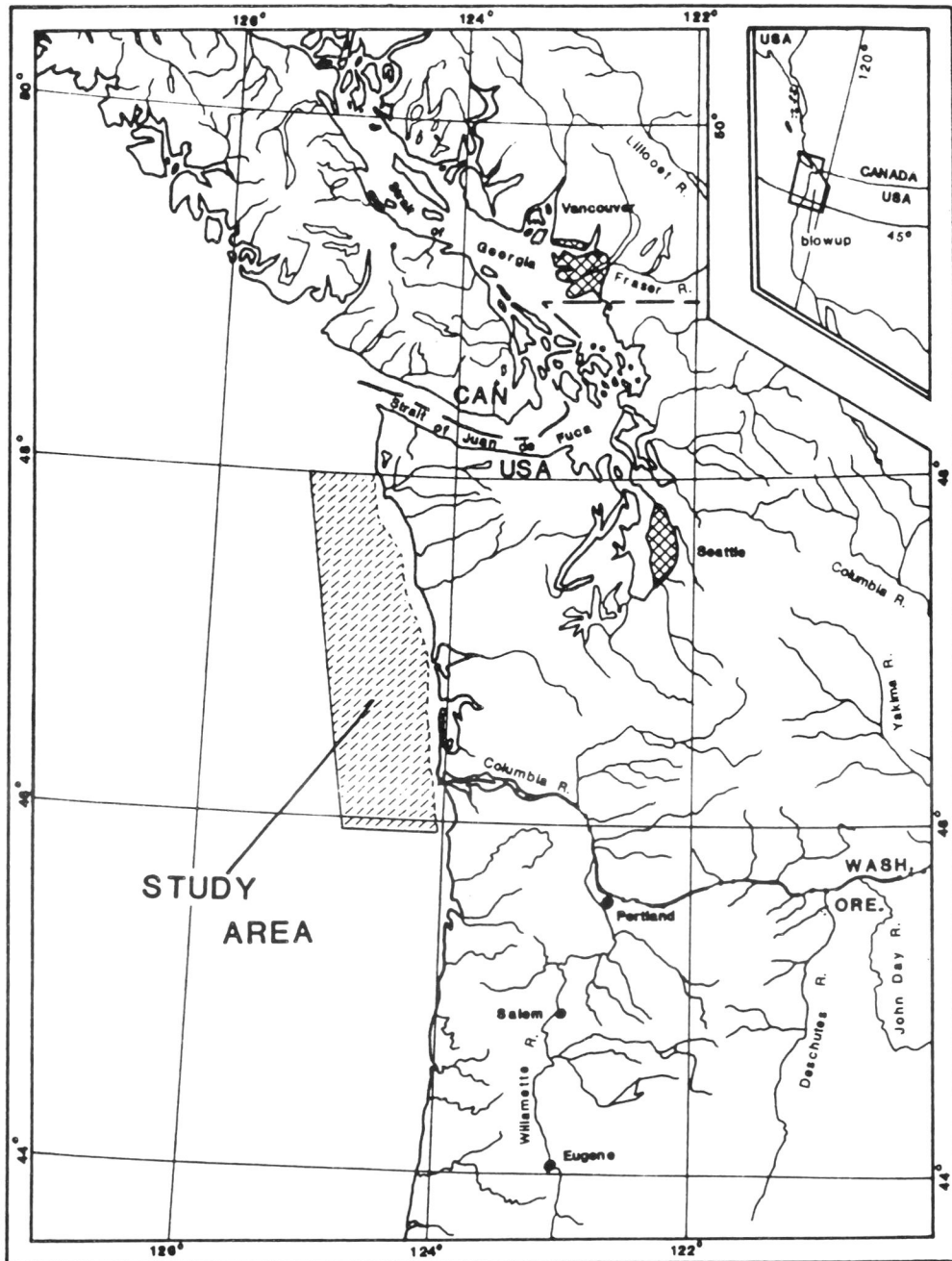


Figure 1. Location of study area.

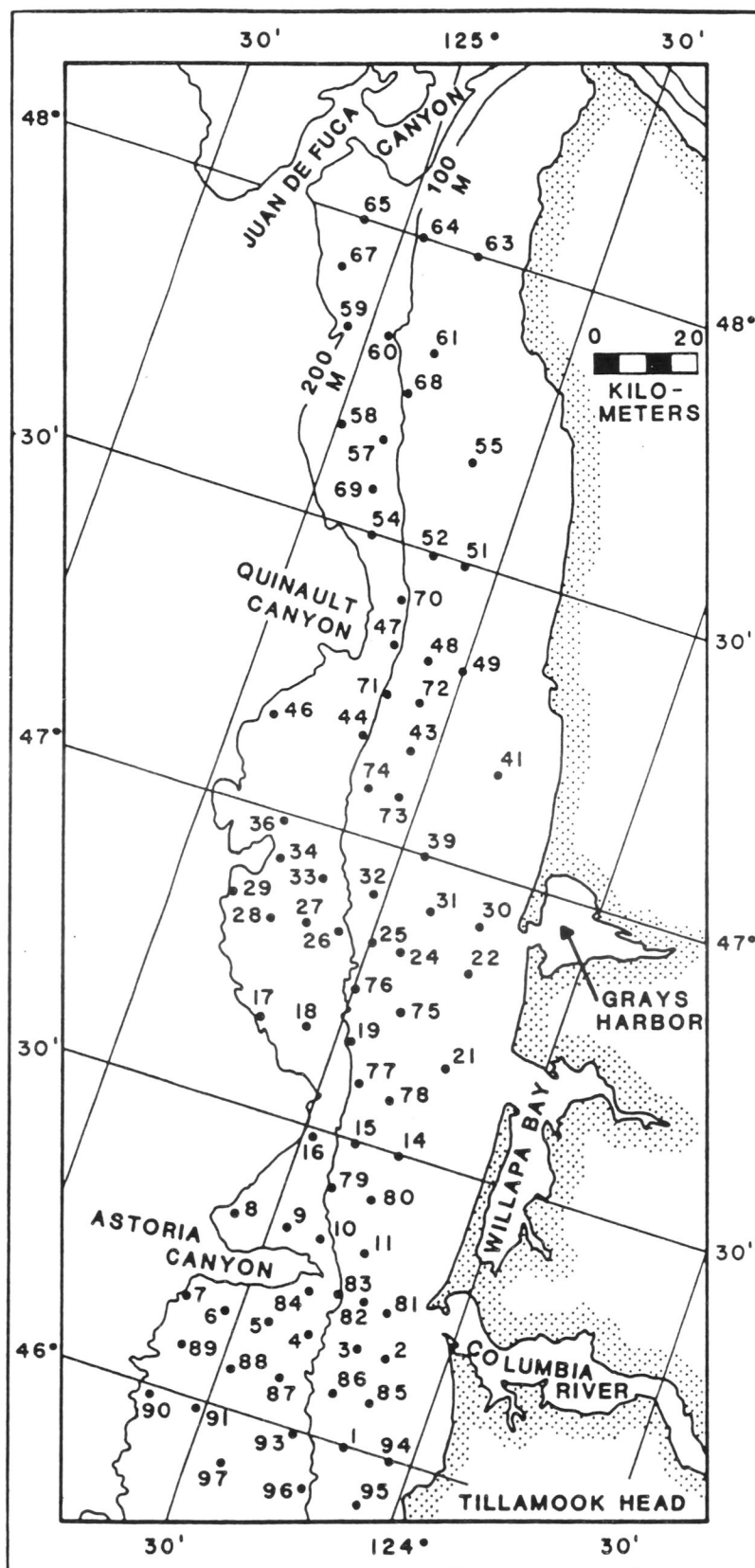


Figure 2. Sample locations (in text preceded by WA-).

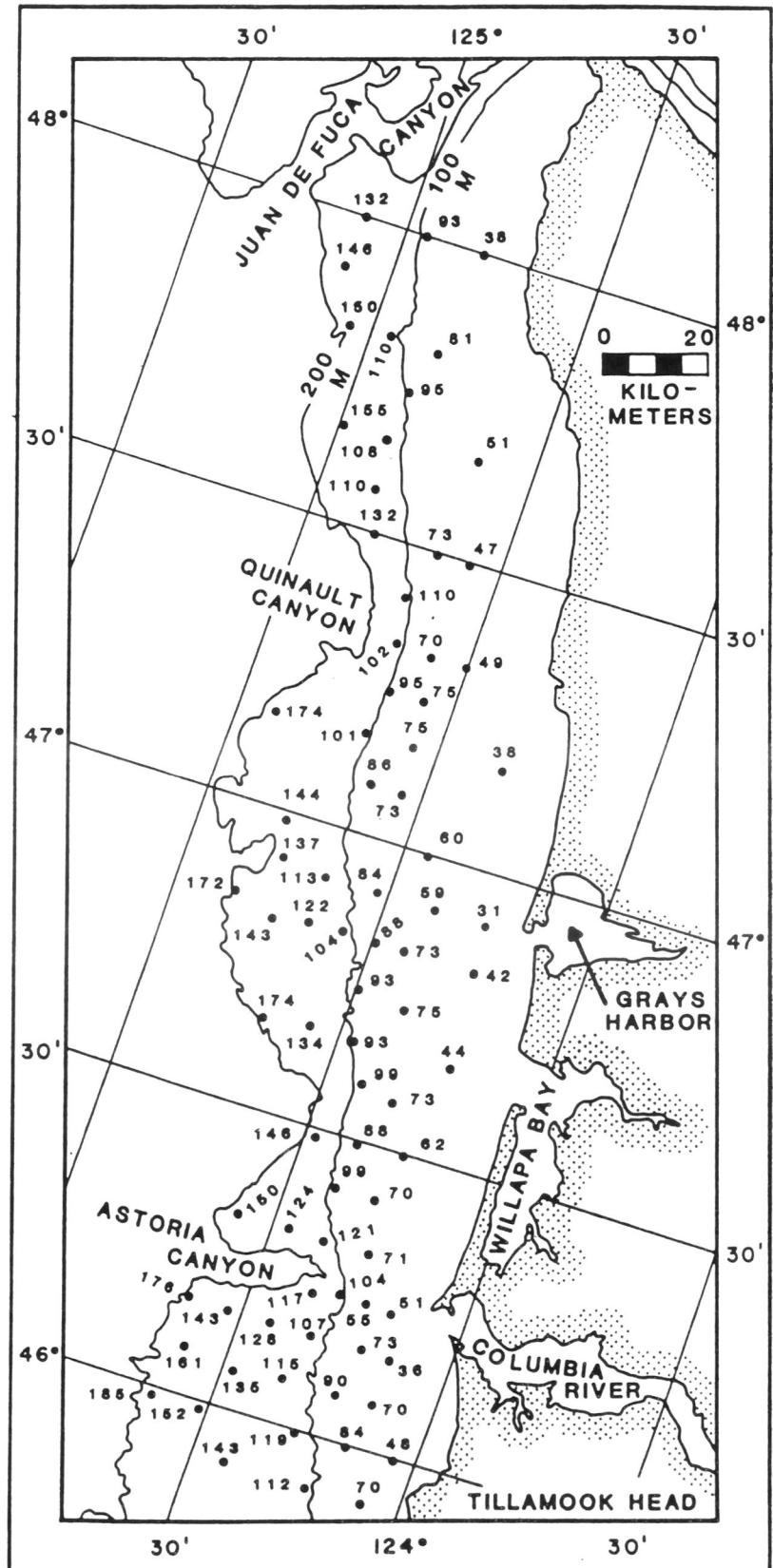


Figure 3. Bathymetry at sample stations (in meters).

short coastal rivers and streams. The shore from Grays Harbor southward is characterized by broader beaches and barrier spits protecting estuarine areas, and the Columbia River provides large quantities of sediment to the beaches and shelf.

Between Grays Canyon and Astoria Canyon the outer shelf has a hummocky topography with up to 10 meters of relief (Nittrouer, 1979b). South of Astoria Canyon maximum relief increases to 30 meters (McManus, 1972). North of Grays Canyon, the rougher topography of the outer shelf persists, but it is not as prominent as in the south. The rough topography of the outer shelf has been interpreted as relict topography which is not overlain by the sediment wedge which covers the inner and middle shelf (McManus, 1972; Nittrouer et al., 1979a; Nittrouer et al., 1979b; Nittrouer and Sternberg, 1981).

The most obvious sedimentary feature of the Washington continental shelf is a mid-shelf silt deposit which extends from near the mouth of the Columbia River to the head of Quinault Canyon. The axis of this deposit trends about 15° west of north. The silt deposit is interpreted to be a modern feature which overlies a transgressive sand layer that is exposed seaward and landward of the silt deposit. The inner shelf sand marks the modern landward limit of this transgressive sand (Nittrouer et al., 1979b; Nittrouer and Sternberg, 1981). Sediment size distributions will be discussed in greater detail in the section entitled "Assessment of Post-mortem Transport."

Oceanographic Setting

The surface currents over the Washington shelf vary with the seasons

as a result of regional weather systems. The prevailing winds produce a northerly flow in winter and a southerly flow in summer (Barnes et al., 1972; Venkatarathnam & McManus, 1973; Nittrouer et al., 1979a). The bottom and near-bottom currents on the shelf are generally northward year-round, with a slight westward, or seaward component. The peak average bottom velocity in water deeper than about 40 meters is around 70 cm/sec (Smith & Hopkins, 1972; Baker, 1973).

The major source of sediment to the shelf is the Columbia River. This sediment is transported generally northward and offshore, reflecting bottom-current direction. The coarser grains (sand-sized) may be held nearshore and moved along the coast at depths of less than 60 meters. Finer-grained material is transported along the middle shelf and is alternately deposited on and eroded from the mid-shelf silt deposit. This silt deposit narrows toward Quinault Canyon, which is a major pathway for the transport of sediment off the shelf. There is, however, a net accumulation of silt on the middle shelf, which indicates that supply by the river exceeds off-shelf transport by the submarine canyons (Nittrouer et al., 1979a; Nittrouer et al., 1979b). Some fine silt and clay are carried to the outer shelf, there to be mixed with the relict sands and gravel (Baker, 1973; Nittrouer et al., 1979a).

Significant sediment movement across and along the shelf occurs only during storms, which are more frequent during winter months (Smith and Long, 1976). The intermittent nature of the near-bottom currents has been documented by current-meter measurements. A more detailed discussion of current speeds and directions will be given in the section entitled "Assessment of Post-mortem Transport."

METHODOLOGY

Samples for this study are from the top three centimeters of box cores from the Washington continental shelf. These cores were collected in 1976 (cruise W7606A) by C.A. Nittrouer and R.W. Sternberg (see Nittrouer and Sternberg, 1981 for coring details). Of 95 samples made available for this study in 1983 by C.A. Nittrouer, 86 were used in cluster analyses due to the paucity of specimens in the remaining samples. Data from 81 samples are presented on species distribution and other maps (see Fig. 2) because of duplication of several samples and imprecise location for several others. Because samples were not treated with any indicator stains (e.g. Rose Bengal) at the time they were collected, recognition of living specimens was not possible.

All the samples were soaked in a weak solution of Calgon for approximately 24 hours to break up the clays. In most cases further deflocculation was required, and the samples were boiled for 25-30 minutes in a dilute solution of Quaternary-"0" (alkyl imidazolinium chloride) and tap water. In cases where the clays were persistent, this step was repeated as many as three times. Next the samples were washed gently through U.S. Standard Sieves No. 14 (1.41 mm) and No. 230 (63 μ m) to concentrate the sand fraction containing identifiable foraminifera.

The sand fractions were split using a microsplitter and examined for the presence of foraminiferal tests, with the objective of obtaining at least 300 specimens from each sample. The large ratio of sand-sized terrigenous grains to foraminiferal specimens prohibited picking sufficient numbers of specimens within a reasonable time frame. Because the samples are from recent sediment which has not undergone significant

diagenesis, there is negligible recrystallization of the tests and chamber filling by sediment or authigenic minerals is virtually absent. Therefore, flotation was considered an acceptable method of concentrating the tests. The sand fractions were floated once in carbon tetrachloride, then the residue was floated again. Examination of both floats and residue indicated that floated material provided accurate and reliable faunal analyses. Rarely were specimens present in the residue after two floats. Also, comparisons of assemblages obtained from floated and unfloated splits of the same sample revealed no significant faunal differences.

The floated sample splits were spread on picking trays and all specimens in predetermined sections of a grid were picked. Four samples were eliminated from the study because fewer than fifty specimens were obtained from them. Even including these four samples, however, the average number of specimens per sample was 321.

Specimens were identified to species level by comparison to both original and subsequently published descriptions and figures, and by comparison to type specimens at the U.S. National Museum in Washington, D.C. Relative abundances of species in each sample were determined, as well as species diversity and equitability, using the CHECKLIST program for the APPLE IIe microcomputer (Phillips, 1982). Diversity is reported as the Shannon-Weiner Information Function, expressed as:

$$H(S) = - \sum p_i \ln p_i,$$

where p_i is the proportion of the sample represented by species i . If a sample contains only one species, $H(S)$ is equal to 0. There is no maximum value for $H(S)$, but values over 3.0 approach the upper limit

commonly encountered in foraminiferal assemblages (S.W. Snyder, pers. comm.). In a living benthic assemblage, low values usually reflect a more stressful environment, in which limiting parameters (temperature, salinity, etc.) exhibit relatively large variations. Higher values normally reflect a more stable environment, where the number of species present is high, and the relative abundance of each species is low. The Shannon-Weiner index is commonly used to represent diversity because it is responsive to most of the species in a sample, and it is not affected by sample size as severely as other indices (Phillips, 1982). Equitability is commonly used in conjunction with the Shannon-Weiner index and is computed by the formula:

$$E = e^{H(s)} / S,$$

where e is the natural log base (approximately 2.72), and S is the number of species in the sample. This value indicates the evenness, or equitability of the distribution of species abundances within a sample. For example, if all species present are of equal abundance, then $E = 1$; as predominance by one or a few species increases, then E decreases to a minimum of 0.0 when only one species is present (Phillips, 1982).

Cluster analysis was carried out, using the Statistical Analysis System (SAS) through the Triangle Universities Computation Center (TUCC) in Cary, North Carolina, in order to define major biofacies. The clusters were computed by an average linkage method to group samples which contained similar species with similar abundances (SAS Institute, Inc., 1982).

Of the 106 species identified, the 31 most common were measured to estimate their respective traction velocities. Approximately 20

specimens of each of these common species were individually measured under a WILD binocular light microscope at 100X to determine the long, intermediate and short axis lengths. Maximum projection sphericity (MPS) was determined for each specimen. MPS is defined as $\sqrt[3]{S^2/L(I)}$, where S is the short axis of the particle, and L and I are the long and intermediate axes, respectively. The traction velocities for each specimen were then estimated using a regression equation revised by Kontrovitz (pers. comm., 1985):

$$Y = 22.3 - 19.8(\text{MPS}),$$

where Y is the estimated traction velocity, MPS is the maximum projection sphericity, and 22.3 is the intercept of the Y-axis. Within-species variation of traction velocity versus between-species variation was evaluated using Scheffé's method of multiple comparisons. By this method it was possible to identify groups of species with similar traction velocities. Theoretically, the species within each group should be transported together.

Finally, maps were drawn showing:

- 1) Abundance distributions of the 31 most common species,
- 2) Contoured diversity values,
- 3) Contoured equitability values,
- 4) Estimated abundance of specimens per gram of sediment,
- 5) Percentage of agglutinated foraminifera in each sample,
- 6) Groups obtained from cluster analysis,
- 7) Abundance distributions of traction-velocity groups obtained by Scheffé's method.

These maps were compared to existing data on bottom-current

direction and velocity, and to sediment-size data to determine the extent to which foraminiferal tests are being transported on the Washington continental shelf.

PREVIOUS WORK

Foraminiferal Distribution

Detailed studies of recent benthic foraminifera off the west coast of North America provided a comprehensive base of species descriptions useful in identifying Washington shelf taxa. These studies have focused on areas from the central Arctic Ocean (Lagoe, 1977), to the Canadian and Alaskan Arctic (Loeblich and Tappan, 1953; Todd and Low, 1967; Vilks, 1969) to as far south as the Gulf of California (Bandy, 1961). Closer to my study area, Cushman and Todd (1947) described benthic foraminifera from around the bays and islands in the Strait of Juan de Fuca and in Puget Sound. More geographically extensive studies covering areas from Washington to Baja, California were provided by Cushman (1927) and Lankford and Phleger (1973).

Studies that partially overlap or are contained within my study area (Echols, 1969; Harmon, 1972) do not address systematic paleontology nor provide complete faunal lists. Samples examined by Echols (1969) are largely restricted to the inner sublittoral zone, with the deepest station being in 59 meters of water. He found concentrations of microscopic skeletons (including foraminifera, diatoms and tintinnids) which ranged from less than one to several hundred individuals per gram of dry sediment. Benthic foraminiferal tests were the most abundant micro-organisms, while tests of planktonic foraminifera occurred only rarely. Echols also reported a "stepped" increase of foraminiferal tests at a depth of about 20 meters, which he cited as evidence of test transport from depths less than 20 meters to deeper water. Species reported by Echols to be most abundant and widespread in the inner

sublittoral zone off Washington are Buliminella elegantissima, Buccella frigida, B. tenerrima, Eggerella advena, Elphidium magellanicum, and E. microgranulosum. He also noted trends of increasing relative abundance for Eggerella advena and decreasing abundance for Elphidium spp. with increasing water depth. In his deeper samples (40-59 meters), Echols reported rare specimens of Florilus japonicus, Nonionella miocenica stella, Recurvoides turbinatus and Spiroplectammina biformis, all of which he predicted would increase in deeper waters.

Harmon (1972) sampled the southernmost part of the present study area (south of Grays Harbor). His coverage extended seaward to the shelf edge, but also included numerous samples closer to shore (as shallow as 20 meters). He noted a paucity of planktonic specimens in his samples. Harmon reported that high concentrations of arenaceous forms nearshore decreased gradually seaward, with higher concentrations occurring again on the outer shelf just south of Astoria Canyon and just south of Grays Canyon. Eggerella advena, the predominant arenaceous species, appeared more frequently in samples with low mud content. Harmon recognized two morphotypes of E. advena: nearshore forms are larger, more inflated and elongated; deeper water forms are smaller, more triangular and more tapered. He also noted an abundance of the calcareous species Buliminella elegantissima in nearshore areas north of the mouth of the Columbia River. On the middle shelf Harmon found an arenaceous assemblage composed of Recurvoides turbinatus, Spiroplectammina biformis, the deeper water form of E. advena, and Reophax arctica. Calcareous forms on the middle to outer shelf included Nonionella miocenica and Florilus labradoricus (reported as Nonionella labradoricum). Recurvoides

turbinatus increased in abundance from north to south on the middle shelf. Outer shelf calcareous species included Epistominella exigua, Eponides leviculus, Bolivina pacifica, Uvigerina juncea, Cassidulina subglobosa, and C. minuta. On the outermost shelf calcareous species were predominated by Trifarina angulosa, while Adercotryma glomerata and Haplophragmoides bradyi were the predominant arenaceous species. He also reported the presence of Trochammina charlottensis in rocky or gravelly areas of the outer shelf, and Gaudryina arenaria in middle- and outer-shelf environments where mud content is low.

Harmon implied seaward transport of nearshore forms, basing his interpretation on higher ratios of dead to living specimens of Buliminella elegantissima away from shore. Although he did not mention specific depths, he said that nearshore forms are displaced seaward onto the middle shelf.

Post-mortem Transport of Foraminiferal Tests

As early as the 1950's, workers were beginning to recognize that displacement of microfossils was a common phenomenon which could affect paleoecological interpretations. Menard and Boucot (1951) stated that moving water was the primary agent for transportation of unattached dead shells. Although they were primarily concerned with transport of brachiopod shells, this observation certainly holds true for foraminifera. Ellison (1951) observed that upper depth limits of benthic micro-organisms are most reliable for bathymetric interpretations because downslope movement may occur after death. Nearshore wave turbulence was recognized by Jones (1958) as effective in displacing foraminifera.

Schafer and Young (1977) reported that some common nearshore foraminifera have settling velocities equal to quartz grains with diameters of 0.14 to 0.10 mm. This corresponds to fine to very fine sand sizes, which are in the range of most easily eroded particles (Friedman and Sanders, 1978). Assuming that settling velocity is related to ease of transport, post-mortem transport would be a common phenomenon and would have been common in the geologic past.

Based on the amount of preburial alteration, four "end-member" types of fossil assemblages were suggested by Fagerstrom (1964): 1) fossil communities, in which all members of the original community are present in the same relative abundances as when they were living; 2) residual or winnowed fossil communities, in which specimens present were members of the living community, but some have been selectively removed by winnowing; 3) transported fossil assemblages, composed mainly of specimens which have been brought in from other locations; and 4) mixed fossil assemblages, comprising many specimens from the original community and some transported from other communities. He also stressed the interpretive limitations when working with transported or mixed assemblages.

Post-mortem transport of foraminiferal tests in modern seas has been documented by several workers. Culver (1980) reported the presence of size-sorted, dead, benthic foraminifera suspended in the eastward-flowing tidal currents of the Bristol Channel in southwestern Great Britain. Tidal flats to the east contain an abundance of dead specimens of these transported forms. Other studies which have illustrated the importance of tidal currents as transport mechanisms include those of Murray (1965),

Schafer (1976), Murray et al. (1982), and Thomas and Schafer (1982). Culver (1980) also described seasonal differences in sediment transport direction off Sierra Leone, West Africa, where landward transport occurs during the dry season and offshore transport occurs during the wet season. Upwelling of deep water is reported to be responsible for the presence of high concentrations of planktonic and deep-water benthic foraminifera in shallow water near Panama City, Florida (Bock, 1980). In the fossil record, this kind of association might be incorrectly interpreted as a deep-water assemblage containing downslope contamination by nearshore forms. The effects of transport of foraminifera in marginal basins of the California borderland, were interpreted to be the result of mass slope movement (Douglas, 1980).

Many criteria have been proposed for recognizing the effects of post-mortem transport in the fossil record. Boucot (1953) recognized that hydrodynamic qualities varied from one species to another, so that assemblages of species having similar hydrodynamic qualities would be evidence for transport. Jones (1958) listed several criteria for recognizing the displacement of microfossils:

- 1) a high percentage of fragments of tests;
- 2) destruction of ornamentation;
- 3) particle size distribution of microfauna similar to that of the sediment [According to Berger and Piper (1972) this criterion is probably not valid because of hydrodynamic differences between microfossils and mineral grains];
- 4) variation in color, texture, or mineral composition within a given species;

5) absence of normal growth stage series and immature forms (suggests winnowing);

6) preferred orientation of elongate forms (eg. fusulinids).

Other criteria that have been proposed include:

1) smooth lateral boundaries between communities (Loose, 1970);

2) statistical criteria such as cluster analysis, size frequency, etc. (Fagerstrom, 1964; Loose, 1970);

3) faunal composition, particularly occurrences of species in unusual associations (Fagerstrom, 1964; Thomas and Schafer, 1982);

4) abrasion of robust forms due to bed-load transport (Thomas and Schafer, 1982).

Attempts to quantitatively assess transport have focused on laboratory experiments to determine settling velocities. Berger and Piper (1972) compared the settling velocities between planktonic foraminifera and glass spheres. They discovered that for a given velocity, diameters of glass beads averaged 2.4 times smaller than diameters of foraminiferal tests. In other settling tube experiments, shape has proven to be a major factor in determining settling velocity for both natural sand grains (Baba and Komar, 1981) and planktonic foraminifera (Fok-Pun and Komar, 1983).

Laboratory flume studies to determine the current speed required to initiate shell movement were first conducted by Menard and Boucot (1951) on brachiopod shells. The first flume runs measuring traction velocities of microfossils were carried out by Kontrovitz (1975) using five diverse species of ostracodes. This study suggested the importance of shape in determining traction velocity and illustrated the feasibility of flume

study applications to the differential transport of microfossils. The first experimentally derived traction velocities for foraminifera were obtained by Kontrovitz et al. (1978, 1979) in similar flume studies. The mean traction velocity for each species was matched with mass and linear measurements in a regression analysis such that traction velocity could be estimated from direct measurements of tests. The first practical application of this regression equation (Kontrovitz et al., 1978) was carried out with benthic foraminifera from Hatteras Embayment, North Carolina by Snyder et al. (1980). Comparing estimated traction velocities to measured bottom-current velocities, they interpreted the assemblages present as residual communities.

FORAMINIFERAL DISTRIBUTION

The foraminiferal fauna of the Washington continental shelf from depths of 30 to 185 meters largely comprises benthic species. From the 90 samples examined, 28,879 benthic tests were picked and identified, while only 53 planktonic specimens were observed. Because of the paucity of planktonic forms, they are not included in any of the descriptive or statistical discussions of this study.

The estimated number of foraminiferal tests present per gram of sediment ranges from three to 197 (Fig. 4 and Appendix 4). Highest concentrations occur on the outer shelf north of the Columbia River, and on the middle shelf south of the river mouth. This pattern is influenced by both sedimentation rates and primary productivity. Maximum sedimentation rates occur along a north-northwest trending silt deposit extending from the Columbia River mouth to the head of Quinault Canyon (Nittrouer et al., 1979a). Relatively high numbers of specimens in several samples from this area suggest high rates of productivity, especially considering that samples were taken in June, one of the months with highest sediment supply from the Columbia River (Nittrouer and Sternberg, 1981). One possible cause of high productivity is that spring floods may bring a large quantity of nutrients to the shelf. Elsewhere along the shelf, high concentrations of foraminiferal tests are primarily due to lack of dilution by terrigenous sediments.

Of 106 benthic species identified, most are agglutinated forms. In 69% of the samples the assemblage comprises at least 80% agglutinated specimens (see Fig. 5 and Appendix 4). The majority of calcareous specimens occur on the outer shelf (Fig.5). High concentrations of

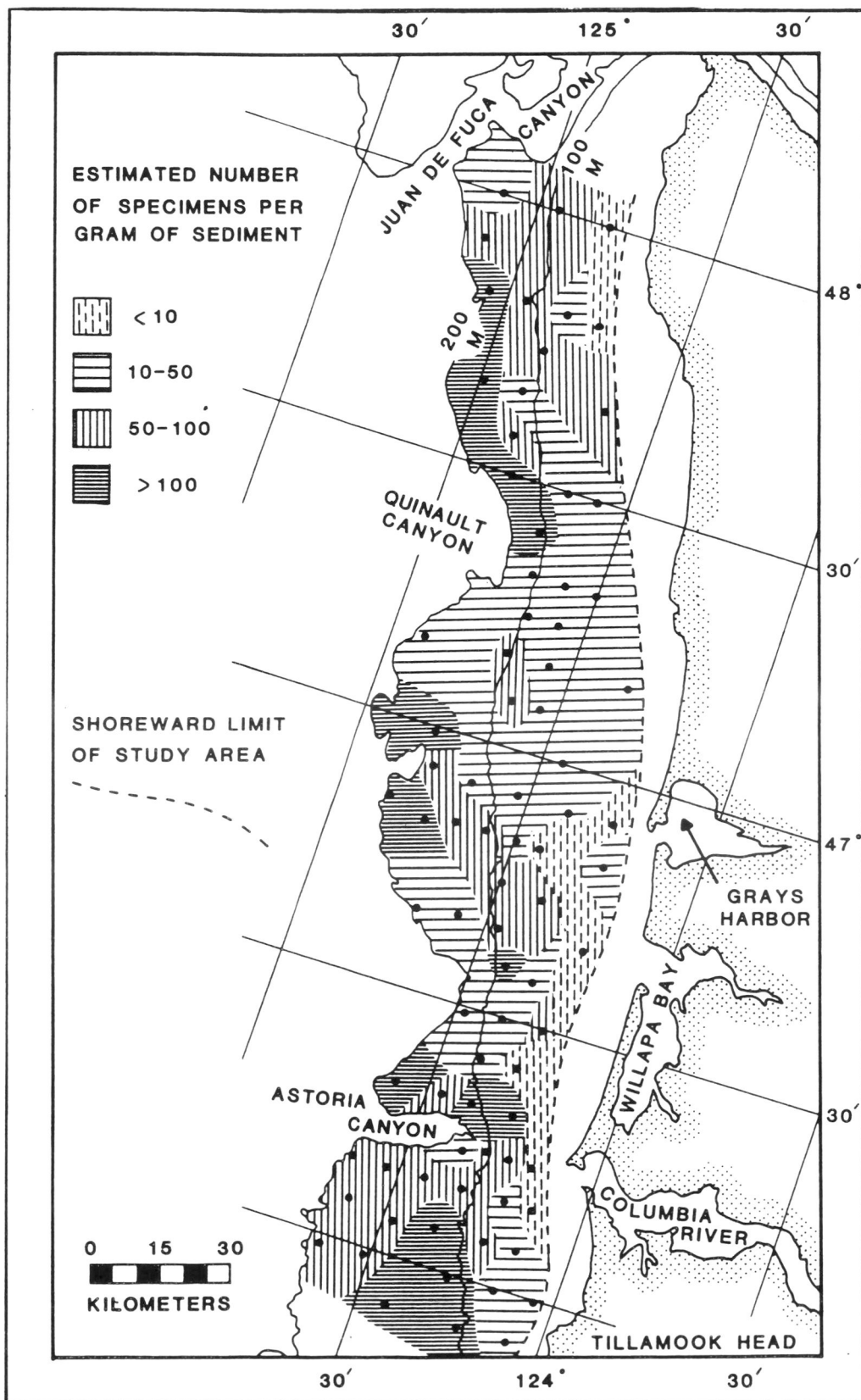


Figure 4. Density of foraminiferal specimens.

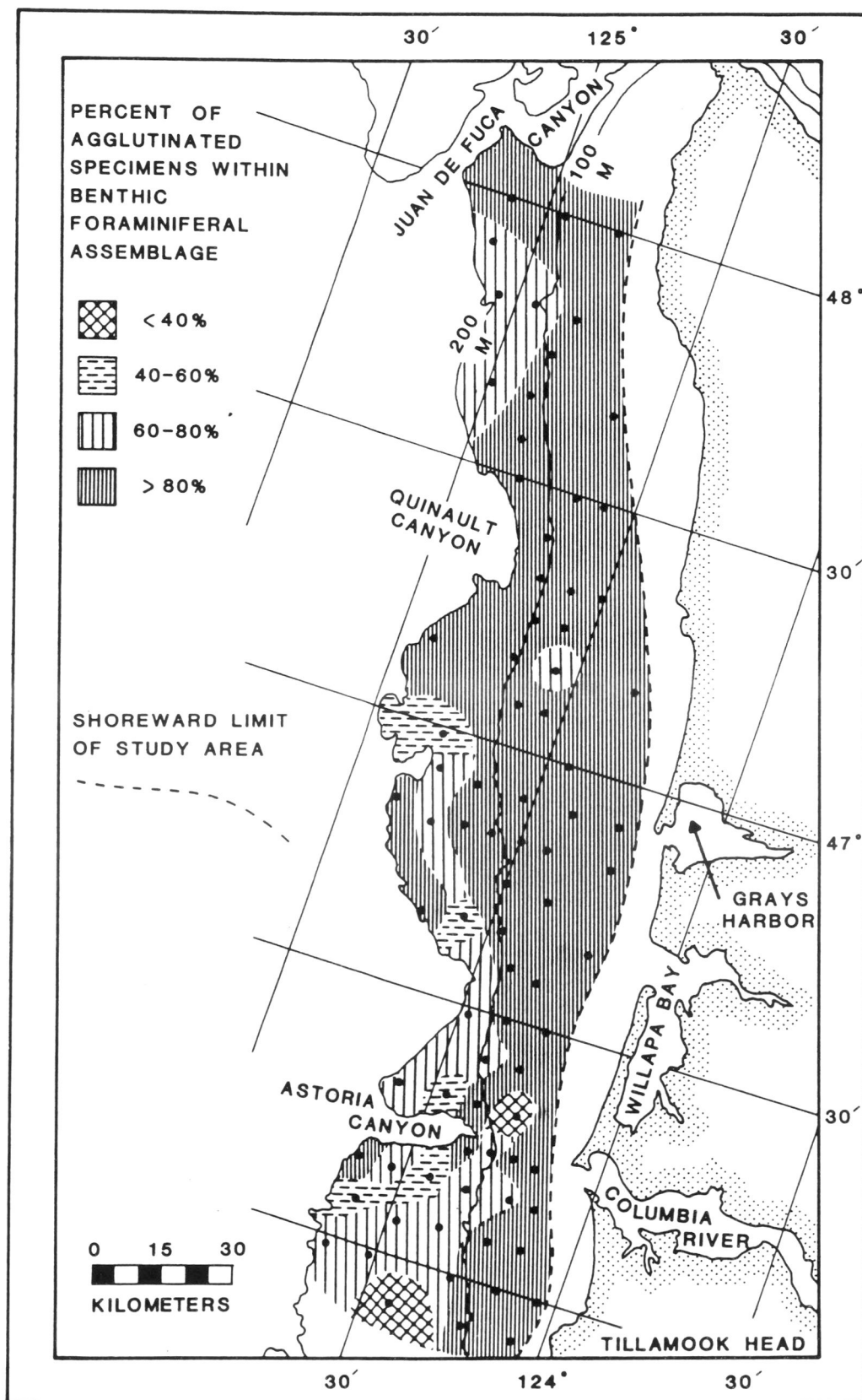


Figure 5. Relative abundance of agglutinated specimens.

arenaceous forms on the outermost shelf south of Grays Canyon and south of Astoria Canyon are consistent with the observations of Harmon (1972).

Faunal diversity generally increases from nearshore to offshore (Fig. 6). In areas near submarine canyons, however, lower values of diversity extend farther offshore. Nearshore areas with low diversity values correspond to the predominance zone of Eggerella advena (Fig. 7). Higher diversity values on the outer shelf result from the presence of a greater variety of calcareous forms as well as several agglutinated species that do not occur in the nearshore area. The pattern of equitability values (Fig. 8) is more irregular than that of diversity. Relatively higher values characterize the outer shelf, but several stations in shallower water also have high values. Five nearshore stations with high equitability values have specimen counts of less than 100 (Appendix 4). If these five are not included, the nearshore pattern becomes more uniform.

Eggerella advena (Fig. 7), which occurs at every station, is the most abundant and ubiquitous species in the study area. Relative abundance is very high nearshore (91.5% at station WA-22), but decreases in an offshore direction to 17.7% at station WA-8. There are two distinct morphotypes of this species. The most abundant form, here termed "average", is smaller, tapers rapidly and is triangular; the "large" form attains greater size, is more elongate and has more inflated chambers (Plate 2, figs. D and G). Although "average" forms are predominant throughout the area, there is a trend toward higher concentrations of "large" forms in more shallow water. This pattern was observed by Harmon (1972) in nearshore areas of the southern Washington

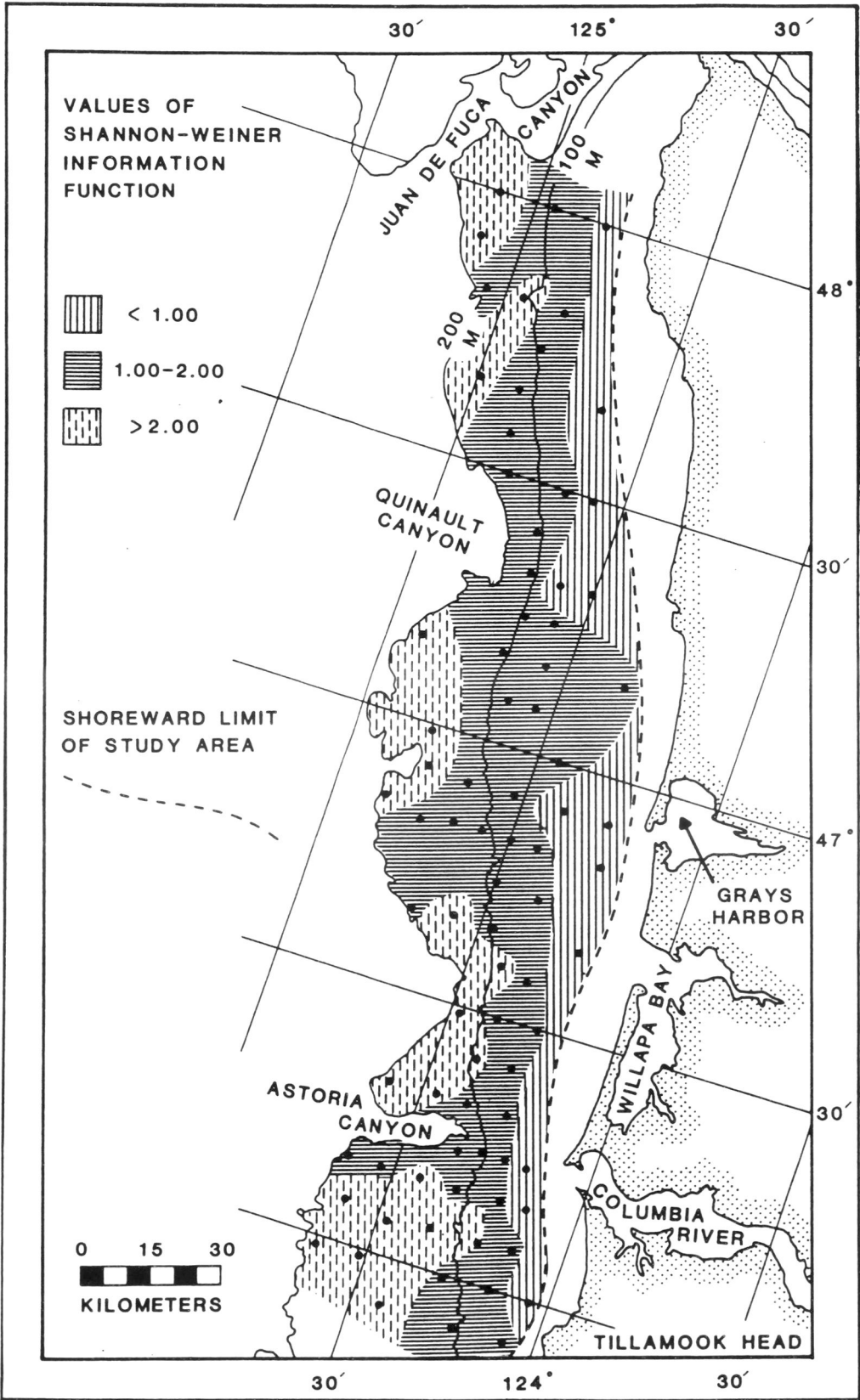


Figure 6. Diversity values.

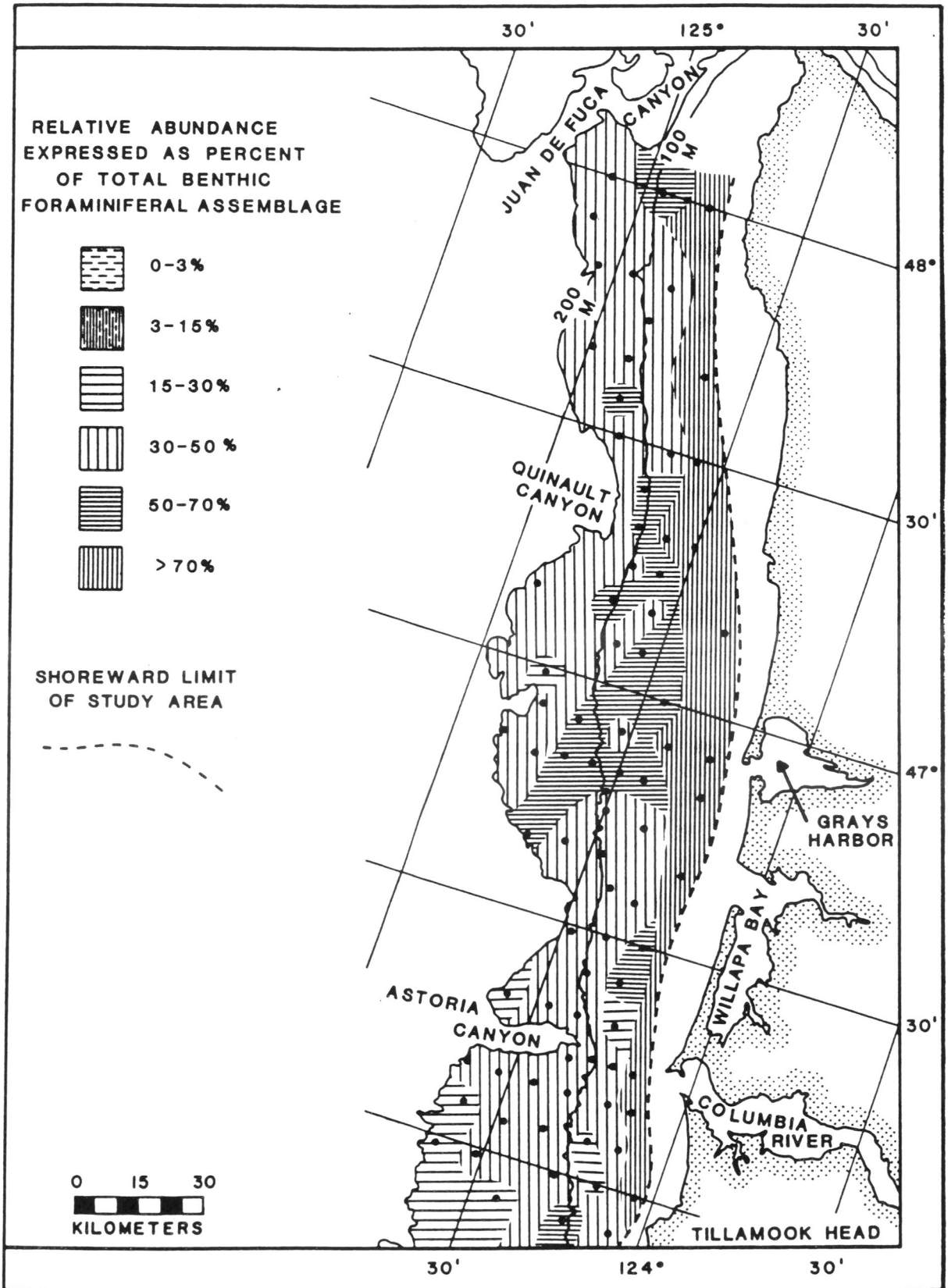


Figure 7.

Distribution pattern of *Eggerella advena*

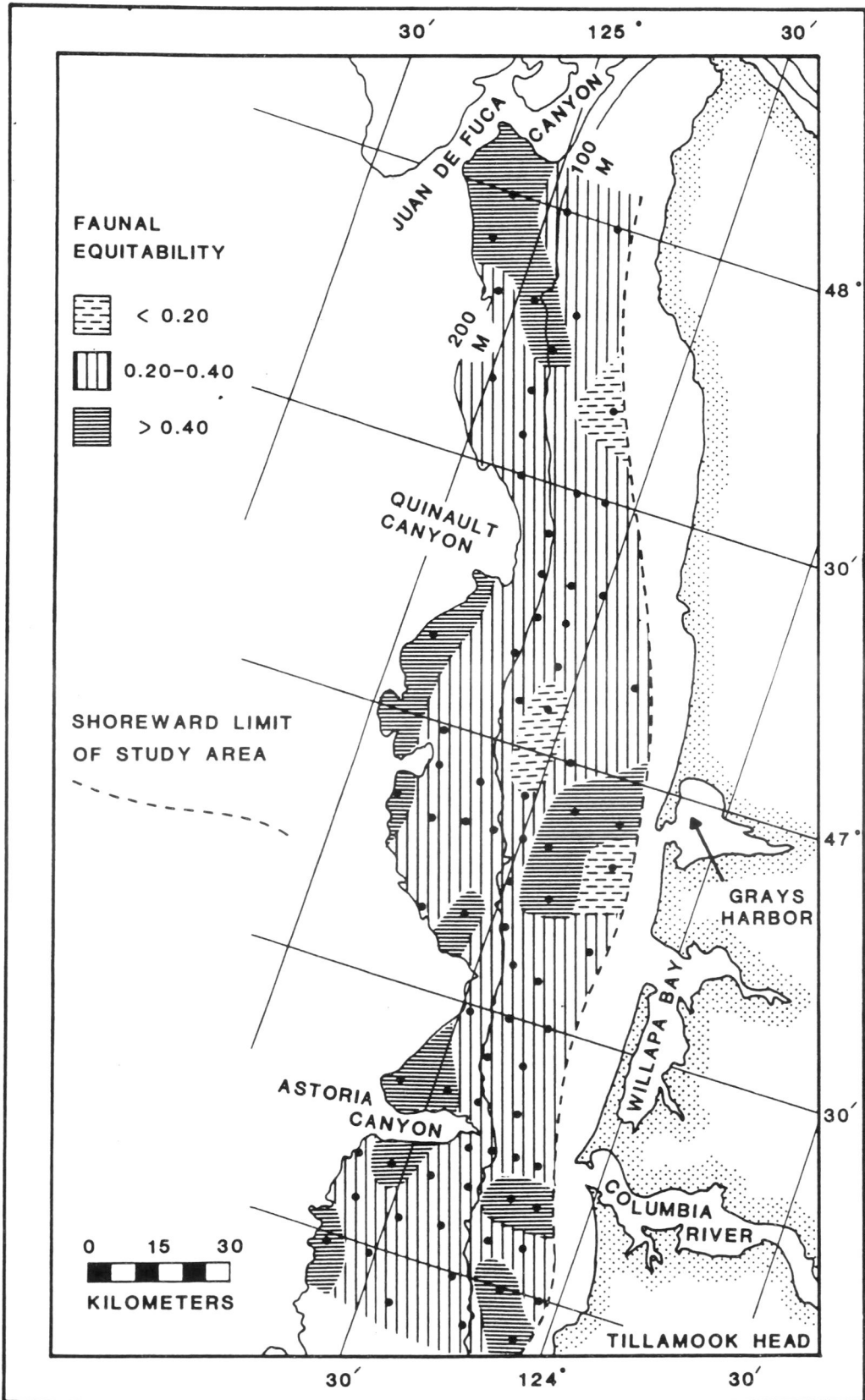


Figure 8. Equitability values.

shelf, and by Resig (1963) on the southern California mainland shelf.

Biofacies in the study area were delineated by cluster analysis (Fig. 9). The choice of nine clusters was made on the basis of the cubic clustering criterion, as suggested and explained by the SAS Institute, Inc. (1982). Clusters "D" and "H" were eliminated from consideration because they are both single-sample clusters attributable to local faunal patchiness, (each is a duplicate of another sample at a given location). "I" and "F" are also single-sample clusters, but are included on the cluster map (Fig. 10) because they are not duplicates of other samples.

The biofacies defined by cluster "G" is located along the nearshore edge of the study area (Fig. 10). Water depths here range from 31 to 70 meters. In addition to the predominant E. advena (greater than 60%), other agglutinated species, Spiroplectammina biformis (Fig. 11) and Recurvoides turbinatus (Fig. 12), are present in abundances of 3 to 10% within the area of cluster "G". The dominant modal grain size in this area varies from 2.75 to 3.75 ϕ as far north as the Quinault River, the northern limit of the area from which sediment-size data are available (Fig 13). This is equivalent to fine to very fine sand. Values of the Shannon-Weiner Information Function are less than 1.00 for most of the stations in this cluster (Fig. 6).

The cluster "C" biofacies encompasses a large portion of the middle shelf north of the Columbia River (Fig. 10). It pinches out near Quinault Canyon and then widens again to the north. Water depth in the area characterized by this cluster ranges from 55 to 132 meters. The abundance of E. advena in this area drops to 40 to 60%, largely because of the dramatic increase in abundance of S. biformis to values of 20 to

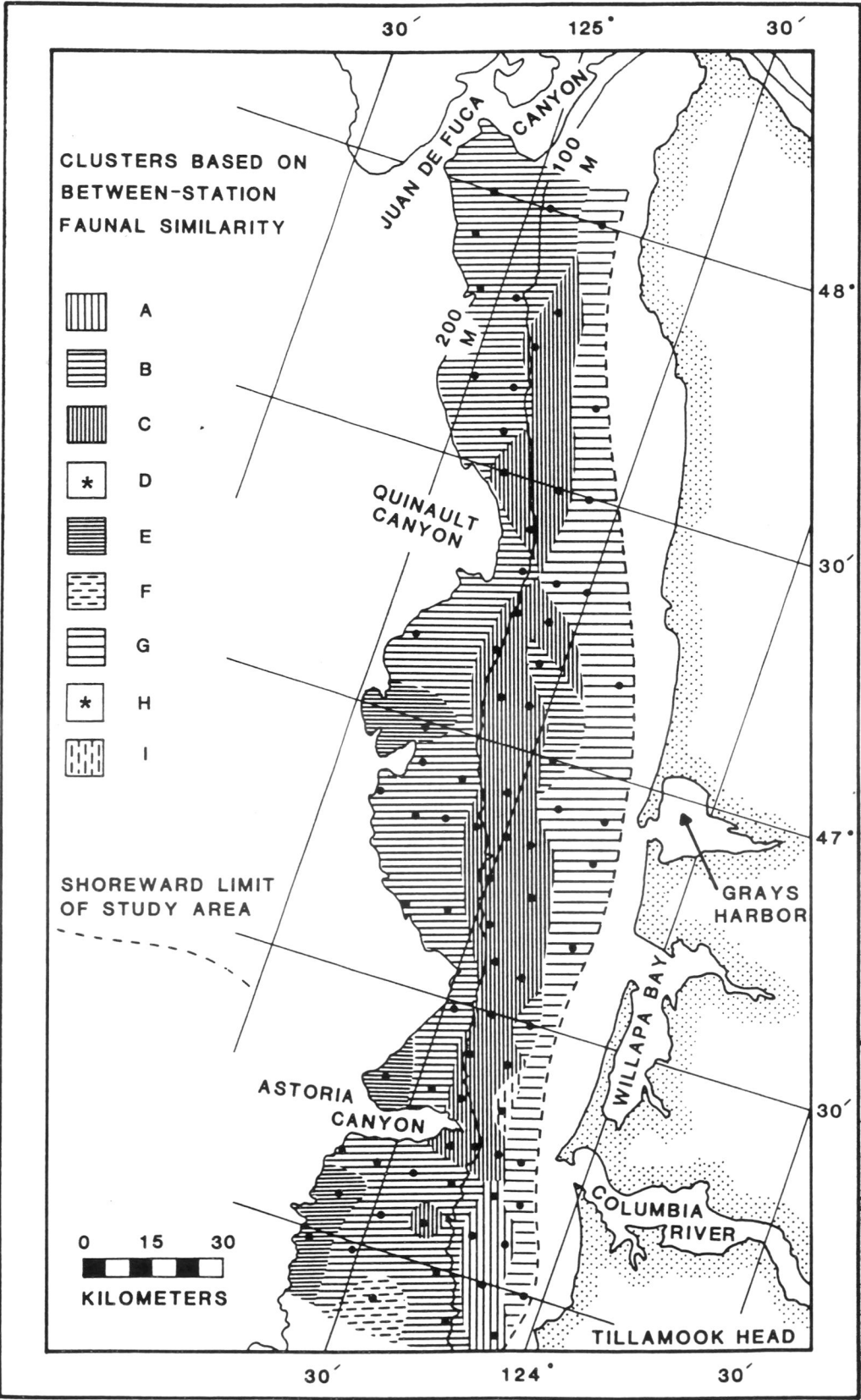


Figure 10. Geographical distributions of clusters.

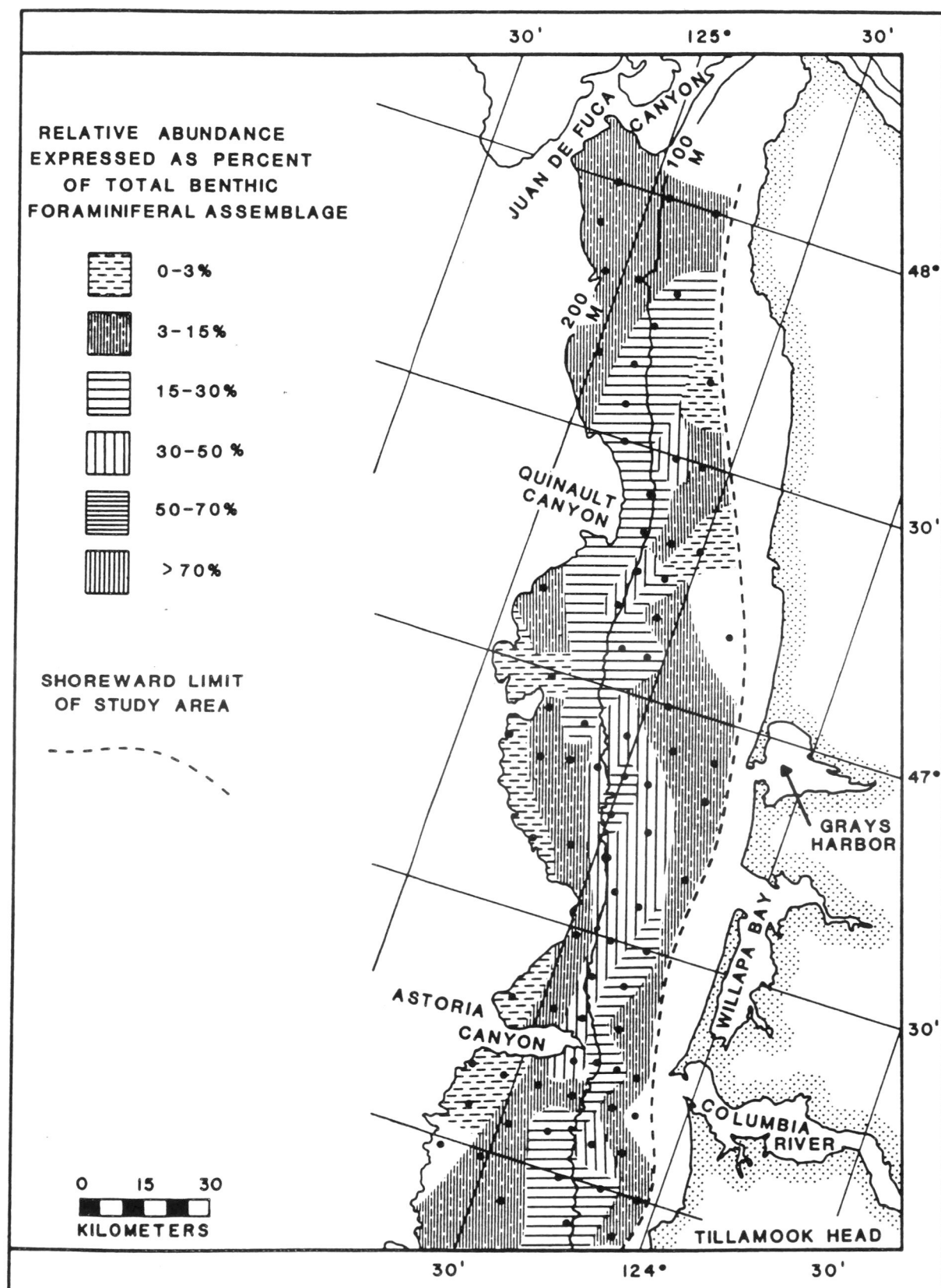


Figure 11.

Distribution pattern of Spiroplectammina biformis

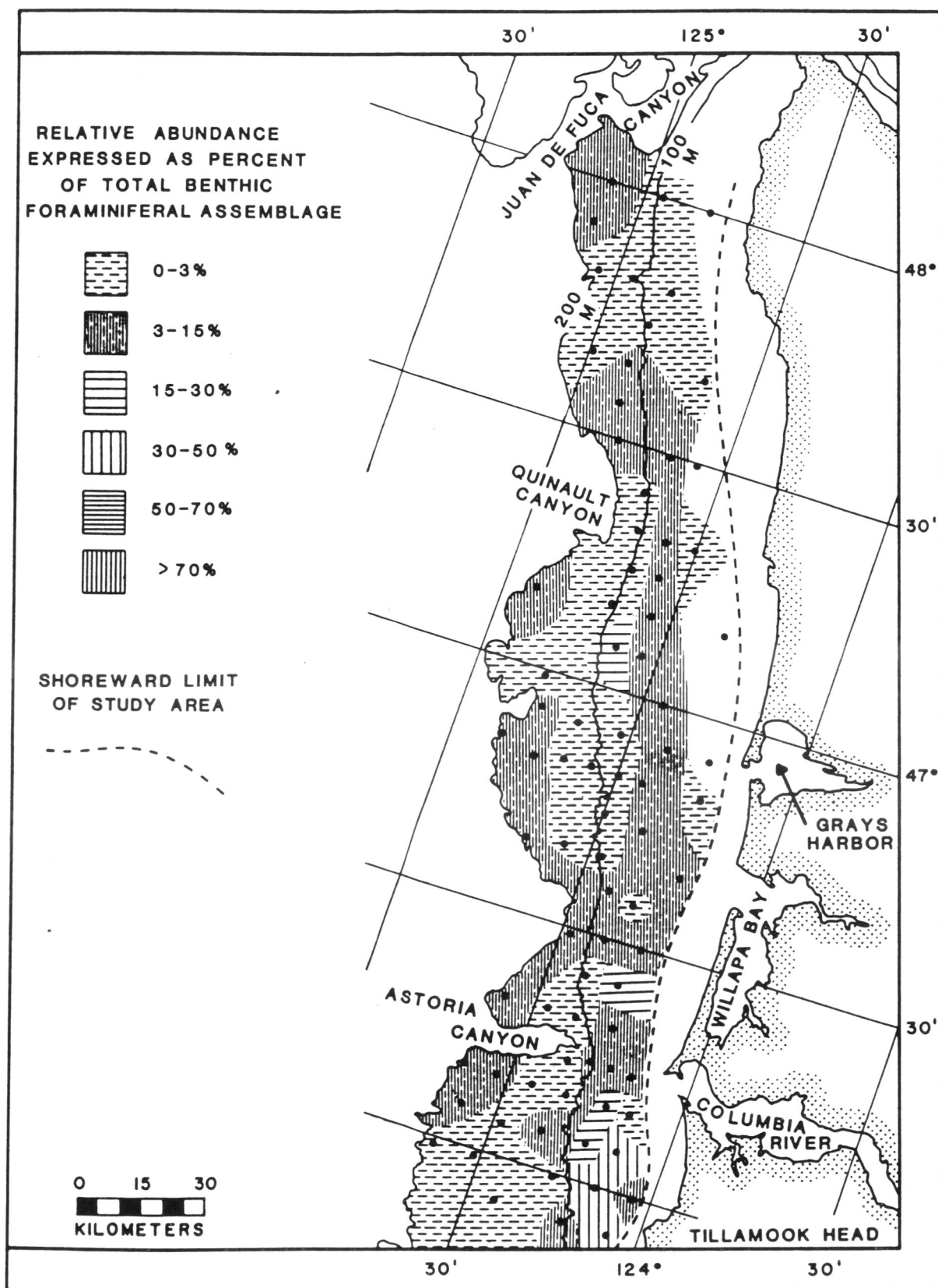


Figure 12.

Distribution pattern of Recurvovoides turbinatus

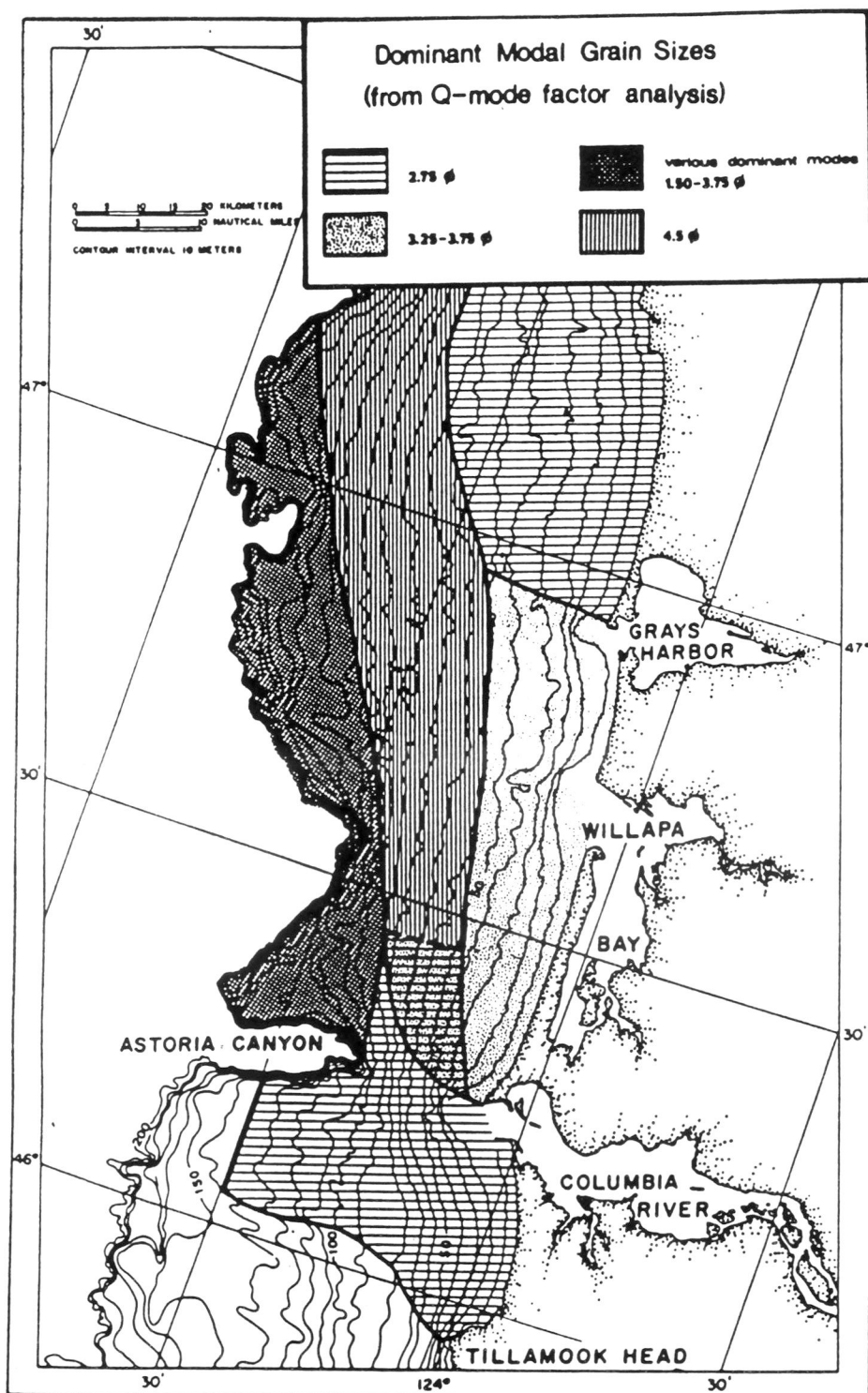


Figure 13. Sediment-size distribution (From Nitttrouer & Sternberg, 1981).

45% (Fig. 11). R. turbinatus is present on the middle shelf in about the same abundances (3-10%) as in the more nearshore cluster. Another agglutinated species, Adercotryma glomerata (Fig. 14) has abundances of 3-10% in cluster "C". The middle shelf south of Quinault Canyon and north of the Columbia River has a modal grain size of 4.5 ϕ , which is in the range of coarse silt (Fig. 13). The highest sedimentation rates on the shelf are in the area of cluster "C" (Fig. 15). Rates decrease generally northward toward Quinault Canyon. Sediment data are not available north of Quinault Canyon. The stations in this cluster have diversity values ranging from 1.00 to 2.00.

Cluster "A" is similar to "C" in that it characterizes comparable water depths (70 to 90 meters), contains the same major foraminiferal faunal components, and occupies an area that is the southern extension of biofacies "C" (Fig. 10). The major difference between the two biofacies is the increase in abundance of R. turbinatus to values of 20 to 45% south of the Columbia River. That increase corresponds with a decrease in E. advena (to 20-40%) and in S. biformis (to 15-35%). The relative abundance of A. glomerata remains at 3 to 10%. The dominant modal grain size in this region is 2.75 ϕ , which is in the fine sand range (Fig. 13). Sediment size difference may partially explain differences in relative abundances, as S. biformis is known to prefer a silty substrate, and its increased abundance is one of the significant factors which defines cluster "C". The diversity values for cluster "A" are also similar to those of "C", ranging from 1.00 to 2.00.

Cluster "I" defines a biofacies consisting of a single sample, WA-11. It is located just north of the Columbia River mouth in 71 meters of

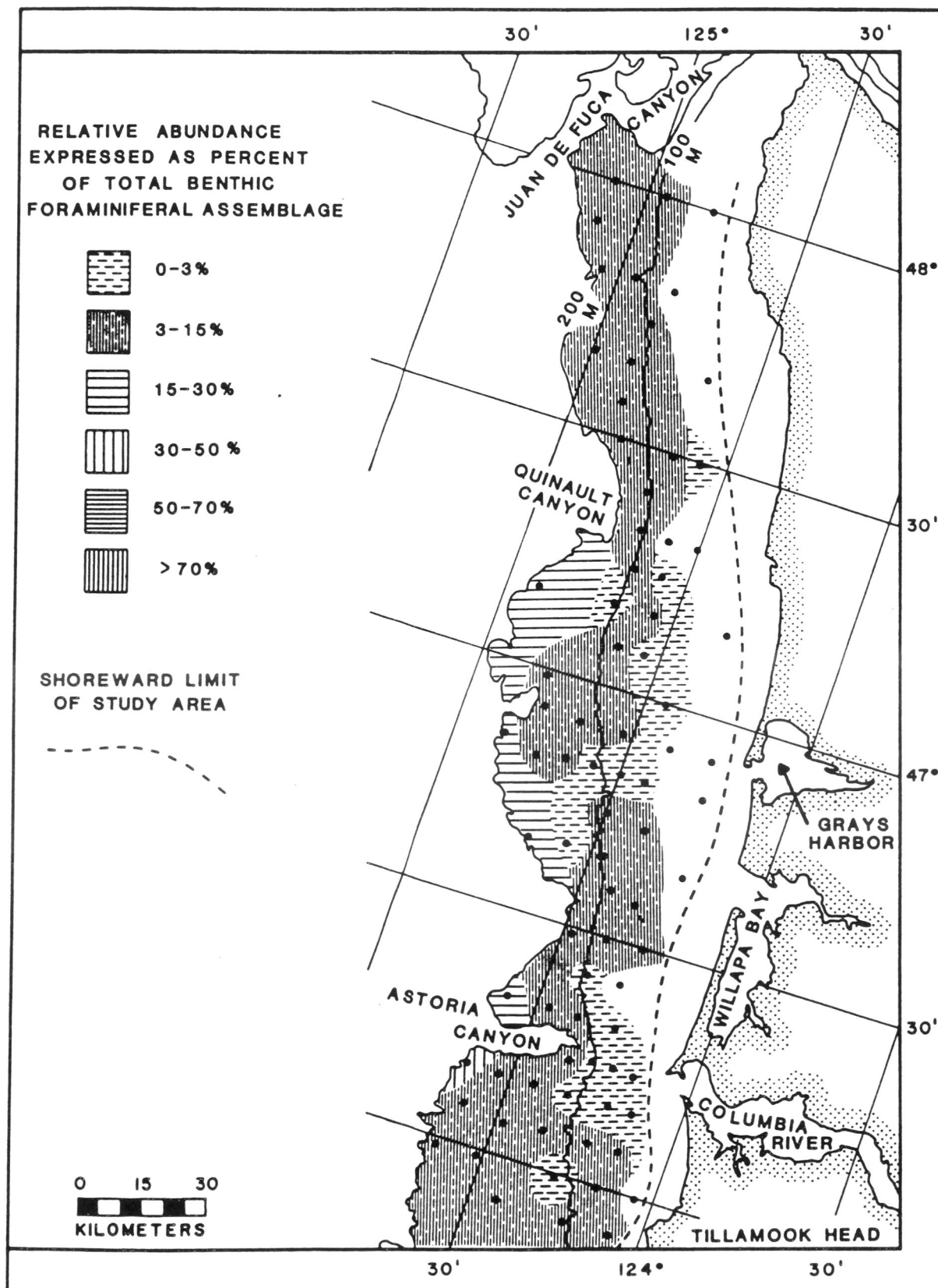


Figure 14.

Distribution pattern of Adercotryma glomerata

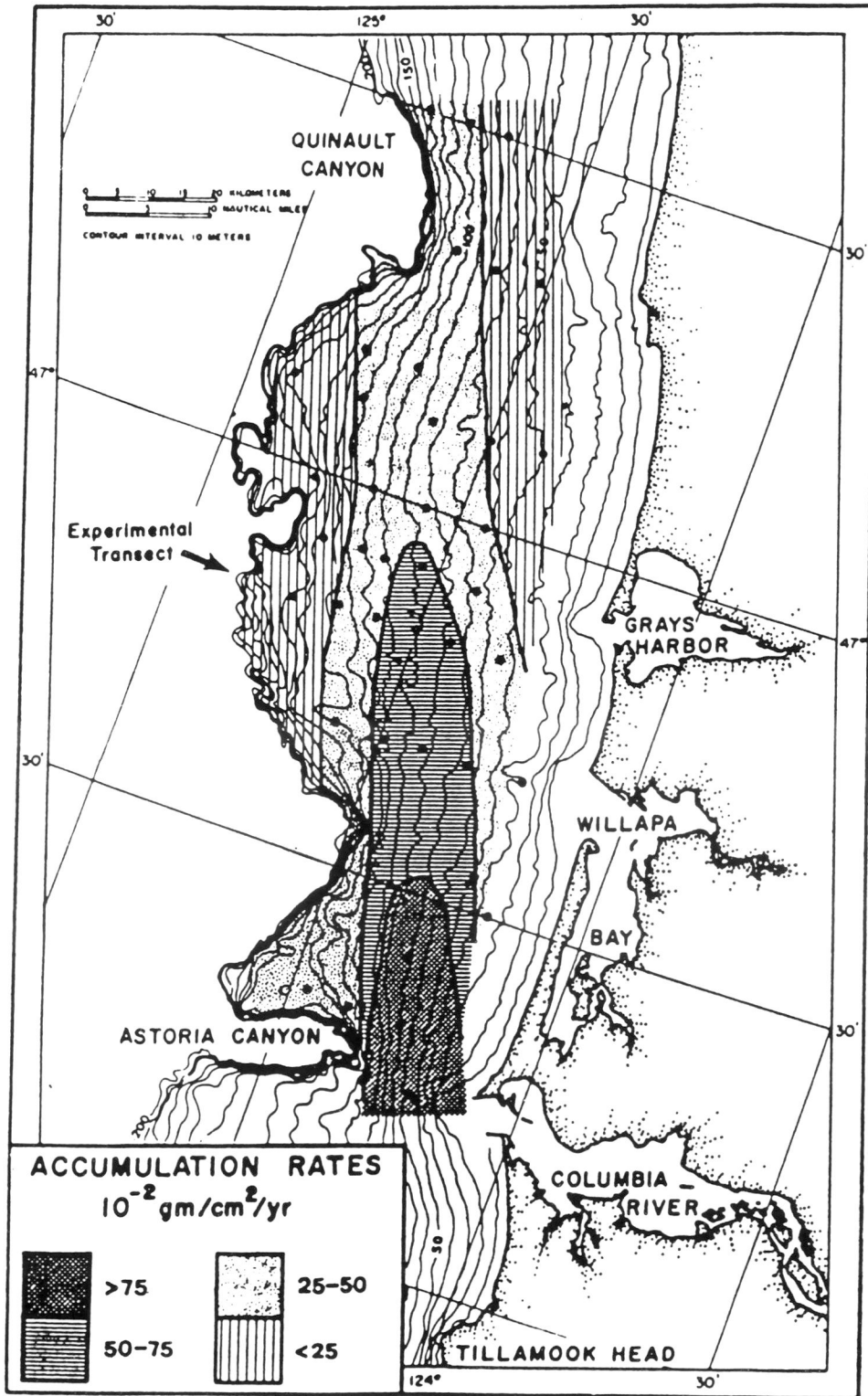


Figure 15. Sedimentation rates (From Nitttrouer et al., 1979a).

water (Fig. 10). This sample is dissimilar to all others because of the unusually high relative abundance of the calcareous species, Buliminella elegantissima which composes 55% of the faunal assemblage (Fig. 16). Harmon (1972) noted an abundance of this species north of the Columbia River in nearshore waters. This station may be the seaward limit of that assemblage. Eggerella advena and Recurvoides turbinatus are also important members of this sample with relative abundances of 20% and 16%, respectively. The grain size has multiple modes between 2.75 ϕ and 3.75 ϕ , which include fine to very fine sand. Species diversity is 1.59 for this sample.

Cluster "B" encompasses more stations than any of the other biofacies. It characterizes the middle to outer shelf in water depths of 93 to 176 meters, but it also includes three outlying stations on the inner middle shelf in depths as shallow as 60 meters (Fig. 10). E. advena (Fig. 7) is the predominant species with relative abundances of 20 to 40%. The calcareous species, Uvigerina juncea (Fig. 17), becomes prominent (5-20%) in this cluster. Adercotryma glomerata (Fig. 14) also composes 5 to 20% of the benthic assemblage in this cluster. Spiroplectammina biformis decreases dramatically from its middle-shelf abundances to values ranging from 0 to 15%. Haplophragmoides bradyi, a fine-grained arenaceous form that does not occur on the inner shelf, occurs in relative abundances from 0 to 10% in cluster "B" (Fig. 18). Textularia earlandi, another arenaceous form rare in shallow water, accounts for 3 to 8% of assemblages on the outer shelf (Fig. 19). Many other species comprise less than 3% of this biofacies, which results in diversity values as high as 2.4. For the area of available data (south

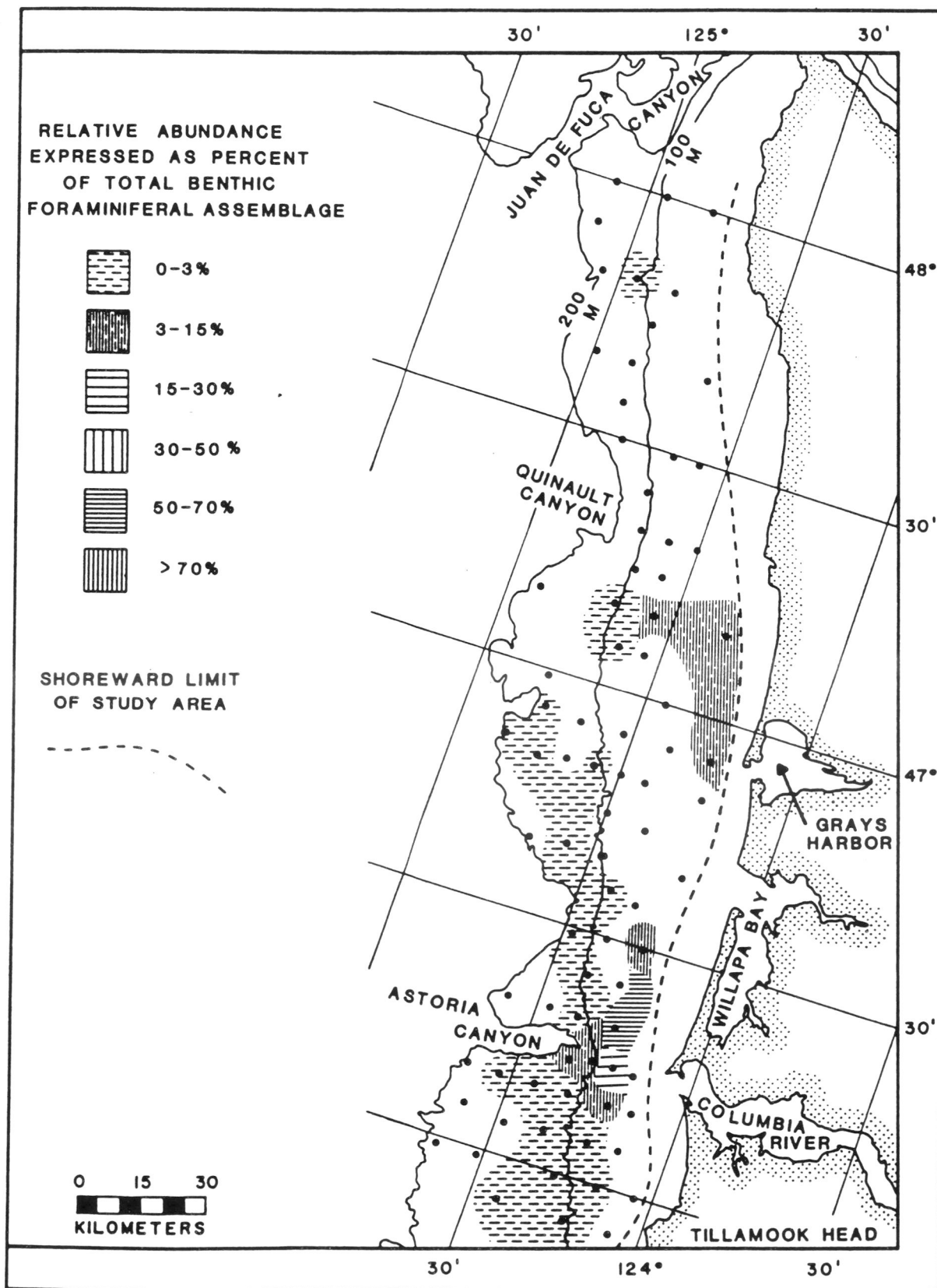


Figure 16.

Distribution pattern of *Buliminella elegantissima*

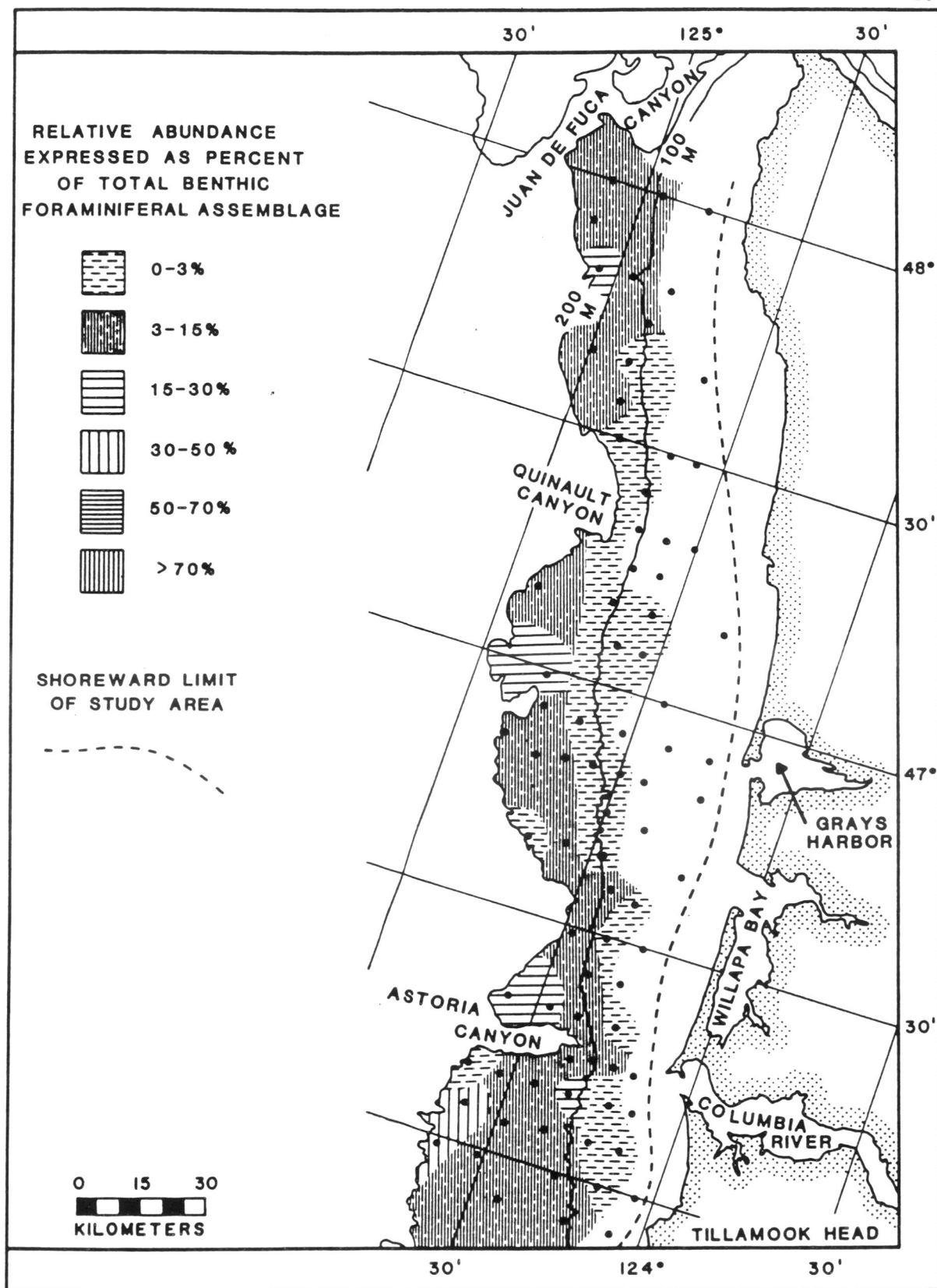


Figure 17.

Distribution pattern of *Uvigerina juncea*

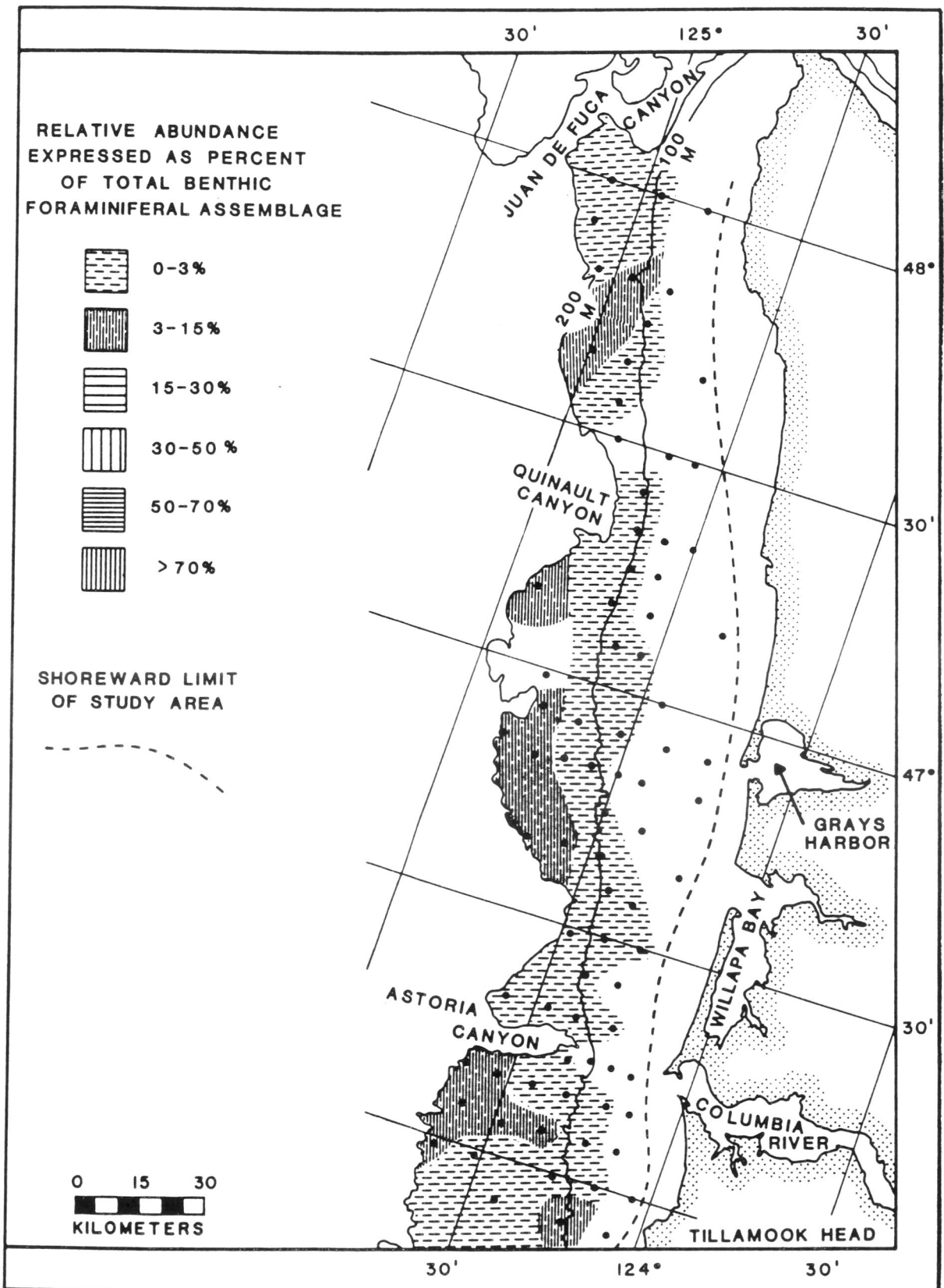


Figure 18.

Distribution pattern of Haplophragmoides bradyi

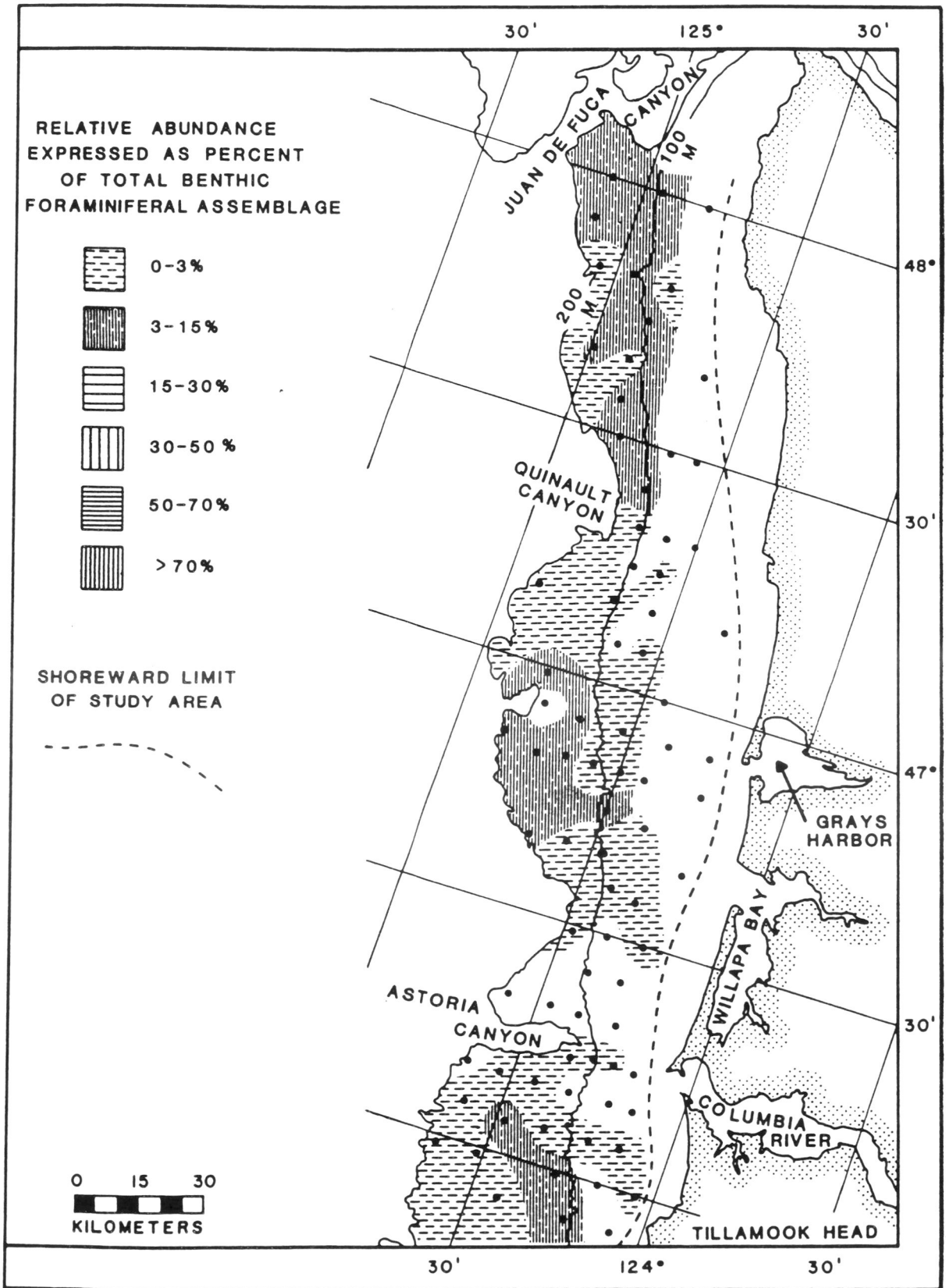


Figure 19.

Distribution pattern of Textularia earlandi.

of Quinault Canyon), modal grain sizes vary from 1.5 to 3.75 ϕ (medium to very fine sand), and sedimentation rates are generally lower (less than $50 \times 10^{-2} \text{ gm/cm}^2/\text{yr}$) than for the middle shelf area represented by cluster "C" (Fig. 15).

Cluster "F" contains a single sample, WA-97, on the southern boundary of the study area at a water depth of 143 meters (Fig. 10). It is unique because of the anomalously high abundance (28% of the assemblage) of the small calcareous species, Epistominella vitrea (Fig. 20). Eggerella advena composes 15% of the assemblage, and U. juncea accounts for 14%. Eponides leviculus (Fig. 21), which is closely associated with the occurrence of E. vitrea, is present with a relative abundance of 12%. Many other species occur in lesser abundances, resulting in a diversity index of 2.34. Sedimentary data is not available for this station.

Cluster "E" comprises four stations that define three isolated patches on the outermost shelf at water depths from 144 to 185 meters (Fig. 10). Uvigerina juncea reaches its highest abundances (20 to 35%) and is the predominant species in this biofacies. Eggerella advena composes 15 to 20% and Adercotryma glomerata 7 to 15% of the assemblage. The abundance of Haplograptoides bradyi increases slightly (3 to 15% of the assemblage). The calcareous species, Trifarina angulosa (Fig. 22), a minor constituent of cluster "B", increases to abundances of 5 to 14%. The isolated samples of cluster "E" contain many other species and so are characterized by diversity values greater than 2.00. Sediment data is available only for the two samples north of Astoria Canyon, and in both cases modal grain sizes vary from 1.50 to 3.75 ϕ and sediment

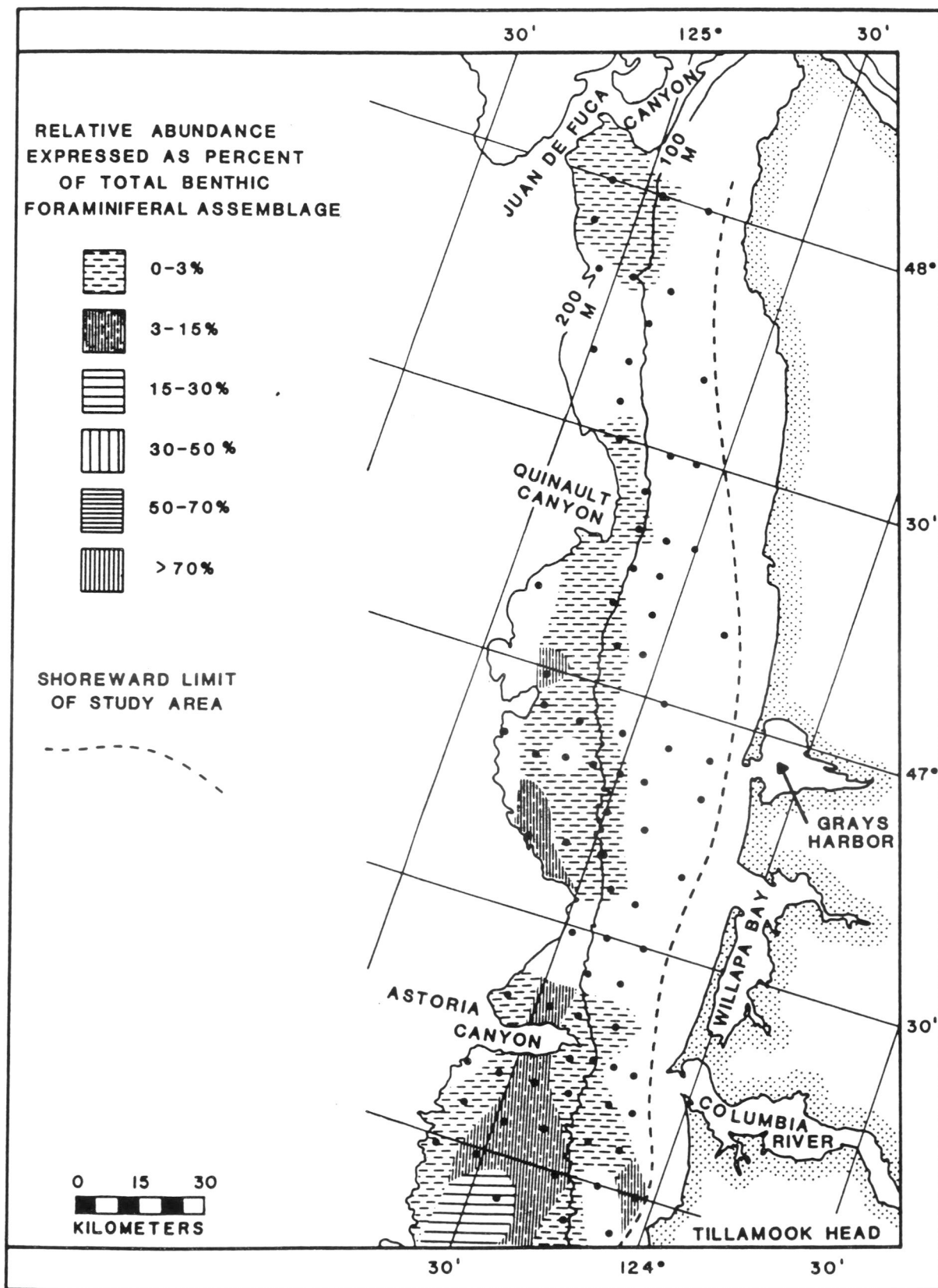


Figure 20.

Distribution pattern of Epistominella vitrea

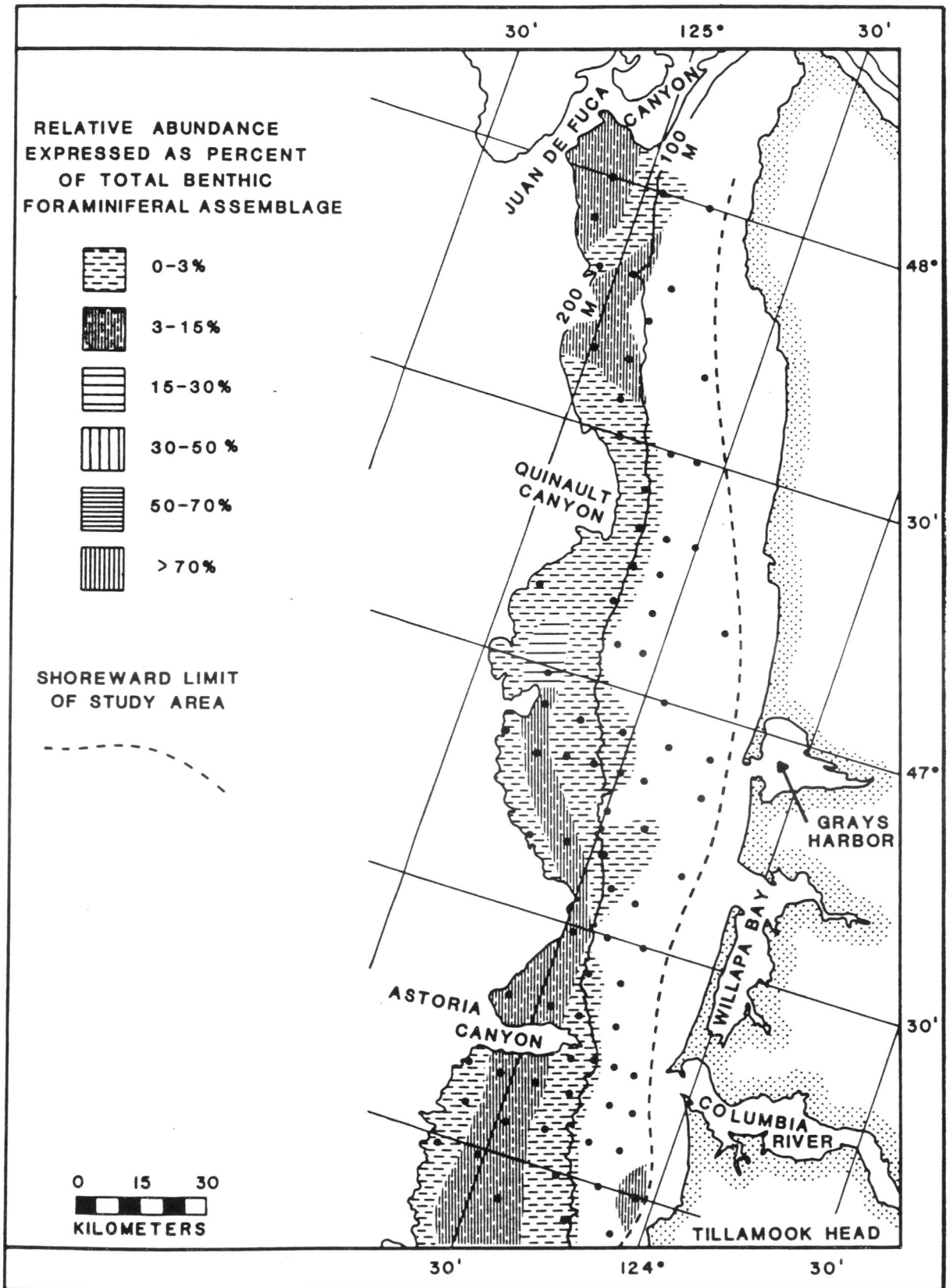


Figure 21.

Distribution pattern of Eponides leviculus

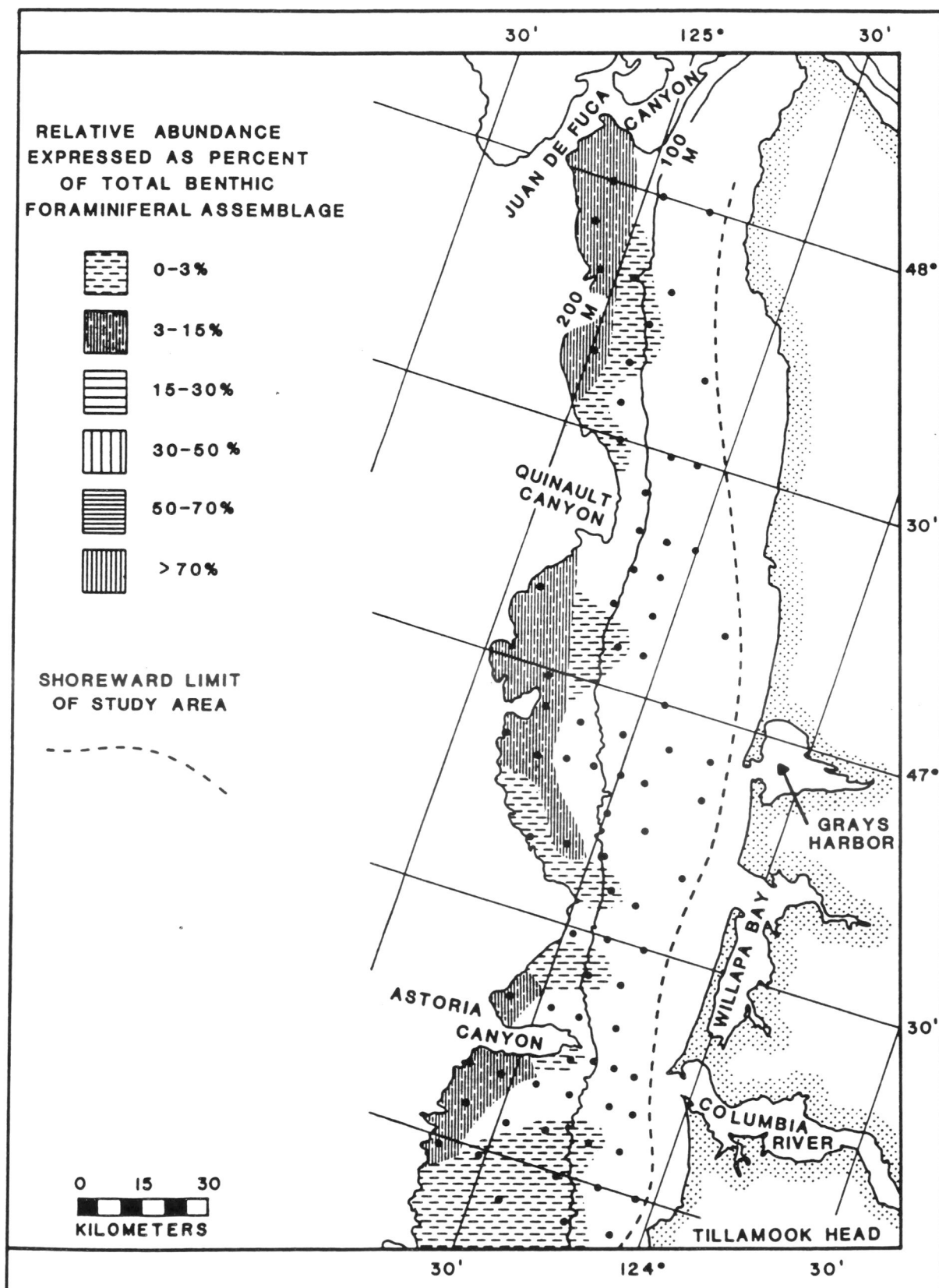


Figure 22.

Distribution pattern of *Trifarina angulosa*

accumulation rates are less than $50 \times 10^{-2} \text{ gm/cm}^2/\text{yr}$.

The distributional patterns for the most abundant species (those making up more than 3% of the fauna in most of the samples in a cluster) have been described in terms of nearshore ("G"), middle shelf ("C" and "A"), outer shelf ("B"), outermost shelf ("E") and isolated stations ("F" and "I"). The patterns in the southern part of the area agree for the most part with those described by Harmon (1972). The only exceptions are that I did not observe species of Cassidulina in significant numbers, and that the outer-shelf calcareous species he called Epistominella exigua is probably the same species I identify as E. vitrea (see Plate 5, Figs. D-F). The major biofacies parallel the isobaths, as do patterns of mean sediment-size and sedimentation rate, strongly suggesting that distributional patterns on the Washington continental shelf are related to these parameters.

Distribution maps for other common species are given in Appendix 2, and relative abundance values for all species identified are given in Appendix 1.

ASSESSMENT OF POST-MORTEM TRANSPORT

Regression Background

The equation used in this study to estimate traction velocities of benthic foraminiferal tests is based on the work of Kontrovitz et al. (1978). Traction velocity, defined as the water-current speed required to initiate movement of a specimen, can be used to recognize assemblages as current-sorted when all species present have similar values. A brief summary of procedures used by Kontrovitz and his colleagues is given below to explain the theoretical background on which this study is based. For more detailed background, see Kontrovitz et al. (1978).

Specimens of 12 benthic foraminiferal species were measured under a binocular microscope to determine the longest, intermediate and shortest dimensions. Specimens were also weighed with a Cahn Gram Electrobalance. Mean traction velocity for each species was determined experimentally in a flume, using the same specimens that had been measured and weighed. Multiple regression analysis was applied to these data, with experimentally determined traction velocity as the dependent variable. The resulting equation is:

$$X_1 = 18.4 - 11.4X_2 - 38.9X_3 \quad (1)$$

where X_1 is the mean traction velocity (cm/sec), X_2 is the mean value of maximum projection sphericity, X_3 is the mean weight (mg) and 18.4 is the regression plane intercept. Maximum projection sphericity is defined as:

$$X = \sqrt[3]{S^2/LI} \quad (2)$$

where S, L, and I are the lengths of the short, long and intermediate axes, respectively. Use of equation #1 makes it possible to estimate traction velocity of a species from weight and linear measurements. The

published equation was subsequently revised to a linear form which no longer takes weight into account (Kontrovitz and Snyder, 1981):

$$Y = 22.3 - 19.8X \quad (3)$$

where Y is the threshold (traction) velocity (cm/sec), X is the maximum projection sphericity (equation #2) and 22.3 is the intercept of the regression line.

My study employs equation #3 to predict the traction velocities of selected benthic foraminiferal species found on the Washington continental shelf. Use of this equation yields values for traction velocity that vary with differences in test shape, which changes from species to species but is relatively consistent within any given species. Theoretically, an assemblage which contains species having similar traction velocities indicates current sorting, while an assemblage containing species with a large range of traction velocities suggests preservation in place.

Scheffé's Method

Scheffé's method of multiple comparison is a rigorous statistical procedure for comparing means between groups of observations. It results in fewer significant differences than other multiple comparison methods, and unequal numbers of observations between groups is not a problem when employing this procedure (Ferguson, 1966). Because the method is so rigorous, Scheffé (1959) recommends using the 0.10 level of significance. F-distribution tables at this level are provided by Winer (1971). This method was carried out through the use of the APPLE Basic program listed in Appendix 3. Application of this method to estimated traction

velocities for the 31 most common species in this study produced the pattern in Figure 23. Florilus basispinatus is not included in this analysis because it is nearly identical in shape to F. auriculus. Eggerella advena is subdivided into two forms (average and large) because of a distinct difference in shape. Average forms are smaller and more triangular, while large forms are elongated with more inflated chambers (Plate 2, Figs. D and G). The length of each bar in Fig. 23 encompasses all species with traction velocities that do not differ significantly from the velocity of the species labeled on that bar. Visual examination of the bar arrangement reveals three groups of species with similar traction velocities. The low-velocity and intermediate-velocity groups can be divided between Lagenammina atlantica and Trifarina angulosa; the intermediate- and high-velocity groups can be divided between Reophax scorpiurus and Spiroplectammina biformis.

In addition to permitting comparison of mean traction velocities between one species and another, Scheffé's method allows comparison of any and all combinations of groups (species) (Edwards, 1972). Any group of species can be compared to any other group of species. Comparison of the three traction-velocity groups in Fig. 23 reveals significant differences between traction velocities of the groups. Hence, species within each group are moved by velocities from the same statistical population. These groups are shown in Fig. 24, with species listed in order of ascending mean traction velocity. Mean values for each species are used for ordering purposes only. The application of Scheffé's method requires values for individual specimens because it is a comparison of within species variation to between species variation. Results from

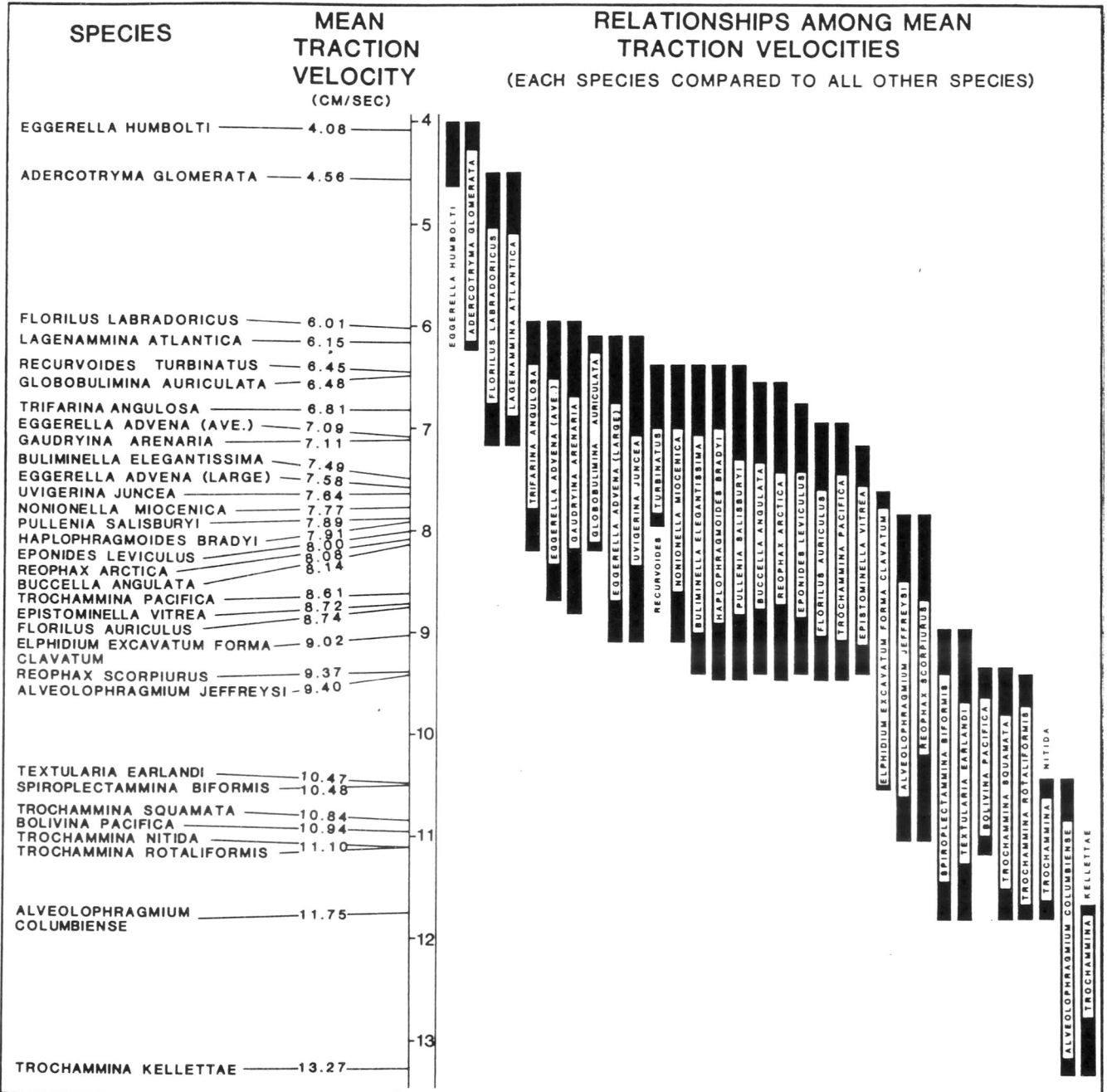


Figure 23. Results of comparisons by Scheffe's method.

SPECIES	MEAN	GROUPING BY MOVEMENT AT SIMILAR VELOCITIES
	TRACTION VEL.	
EGGERELLA HUMBOLTI	4.08	GROUP 1
ADERCOTRYMA GLOMERATA	4.56	
FLORILUS LABRADORICUS	6.01	
LAGENAMMINA ATLANTICA	6.15	
RECURVOIDES TURBINATUS	6.45	
GLOBOBULIMINA AURICULATA	6.48	
TRIFARINA ANGULOSA	6.81	
EGGERELLA ADVENA (AVE.)	7.09	
GAUDRYINA ARENARIA	7.11	
BULIMINELLA ELEGANTISSIMA	7.49	
EGGERELLA ADVENA (LARGE)	7.58	GROUP 2
UVIGERINA JUNCEA	7.64	
NONIONELLA MIOCENICA	7.77	
PULLENIA SALISBURYI	7.89	
HAPLOPHRAGMOIDES BRADYI	7.91	
EPONIDES LEVICULUS	8.00	
REOPHAX ARCTICA	8.08	
BUCCELLA ANGULATA	8.14	
TROCHAMMINA PACIFICA	8.61	
EPISTOMINELLA VITREA	8.72	GROUP 3
FLORILUS AURICULUS	8.74	
ELPHIDIUM EXCAVATUM FORMA CLAVATUM	9.02	
REOPHAX SCORPIURUS	9.37	
ALVEOLOPHRAGMIUM JEFFREYSI	9.40	
TEXTULARIA EARLANDI	10.47	
SPIROPLECTAMMINA BIFORMIS	10.48	
TROCHAMMINA SQUAMATA	10.84	
BOLIVINA PACIFICA	10.94	
TROCHAMMINA NITIDA	11.10	
TROCHAMMINA ROTALIFORMIS	11.10	
ALVEOLOPHRAGMIUM COLUMBIENSE	11.75	
TROCHAMMINA KELLETTAE	13.27	

Figure 24. Comparison of groups by Scheffe's method.

Scheffé's method are based on twenty specimens of each species in most cases, but as few as fifteen specimens were used for one species.

Species composing Group 1 are most easily transported, and are the most equidimensional forms (Plate 1). Group 3 comprises flattened-discoidal and elongate-compressed forms which are most difficult to transport (Plates 7 and 8). Group 2 is made up of species with intermediate shapes and intermediate traction velocities (Plates 2 through 6). As previously suggested, an assemblage that has been current-sorted is expected to contain species with similar traction velocities. For example, an assemblage containing only Group 3 species could be interpreted as winnowed (residual). An assemblage predominated by species from Group 1 would suggest that many individuals had been transported in from another location. An assemblage containing species with variable and random traction velocities would be evidence for the absence of sorting in that particular environment.

Comparison of Estimated Traction Velocities to Biofacies

In the section entitled "Benthic Foraminiferal Distribution", five major biofacies were identified on the basis of a cluster analysis (Fig. 25). If transport has occurred on a broad scale in the study area, each biofacies in the affected area should contain foraminifera with similar traction velocities (i.e., foraminifera belonging to the same statistical group as determined by Scheffé's method of multiple comparison).

Figure 26 lists the most representative species within each biofacies (in terms of the cluster letter assigned to it) and divides them into columns corresponding to the traction velocity group to which

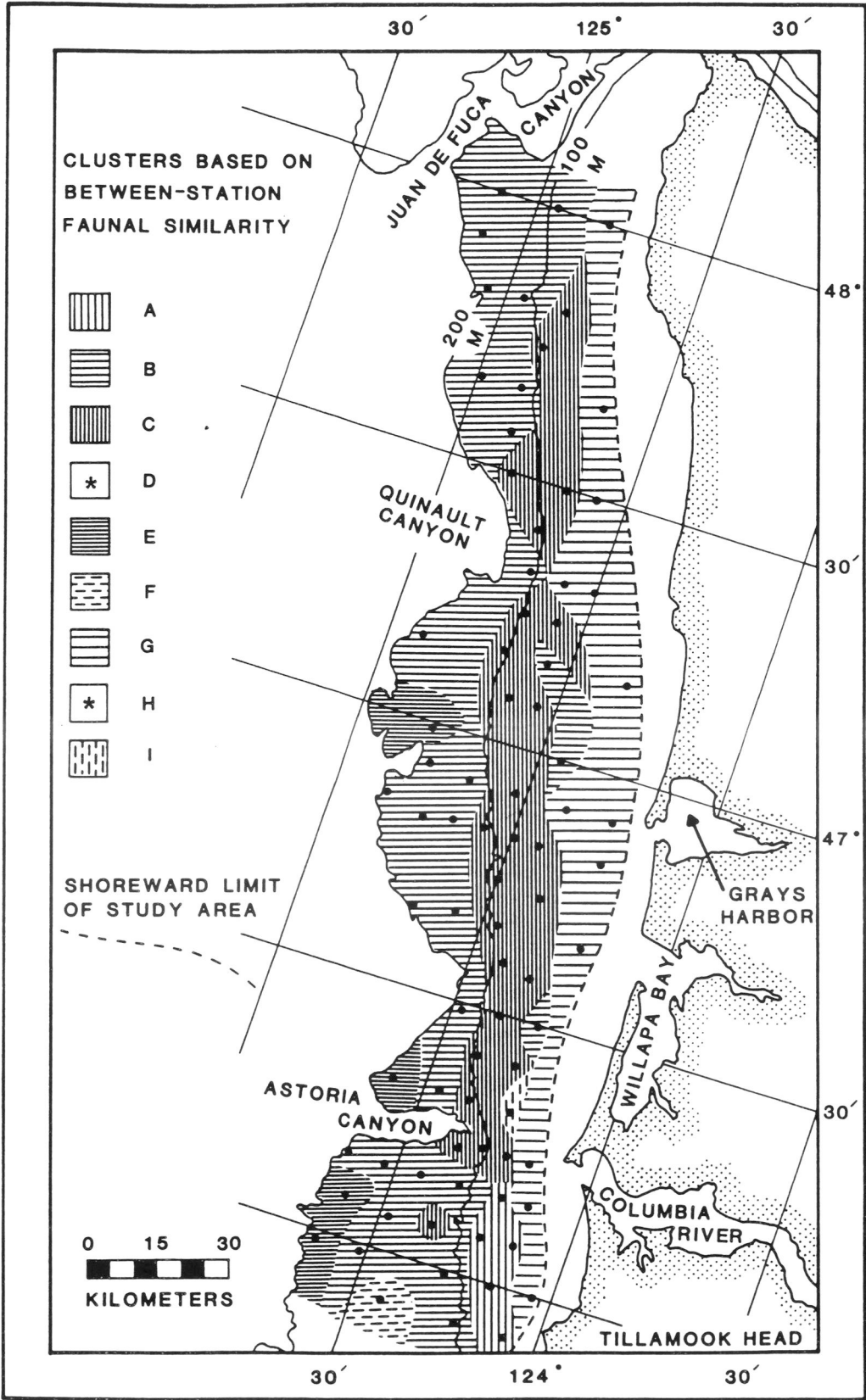


Figure 25. Geographical distributions of clusters.

CLUSTERS (BIOFACIES)	TRACTION VELOCITY GROUP					
	GROUP 1 SPECIES	MEAN TRACTION VELOCITY (cm/sec)	GROUP 2 SPECIES	MEAN TRACTION VELOCITY (cm/sec)	GROUP 3 SPECIES	MEAN TRACTION VELOCITY (cm/sec)
SHOREWARD ↑ G C A I B F E			EGGERELLA ADVENA	7.09	SPIROPECTAMMINA BIFORMIS	10.48
			RECURVOIDES TURBINATUS	6.45		
	ADERCOTRYMA GLOMERATA	4.56	EGGERELLA ADVENA	7.09	SPIROPECTAMMINA BIFORMIS	10.48
			RECURVOIDES TURBINATUS	6.45		
	ADERCOTRYMA GLOMERATA	4.56	EGGERELLA ADVENA	7.09	SPIROPECTAMMINA BIFORMIS	10.48
			RECURVOIDES TURBINATUS	6.45		
			BULMINELLA ELEGANTISSIMA	7.49		
			EGGERELLA ADVENA	7.09		
			RECURVOIDES TURBINATUS	6.45		
	ADERCOTRYMA GLOMERATA	4.56	EGGERELLA ADVENA	7.09	SPIROPECTAMMINA BIFORMIS	10.48
SEAWARD ↓			UVIGERINA JUNCEA	7.64	TEXTULARIA EARLANDI	10.47
			HAPLOPHRAGMOIDES BRADYI	7.91		
			EPISTOMINELLA VITREA	8.72		
			EGGERELLA ADVENA	7.09		
			UVIGERINA JUNCEA	7.64		
			EPONIDES LEVICULUS	8.00		
	ADERCOTRYMA GLOMERATA	4.56	UVIGERINA JUNCEA	7.64		
			EGGERELLA ADVENA	7.09		
			HAPLOPHRAGMOIDES BRADYI	7.91		
			TRIFARINA ANGULOSA	6.81		

Figure 26. Clusters vs. traction-velocity groups.

each belongs. All 31 of the "most common" species are not found on this figure. Rather it contains only those species which characterized a particular biofacies by their presence or by abundances unique to a single biofacies.

In the area characterized by cluster "G" (the cluster nearest shore in relatively shallow water), Eggerella advena is the predominant species (relative abundance greater than 60%). E. advena, with an average traction velocity of 7.09 cm/sec, is in traction-velocity Group 2. Another Group-2 species present in cluster "G" is Recurvoides turbinatus which has a mean traction velocity of 6.45 cm/sec. However, there is also a significant percentage of Spiroplectammina biformis (relative abundances up to 8%). S. biformis, with an average traction velocity of 10.48 cm/sec, belongs to transport Group 3, the most difficult to transport.

Although cluster "G" is predominated by E. advena, both large- and average-sized forms from the same traction-velocity group, transport-velocity theory requires that several species within a single traction-velocity group be present in order to interpret the assemblage as sorted. The fact that more nearshore (higher stress) environments may simply have lower diversity and lower equitability, could also explain the predominance of E. advena in this cluster. If cluster "G" is interpreted as an in-place assemblage, then its constituent species should compare closely with published occurrences from other regions in terms of water depth, substrate type, etc. Many workers (Cushman, 1927; Anderson, 1963; Cooper, 1964; Todd and Low, 1967; Scott, 1974) have reported the widespread occurrence of E. advena in relatively shallow water of the

east Pacific, from the arctic off Point Barrow, Alaska (Loeblich and Tappan, 1953) to sandy sediments off the Baja Peninsula (Lankford and Phleger, 1973). S. biformis has also been widely reported in water less than 70 meters deep, especially in the colder waters around Alaska (Loeblich and Tappan, 1953; Todd and Low, 1967; Vilks, 1969). However, the distribution of S. biformis on the Washington shelf appears to be associated more with substrate type than with water depth, as it is most abundant where the percentage of silt-sized material is greatest. R. turbinatus has been reported in high latitude waters at a depth of 48 meters by Bergen and O'Neil (1979), and off Point Barrow, Alaska, as shallow as 64 meters by Loeblich and Tappan (1953). Significant abundances of R. turbinatus are described from the Canadian arctic by Vilks (1969) in water as shallow as 17 meters. Based on the presence of tests from more than one traction-velocity group, and on the fact that constituent species commonly live in this kind of environment, the portion of the study area defined by cluster "G" has not been significantly affected by post-mortem transport of foraminiferal tests. This does not contradict interpretations by Harmon (1972) or Echols (1969), who stated that dead organisms are being transported seaward from the inner shelf of Washington. Those studies refer to shallower water depths (approximately 20 meters) and are based on more closely spaced samples than were available for this study.

The scarcity of Adercotryma glomerata in cluster "G", a Group-1 species common in the rest of the study area, may result from winnowing of dead specimens. This cannot be stated unequivocally, however, because living specimens may be excluded from nearshore areas. Except for one

occurrence reported by Loeblich and Tappan (1953) at 48 meters, A. glomerata is restricted to depths greater than 100 meters of water (Vilks, 1969; Anderson, 1963; Phleger, 1964). Hence, A. glomerata may be restricted to deeper water by some depth-related environmental factor(s) rather than being transported from the nearshore environment after death.

Cluster "C" covers an area just seaward of "G" on the middle shelf. It trends parallel to isobaths and its geometric center is at depths of 80 to 90 meters. It follows closely the mid-shelf silt deposit which extends from the head of Astoria Canyon to near the head of Quinault Canyon (Nittrouer, 1979b). Cluster "C" tapers off at that point, and is re-established to the north of Quinault Canyon. Although sedimentological data is not available north of Quinault Canyon, the area encompassed by cluster "C" probably has a high silt content because the southern part of this cluster is limited by the boundaries of the known silt deposit, and it also contains other species with an affinity for high concentrations of silt.

Eggerella advena remains the predominant species in cluster "C", but it is less abundant (40-60%) than in shallower water (cluster "G"). Recurvoides turbinatus is also a significant Group-2 species in cluster "C". Adercotryma glomerata (average traction velocity = 4.56 cm/sec) is present as a representative of transport-group 1. Again Spiroplectammina biformis is present from Group 3, but in much greater abundance (20-45%) than in more nearshore environments. Based on estimated traction velocities, the middle-shelf biofacies of cluster "C" was not affected by post-mortem transport. It contains species from Groups 1, 2 and 3 in significant abundances, with estimated traction velocities ranging from

4.56 to 10.48 cm/sec.

Occurrences of these main species have also been reported in similar environments from other geographic regions. Anderson (1963) found abundant specimens of E. advena, S. biformis and A. glomerata at depths up to 250 meters in the Bering Sea. Douglas and Heitman (1979) found E. advena to be an abundant component of the California borderland at a depth of 90 meters, especially in the summer months. R. turbinatus was reported by Loeblich and Tappan (1953) at depths greater than 64 meters a few miles off Point Barrow, Alaska. The marked increase in abundance of S. biformis in the mid-shelf area is related to higher silt content and/or higher sedimentation rate (see Figs. 27 and 28). It has been reported in greatly varying water depths, but always in silty sediments (Todd and Low, 1967; Cooper, 1964; Vilks, 1969).

Cluster "A" is a southern extension of "C", occurring at slightly shallower depths but containing the same major benthic foraminiferal species. The two areas were separated in the cluster analysis based on differences in relative abundance among these species. From "C" to "A", the abundance of Adercotryma glomerata is about the same; Eggerella advena decreases to 20-40%; Spiroplectammina biformis decreases slightly to 15-35%; and Recurvoides turbinatus increases from less than 10% to 20-45%. The decrease in E. advena and S. biformis, and the resulting increase in R. turbinatus correlates with increased sediment grain size (mode = 2.75 ϕ) south of the Columbia River mouth (Fig. 27). Both E. advena and S. biformis appear to be more abundant in silty sediments when other factors are the same (Cooper, 1964). Because major benthic foraminiferal faunal elements are the same in clusters "C" and "A"

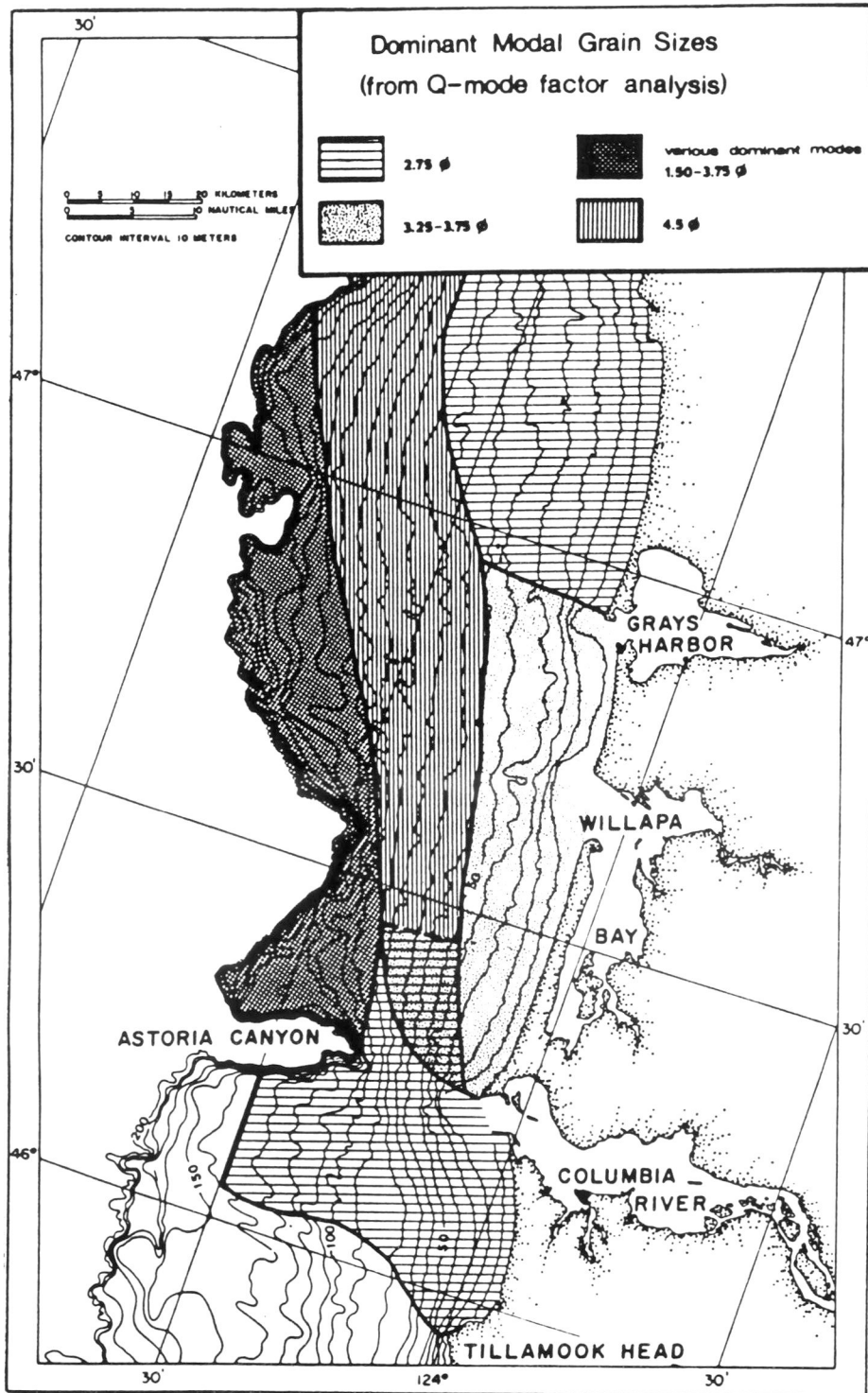


Figure 27. Sediment-size distribution (From Nittrouer & Sternberg, 1981).

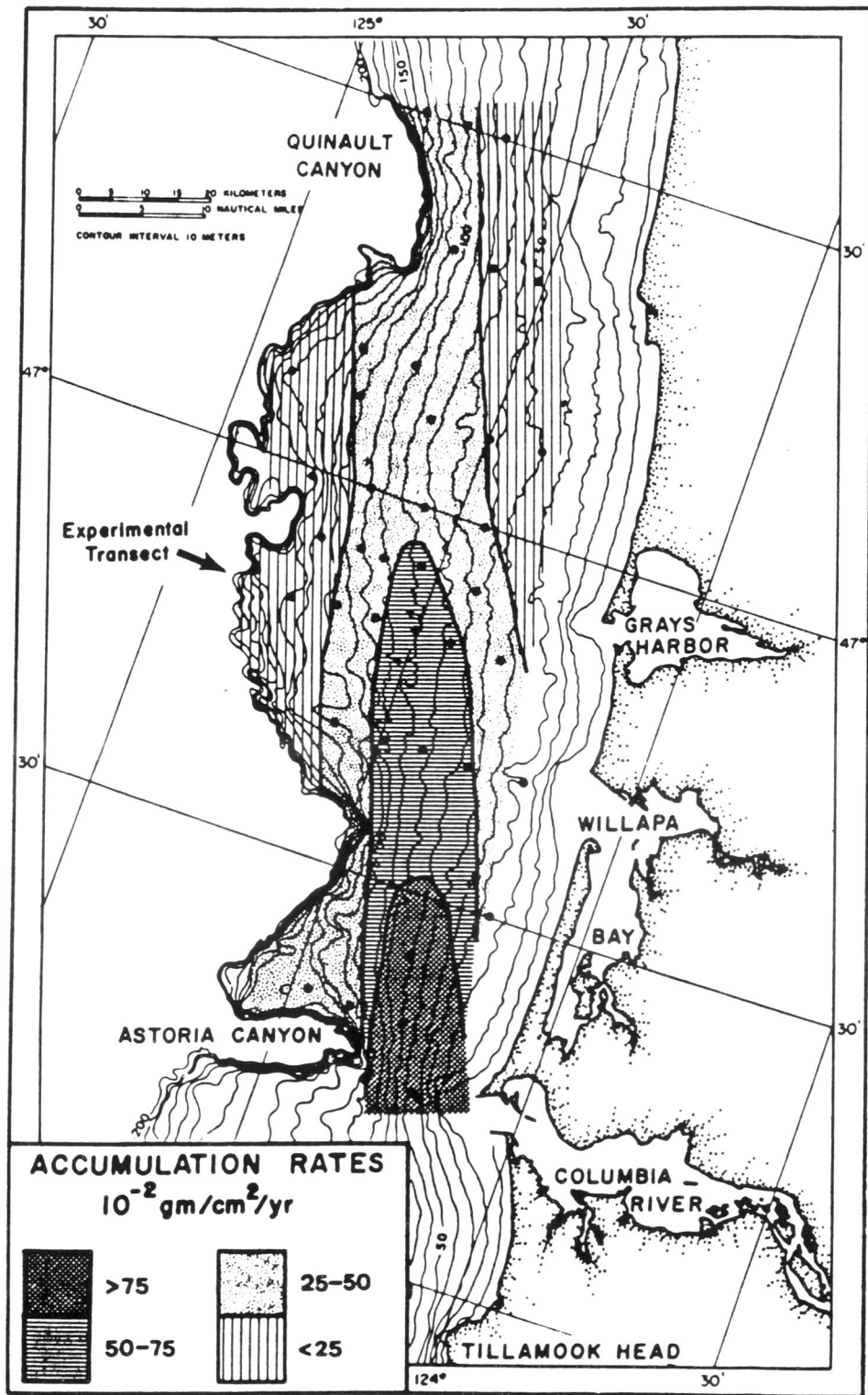


Figure 28. Sedimentation rates (From Nittrouer et al., 1979a).

(representatives of all three traction velocity groups present), post-mortem transport is not indicated for cluster "A".

Cluster "I" consists of one sample from the inner middle shelf (depth of 71 meters) just north of the Columbia River mouth. Major faunal components of this sample are Buliminella elegantissima (traction velocity = 7.49 cm/sec), Eggerella advena and Recurvoides turbinatus. Although all of these species belong to traction-velocity Group 2 (Fig. 26), implications concerning transport based on a single sample are not warranted in a large-scale study such as this. This sample clustered alone because of an anomalously high abundance of B. elegantissima. Bergen and O'Neil (1979) reported B. elegantissima from the Gulf of Alaska at water depths of 51 to 167 meters. It is also common in the Gulf of California from depths of 7 to over 400 fathoms (approximately 14 to 800 meters) (Phleger, 1964). The high abundance of B. elegantissima here may be attributable to a fine sand mode (2.75 ϕ) in this sample (Fig. 27). Lankford and Phleger (1973), in a geographically extensive study of the western U.S. coast, found highest abundances of this species in fine sand. Another factor which may contribute to the abundance of B. elegantissima in this sample is its affinity for high-nutrient and organic-rich conditions. It is commonly an abundant species and frequently the predominant species in sewage outfall areas on the California continental shelf (Watkins, 1961; Bandy et al., 1964, 1965), and is reported as one of the predominant benthic species from polluted waters of Cienfuegos Bay, Cuba (Seiglie, 1968). The highest nutrient levels provided by the Columbia River are during the spring floods (Duxbury, 1972). Samples for the present study were taken in June,

corresponding to maximum input of nutrients, and the geographic position of this sample is directly in the path of the north-northwest bottom currents.

Cluster "B" parallels isobaths and lies primarily on the outer shelf, with a few outlier samples on the middle shelf (shallowest at 60 meters). Due to higher faunal diversity along the outer shelf, this cluster is characterized by the presence of more species at lower relative abundances. Adercotryma glomerata is present from traction-velocity Group 1. Group-2 species include Eggerella advena, Uvigerina juncea (traction velocity = 7.64 cm/sec) and Haplophragmoides bradyi (traction velocity = 7.91 cm/sec). Also common in this cluster are two Group-3 species, Spiroplectammina biformis and Textularia earlandi (traction velocity = 10.47 cm/sec). This wide range of traction velocities, encompassing species from all three transport groups (Fig. 26), suggests that cluster "B" does not represent a sorted assemblage. A. glomerata has been found in the Bering Sea at outer-shelf depths by Anderson (1963) and at a depth of 440 meters by Vilks (1969) in the Canadian Arctic. E. advena is found at depths up to 140 meters off Point Barrow, Alaska (Loeblich and Tappan, 1953), and abundantly at widely varying depths in the eastern Pacific and Arctic Oceans by many authors (Cushman, 1927; Cooper, 1964; Todd and Low, 1967; Bergen and O'Neil, 1979). Anderson (1963) found U. juncea in the Bering Sea at depths of 130-250 meters, and H. bradyi at a depth of 155 meters. U. juncea was reported at similar depths by Douglas and Heitman (1979) off the coast of California. S. biformis, as previously cited, occurs in a great variety of water depths, and its lower abundance on the outer shelf than on the

middle shelf is probably related to a decrease in silt content. Cooper (1964) reported the presence of T. earlandi at depths of 25 to 30 fathoms (approximately 50 to 60 meters) in the Chukchi Sea. The presence of these species in comparable environments elsewhere supports the suggestion that transport of foraminiferal tests has not been significant in the area covered by cluster "B".

Cluster "F" is another single-sample grouping. It is located on the southern edge of the study area at a depth of 143 meters. Major foraminiferal species are Epistominella vitrea (traction velocity = 8.72 cm/sec), Eggerella advena, Uvigerina juncea and Eponides leviculus (traction velocity = 8.00 cm/sec). This sample clustered alone because of the unusually high abundance of E. vitrea and E. leviculus (together 40 % of the foraminiferal assemblage). As in cluster "I", all abundant species belong to traction-velocity Group 2, but a single sample is not sufficient to draw any inferences about transport of tests. Bergen and O'Neil (1979) reported the presence of E. vitrea from 57 to 180 meters in the Gulf of Alaska. Comparable occurrences of U. juncea and E. advena have already been cited. E. leviculus has been reported more often in deeper water (Resig, 1958; Phleger, 1964), but Douglas and Heitman (1979) reported it as shallow as 200 meters in the outer borderland basin slopes off the coast of California. The deeper occurrences are to the south of the study area, which suggests that water temperature could be a controlling factor in its distribution, forcing it to deeper, cooler water at lower latitudes. The fact that this cluster is composed of a single sample, along with the presence of its constituent species in similar environments elsewhere, prevents any conclusions concerning

transport.

Cluster "E" comprises four samples on the outermost shelf. This biofacies is distinguished by its high diversity and its five major species. Adercotryma glomerata is again present from traction-velocity Group 1. Group-2 species include Uvigerina juncea, Eggerella advena, Haplophragmoides bradyi and Trifarina angulosa (traction velocity = 6.81 cm/sec). The common occurrence of species from two traction velocity groups suggests that transport has not been effective in the area covered by this cluster. A. glomerata, U. juncea, E. advena and H. bradyi have already been cited at similar depths from various locations. T. angulosa was reported as common by Anderson (1963) from the Bering Sea at depths of 130 to 250 meters, and from 50 to 300 fathoms (approximately 100 to 600 meters) in the Santa Cruz Basin by Resig (1958). Like Eponides leviculus of cluster "F", T. angulosa may also live in deeper, cooler water at lower latitudes.

Based on theoretical principles offered by Kontrovitz et al. (1978) and on observed foraminiferal distribution patterns, no definitive evidence of post-mortem transport can be seen from data acquired in this study. Faunal distributions are associated with environmental factors, many indirectly related to water depth, such as substrate grain size, water temperature, and natural diversity trends. Abundance maps of many species (Appendix 2) illustrate distributional trends parallel to the coastline and to isobaths. Comparison of such patterns to maps showing sediment size distribution and sedimentation rate reveals a striking similarity. The distribution of Spiroplectammina biformis, for example, is related to the amount of silt present, based on a comparison of its

geographic distribution (Fig. 29) to that of dominant grain sizes (Fig. 27). These patterns suggest a relationship between species distribution and natural environmental factors. Further evidence of a natural distributional pattern in my study area is provided by the maps in Figs. 30-32. They show the distributional patterns of all species in Groups 1, 2 and 3, respectively. Comparison of these patterns to biofacies patterns (Fig. 25) iterates the fact that all major biofacies (G, C, A, B and E) contain species from more than one traction velocity group. If transport velocity theory is correct, then bottom current patterns on the Washington continental shelf should be of such magnitude and directional consistency (or inconsistency) that a clear pattern of erosion and transport of sediment grains (including foraminiferal tests) would not be expected.

Comparison of Faunal-based Interpretation to Oceanographic Observations

Over the Washington continental shelf, surface currents flow generally from north to south in summer and south to north in the winter in response to seasonal prevailing winds. Bottom currents are generally northward year-round (Nittrouer and Sternberg, 1981). Southerly winter winds produce a northerly surface current, but Ekman transport toward the coast causes water to "pile up" near the coast, resulting in a downwelling effect which produces a seaward (westward) component in the northerly bottom currents. The reverse situation in summer results in upwelling of colder deep water (Smith and Hopkins, 1972; Smith et al., 1976).

Direct evidence for bottom-current directional trends in the area

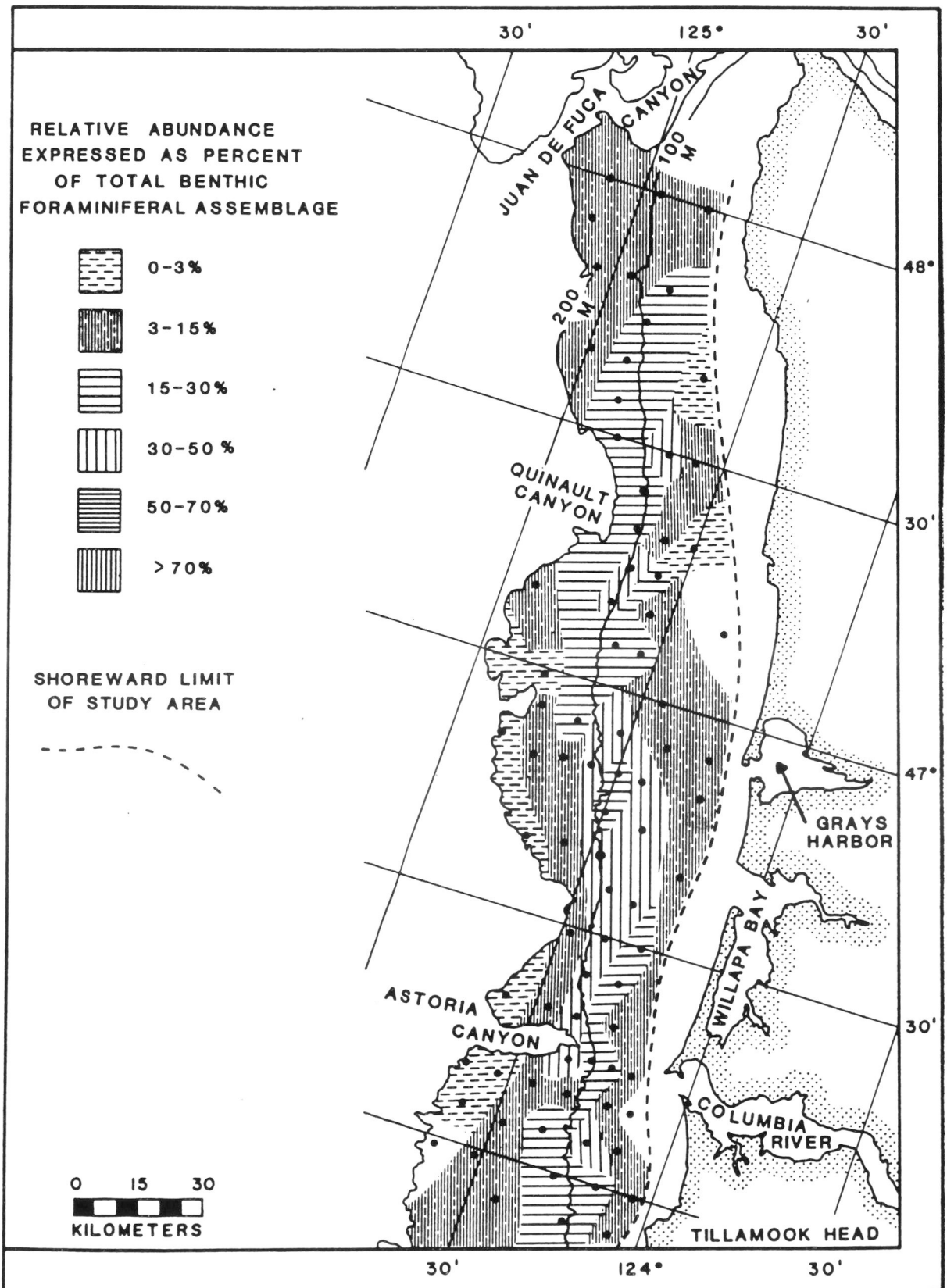


Figure 29.

Distribution pattern of *Spiroplectammina biformis*

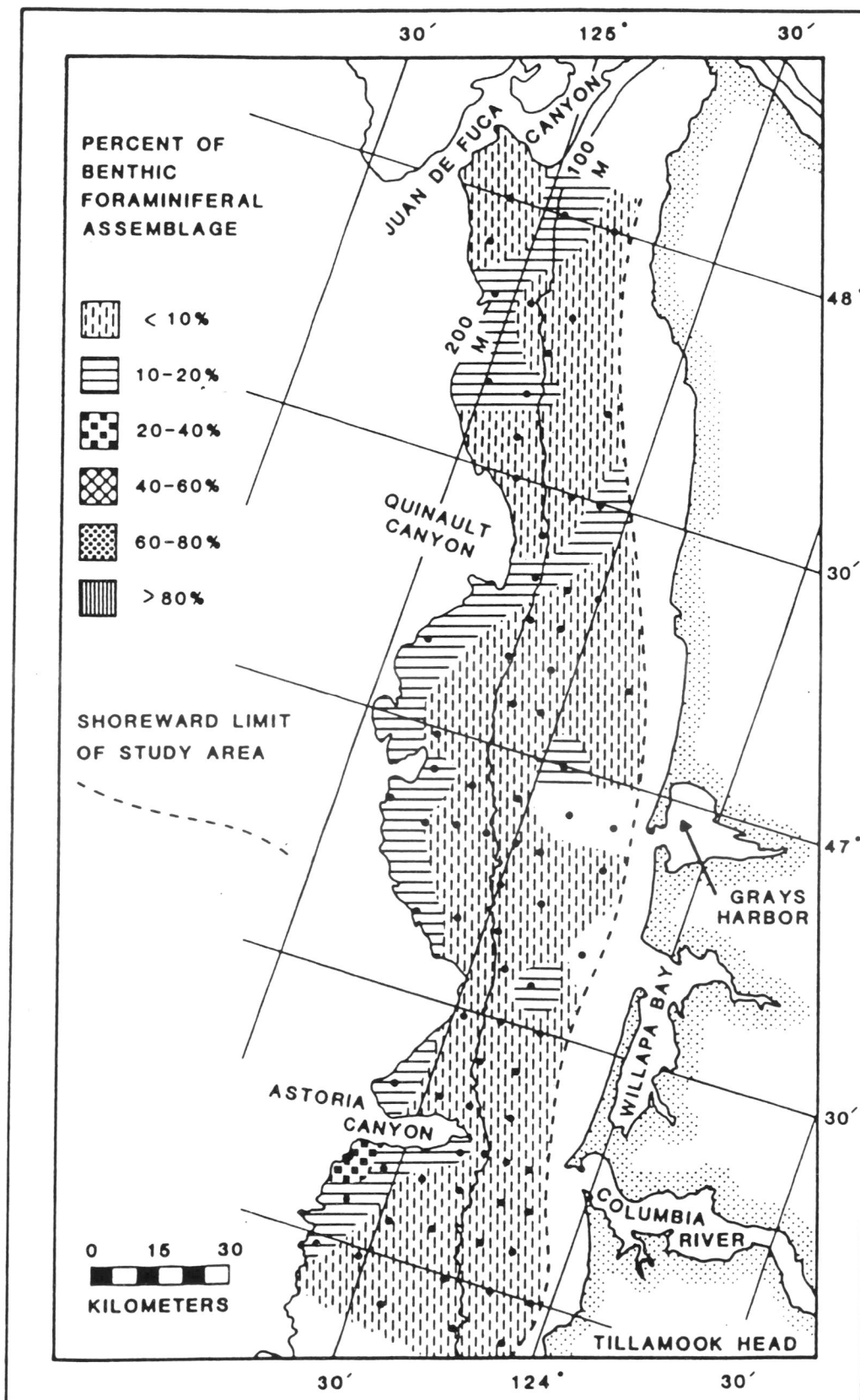


Figure 30. Distribution of all species in traction-velocity Group 1.

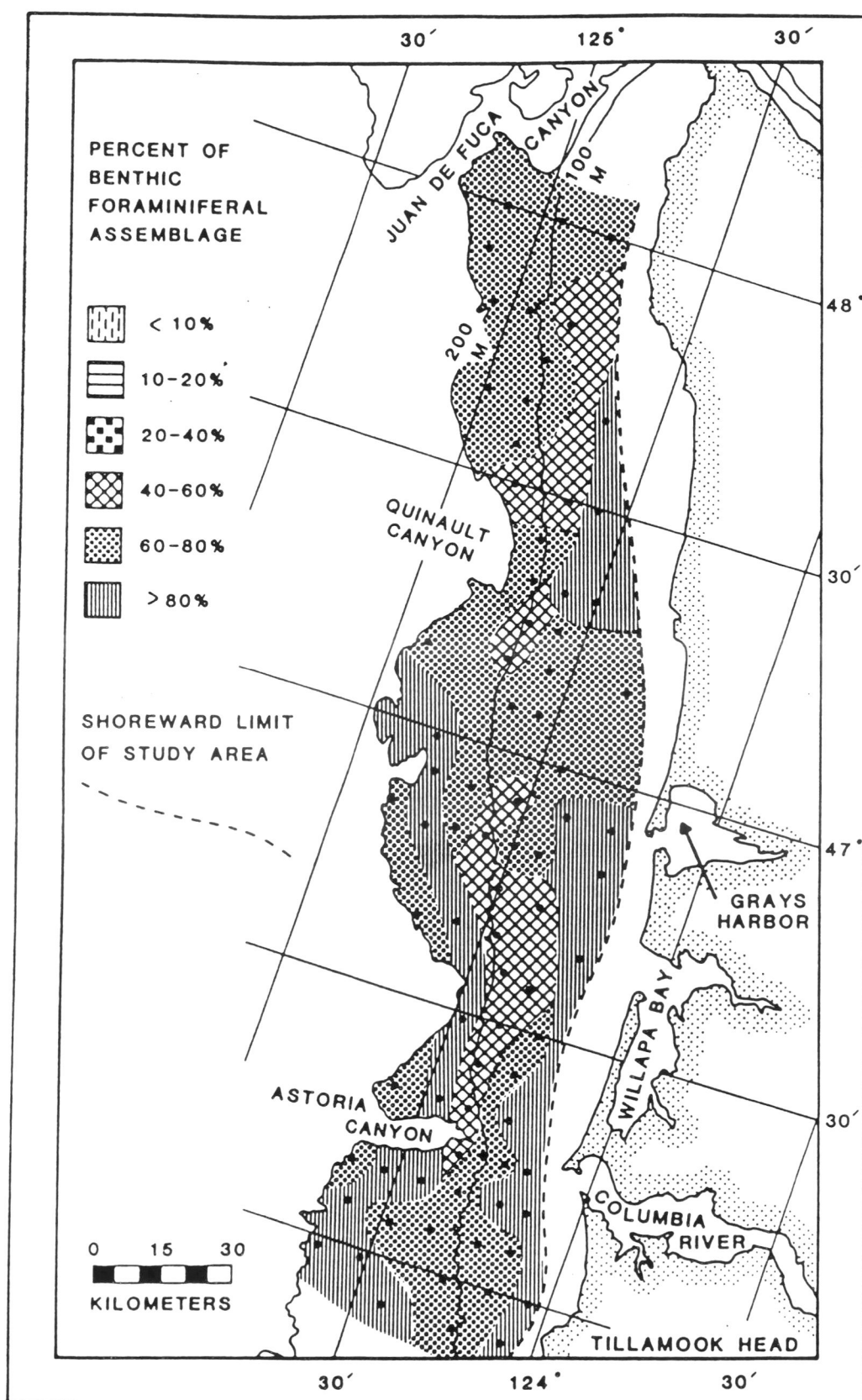


Figure 31. Distribution of all species in traction-velocity Group 2.

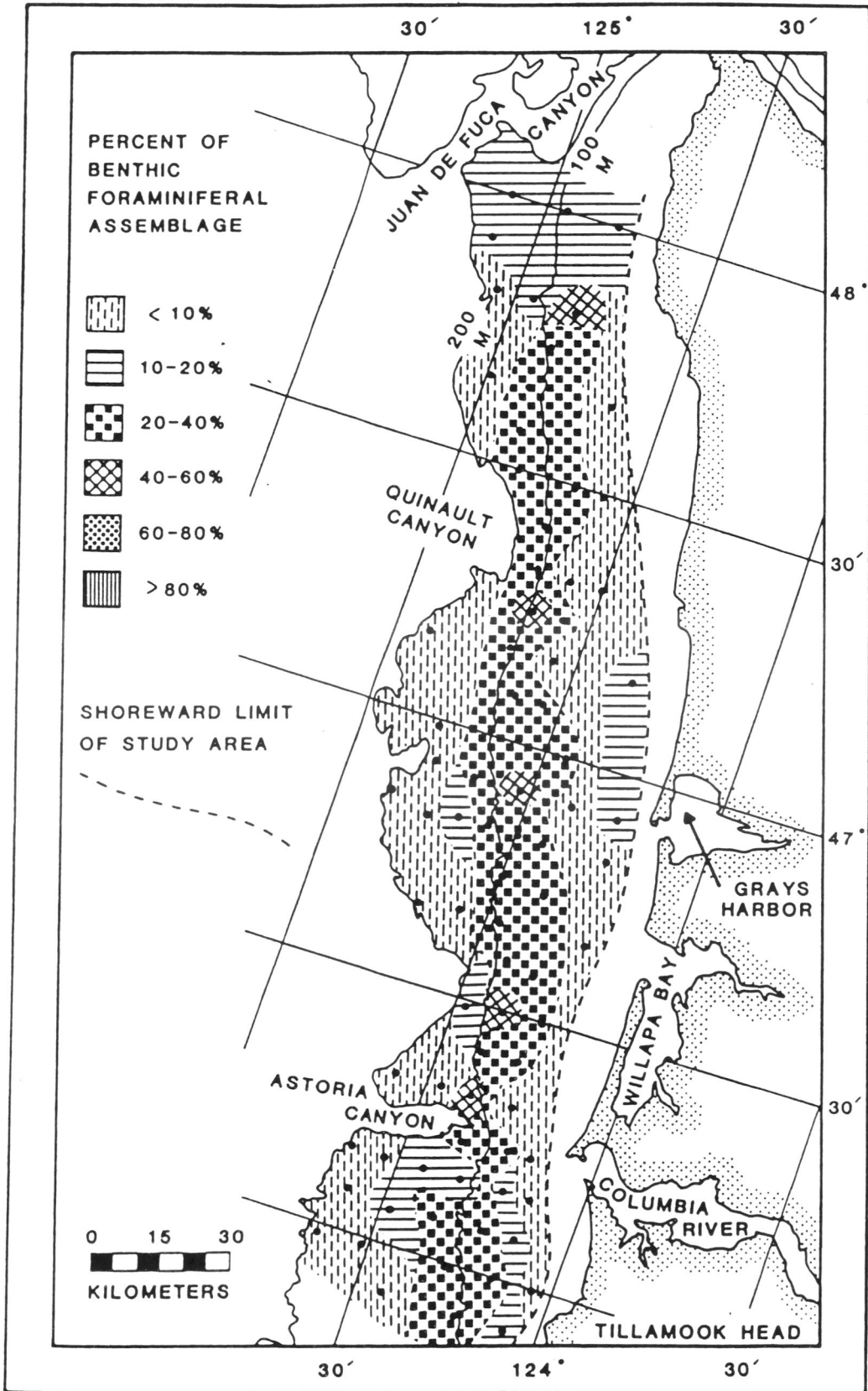


Figure 32. Distribution of all species in traction-velocity Group 3.

comes largely from studies of seabed drifters (Morse et al., 1968; Gross et al., 1969). During the period between June, 1966, and February, 1968, 13,875 seabed drifters were released at 30 different stations ranging from off the coast of northern Oregon to southern Vancouver Island. According to Gross et al. (1969), the drifters have a slight positive bouyancy and move with the currents "within a few meters of the bottom." Based on recovery times and locations, they described four areas in which the bottom currents have different directional qualities.

- 1) Columbia River estuary extension - Drifters dropped within 10 kilometers of the mouth moved predominantly toward the river mouth. Those recovered were found on the beach just north or just south of the river mouth.

- 2) Strait of Juan de Fuca entrance - Drifters dropped within 70 kilometers of the entrance moved toward and into the strait. Many were recovered on the southern tip of Vancouver Island, and some were even transported into the Strait of Georgia and Puget Sound.

- 3) Inner continental shelf - Drifters dropped in water less than 40 meters deep moved mainly toward the shore. Gross et al. (1969) attributed this movement to the influence of waves and wind-induced upwelling caused by the northerly summer winds. This may cast some doubt on the interpretations of Echols (1969) and Harmon (1972), who, as mentioned in the previous section, hypothesized offshore transport of dead organisms in shallow coastal water. At least during summer months, seabed drifters seem to indicate onshore movement of these bottom waters.

- 4) Outer continental shelf - Drifters released in water deeper than

40 meters moved generally northward in response to regional current systems on the continental shelf. These data are of greatest importance to my study, because the vast majority of sediment samples analyzed for foraminiferal content are from this area. Only one of my samples falls on the boundary of each of the other 3 areas described.

In the studies of Gross et al. (1969), some drifters (4.4% of those recovered) traveled over 100 kilometers northward along the continental shelf. Most of these were released in water depths greater than 40 meters. The highest rates of transport were about 3.70 cm/sec. The speeds, however, are based only on time of release and time and position of recovery. The path of any given drifter is not known to be a straight line, nor can the exact position of recovery be known if it was brought in by a trawler, which was the case for many of those released in relatively deeper shelf waters. In these cases, recovery positions were usually reported as "the midpoints of the distance and direction that the trawls traveled" (Morse et al., 1968). Also, travel may be intermittent, rather than steady at a constant velocity. Another concern is whether the drifters actually travel at the same speed as the water around them. Morse et al. (1968) cite flow tank experiments by Woodhead and Lee which show that similar drifters travel at water speed in currents faster than 25 cm/sec, and at 85% of the water speed in currents of 5 cm/sec.

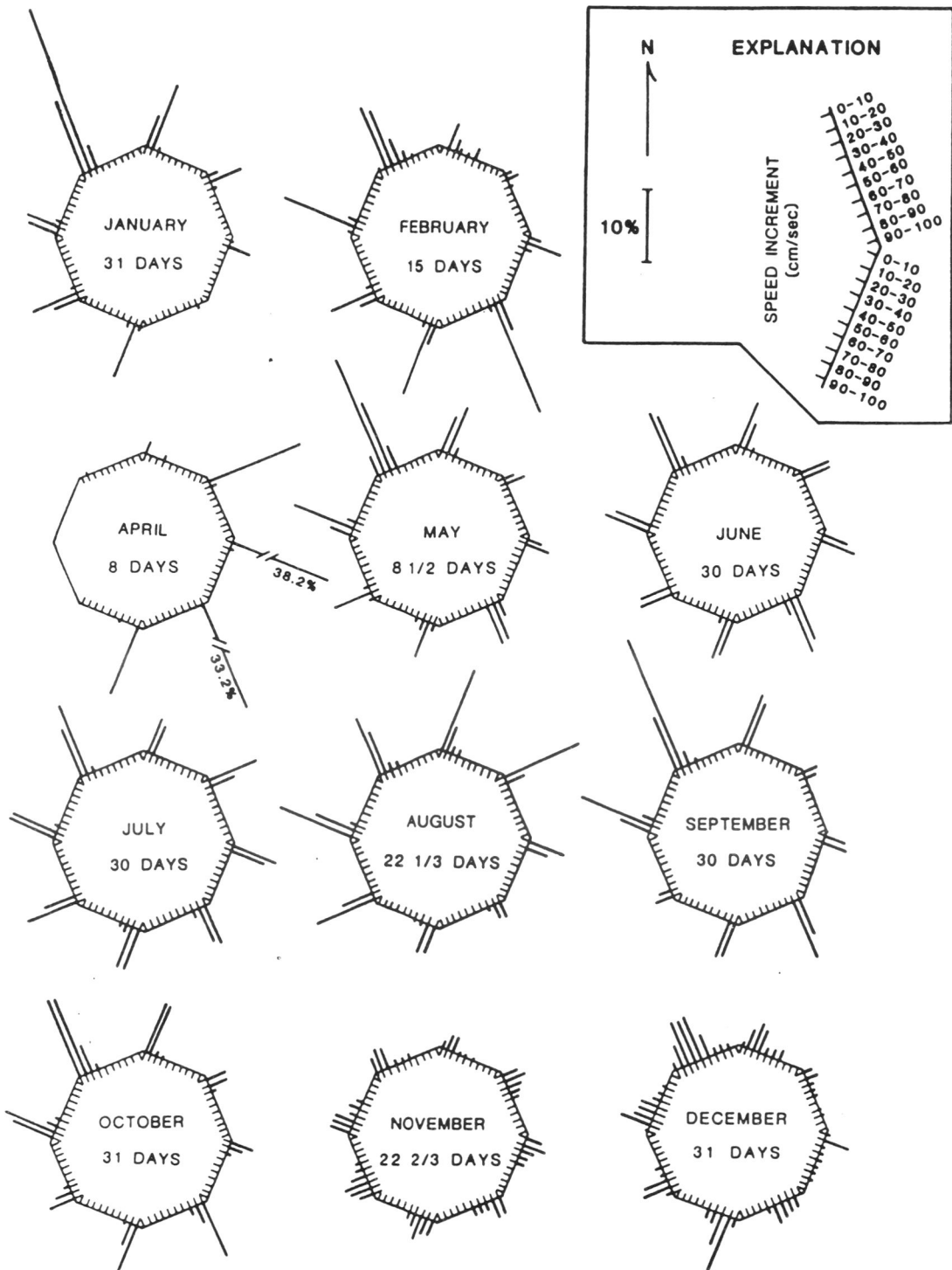
Although seabed drifter experiments are informative for net bottom-current direction, the speeds calculated cannot be used to make definite statements about actual current speeds interacting with sediments of the Washington continental shelf. Presence of northerly bottom currents

along the shelf is supported by earlier studies on abundance and activity of radionuclides, derived from the Hanford reactors, in these sediments (Gross and Nelson, 1966). In order to relate bottom current patterns to traction velocity patterns of foraminifera, it is necessary to have bottom-current velocity data in addition to directional information.

Bottom-current velocity data for the Washington continental shelf are limited to those acquired from two current meters located three meters above the seabed in 50 and 80 meters of water. They are located at approximately $46^{\circ} 25' \text{N}$. Data from these current meters were reported by Smith and Hopkins (1972), Sternberg and McManus (1972), and Sternberg and Larsen (1976). Directional trends from seabed-drifter studies were confirmed by these meters, but only in terms of net direction over significant periods of time. The current-meter studies show a great deal of temporal variation in current speed and direction.

Given the temperature, viscosity and grain size conditions of the Washington shelf, a shear velocity of approximately 1.3 cm/sec is required to erode material (Smith and Hopkins, 1972). They determined mathematically that this critical shear velocity at the seabed corresponds to a velocity of 40 cm/sec at a distance three meters above the seabed. Direct numerical comparison between these values and foraminiferal traction velocity values based on flume measurements cannot be made, but an order-of-magnitude similarity is assumed in order to relate traction velocity interpretations to measured current speeds. Sternberg and McManus (1972) concurred that 40 cm/sec is the critical velocity at three meters above the seafloor to initiate sediment motion and/or suspension.

Sternberg and Larsen (1976) reported that during winter months current speeds greater than 40 cm/sec are frequently exceeded at the 80-meter-deep station, and that although current-direction vectors are highly variable throughout the year, those exceeding 40 cm/sec have a net direction toward the north-northwest. They presented their data as "current roses" (Fig. 33), which consist of data from the 80-meter station pieced together as a 260-day sequence over an 11-month period. Each "rose" is divided into octants, each of which represents a general current direction. On each of the eight possible directions, there is a histogram divided into speed increments. The bars represent the percentage of the time of record for that month (based on the scale bar) that velocities of each speed were recorded within that octant. In the course of almost a full year, currents exceeding 40 cm/sec occurred only a small percentage of time. Higher speeds occurred only during November (in all directions), December (also in all directions), and during February (to the north-northeast and north-northwest). Figure 33 shows the inconsistent nature of bottom currents at this depth on a monthly scale, and it reflects the predominance of high bottom velocities during winter storms. Smith and Hopkins (1972) presented data from the 50-meter station averaged over 24-hour periods from winter months between late November, 1967, and middle January, 1968. These data are shown in Fig. 34. The upper graph shows averages of measured current speed, and the bottom graph uses vector averages to indicate directions and velocities of the currents. On only three occasions during the stormy winter months was 40 cm/sec exceeded. However, recalling the "current rose" data, it might be expected that one or two more storms could occur during



MONTHLY BOTTOM-CURRENT VELOCITY AVERAGES

Modified from Sternberg & Larsen, 1976

Figure 33.

DAILY BOTTOM-CURRENT VELOCITIES (for winter months)

From Smith & Hopkins, 1972

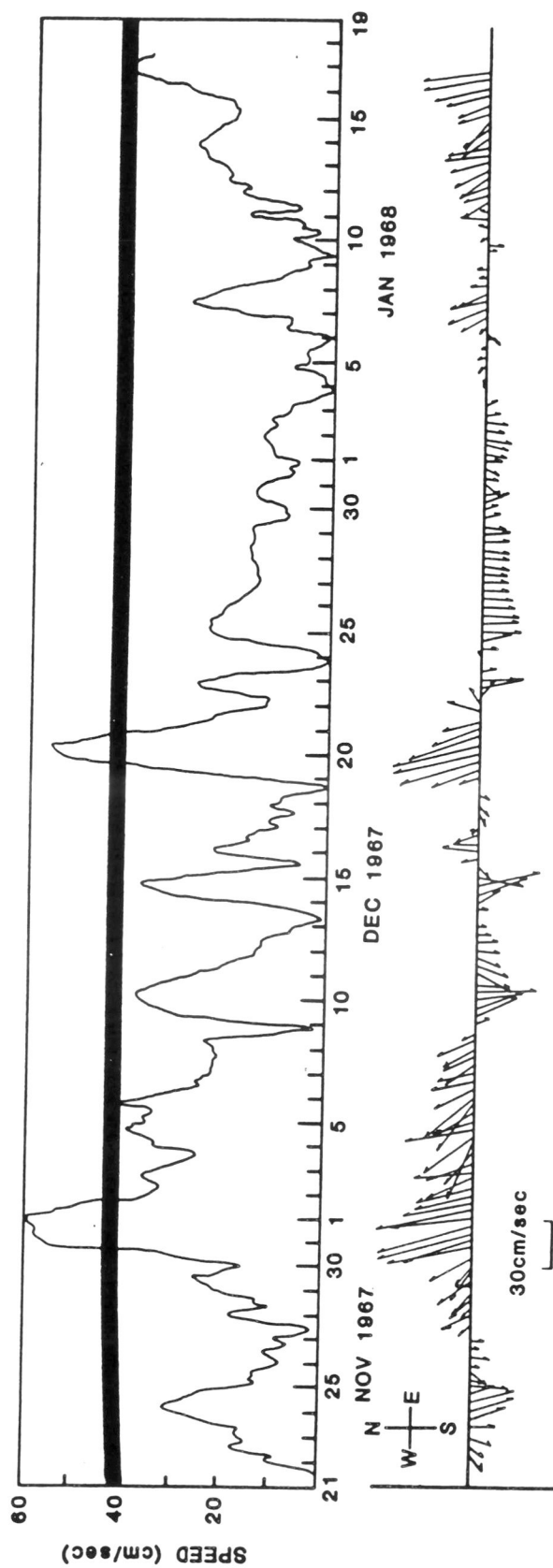


Figure 34. Daily-averaged bottom velocities (intensity chart and directional vectors).

February. Again, the erratic nature of current speed can be seen, but on a much finer scale which reveals that high-velocity currents rarely last more than a few days. According to Smith and Hopkins (1972), similar storms resulted in higher bottom-current velocities at the 50-meter station than at the 80-meter station, suggesting that current speeds in Fig. 34 are probably higher than those in deeper waters. Fifty meters is near the shallow limit of samples used in the present study.

Schafer (1976) placed sterile sand on the substrate in 13 meters of water in St. Georges Bay, Nova Scotia. The sand was sampled periodically, and within two days living foraminiferal specimens were observed on the sand. Evidently, repopulation is a relatively rapid phenomenon, even though the area covered was relatively small. The samples for the present study were taken from the Washington shelf in June of 1976, a few months after the stormy winter period of high-velocity currents. If foraminiferal specimens were transported away from any part of the study area by the winter storms, it is likely that the span of time before sampling was sufficient for the natural repopulation of the area.

The fact that transport cannot be documented for this area based on estimated traction velocities of foraminifera is consistent with observed bottom current data. Bottom-current speeds are significant only sporadically and their directions are generally random and sporadic in the study area. Consistent patterns of transport and sorting would not be expected under such conditions. Sampling during early summer means that several months had passed since bottom currents of sufficient velocity to transport sediment grains, including foraminiferal tests, had

occurred. Any sorting patterns developed during winter storms may have been masked by repopulation during the interim.

SUMMARY

The benthic foraminiferal fauna of the Washington continental shelf between 30 and 185 meters are predominated by agglutinated forms. The majority of calcareous forms occur on the outer shelf. Tests of planktonic species are too rare to be considered in this study.

The most abundant and ubiquitous species is Eggerella advena, which predominates the nearshore portion of the study area and decreases generally seaward. The nearshore-to-offshore decrease in predominance is accompanied by an increase in the number of species present and in equitability, resulting in higher diversity values (Shannon-Weiner) in deeper water.

Cluster analysis of between-station faunal similarity reveals biofacies which generally parallel isobaths. Five major clusters are designated as follows: "G" - nearshore (30-70 meters), dominated by specimens of E. advena (>60%); "C" - middle shelf north of the Columbia River (55-130 meters), characterized by E. advena (40-60%), Spiroplectammina biformis (20-45%), Recurvoides turbinatus (3-10%), and Adercotryma glomerata (3-10%); "A" - middle shelf south of the Columbia River (70-90 meters), comprising the same species as "C", but with a dramatic increase in abundance of R. turbinatus (20-45%); "B" - middle to outer shelf (90-175 meters), a more diverse assemblage containing specimens of E. advena (20-40%), A. glomerata (5-20%), S. biformis (0-15%), Haplophragmoides bradyi, (0-10%), Textularia earlandi (3-8%), and the calcareous species Uvigerina juncea (5-20%); and "E" - patches on the outermost shelf (145-185 meters), similar to "B" but without S. biformis or T. earlandi, and with the addition of another calcareous species,

Trifarina angulosa (5-14%).

The distributional patterns observed appear to be related to previously reported sediment patterns. A well-developed silt deposit on the middle shelf extending from the Columbia River mouth to the head of Quinault Canyon corresponds closely to the area covered by biofacies "C". This assemblage is characterized by a dramatic increase in Spiroplectammina biformis, which has been reported from a wide range of water depths, but always in silty sediments.

Kontrovitz et al. (1978) provide a linear regression equation by which traction velocity (the bottom-current velocity required to initiate movement of foraminiferal tests) can be estimated, using linear measurements of the tests to compute the independent variable, maximum projection sphericity. Theoretically, an assemblage containing species with similar traction velocities would suggest sorting, whereas a large range of values would indicate an in-place community. There are, of course, a variety of processes which could result in the "mixing" of assemblages: transport of low-velocity taxa into an area where they are mixed with indigenous species, resuspension and redeposition resulting from storm events, bioturbation, etc. However, large-scale sorting operating over long spans of time should still produce sorted assemblages. For example, resuspension and bioturbation may temporarily disrupt sorting patterns, but would eventually re-expose tests to currents which, given time, would again produce sorted assemblages.

For this study specimens of the 31 most common species were measured and traction velocities determined. Average values range from 4.08 (Eggerella humboldti) to 13.27 cm/sec (Trochammina kellettae).

Scheffé's method of multiple comparisons reveals three groups of species with similar traction velocities. The species within each group should be transported by similar current velocities. Group-1 species (low velocity) are near spherical in shape, Group-3 species (high velocity) are flattened-discoidal or flattened-elongate and Group-2 species (intermediate velocity) are intermediate in shape.

To be interpreted as a sorted assemblage, a biofacies would have to contain (almost exclusively) foraminiferal tests with similar traction velocities. Examination of the major biofacies shows that this requirement is not met for any of them. There are common species from at least two traction-velocity groups present in each major biofacies. This suggests that post-mortem transport of foraminiferal tests is not occurring on a large scale in the study area. Comparison of species occurrences with published occurrences by other authors does not reveal any species outside its expected environmental tolerances, which tends to support the lack of large-scale transport.

These results are consistent with physical oceanographic data provided by Smith and Hopkins (1972), Sternberg and McManus (1972) and Sternberg and Larsen (1976). Their current-meter data show that bottom currents are sporadic and capable of sediment transport at only a few times a year (during winter storms).

The purpose of this study is not to address the validity of existing criteria for determining post-mortem transport of fossils. The criteria used in any given study will depend on the type and age of material being examined. The value of the regression method employed in this study is as an additional tool to be used in assessing post-mortem transport of

foraminiferal tests. It is a viable technique when the tests can be separated from the surrounding material and when physical measurements on whole tests are possible.

ANNOTATED FAUNAL LIST

The 31 common benthic species for which traction velocities were determined are listed alphabetically by genus. Common forms include all species that compose 2% or more of at least two samples, or that occur in any abundance in at least 20 samples. Brief morphological descriptions are given for each of these species, as well as citation of the original description and a general statement of its geographical distribution in the study area. All percentages given are relative percentages of the benthic foraminiferal assemblage. Following the annotated list is a list of all species identified. Tables of relative abundance for all species in all samples and distribution maps for the common species are presented in Appendices 1 and 2, respectively.

Generic names are consistent with Loeblich and Tappan (1964).

Genus: Adercotryma Loeblich & Tappan, 1952

Adercotryma glomerata (Brady)

Pl. 1, fig. B-C

Lituola glomerata BRADY, 1878, On the reticularian and radiolarian Rhizopoda (foraminifera and polycystina) of the North-Polar Expedition of 1875-1876: Ann. Mag. Nat. Hist., London, England, ser. 5, vol. 1, p. 433, pl. 20, figs. 1a-c.

Test rather coarsely arenaceous, subglobular; spiral chamber arrangement, chambers elongate parallel to axis of coiling; aperture interiomarginal extraumbilical; specimens compare well with hypotypes (U.S.N.M.) from the Gulf of Mexico, Greenland, and Alaska, including the uniform chambering and characteristic rusty-orange hue.

Distribution: Absent on inner shelf; relative abundance increases seaward to about 15-20% on outer shelf, with an abundance of 35% at one station on outermost shelf.

Genus: Alveolophragmium Shchedrina, 1936

Alveolophragmium columbiense (Cushman)

Pl. 8, fig. D-E

Haplophragmoides columbiensis CUSHMAN, 1925, Recent foraminifera from British Columbia: Contr. Cushman Lab. Foram. Res., vol. 1, pt. 2, p. 39, pl. 6, figs. 2a-b.

Test arenaceous, planispiral, flattened; usually with 6 or 7

chambers in the last whorl in mature specimens; specimens compare well with hypotype (U.S.N.M. #626596) in chamber shape and overall shape, but aperture higher in chamber face than on hypotype.

Distribution: When present, generally less than 2% of benthic foraminiferal assemblage; found on central shelf in northern 1/3 of study area (including an anomalously high abundance of 20% in one sample); occurs on inner to middle shelf in central 1/3 of study area; occurs very sparsely on middle shelf in southern 1/3 of the study area.

Alveolophragmium jeffreysi (Williamson)

Pl. 6, fig. E-F

Nonionina jeffreysi WILLIAMSON, 1858, On the recent foraminifera of Great Britain: Roy. Society, London, England, p. 34, pl. 3, figs. 72-73.

Test arenaceous, planispiral, compressed, involute, and umbilicate; aperture oval-shaped, areal, with distinct lip; hypotypes (U.S.N.M. #375874) vary in degree of lobation and, except for being smaller, Washington shelf specimens compare well with less lobate of these.

Distribution: Generally less than 2% of benthic foraminiferal assemblage where present; patchy on middle and outer shelf.

Genus: Bolivina d'Orbigny, 1839

Bolivina pacifica Cushman & McCulloch

Pl. 7, fig. G-H

Bolivina acerosa Cushman, var. pacifica CUSHMAN & MCCULLOCH, 1942, Allan

Hancock Pacific Exped., v. 6, no. 4, p. 185, pl. 21, figs. 2-3.

Test calcareous, biserial, moderately tapered; tops of chambers glassy and transparent, accentuating angled sutures.

Distribution: Less than 3% of benthic foraminiferal fauna where present, middle to outer shelf in southern region, outer shelf in north.

Genus: Buccella Andersen, 1952

Buccella angulata Uchio

Pl. 4, fig. E-G

Buccella angulata UCHIO, 1960, Ecology of living benthonic foraminifera from the San Diego, California area: Cushman Found. Foram. Res., Spec. Publ., no. 5, p. 67, pl. 9, figs. 1-3.

Test calcareous, trochospiral, periphery subangular in edge view, lobate outline in side view, spiral side nearly planar; sutures depressed on spiral side; usually five chambers in final whorl; specimens compare well with paratypes (U.S.N.M. #626807) except for being smaller and having only two whorls, while type specimens have three, suggesting Washington shelf specimens are immature.

Distribution: Patchy on middle to outer shelf, making up less than 1% of benthic foraminiferal assemblage in most samples where present.

Genus: Buliminella Cushman, 1911

Buliminella elegantissima (d'Orbigny)

Pl. 2, fig. F

Bulimina elegantissima D'ORBIGNY, 1839, Voyage dans l'Amérique Méridionale: "Foraminifères," Strasbourg, France, Levrault, tome 5,

pt. 5, p. 51, pl. 7, figs. 13-14.

Test calcareous, elongate, high spiral; chambers numerous in each whorl, chambers elongate parallel (approximately) to coiling axis; aperture loop-shaped at base of apertural face.

Distribution: Most abundant nearshore and just north of effluent areas (Columbia River and Grays Harbor) as 5 to 20% of benthic assemblage (with one anomalously high occurrence of 55% northwest of Columbia River mouth), less abundant (less than 3%) on middle to outer shelf in southern half of study area.

Genus: Eggerella Cushman, 1933

Eggerella advena (Cushman)

Pl. 2, fig. D,G

Verneuilina advena CUSHMAN, 1922, Results of the Hudson Bay expedition, 1920; I - The foraminifera: Canada, Biol. Board, Contr. Canadian Biol. (1921), Toronto, no. 9, p. 9 (141), type figure not given. [see Cushman, 1920, Rep. Canadian Arctic Exped., vol. 9, pt. M, p. 8m, pl. 1, fig. 5 for synonymy with Verneuilina polystropha (Reuss)].

Test arenaceous, triserial, quite variable in size, rate of tapering, and total number of chambers; aperture at junction of last three chambers; early chambers frequently dark reddish-brown, lightening toward white in later chambers, but many tests uniformly orange or white. Distribution: Ubiquitous throughout study area, highest relative concentrations on inner shelf (70-90%), tapering off to lower, but still significant relative abundances on outer shelf (15-35%).

Eggerella humboldti Todd & Bronnimann

Pl. 1, fig. A

Eggerella humboldti TODD & BRONNIMANN, 1957, Recent foraminifera and Thecamoebina from the eastern Gulf of Paria, Trinidad: Cushman Found. Foram. Res., Spec. Publ., Ithaca, N.Y., no. 3, p. 26, pl. 2, figs. 26a-b.

Test arenaceous, short, triserial, final three chambers making up most of test; similar to and grading into E. advena, differing mainly in width to height ratio, w/h of 0.75 chosen as minimum for E. humboldti based on visual comparisons with holotype (U.S.N.M. #64644) and paratypes (U.S.N.M. #46996); initial chambers frequently orange-colored as in E. advena.

Distribution: More common in northern half of study area, 7 to 10% on inner shelf and decreasing in abundance seaward; patchy in southern region, with low abundances (most less than 1%).

Genus: Elphidium de Montfort, 1808

Elphidium excavatum (Terquem)

forma clavata Cushman

Pl. 6, fig. D

Elphidium incertum (Williamson) var. clavatum CUSHMAN, 1930, The foraminifera of the Atlantic Ocean, pt. 7: Nonionidae, Camerinidae, Peneroplidae, and Alveolinellidae: U.S. National Museum Bulletin 104, pt. 7, p. 20, pl. 7, figs. 10a-b.

Test calcareous, planispiral, periphery rounded; sutures curving

backward, with sutural bridges; often with umbilical boss, always with imperforate collar around the umbilicus.

Distribution: Patchy occurrence and low abundance (less than 2% except at two stations), nearshore in north and more toward middle to outer-middle shelf in south.

Genus: Epistominella Husezima & Maruhasi, 1944

Epistominella vitrea Parker, Phleger and Peirson

Pl. 5, fig. D-F

Epistominella vitrea PARKER, F.L., Phleger, F.B., and Peirson, J.F., 1953, Ecology of foraminifera from San Antonio Bay and environs, southwest Texas: Cushman Found. Foram. Res., Spec. Pub., Washington, D.C., no. 2, p. 9, pl. 4, figs. 34-36, 40-41.

Test calcareous, trochospiral, periphery rounded; wall translucent, transparent when wet; aperture a narrow slit parallel to periphery; specimens smaller and with fewer whorls than hypotypes from Pleistocene of Alaska (U.S.N.M. #'s 241984-241986), suggesting that Washington shelf specimens are immature.

Distribution: Less than 3% of benthic assemblage on outer shelf in north, increasing in abundance southward and spreading out to include middle shelf and at one station (south of the Columbia River) to inner shelf, highest abundances in south on outer-middle shelf (10 to 25%).

Genus: Eponides de Montfort, 1808

Eponides leviculus (Resig)

Pl. 4, fig. A-C

Epistominella levicula RESIG, 1958, Ecology of foraminifera of the Santa Cruz Basin, California: Micropaleontology, v. 4, no. 3, p. 304, text-figs. 16a-c.

Test calcareous, small, trochospiral, biconvex (more convex on umbilical side); numerous whorls, with five chambers in final whorl; sutures curved on umbilical side with last two becoming sinuous; specimens compare well with holotype, Epistominella levicula Resig, 1958 (U.S.N.M. #237490).

Distribution: Very similar to Epistominella vitrea; outer shelf in north and widening to include middle shelf in south, but with higher abundances (up to 12%) than E. vitrea in north.

Genus: Florilus de Montfort, 1808

Florilus auriculus (Heron-Allen & Earland)

Pl. 5, fig. G-H

Nonionella auricula HERON-ALLEN & EARLAND, 1930, The foraminifera of the Plymouth district; Part II: Roy. Micr. Soc., Jour., London, England, ser. 3, vol. 50, p. 192, pl. 5, figs. 68-70.

Test calcareous, somewhat compressed, spiral slightly off planar; chambers embracing and variable in number, increasing rapidly in size; rounded periphery; sutures depressed, especially in later chambers, specimens compare well with hypotypes from off Point Barrow, Alaska (U.S.N.M. #385282) except for being smaller.

Distribution: Less than 10% of benthic assemblage where present, on middle to outer shelf.

Florilus basispinatus(Cushman & Moyer)

Pl. 6, fig. A-B

Nonion pizarrense Berry var. basispinatum CUSHMAN & MOYER, 1930, Some

recent foraminifera from off San Pedro, California: Cushman Lab.
Foram. Res., Contr., vol. 6, pt. 3, p. 54, pl. 7, fig. 18.

Test calcareous, compressed, low trochospire; very similar to F. auriculus, main difference being spinose growths in umbilical area, not as prominent as in hypotype specimens (U.S.N.M. #'s 626691 and 626692 from off San Diego, California).

Distribution: Sparse, patchy in central and southern part of study area, generally less than 3% of benthic foraminiferal assemblage, and present in only eight samples.

Florilus labradoricus (Dawson)

Pl. 1, fig. D-F

Nonionina labradorica DAWSON, 1860, Notice of Tertiary fossils from

Labrador, Maine, etc., and remarks on the climate of Canada in the newer Pliocene or Pleistocene period: Canadian Nat. Geol., Montreal, Canada, vol. 5, p. 191, 192, text-fig. 4.

Test calcareous, planispiral, final chamber greatly inflated, even in young specimens, with lobes extending laterally beside earlier whorls; specimens compare well to hypotype (U.S.N.M. #242035) from Pleistocene of Alaska, and plesiotype (U.S.N.M. #642495) from Recent off southeastern Alaska.

Distribution: Low abundance (never greater than 2.5%); occurs widely in southern outer-middle shelf and in a few isolated samples farther

north.

Genus: Gaudryina d'Orbigny, 1839

Gaudryina arenaria Galloway & Wissler

Pl. 2, fig. E

Gaudryina arenaria GALLOWAY & WISSELER, 1927, Pleistocene foraminifera from the Lomita Quarry, Palos Verdes Hills, California: Jour. Pal., vol. 1, p. 68, pl. 11, fig. 5.

Test finely arenaceous containing occasional larger grains, triserial in early chambers, changing to biserial with subrectangular shape in later chambers ; sutures indistinct; aperture a small arch at base of final chamber.

Distribution: Sparse and patchy on middle to outer shelf; less than 1% in all but one sample (2.2% of the assemblage).

Genus: Globobulimina Cushman, 1927

Globobulimina auriculata (Bailey)

Pl. 2, fig. B

Bulimina auriculata BAILEY, 1851, Microscopical examination of soundings made by the U.S. Coast Survey off the Atlantic Coast of the United States: Smithsonian Inst. Contr. Knowledge, Washington, D.C., v.2, pt.3, p. 12, pl. 1, figs. 25-27.

Test large, calcareous, ovate, triserial, with later chambers greatly overlapping earlier ones; wall thin, fragile; aperture terminal, loop-shaped, with fan-like tooth plate.

Distribution: Sparse (generally less than 1%) on outer-middle to outer

shelf.

Genus: Haplophragmoides Cushman, 1910

Haplophragmoides bradyi (Robertson)

Pl. 3, fig. F-G

Trochammina bradyi ROBERTSON, 1891, Ann. Mag. Nat. Hist., London, England, ser. 6, vol. 7, p. 388, nom. nov. for Trochammina robertsoni Brady, 1887, (not 1876), A Synopsis of the British Recent Foraminifera.

Test planispiral, finely agglutinated, with light-orange color common to many arenaceous species in this area; most specimens tightly coiled and nearly involute, rarely more loosely coiled and convolute, more involute specimens usually with five chambers in last whorl; periphery rounded; aperture an arch at base of final chamber, with distinct lip; specimens essentially identical to hypotypes (#81012) and plesiotypes (#'s 81010 and 81011) in the U.S.N.M. collections.

Distribution: Absent on inner shelf, generally less than 2% on middle shelf, increasing to 5-15% on outer shelf.

Genus: Lagenammina Rhumbler, 1938

Lagenammina atlantica (Cushman)

Pl. 1, fig. G-H

Proteonina atlantica CUSHMAN, 1944, Foraminifera from the shallow water of the New England coast: Cushman Lab. Foram. Res., Spec. Pub. 12, p. 5, pl. 1, fig. 4.

Test very coarsely agglutinated, generally flask-shaped but variable; single chamber, aperture terminal at end of tapering neck.

Distribution: Sparse, less than 2% where present, mainly on middle to outer shelf in northern part of study area.

Genus: Nonionella Cushman, 1926

Nonionella miocenica Cushman

Pl. 3, fig. A-C

Nonionella miocenica CUSHMAN, 1926, Contr. Cushman Lab. Foram. Res., vol. 2, pt. 3, p. 64, type figure not given. (see Cushman, Stewart and Stewart, 1930, Trans. San Diego Soc. Nat. Hist., vol. 6, p. 61, pl. 8, figs. 6a-c).

Test calcareous, low trochospire, umbilical side involute, umbilicus covered by extension of last chamber; eight to ten chambers in final whorl, chambers increasing rapidly in size; aperture very low at base of final chamber, extending slightly over onto ventral side.

Distribution: Sparse (less than 1% in all but two samples) and spotty on middle to outer shelf.

Genus: Pullenia Parker & Jones, 1862

Pullenia salisburyi Stewart and Stewart

Pl. 3, fig. D-E

Pullenia salisburyi STEWART & STEWART, 1930, Post-Miocene foraminifera from the Ventura Quadrangle, Ventura County, California: Jour. Pal., Menasha, Wis., U.S.A., vol. 4, no. 1, p. 72, pl. 8, figs. 2a-b.

Test calcareous, planispiral, involute; periphery rounded, slightly lobate in side view; typically six chambers in final whorl; aperture a thin slit, interiomarginal; specimens essentially identical to holotype (Cushman Coll. 12547).

Distribution: Less than 2% of any sample where present, mainly on outer shelf, but few isolated occurrences on middle shelf.

Genus: Recurvoides Earland, 1934

Recurvoides turbinatus (Brady)

Pl. 2, fig. A

Haplophragmium turbinatum BRADY, 1881, Quart. Jour. Micr. Soc., vol. 21, p. 50; 1884, Rep. Voy. Challenger, vol. 9 (Zoology), p. 312, figs. 9a-c.

Test arenaceous, streptospiral, commonly brownish-orange; periphery rounded; aperture areal, oval-shaped; specimens compare closely to hypotypes from off Greenland (U.S.N.M. #'s 57585 and 57589), particularly to smaller of these hypotypes.

Distribution: Present in all but four samples in widely varying percentages, highest abundances (20-40%) on inner-middle shelf in southern part of study area, decreasing generally seaward and northward.

Genus: Reophax de Montfort, 1808

Reophax arctica Brady,

Pl. 4, fig. D

Reophax arctica BRADY, 1881, On some Arctic foraminifera from soundings obtained on the Austro-Hungarian North-Polar Expedition of 1872-1874: Ann. Mag. Nat. Hist., London, ser. 5, vol. 8, no. 48, p. 405, pl. 21, figs. 2a-b.

Test small, uniserial, arenaceous, tapering uniformly; sutures

indistinct; aperture terminal.

Distribution: Generally less than 5% of benthic foraminiferal fauna where present, mostly on middle to outer-middle shelf, abundance increasing gradually northward.

Reophax scorpiurus de Montfort

Pl. 6, fig. C

Reophax scorpiurus DE MONTFORT, 1808, Conchyliologie systématique et classification méthodique des coquilles, Paris, France, F. Schoell, v. 1, p. 331, p. 330, text fig.

Test very similar to R. arctica, except sutures more distinct and constricted; initial end narrow, and flexible when wet; specimens smaller and with less dramatic increase in chamber height than most secondary type specimens in U.S.N.M. collection.

Distribution: Generally less than 2% of benthic foraminiferal fauna where present; broadly patchy on middle to outer-middle shelf.

Genus: Spiroplectammina Cushman, 1927

Spiroplectammina biformis (Parker & Jones)

Pl. 7, fig. C

Textularia agglutinans d'Orbigny var. biformis PARKER & JONES, 1865, On some foraminifera from the North Atlantic and Arctic Oceans, including Davis Straits and Baffin's Bay: Roy. Soc. London, Philos. Trans., vol. 155, p. 370, pl. 15, figs. 23-24.

Test small, arenaceous, elongate, flattened, biserial with early

portion a planispiral coil, most specimens showing virtually no tapering; aperture a low arch at base of final chamber; specimens lack rusty color of hypotype specimens at U.S.N.M.

Distribution: Nearly ubiquitous throughout study area (absent in only three samples); greatest abundance (15-48%) on middle shelf, becoming less abundant seaward and shoreward; high abundances apparently associated with mid-shelf silt deposit.

Genus: Textularia DeFrance, 1824

Textularia earlandi Parker

Pl. 7, fig. A-B

Textularia earlandi PARKER, 1952, Foraminiferal distribution in the Long Island Sound - Buzzards Bay area: Harvard Coll., Mus. Comp. Zoöl., Bull., vol. 106 (1951-1952), no. 10, p. 458, nom. nov. for Textularia tenuissima Earland, 1933, Discovery Repts., vol. 7, p. 95, pl. 3, figs. 21-30 (not Hausler, 1881).

Test small, arenaceous, elongate, flattened, biserial, showing various degrees of tapering; sutures fairly distinct; aperture a low arch at base of final chamber; specimens compare well with hypotypes (U.S.N.M. #'s 390167, 390169, and 626622).

Distribution: Occurs on middle to outer shelf; most abundant (up to 10%) in north, decreasing to less than 1% in southern part of study area.

Genus: Trifarina Cushman, 1923

Trifarina angulosa (Williamson)

Pl. 2, fig. C

Uvigerina angulosa WILLIAMSON, 1858, On the Recent foraminifera of Great Britain: Roy. Soc., London, England, p. 67, pl. 5, fig. 140.

Test calcareous, elongate, triserial, triangular in cross-section; costae most distinct in later chambers; aperture terminal at the end of a short neck; specimens compare well with paratype specimens (U.S.N.M. #372048).

Distribution: On outer shelf in abundances up to 14%, and in isolated spots on middle shelf in very low abundances (less than 1.5%).

Genus: Trochammina Parker & Jones, 1859

Trochammina kellestae Thalmann

Pl. 8 fig. I-J

Trochammina kellestae THALMANN, 1932, Nonion jarvisi nom. nov. and Trochammina kellestae nom. nov.: Eclogae Geol. Helv., Lausanne, Suisse, vol. 25, p. 313; nom. nov. for T. peruviana Cushman and Kellest, 1929 (not Berry 1928), Recent foraminifera from the west coast of South America: Proc. U.S. Nat. Mus., vol. 75, Art. 25, p. 4, pl. I, fig. 8.

Test small, finely arenaceous, trochospiral, flattened, concave on umbilical side; chambers numerous; sutures curved; specimens compare well to some hypotypes (U.S.N.M. #'s 626661 and 626662), but lack slight inflation of final two chambers evident on many others.

Distribution: Usually less than 2% of any sample where present, mainly on middle to outer shelf, with notable shallow-water appearance just off mouth of Grays Harbor (3.6% of the benthic foraminiferal fauna).

Trochammina nitida Brady

Pl. 7, Fig. D-F

Trochammina nitida BRADY, 1881, Notes on some of the reticularian Rhizopoda of the "Challenger" Expedition; Part III: Quart. Jour. Micr. Sci., London, vol. 21, p. 52; 1884, Rep. Voy. Challenger, vol. 9 (Zoology), pl. 41, figs. 5,6.

Test arenaceous, trochospiral, slightly flattened, but not to extent of T. kellettae; margin rounded, slight constriction of sutures; specimens compare well with some hypotypes from Recent off San Diego (U.S.N.M. #'s 626667 and 626666), but other hypotypes much more lobate (not in agreement with Brady's original description).

Distribution: Usually less than 2% where present, on inner, middle, and outer shelf throughout area, but absent in patches in each of these areas.

Trochammina pacifica Cushman

Pl. 5, fig. A-C

Trochammina pacifica CUSHMAN, 1925, Contrib. Cushman Lab. Foram. Res., vol. 1, pt. 2, p. 39, pl. 6, figs. 3a-c.

Test finely arenaceous with occasional larger grains included, trochospiral, periphery rounded; usually five chambers in last whorl; chambers slightly inflated, increasing in size; sutures distinct; aperture extraumbilical-umbilical; specimens compare well with holotype (Cushman Coll. #492), some specimens with yellowish-brown color as in original discription, but many white, especially in northern part of study area.

Distribution: From 1-2% on middle shelf, increasing seaward in central and southern part of study area to 6-8% on outermost shelf; 3.6% of benthic foraminiferal fauna in one sample on outer shelf near head of Grays Canyon.

Trochammina rotaliformis Wright

Pl. 8, fig. F-H

Trochammina rotaliformis WRIGHT, 1911, in Heron-Allen and Earland, On the Recent and fossil foraminifera of the shore-sands of Selsey Bill, Sussex; Part VII-Supplement (Addenda et Corrigenda): Roy. Micr. Soc., Jour., London, England, p. 309, type figure not given. (see CUSHMAN, 1920, U.S. Nat. Mus. Bull. 104, pt. 2, p. 77, pl. 16, figs. 1,2).

Test arenaceous, trochospiral, concave on umbilical side, excavated umbilicus; five or six chambers in last whorl, last chamber making up about one-third of umbilical side; specimens compare well with plesiotypes from Greenland and Gulf of Alaska (U.S.N.M. #'s 27948 & 642421) and with hypotypes from Greenland (U.S.N.M. #'s P.2123 & 390369), but differ from many secondary type specimens in having cleaner and more open umbilical region.

Distribution: Patchy, occurring in fairly isolated spots on inner, middle, and outer shelf in abundances generally less than 2%, but at one station at head of Grays Canyon as 5.6% of the benthic foraminiferal fauna.

Trochammina squamata Jones & Parker

Pl. 8, fig. A-C

Trochammina squamata JONES & PARKER, 1860, On the Rhizopodal fauna of the Mediterranean, compared with that of the Italian and some other Tertiary deposits: Geol. Soc. London, Quart. Jour., London, England, vol. 16, p. 304, type figure not given. (see Todd & Low, 1967, U.S.G.S. Prof. Papers, 573-A, pp. 1-46, pl. 1, fig. 17).

Test finely arenaceous, trochospiral, somewhat flattened; chambers lunate, numerous, usually eight to ten in final whorl; sutures curved; umbilical region open; specimens compare well with plesiotypes (U.S.N.M. #'s 27933, 642531, and 312107), except for grayish rather than orange-brown tint typical of type material.

Distribution: Generally less than 3% where present, in large patches on outer to middle shelf in north and on middle shelf in southern part of area; an abundance of 7.1% at one station near mouth of Grays Harbor.

Genus: Uvigerina d'Orbigny 1826

Uvigerina juncea Cushman & Todd

Pl. 2, fig. H

Uvigerina juncea CUSHMAN & TODD, 1941, Notes on the species of Uvigerina and Angulogerina described from the Pliocene and Pleistocene: Contr. Cushman Lab. Foram. Res., Sharon, Mass., vol. 17, p. 78, pl. 20, figs 4-11.

Test calcareous, elongate, triserial, frequently becoming more biserial in later chambers of mature specimens, rounded in section; having about 10 costae per chamber, not continuous between chambers,

costae usually best developed in mid portion of test, wide variation in strength of costae; aperture terminal on narrow neck with flaring lip.

Distribution: Low to moderate abundance (0.2 to 8%) on middle shelf, increasing seaward to values of 25 to 35% on outermost shelf.

LIST OF ALL SPECIES IDENTIFIED IN THE STUDY AREA

<u>Adercotryma glomerata</u>	<u>Gaudryina arenaria</u>
<u>Alveolophragmium columbiense</u>	<u>Globobulimina auriculata</u>
<u>Alveolophragmium crassimargo</u>	<u>Globobulimina glabra</u>
<u>Alveolophragmium jeffreysi</u>	<u>Globobulimina sp.</u>
<u>Ammodiscus minutissimus</u>	<u>Haplophragmoides bradyi</u>
<u>Ammodiscus planus</u>	<u>Haplophragmoides sphaeriloculum</u>
<u>Ammotium planissimum</u>	<u>Hyperammina (?) sp.</u>
<u>Astrononion aff. A. incilis</u>	<u>Lagena amphora</u>
<u>Astrononion gallowayi</u>	<u>Lagena apiopleura</u>
<u>Astrononion umbilicatum</u>	<u>Lagena cf. L. meridionalis</u>
<u>Bolivina alata</u>	<u>Lagena cf. L. mollis</u>
<u>Bolivina basisenta</u>	<u>Lagena distoma</u>
<u>Bolivina pacifica</u>	<u>Lagena gracillima</u>
<u>Bolivina punctata</u>	<u>Lagena intermedia</u>
<u>Bolivina vadesens</u>	<u>Lagena laevis</u>
<u>Buccella angulata</u>	<u>Lagena setigera</u>
<u>Buccella frigida</u>	<u>Lagena striata</u>
<u>Buccella inusitata</u>	<u>Lagena substriata</u>
<u>Bulimina aff. B. elongata</u>	<u>Lagenammina atlantica</u>
<u>Bulimina sp.</u>	<u>Laryngosigma hyalascidia</u>
<u>Buliminella elegantissima</u>	<u>Martinottiella primaeva</u>
<u>Cassidulina californica</u>	<u>Neoconorbina cf. N. terquemi</u>
<u>Cassidulina crassa</u>	<u>Nonionella miocenica</u>
<u>Cassidulina islandica</u>	<u>Nonionella sp.</u>
<u>Cibicides aff. C. praecinctus</u>	<u>Oolina cf. O. caudigera</u>
<u>Cibicides fletcheri</u>	<u>Oolina costata</u>
<u>Cibicides lobatulus</u>	<u>Oolina striatopunctata</u>
<u>Cibicides Mckannai</u>	<u>Pullenia salisburyi</u>
<u>Dentalina cf. D. frobisherensis</u>	<u>Recurvoides turbinatus</u>
<u>Dentalina sp.</u>	<u>Reophax aff. R. fusiformis</u>
<u>Eggerella advena</u>	<u>Reophax arctica</u>
<u>Eggerella humboldti</u>	<u>Reophax scorpiurus</u>
<u>Eggerella pusilla</u>	<u>Sigmoilina aff. S. distorta</u>
<u>Elphidiella nitida</u>	<u>Sigmomorphina aff. S. trilocularis</u>
<u>Elphidium excavatum forma clavatum</u>	<u>Spiroplectammina biformis</u>
<u>Elphidium excavatum forma selseyensis</u>	<u>Textularia aff. T. foliacea</u>
<u>Elphidium frigidum</u>	<u>Textularia earlandi</u>
<u>Elphidium incertum</u>	<u>Textularia schencki</u>
<u>Elphidium subarcticum</u>	<u>Textularia torquata</u>
<u>Epistominella vitrea</u>	<u>Trifarina angulosa</u>
<u>Eponides aff. E. tenerus</u>	<u>Trochammina inflata</u>
<u>Eponides leviculus</u>	<u>Trochammina kellestae</u>
<u>Eponides repandus</u>	<u>Trochammina nana</u>
<u>Eponides umbonatus</u>	<u>Trochammina nitida</u>
<u>Fissurina aff. F. cucurbitasema</u>	<u>Trochammina pacifica</u>
<u>Fissurina lucida</u>	<u>Trochammina rotaliformis</u>
<u>Fissurina marginata</u>	<u>Trochammina sp.</u>
<u>Fissurina sp.</u>	<u>Trochammina squamata</u>
<u>Florilus auriculus</u>	<u>Turritellella shoneana</u>
<u>Florilus basispinatus</u>	<u>Uvigerina aff. U. senticosa</u>
<u>Florilus labradoricus</u>	<u>Uvigerina auberiana</u>
<u>Fursenkoina pontoni</u>	<u>Uvigerina farinosa</u>
<u>Gaudryina arenaria</u>	<u>Uvigerina juncea</u>

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Plate 1

Species in Traction Velocity Group no. 1
(all scale bars = 100 microns)

Figure:

- A. Eggerella humboldti Todd & Bronniman
- B-C. Adercotryma glomerata (Brady)
 - B. Side view
 - C. Edge view
- D-F. Florilus labradoricus (Dawson)
 - D. Edge view (apertural)
 - E. Edge view (chamber face)
 - F. Side view
- G-H. Lagenammina atlantica (Cushman)
 - G. Side view
 - H. Apertural view

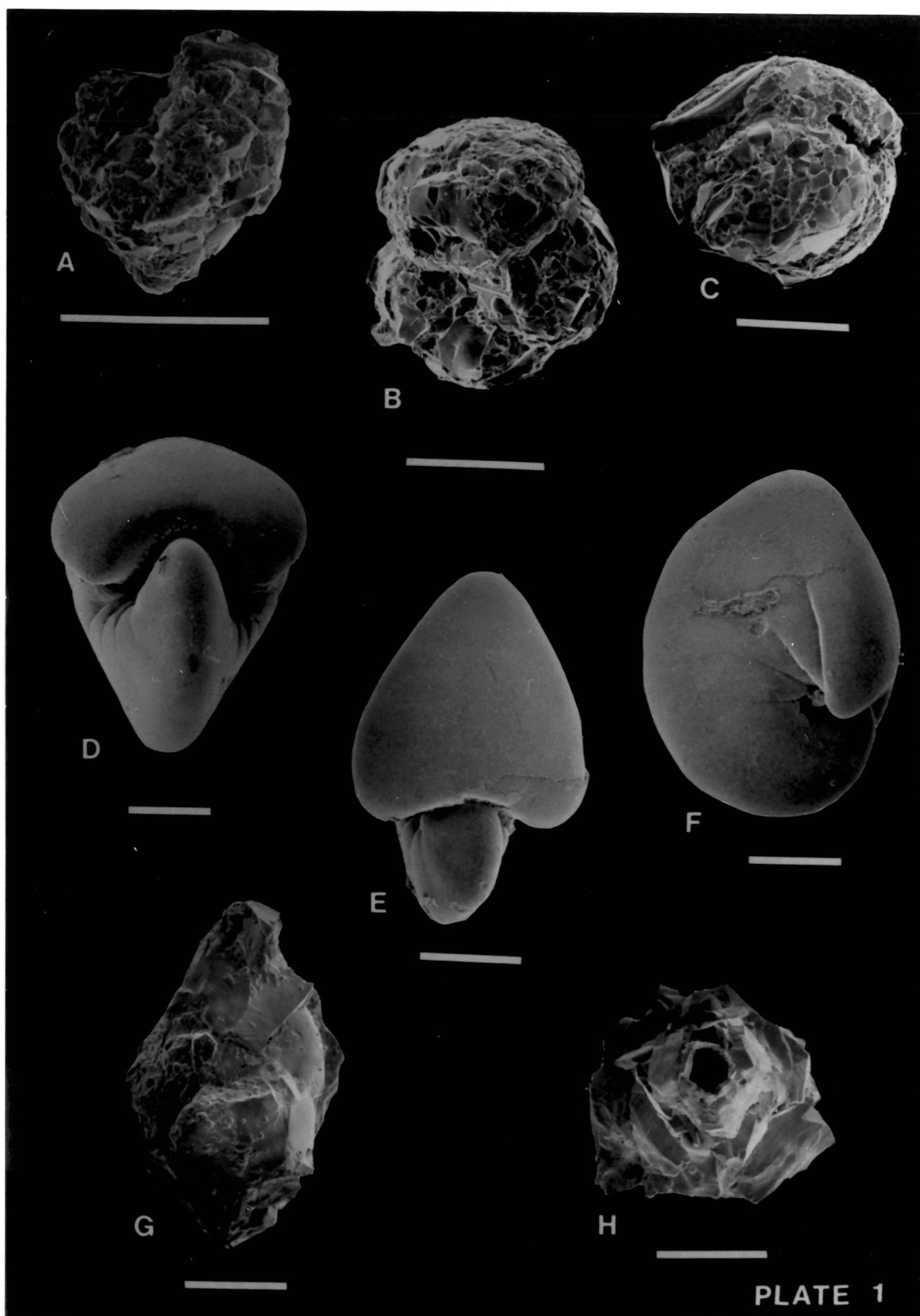


Plate 2

Species in Traction Velocity Group no. 2
(all scale bars = 100 microns)

Figure:

- A. Recurvoides turbinatus (Brady)
 Edge view
- B. Globobulimina auriculata (Bailey)
 Side view
- C. Trifarina angulosa (Williamson)
 Side view
- D. & G. Eggerella advena (Cushman)
 D. Average specimen - side view
 G. Large specimen - side view
- E. Gaudryina arenaria Galloway & Wissler
 Side view
- F. Buliminella elegantissima (d'Orbigny)
 Side view
- H. Uvigerina juncea Cushman & Todd
 Side view

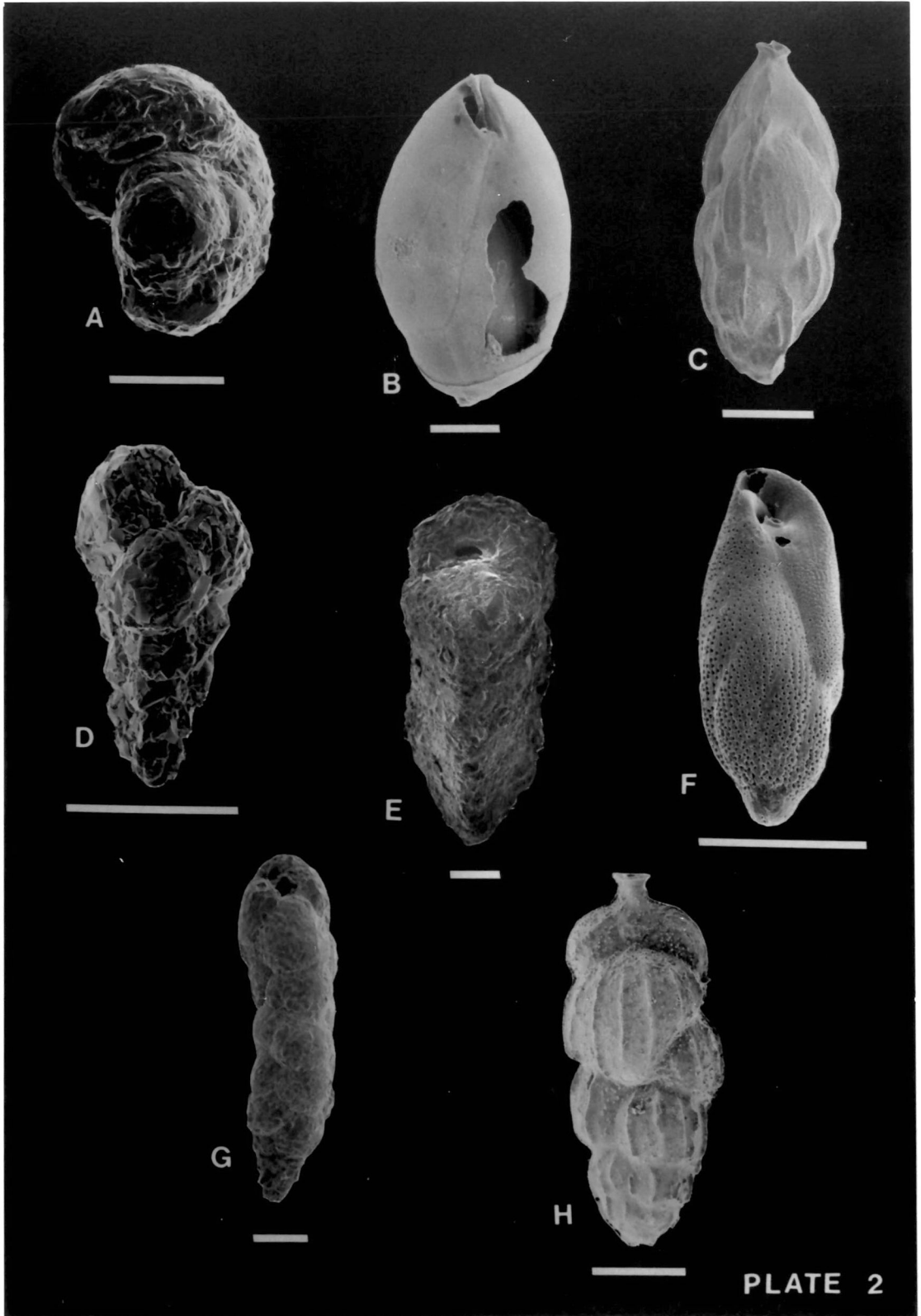


Plate 3

Species in Traction Velocity Group no. 2 (continued)
(all scale bars = 100 microns)

Figure:

A-C. Nonionella miocenica Cushman

A. Umbilical view

B. Edge view

C. Spiral view

D-E. Pullenia salisburyi Stewart & Stewart

D. Side view

E. Edge view

F-G. Haplophragmoides bradyi (Robertson)

F. Edge view

G. Side view

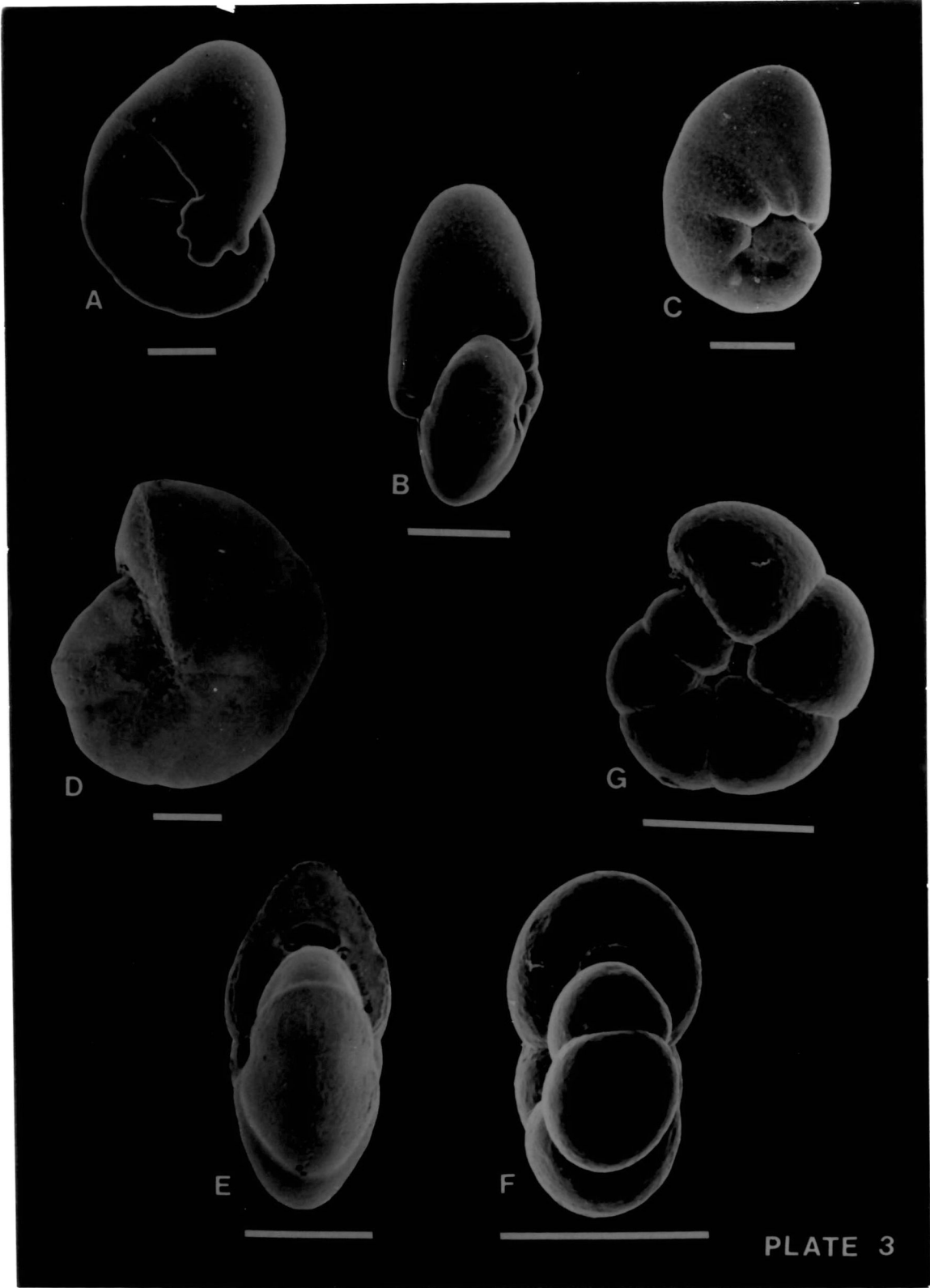


Plate 4

Species in Traction Velocity Group no. 2 (continued)
(all scale bars = 100 microns)

Figure:

- A-C. Eponides leviculus (Resig)
 A. Spiral view
 B. Umbilical view
 C. Edge view
- D. Reophax scorpiurus de Montfort
 Side view
- E-G. Buccella angulata Uchio
 E. Spiral view
 F. Umbilical view
 G. Edge view

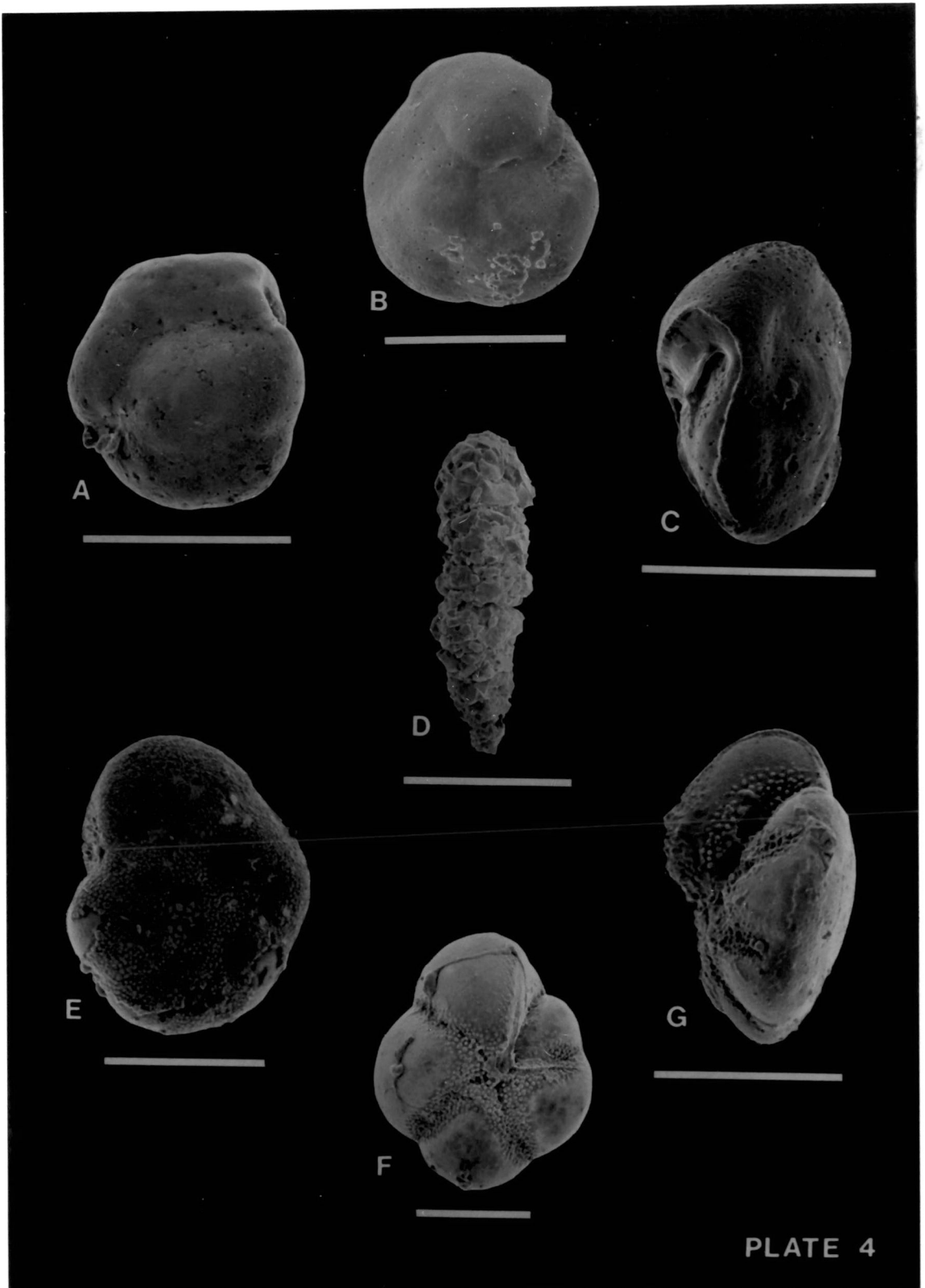


Plate 5

Species in Traction Velocity Group no. 2 (continued)
(all scale bars = 100 microns)

Figure:

A-C. Trochammina pacifica Cushman
A. Spiral view
B. Edge view
C. Umbilical view

D-F. Epistominella vitrea Parker
D. Umbilical view
E. Edge view
F. Spiral view

G-H. Florilus auriculus (Heron-Allen & Earland)
G. Side view
H. Edge view

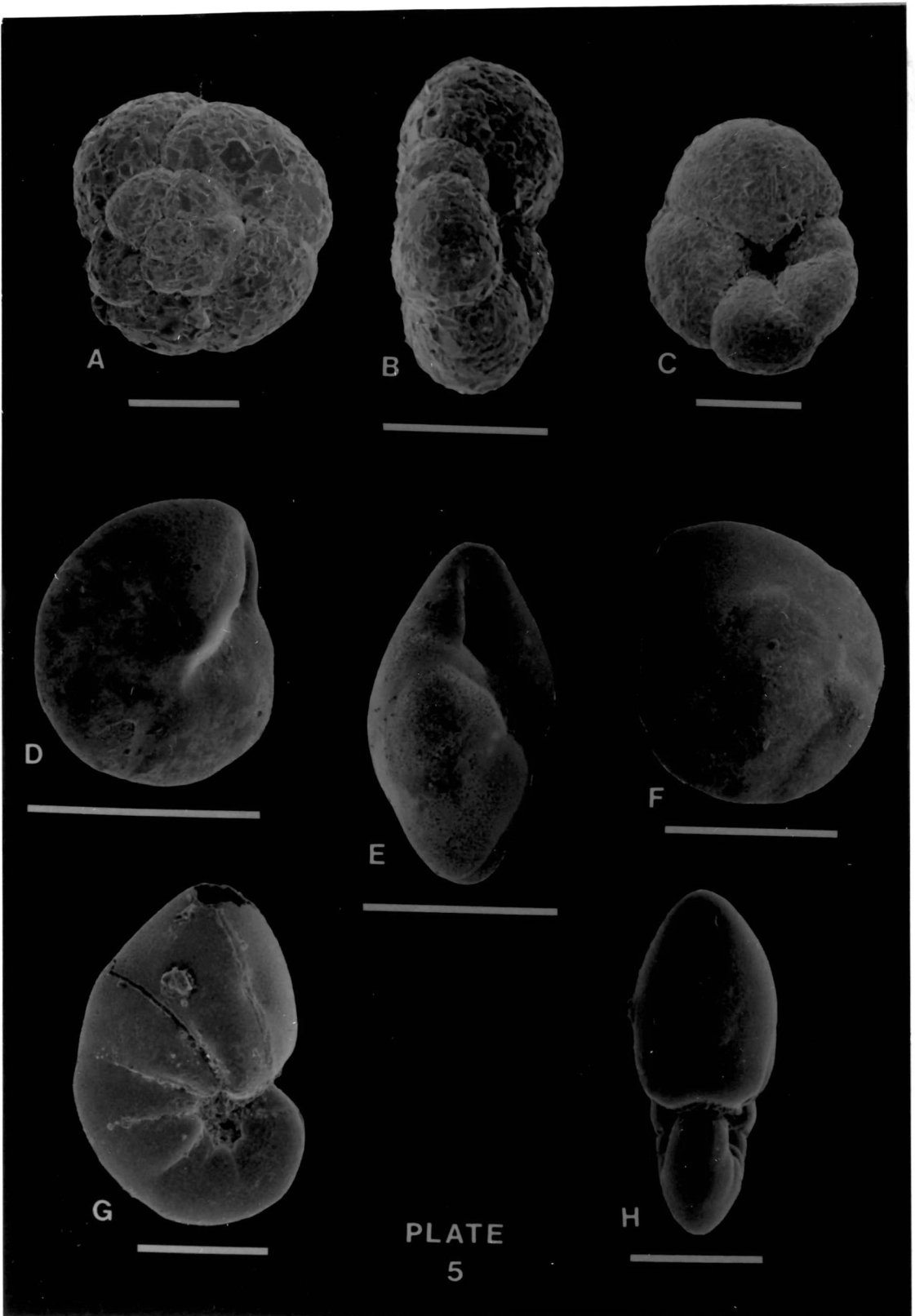


Plate 6

Species in Traction Velocity Group no. 2 (continued)
(all scale bars = 100 microns)

Figure:

- A-B. Florilus basispinatus (Cushman & Moyer)
 A. Edge view
 B. Side view
- C. Reophax scorpiurus de Montfort
 Side view
- D. Elphidium excavatum (Terquem) forma clavata Cushman
 Side view
- E-F. Alveolophragmium jeffreysi (Williamson)
 E. Side view
 F. Edge view

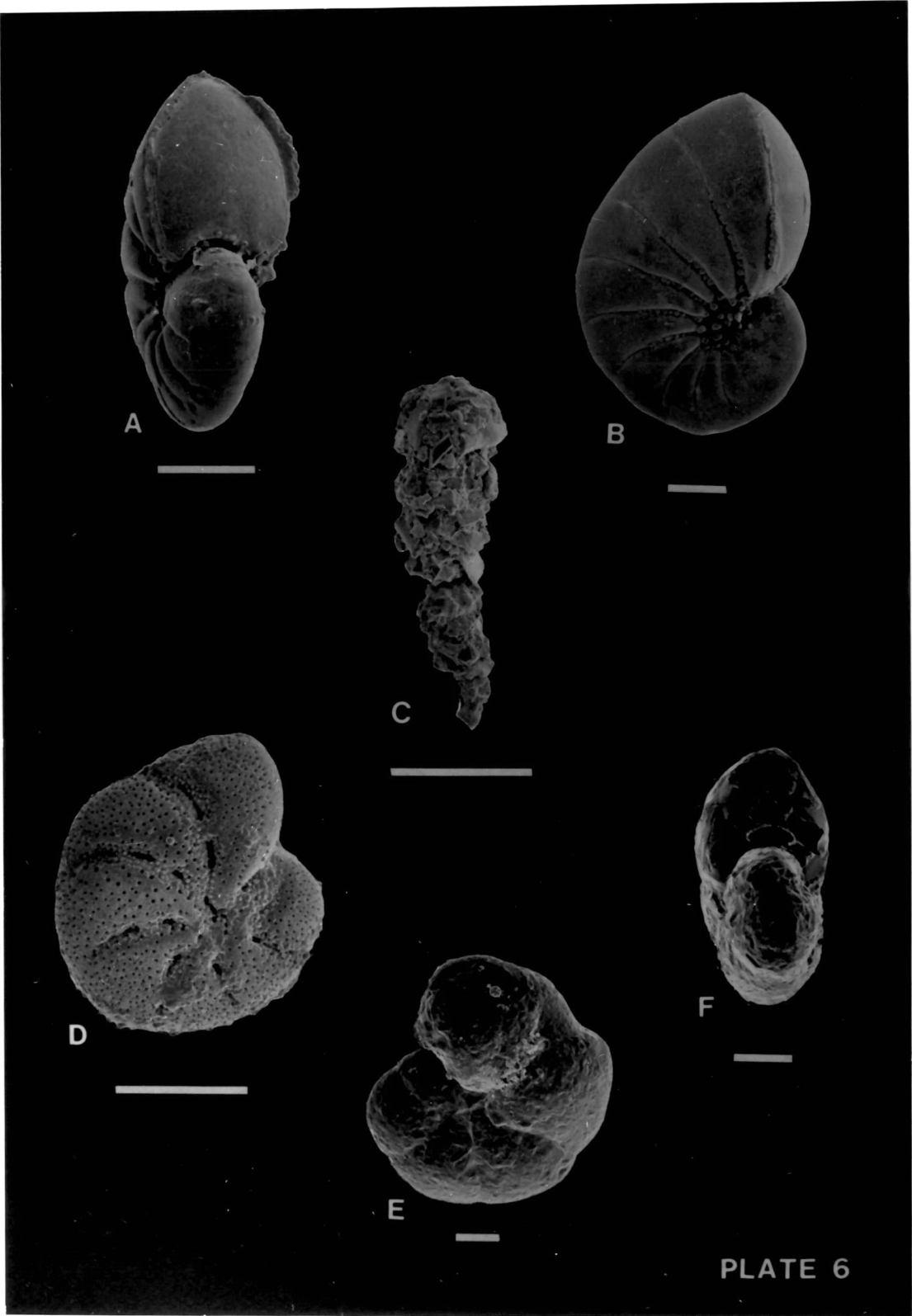


Plate 7

Species in Traction Velocity Group no. 3
(all scale bars = 100 microns)

Figure:

A-B. Textularia earlandi Parker

A. Side view

B. Edge view

C. Spiroplectammina biformis (Parker & Jones)

Oblique view showing aperture and initial spiral

D-F. Trochammina nitida Brady

D. Umbilical view

E. Edge view

F. Spiral view

G-H. Bolivina pacifica Cushman & McCulloch

G. Edge view

H. Side view

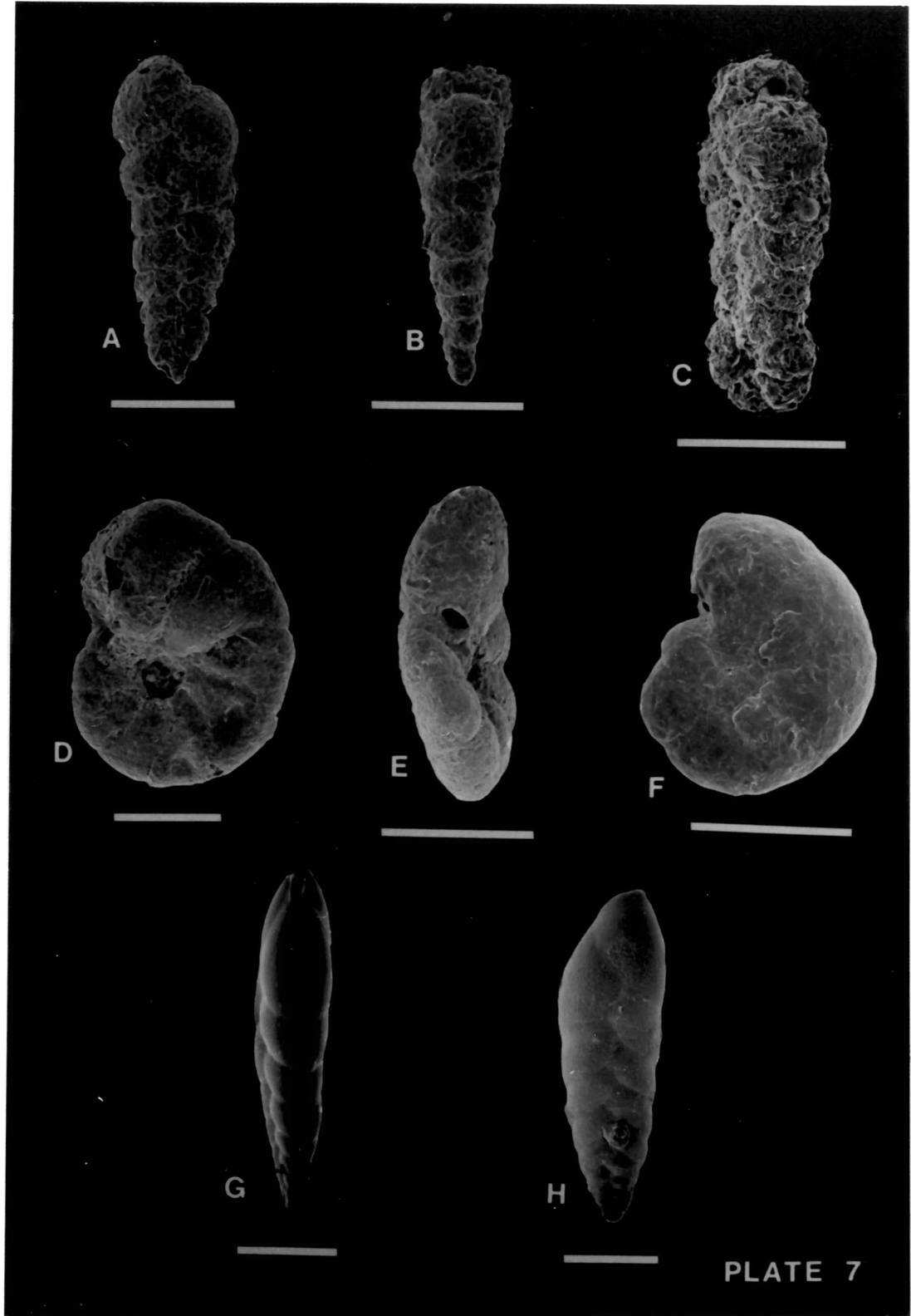


Plate 8

Species in Traction Velocity Group 3 (continued)
(all scale bars = 100 microns)

Figure:

A-C. Trochammina squamata Jones & Parker

A. Spiral view

B. Edge view

C. Umbilical view

D-E. Alveolophragmium columbiense (Cushman)

D. Edge view

E. Side view

F-H. Trochammina rotaliformis Wright

F. Spiral view

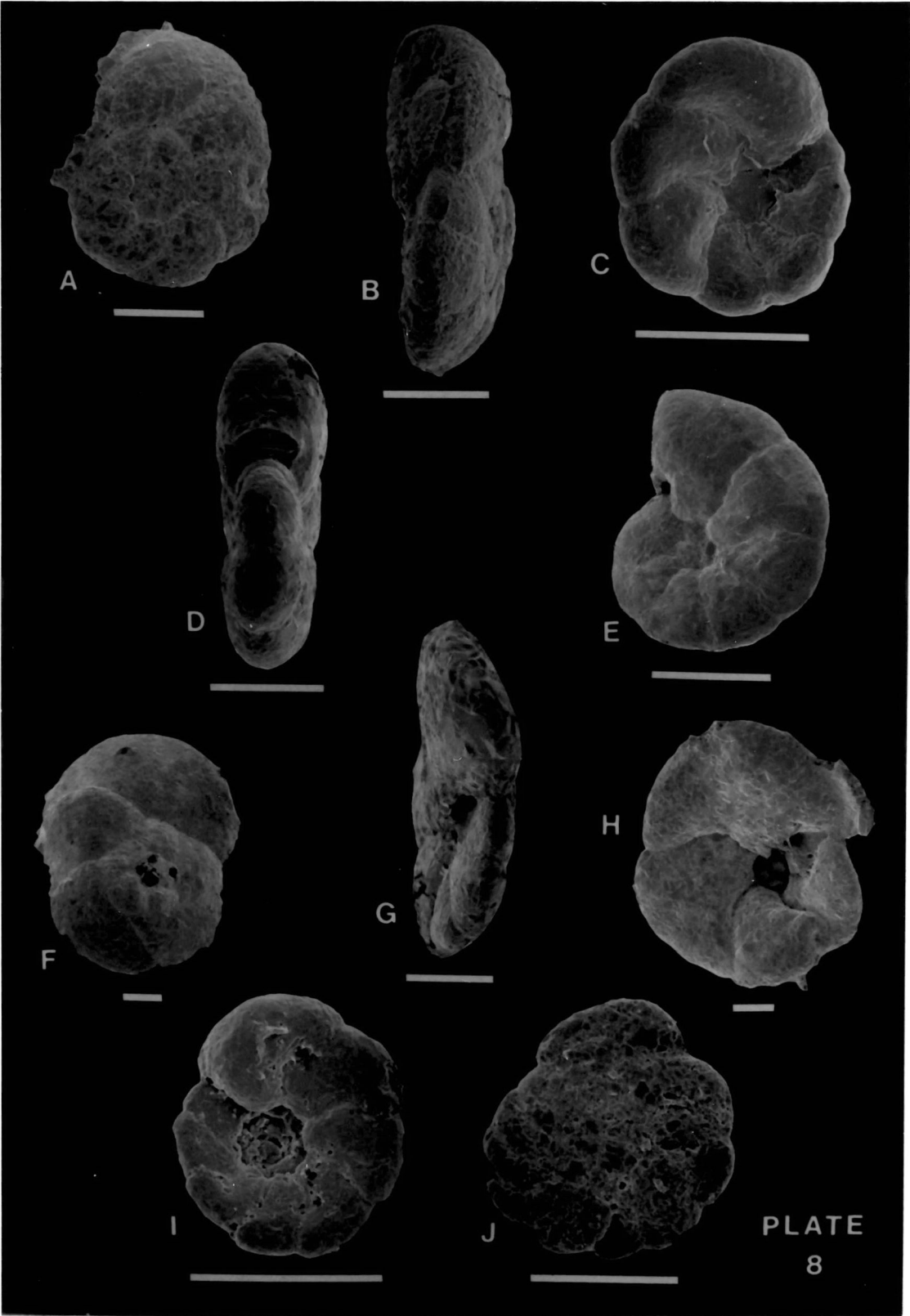
G. Edge view

H. Umbilical view

I-J. Trochammina kellettae Thalmann

I. Umbilical view

J. Spiral view



APPENDIX 1

RELATIVE ABUNDANCE TABLE FOR ALL SPECIES IDENTIFIED

	ALUSCOTRYNA U. OMBRATA	ALVEOLOPHRAGMUM COLUMBIFRONS	ALVEOLOPHRAGMUM CRASSIMARGUS	ALVEOLOPHRAGMUM JEFFREYSI	AMMELISCUS MINUTISSIMUS	AMMOLISCUS PLANUS	AMMOTUM PLANISSIMUM	ASTRONOTION AFF. A. INCILLIS	ASTRONOTION GALLONAYI	ASTRONOTION UNBILICATULUM	BOLIVINA ALATA	BOLIVINA BASISENTA	BOLIVINA PACIFICA
WA-01B	6.4												
WA-02A	1.9												
WA-02B													
WA-03	1.1												
WA-04	2.2			0.2		0.2							1.0
WA-05	3.4					0.2	0.2						2.7
WA-06	12.5												
WA-07	34.9			0.9		1.6							
WA-08	15.7			1.3		0.3	0.3			0.3	0.3		0.8
WA-09	4.8												1.0
WA-10	4.5			0.4		0.2				0.4			
WA-11	0.3			0.6									
WA-13													
WA-14	3.2			0.3									
WA-15	4.6					0.3							
WA-16	6.6	0.4					0.2			0.2			1.9
WA-17	19.7			0.5									
WA-18B	0.4												2.1
WA-19C	3.1												
WA-21													
WA-22SH													
WA-22													
WA-23A													
WA-24A	2.2												
WA-25	1.6												
WA-26C	2.5						0.6						
WA-27	9.3			0.6									0.3
WA-28A	8.9			0.3	0.2					0.2			0.5
WA-28C	11.2			0.4		0.4							0.1
WA-29B	18.9			2.2		1.5							
WA-30													
WA-31													
WA-32	4.9												
WA-33	3.6					0.3							
WA-34	9.6					1.9							
WA-34SH	11.1												
WA-36SH	7.1			0.3							0.3		1.0
WA-39	0.7	5.1		0.4									
WA-41		1.2											
WA-43	4.1			0.5									
WA-44	2.5	0.3											
WA-46	17.7					1.3							
WA-47	12.5		0.3				0.3						
WA-48		1.5											
WA-49		0.8											
WA-51	1.5												
WA-52	6.5	0.6	0.6										
WA-54	5.9						0.5						
WA-55													
WA-57	6.7	0.4		0.8									
WA-58	11.6			0.2	0.2					0.5	0.4	0.4	0.2
WA-59	13.4									0.1		0.1	0.3
WA-60	5.1												0.5
WA-61 (1)		1.4			2.8	1.4							
WA-61 (2)		20.0				0.7							
WA-62													
WA-63													
WA-64	9.8	0.3											
WA-65	5.9						0.4						0.4
WA-67	7.2				0.3					1.1			0.8
WA-68	6.8	0.9		0.4						0.4			0.9
WA-69	5.7									0.3			
WA-70	6.9	0.3					0.1						
WA-71	4.3												
WA-72	1.8	0.4											
WA-73	0.5	1.6	0.3	0.3									
WA-74	4.7		0.4										
WA-75	7.2												
WA-76	3.7												
WA-77	6.9			0.5		0.3				0.8			
WA-78	13.3												
WA-79	1.8												1.4
WA-80				0.8									0.8
WA-81A	0.5												
WA-81B													
WA-82	0.9			0.3									
WA-83	0.3			0.3									1.7
WA-84	10.8			0.5									
WA-85	5.3												
WA-86	5.6	0.3		1.3		1.0							0.5
WA-87	6.1			0.3			0.2			0.1			1.2
WA-88	5.1			1.1			0.2				0.2		0.7
WA-89	14.0			0.7									0.2
WA-90	12.1			1.6	0.3						0.3		
WA-91	3.2	0.2					0.1						
WA-93	2.8	0.3											
WA-94													
WA-95	4.3				1.2								
WA-96	3.5						0.1						0.1
WA-97	3.3	0.1						0.3					0.8

	BULLIMIA PUNCTATA	BULLIMIA UNDULANS	BUCCELLA ANGULATA	BUCCELLA FRIGIDA	BUCCELLA INUSITATA	BULLIMIA AFF. B. EIGHTH	BULLIMIA SP.	BULLIMELLA ELEGANTISSIMA	CASSIDULINA CALIFORNICA	CASSIDULINA CRASSA	CASSIDULINA ISLANDICA	CIBICIDES AFF. C. PARVICTUS	CIBICIDES FLETCHERI
WA-01B								0.9					
WA-02A													
WA-02B								8.8					
WA-03								0.7					
WA-04								1.2					
WA-05	0.2		0.2					0.3					
WA-06													
WA-07													
WA-08										0.5			0.3
WA-09			0.3					0.4					
WA-10			0.2										
WA-11				1.2				54.8					
WA-13								12.9					
WA-14								0.2					
WA-15													
WA-16								0.8					
WA-17													
WA-18B													
WA-19C			0.3										
WA-21	1.3												
WA-22SH													
WA-22		0.6	0.6					0.6					
WA-23A													
WA-24A													
WA-25													
WA-26C		1.4						0.3	0.3				
WA-27		0.3	0.3										
WA-28A		0.2	0.8										
WA-29C	0.1	0.1						0.1					
WA-29B		0.7						0.2					0.2
WA-30								5.4					
WA-31													
WA-32													
WA-33		3.6	0.3	0.7									
WA-34		1.9		1.9		1.9		1.9	9.6				
WA-34SH		1.0						0.3					
WA-36SH			0.8	1.0									
WA-39													
WA-41					2.3			4.7		1.2			
WA-43			3.2	1.4				10.6					
WA-44		0.3		0.3				0.6					
WA-46													
WA-47													
WA-48													
WA-49													
WA-51													
WA-52			0.6										
WA-54				1.9									
WA-55		0.2											
WA-57													
WA-58			0.2	0.7									
WA-59													
WA-60			0.5	4.6				1.0					
WA-61(1)										0.7			
WA-61(2)													
WA-62													
WA-63													
WA-64	0.2												
WA-65			0.4										
WA-67	0.3												
WA-68				0.4									
WA-69													
WA-70	0.1			0.1									
WA-71													
WA-72													
WA-73													
WA-74				0.7				0.4					
WA-75													
WA-76													
WA-77		0.6	0.2	0.2				0.3					0.2
WA-78													
WA-79			1.4					0.5					
WA-80								0.8					
WA-81A													
WA-81B													
WA-82			0.6					18.2					
WA-83			0.3					5.7					
WA-84													
WA-85													
WA-86			0.5	1.5				0.3					
WA-87			0.2					0.2		0.1			
WA-88													
WA-89													
WA-90													
WA-91	0.1		0.1										
WA-93			0.1					0.9					
WA-94													
WA-95													
WA-96		0.4						0.4					
WA-97			0.8	1.3	0.1			0.6		0.1			

	CIRILLIUS LOBATUS	CIRILLIUS MEXICANA	DENTALINA ST. D. PROBISHERIENSIS	DENTALINA SP.	EDGEPELLA ADVENNA	EDGEPELLA HUMBOLDTI	EDGEPELLA PUSILLA	ELPHIDIELLA NITIDA	ELPHIDIUM EXCAVATUM FORMA CLIVANTUM	ELPHIDIUM EXCAVATUM FORMA SELSEVENSIS	ELPHIDIUM FRIGIDUM	ELPHIDIUM INCERTUM	ELPHIDIUM SUBINJECTUM
WA-01B					19.1								
WA-02A					88.9	3.7							
WA-02B					98.7								
WA-03					34.1	1.1			6.6				
WA-04					48.5	0.2							
WA-05				0.2	38.0				0.2				
WA-06					41.1								
WA-07					33.3								
WA-08					17.0								
WA-09					39.7								
WA-10			0.2		43.0	0.2							
WA-11		0.3			19.6	0.6			0.9	0.6			
WA-13					72.4	10.3							
WA-14					53.1								
WA-15					41.0								
WA-16					40.5								
WA-17					55.7								
WA-18B					36.6				0.4				
WA-19C					49.2	0.6			0.6				
WA-21					84.0								
WA-22SH					84.2	3.5							
WA-22					90.5	0.6			0.6				
WA-23A					89.5								
WA-24A					54.3								
WA-25					51.8								
WA-26C					49.9								
WA-27					53.9								
WA-28A					37.3								
WA-28C					58.0								
WA-29B					35.1								
WA-30					69.6								
WA-31					87.3								
WA-32					42.8								
WA-33					61.2								
WA-34		1.9											
WA-34SH					38.9								
WA-36SH					21.3	0.3							
WA-39					58.8	10.5							
WA-41	2.3				66.3	7.0		2.3	1.2				
WA-43					42.4	2.3			7.4			1.8	1.4
WA-44					51.8	1.4							
WA-46					34.8								
WA-47					56.5	0.5							
WA-48					80.8	4.9							
WA-49					83.1	8.9							
WA-51					83.8	8.8							
WA-52					40.0	1.9							
WA-54					43.4	0.8							
WA-55					98.2	7.2			0.2				
WA-57					51.6	3.2							
WA-58	0.2				30.9								
WA-59					41.3	0.1							
WA-60					37.4	1.0							
WA-61(1)					38.5	3.5							
WA-61(2)					26.7	5.2							
WA-62					78.4	16.2							
WA-63					75.0	8.8	1.5						
WA-64					62.5	1.7							
WA-65					40.1								
WA-67					35.6		0.3						
WA-68					36.6	1.7							
WA-69					53.8	0.5							
WA-70					52.3	0.5							
WA-71					40.1	0.6	0.3						
WA-72					54.6	3.9							
WA-73	0.3				58.4	2.4			0.8				
WA-74					43.2	0.4					0.4		
WA-75					46.7								
WA-76					48.7		0.4						
WA-77					33.7				0.2				
WA-78					47.8								
WA-79					32.3	0.5							
WA-80					50.0								
WA-81A					73.4								
WA-81B					100								
WA-82					38.4				0.3			0.6	
WA-83					40.8								0.3
WA-84					44.8								
WA-85					42.7	0.9							
WA-86					17.5				0.5				
WA-87					35.2							0.5	
WA-88					42.1								
WA-89					21.3								
WA-90					20.8								
WA-91					48.2				0.2				
WA-93					46.7								
WA-94					77.2								
WA-95					40.9								

	EPISURTILLA PACIFICA	EPISURTILLA UTRECH	EPONIDES AFF. E. TENERUS	EPONIDES LEUCICULUS	EPONIDES PEPANOPUS	EPONIDES IMBONATUS	FISSURINA AFF. F. CUCURBITASENA	FISSURINA LUCIDA	FISSURINA MARGINATA	FISSURINA SP.	FLORILUS AURICULUS	FLORILUS BASISPINATUS	FLORILUS LABRADORICUS
WA-01B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-02A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-02B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-03	...	1.1	...	...	...	...	...	...	...	...	2.2	2.2	...
WA-04	...	2.4	...	1.0	...	...	...	...	...	...	4.4	...	1.2
WA-05	...	10.9	...	5.1	...	...	...	...	...	...	4.1	...	0.5
WA-06	...	0.9	...	5.4	...	...	...	...	...	...	1.2	...	...
WA-07	...	...	...	0.3	...	...	...	...	...	...	...	...	...
WA-08	...	0.8	...	5.9	...	...	...	...	...	...	2.4	...	...
WA-09	...	6.7	...	8.3	...	...	...	...	0.6	...	6.3	...	0.3
WA-10	...	0.7	...	0.4	...	...	...	...	...	...	1.4	...	0.7
WA-11	...	...	...	...	...	...	...	...	...	...	0.6	0.9	...
WA-13	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-14	...	...	...	...	...	...	...	...	...	...	0.6	...	...
WA-15	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-16	...	...	...	14.7	...	...	...	...	...	...	2.1	...	...
WA-17	...	...	...	1.4	...	...	...	...	...	...	...	...	...
WA-18B	...	10.5	...	14.7	...	...	...	...	...	...	3.8	...	0.4
WA-19C	...	0.6	...	2.2	...	...	...	...	...	...	...	...	...
WA-21	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-22SH	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-22	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-23A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-24A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-25	...	2.4	...	1.2	...	...	...	...	...	...	1.6	...	...
WA-26C	...	...	...	0.6	...	...	...	...	...	...	...	...	...
WA-27	...	...	...	2.4	...	...	...	...	...	...	0.3	...	...
WA-28A	...	...	...	6.1	...	...	...	...	...	...	9.2	...	1.1
WA-28C	...	0.4	...	2.4	...	...	...	...	...	...	...	...	...
WA-29B	...	...	...	0.2	...	...	...	...	...	...	0.7	...	...
WA-30	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-31	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-32	...	...	...	0.2	...	...	...	...	...	...	0.2	...	...
WA-33	...	2.3	...	1.3	...	...	...	...	...	...	...	...	...
WA-34	...	...	1.9	...	...	...	...	...	...	...	3.8	...	...
WA-34SH	...	0.3	...	4.2	...	...	0.3	...	...	...	...	...	...
WA-36SH	...	3.1	...	19.2	...	...	...	...	...	...	3.4	...	0.3
WA-39	...	...	...	...	...	...	...	...	...	0.4	...	...	...
WA-41	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-43	...	...	...	0.5	...	...	...	...	...	...	3.2	0.9	...
WA-44	...	0.3	...	0.3	...	...	...	...	...	...	0.6	...	...
WA-46	...	...	...	0.7	...	...	...	...	...	...	...	...	...
WA-47	...	0.3	...	0.3	...	...	...	...	...	...	...	...	...
WA-48	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-49	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-51	...	...	...	...	...	1.5	...	...	...	...	...	...	...
WA-52	...	...	...	...	...	...	...	...	...	...	1.3	...	...
WA-54	...	0.5	...	0.8	...	...	...	...	...	...	1.6	...	...
WA-55	...	...	...	...	...	0.2	...	...	...	...	...	...	...
WA-57	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-58	...	...	...	8.4	...	...	...	...	...	...	7.0	...	0.4
WA-59	...	...	...	2.5	...	...	...	...	...	...	0.8	...	...
WA-60	...	1.0	...	3.1	...	...	...	...	...	...	3.6	...	...
WA-61(1)	...	...	...	...	...	...	...	...	...	...	0.7	...	...
WA-61(2)	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-62	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-63	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-64	...	0.2	0.3	...	0.7	...	...	...	...	...	...	...	...
WA-65	...	2.2	...	5.1	...	...	...	...	...	...	...	...	...
WA-67	...	2.8	...	12.2	...	0.3	...	...	...	...	1.1	...	...
WA-68	...	...	...	5.1	...	...	...	...	...	...	4.3	...	...
WA-69	...	...	...	5.5	...	...	...	...	...	...	1.0	...	...
WA-70	...	...	...	0.5	...	...	...	...	...	...	...	...	...
WA-71	...	...	...	0.3	...	...	...	...	...	...	...	...	...
WA-72	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-73	...	...	...	...	...	...	...	...	...	...	0.3	...	...
WA-74	...	0.4	...	...	...	...	...	...	...	...	0.4	...	...
WA-75	...	...	...	0.3	...	...	...	...	...	...	...	...	...
WA-76	...	0.4	...	...	...	...	...	...	...	...	...	1.1	...
WA-77	...	2.0	...	1.1	...	...	...	...	...	...	2.3	...	0.5
WA-78	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-79	...	2.3	...	0.5	...	...	...	...	...	...	6.9	3.2	1.8
WA-80	...	1.6	...	...	...	...	...	...	...	...	...	...	...
WA-81A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-81B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-82	...	0.3	...	...	...	...	...	...	...	...	1.3	...	...
WA-83	...	...	...	0.7	...	...	...	...	...	...	2.3	2.7	...
WA-84	...	0.5	...	...	...	...	...	...	...	...	0.9	...	...
WA-85	...	1.3	...	...	...	...	...	...	...	...	...	...	...
WA-86	...	...	...	...	...	...	...	...	...	...	2.3	1.8	...
WA-87	...	6.4	...	1.3	...	...	...	...	...	...	2.5	0.5	2.2
WA-88	...	4.2	...	6.2	...	...	...	...	...	...	5.3	...	...
WA-89	...	0.4	...	0.7	...	...	0.4	...	...	...	6.2	...	0.2
WA-90	...	0.7	...	1.6	...	...	...	...	...	...	3.9	...	...
WA-91	...	6.9	...	14.9	...	...	...	...	...	...	0.4	...	0.3
WA-93	...	3.9	...	2.2	...	...	...	...	...	...	1.0	...	1.9
WA-94	...	7.3	...	3.3	...	...	...	...	...	...	...	...	...
WA-95	...	...	...	...	...	...	...	...	...	...	0.6	...	...
WA-96	...	0.1	...	0.8	...	...	...	...	...	...	...	...	0.1
WA-97	...	27.4	...	12.2	...	...	...	...	...	...	5.1	...	1.9

	LAGENA GRACILLINA	LAGENA INTERMEDIA	LAGENA LAEVIS	LAGENA SETIGERA	LAGENA STRIATA	LAGENA SUBSTRATA	LAGENAMINA ATLANTICA	LARYNGOSIGMA MYALASCIDIA	MARTINOTIELLA PRIMAEVA	MECONORBINA CF. N. TERQUEMI	MONIDIELLA MIOCENICA	MONIDIELLA SP.	DOLINA CF. O. CAUDIGERA
WA-01B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-02A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-02B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-03	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-04	...	...	...	0.2	0.2	...	...	...	...	...	0.5	...	...
WA-05	0.2	...	...	0.2	0.2	...	...	...	...	...	0.2	...	...
WA-06	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-07	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-08	...	...	0.3	...	...	...	...	...	...	...	...	...	...
WA-09	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-10	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-11	...	...	...	...	...	...	...	...	...	...	4.5	...	...
WA-13	...	...	...	...	...	...	...	...	...	...	...	3.4	...
WA-14	...	...	...	...	...	...	0.3	...	...	...	0.3	...	...
WA-15	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-16	0.2	...	...	...	...	...	...	...	...	...	...	...	...
WA-17	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-18B	...	...	...	...	0.4	...	...	...	...	...	0.8	...	...
WA-19C	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-21	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-22SH	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-22	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-23A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-24A	...	...	...	...	...	...	...	...	...	...	0.4	0.4	...
WA-25	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-26C	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-27	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-28A	...	...	...	...	...	...	...	...	0.2	...	...	...	...
WA-28C	...	...	...	...	...	...	...	...	...	...	...	0.1	...
WA-29B	...	...	...	...	...	...	0.5	...	...	...	...	...	...
WA-30	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-31	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-32	...	...	...	...	...	...	0.2	...	...	...	...	...	...
WA-33	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-34	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-34SH	...	...	0.3	...	...	...	...	...	0.3	...	...	...	...
WA-34SH	...	...	0.3	...	...	...	...	...	0.3	...	0.5	...	...
WA-39	...	...	...	...	...	...	...	...	...	0.4	...	...	...
WA-41	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-43	...	...	...	...	...	...	0.5	...	...	...	3.2	...	...
WA-44	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-46	...	...	...	...	...	...	0.3	...	...	...	...	0.3	...
WA-47	...	...	...	...	...	...	0.5	...	...	...	...	...	...
WA-48	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-49	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-51	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-52	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-54	...	...	...	...	...	...	0.5	...	...	...	...	...	...
WA-55	...	...	...	...	...	...	...	0.2	...	...	0.2	...	...
WA-57	...	...	...	...	...	...	1.2	...	...	...	...	...	...
WA-58	...	...	...	...	...	...	1.3	...	...	...	0.2	...	...
WA-59	...	0.1	...	...	...	...	0.8	...	...	...	0.1	...	...
WA-60	...	...	...	...	...	...	1.0	...	...	...	...	...	...
WA-61(1)	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-61(2)	...	...	...	...	...	...	0.7	...	...	...	...	...	...
WA-62	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-63	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-64	...	...	...	...	...	...	0.5	...	...	...	0.2	...	...
WA-65	...	...	...	...	...	...	1.8	...	...	...	...	...	...
WA-67	...	...	...	...	...	...	0.8	...	0.3	...	...	...	...
WA-68	...	...	...	...	...	...	1.3	...	...	...	...	...	...
WA-69	...	...	...	...	...	...	0.3	...	...	...	...	...	...
WA-70	...	...	...	...	...	...	0.4	...	...	...	...	...	...
WA-71	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-72	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-73	...	...	...	...	...	...	0.3	...	...	...	...	...	...
WA-74	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-75	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-76	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-77	...	...	...	...	...	...	...	...	...	...	0.3	...	...
WA-78	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-79	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-80	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-81A	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-81B	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-82	...	...	...	...	...	...	...	...	...	...	0.4	0.3	...
WA-83	...	...	...	...	...	...	...	...	...	...	0.3	1.0	...
WA-84	...	...	...	...	...	...	...	...	...	0.5	...	...	...
WA-85	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-86	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-87	...	0.1	...	...	...	0.1	...	...	...	0.1	0.3	...	...
WA-88	...	...	0.2	...	...	...	...	...	...	0.2	...	0.2	...
WA-89	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-90	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-91	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-93	...	0.1	...	...	...	0.1	...	...	...	...	0.3	...	...
WA-94	...	...	...	...	...	...	...	...	...	0.1	...	...	...
WA-95	...	...	...	...	...	...	...	...	...	...	...	...	...
WA-96	...	...	0.1	...	...	...	...	...	...	0.1	...	...	...
WA-97	...	0.1	...	...	...	...	...	...	...	...	4.9	...	...

	IOLIA COSTATA										
	IOLIA STRIATOPUNCTATA										
	PILLARIA SALISBURYI										
	MEGAPLOIDES TURBIDATUS										
	PEOPHAX AFF. R. FUSIFORMIS										
	PEOPHAX NAETICA										
	PEOPHAX SCORPIURUS										
	SIGMOILINA AFF. S. DISTORTA										
	SIGMOILINA CF. S. TRILOCULARIS										
	SPIROPLECTANHINA BIFORMIS										
	TEXTULARIA AFF. T. FOLIACEA										
	TEXTULARIA EARLANDI										
	TEXTULARIA SCHENCKI										
WA-01B	47.3	0.9								24.1	
WA-02A	1.9										
WA-02B	1.3										
WA-03	23.1									12.1	
WA-04	2.4	0.7								13.1	
WA-05	0.5	1.5	1.0							7.8	2.2
WA-06	0.6	5.7								0.6	0.9
WA-07		7.5								1.2	
WA-08	0.5	6.9								2.7	
WA-09		1.6								5.7	
WA-10		0.5	2.2							38.2	
WA-11		6.3	1.2							5.1	
WA-13		13.8									
WA-14		3.6								19.7	0.3
WA-15		3.6	0.6	1.2						46.5	
WA-16	0.4	5.2	0.6							7.1	2.3
WA-17		3.5								2.6	3.3
WA-18B	0.8	2.1								5.9	0.8
WA-19C		0.6	0.3	0.3						36.0	0.9
WA-21		5.3								8.0	
WA-22SH		1.8								7.0	
WA-22		1.1								4.5	
WA-23A		5.3									
WA-24A		6.5								33.7	
WA-25		2.4	1.2	1.2						28.2	2.4
WA-26C		0.3	0.8	1.7						33.7	2.3
WA-27		2.7		2.4						14.2	4.8
WA-28A	0.6	3.1		0.2						1.4	4.0
WA-29C										4.0	3.9 0.1
WA-29B	0.5	5.7								0.7	3.2
WA-30			8.9							3.6	
WA-31		5.5								5.5	
WA-32		0.6	0.4	0.2						47.7	0.4
WA-33		1.3	1.0	0.3						15.1	4.3
WA-34		1.9								3.8	1.9
WA-34SH		4.2								2.3	
WA-36BH	0.3	1.0	0.5	0.3						2.1	3.1
WA-39		5.4		0.4						13.0	
WA-41											
WA-43		4.1								6.5	
WA-44		2.3	0.8	0.8						31.5	2.0
WA-46		9.0								4.3	1.0
WA-47	0.3	1.6	2.7							20.3	1.1
WA-48		3.8		0.8						6.2	
WA-49		1.6								1.6	
WA-51				1.5						2.9	
WA-52		9.0	1.3							36.8	
WA-54		3.5	0.3	5.4	0.8					23.9	4.0
WA-55		0.7								2.3	
WA-57		6.7	1.6	0.8						17.1	2.4
WA-58		0.7	2.0							3.0	3.4
WA-59		0.6	0.6	0.1	0.1					3.5	2.9
WA-60		2.1	2.6	1.0						7.2	9.2
WA-61(1)		0.7	0.7							35.0	0.7
WA-61(2)			0.7							16.3	0.7
WA-62		5.4									
WA-63			1.5							5.9	
WA-64		0.5	3.0	1.3						9.0	3.6
WA-65		2.9	2.6	0.7						6.3	8.5
WA-67	0.3	1.9	3.3							6.7	6.4
WA-68		0.4	3.4	1.7						17.4	5.5
WA-69		3.1	1.8	0.5						16.4	3.9
WA-70		1.8	0.1	3.3	0.8					22.9	4.8
WA-71		2.5	1.5	0.3						45.7	
WA-72		4.2	1.4	0.7						28.5	0.7
WA-73		4.2	1.1							23.7	1.3
WA-74		17.3	0.4							29.5	
WA-75		6.6								36.1	0.3
WA-76		0.7	1.9	1.5						28.1	8.2
WA-77		0.3	4.7	1.4	0.5					29.5	1.1
WA-78		1.1	0.4							34.0	0.4 1.1
WA-79		1.8	0.9	1.4						30.4	
WA-80		15.9	0.8							24.6	
WA-81A		10.9	1.0							10.9	0.5
WA-81B											
WA-82		7.9	0.3							28.9	
WA-83		3.0	2.7	2.7						26.8	0.7
WA-84		0.5	0.5							31.6	0.5
WA-85		33.5								13.2	0.4
WA-86	0.3	24.3	0.8		0.3					34.7	1.0
WA-87	0.1	4.2	0.3	0.2						20.3	0.7
WA-88	0.2	2.5	0.5	0.2						8.3	6.0
WA-89	0.2	3.6								0.9	0.2
WA-90	0.7	1.6			0.3						1.0
WA-91	0.3	1.1		0.3						4.4	1.1
WA-93		0.7	1.2	1.0						17.1	3.4
WA-94		6.5								4.1	0.8
WA-95		40.2	0.6							10.4	
WA-96		3.8	0.9							15.2	6.5
WA-97	0.6	0.6	0.1	0.1						7.0	1.0

	TEXTULARIA TORQUATA	TRIFARINA ANGULOSA	TROCHAMMINA INFLATA	TROCHAMMINA KELLETTAE	TROCHAMMINA MINNA	TROCHAMMINA NITIDA	TROCHAMMINA PACIFICA	TROCHAMMINA ROTALIFORMIS	TROCHAMMINA SP.	TROCHAMMINA SUMMATA	TURRITELLELLA SHONKANA	UUGERINA AFF. U. SERTICOSA	UUGERINA AUBERIANA
MA-01B						0.5							
MA-02A							1.9					1.9	
MA-02B													
MA-03										2.2			
MA-04				0.2		1.0	1.2			0.5			
MA-05				0.5		0.5	1.0						
MA-06		9.2		0.3		0.3	1.8						
MA-07		3.1			0.6	0.9	5.6	0.3					
MA-08		13.3			0.5		5.6	0.3					
MA-09				1.0		0.3	0.6						
MA-10				0.7		1.3	0.4						
MA-11				0.3			0.6			1.5			
MA-13													
MA-14	0.3			0.4	2.9	1.0							
MA-15				0.3	0.6		0.6						
MA-16				0.2	0.4	0.4	1.2						
MA-17		0.5				0.7	1.4						
MA-18B		4.2				0.4	0.8						
MA-19C				0.3		0.3				0.6			
MA-21			1.3										
MA-22BH						1.8							
MA-22			0.6										
MA-23A													
MA-24A						2.2				1.1			
MA-25			1.6	0.4	1.2	0.8						0.4	
MA-26C			1.1							0.8			
MA-27			0.3		0.3	0.9							
MA-28A		4.7	0.3		0.2	3.7							
MA-28C		3.1	0.3		0.1	2.7							
MA-29B		5.7		0.5	1.5	8.0							
MA-30			3.6		1.8					7.1			
MA-31					1.8								
MA-32			1.0		1.0	0.2				0.2			
MA-33			0.3		0.3	0.7				0.7			
MA-34		7.7		1.9		25.0	3.8						
MA-34SH		13.7		0.3	0.7	2.3							
MA-36BH		5.2		0.3		1.3							
MA-39			0.7	0.4	1.4	0.7	1.4						
MA-41			1.2	2.3	7.0		1.2						
MA-43				0.5	1.4	1.8	0.5	0.9					
MA-44			1.7			0.3						0.3	
MA-46		6.7		0.3	0.3	6.7	0.3						
MA-47					0.3	1.3				0.3			
MA-48													
MA-49					2.4					0.8		0.8	
MA-51													
MA-52					0.6	0.6							
MA-54		0.8		0.5		1.9	0.3						
MA-55					0.5								
MA-57		1.6		0.4	0.4	1.2	2.4						
MA-58		4.5		0.4		0.5	1.3	0.2		0.2			
MA-59		11.5		0.1		0.3	1.0						
MA-60		2.6				1.5				0.5			
MA-61(1)	0.7			1.4	1.4	6.3	1.4	2.1					
MA-61(2)				10.4	2.2	8.1	2.2	2.2		3.7			
MA-62													
MA-63				2.9		2.9				1.5			
MA-64			0.3	0.2	0.8	1.0	0.2						
MA-65		7.7			0.7	1.8				0.4			
MA-67		7.2		0.8		1.4				0.6			
MA-68		0.4		2.6		1.3	1.3						
MA-69					1.6	0.3							
MA-70	0.4				0.3	1.1	0.7			0.1			
MA-71				0.3		2.5	0.6			0.3			
MA-72			0.4	0.4		1.8	0.4	1.1					
MA-73			0.3		0.8	1.1	1.3			0.3			
MA-74		0.7				0.4							
MA-75			0.3		2.4								
MA-76			0.4		0.7					0.4			
MA-77		1.1		0.5	0.3	1.1	0.3	0.5		0.6			
MA-78						0.2	0.2			0.6			
MA-79		0.5				0.9				1.4			
MA-80				0.8		1.6				1.6			
MA-81A						1.6	1.0						
MA-81B													
MA-82				0.9									
MA-83				0.3						0.7			
MA-84		0.5		0.5		0.5	1.4			0.9			
MA-85							0.4			0.9			
MA-86		0.5		0.3		0.5	0.3			1.0			
MA-87		0.2		0.2			0.3			0.4			
MA-88							1.1						
MA-89		4.4		0.5			3.8						
MA-90		5.2					3.3						
MA-91		0.6		0.3		0.1	1.2			0.3			
MA-93		0.3		1.8		0.9	1.3			1.5		0.3	
MA-94				0.8									
MA-95				1.2			0.6						
MA-96		0.3		1.1	0.6	0.9	0.9			2.9			
MA-97		0.8					0.4						

	UUGERINA FARINOSA	UUGERINA JUNCEA
MA-01B		0.5
MA-02A		
MA-02B		
MA-03	1.1	1.1
MA-04	0.2	15.8
MA-05		13.9
MA-06	0.6	13.4
MA-07	0.3	1.2
MA-08	1.3	16.2
MA-09		18.4
MA-10		3.9
MA-11		
MA-13		
MA-14		
MA-15		0.6
MA-16		12.4
MA-17		1.2
MA-18B		9.7
MA-19C		2.8
MA-21		
MA-22BH		1.8
MA-22		
MA-23A		
MA-24A		
MA-25		0.4
MA-26C		2.5
MA-27		4.2
MA-28A		9.5
MA-28C		7.5
MA-29B		6.0
MA-30		
MA-31		
MA-32		
MA-33		1.3
MA-34		5.8
MA-34BH		17.0
MA-36BH		25.5
MA-39		
MA-41		
MA-43		0.5
MA-44		0.6
MA-46	0.3	4.7
MA-47		
MA-48		
MA-49		
MA-51		
MA-52		
MA-54		2.7
MA-55		
MA-57		0.4
MA-58	0.2	13.4
MA-59		17.3
MA-60		7.2
MA-61 (1)		
MA-61 (2)		
MA-62		
MA-63		
MA-64		3.3
MA-65		7.7
MA-67		5.6
MA-68	0.4	5.1
MA-69		3.1
MA-70		1.8
MA-71		
MA-72		
MA-73		0.3
MA-74		0.4
MA-75		
MA-76		3.0
MA-77	0.2	5.2
MA-78		0.2
MA-79		7.8
MA-80		0.8
MA-81A		
MA-81B		
MA-82		
MA-83		5.0
MA-84		3.8
MA-85		0.9
MA-86		2.0
MA-87	0.2	7.8
MA-88		10.3
MA-89		34.0
MA-90		31.3
MA-91		13.8
MA-93		9.6
MA-94		
MA-95		
MA-96		5.8
MA-97		13.6

· APPENDIX 2

DISTRIBUTION MAPS FOR COMMON SPECIES
(alphabetically by genus)

APPENDIX FIGURES

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1A. <u>ADERCOTRYMA GLOMERATA</u>	137
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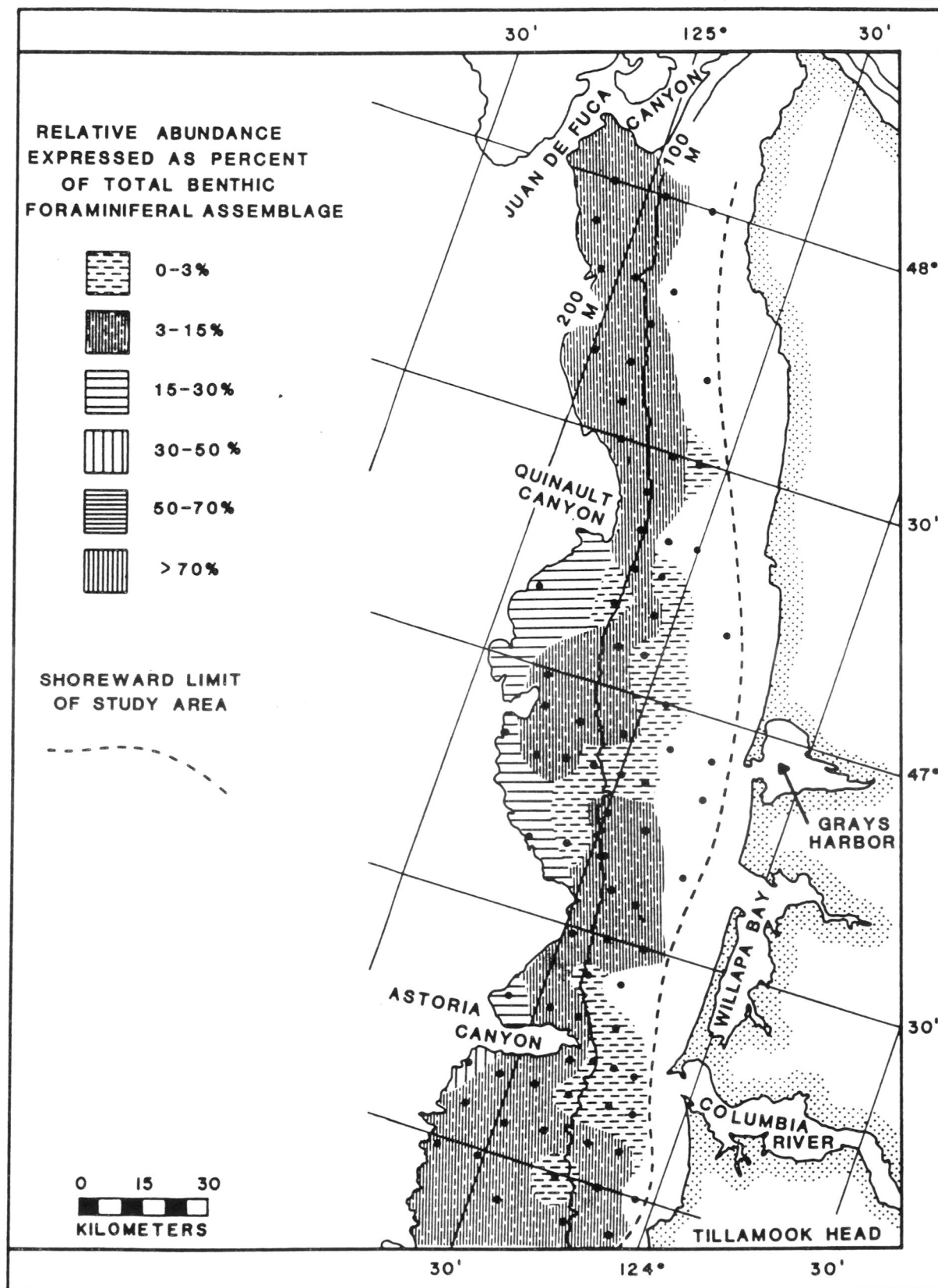


Figure 1A.

Distribution pattern of *Adercotryma glomerata*

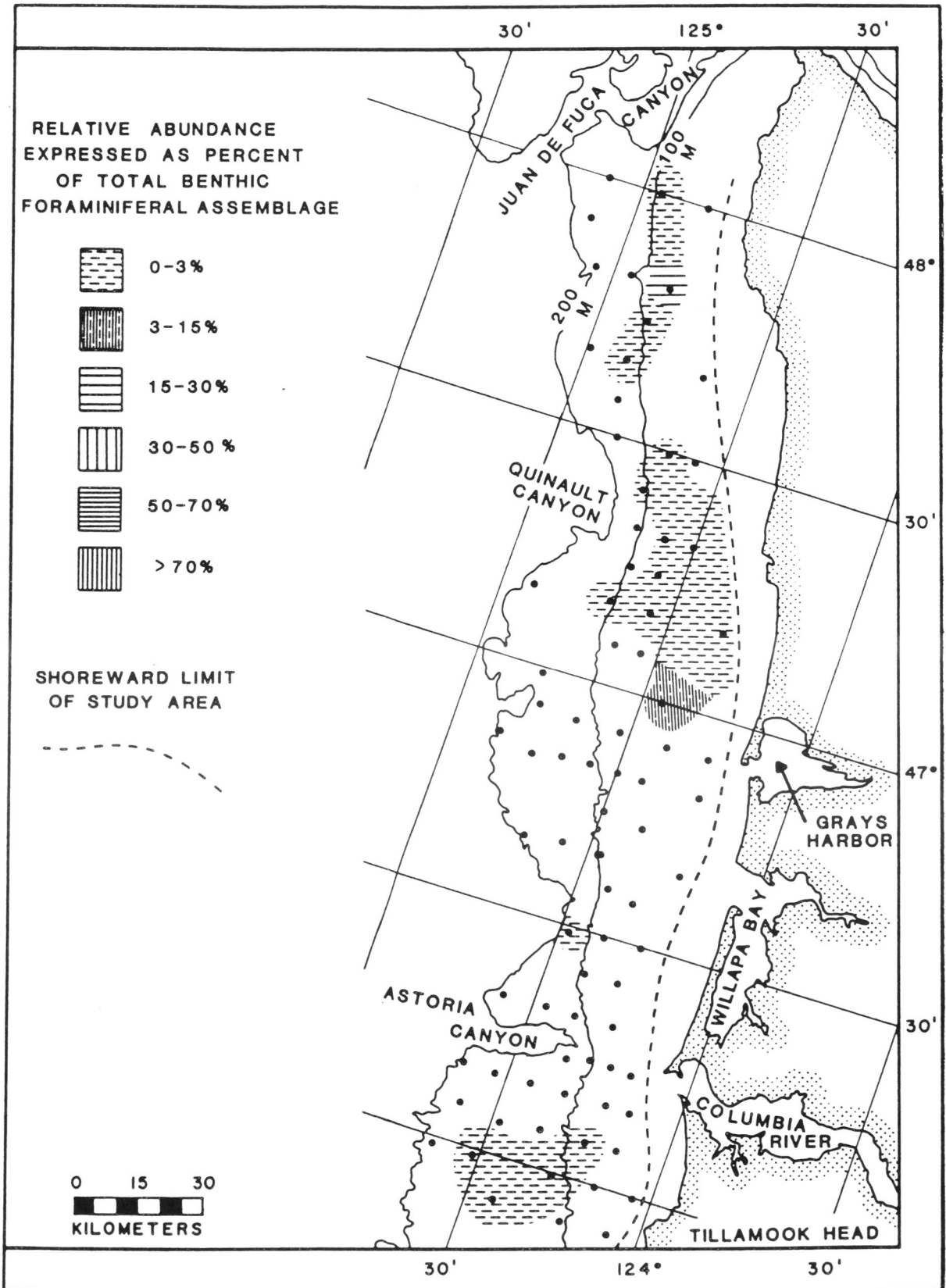


Figure 2A.

Distribution pattern of Alveolophragmium columbiense

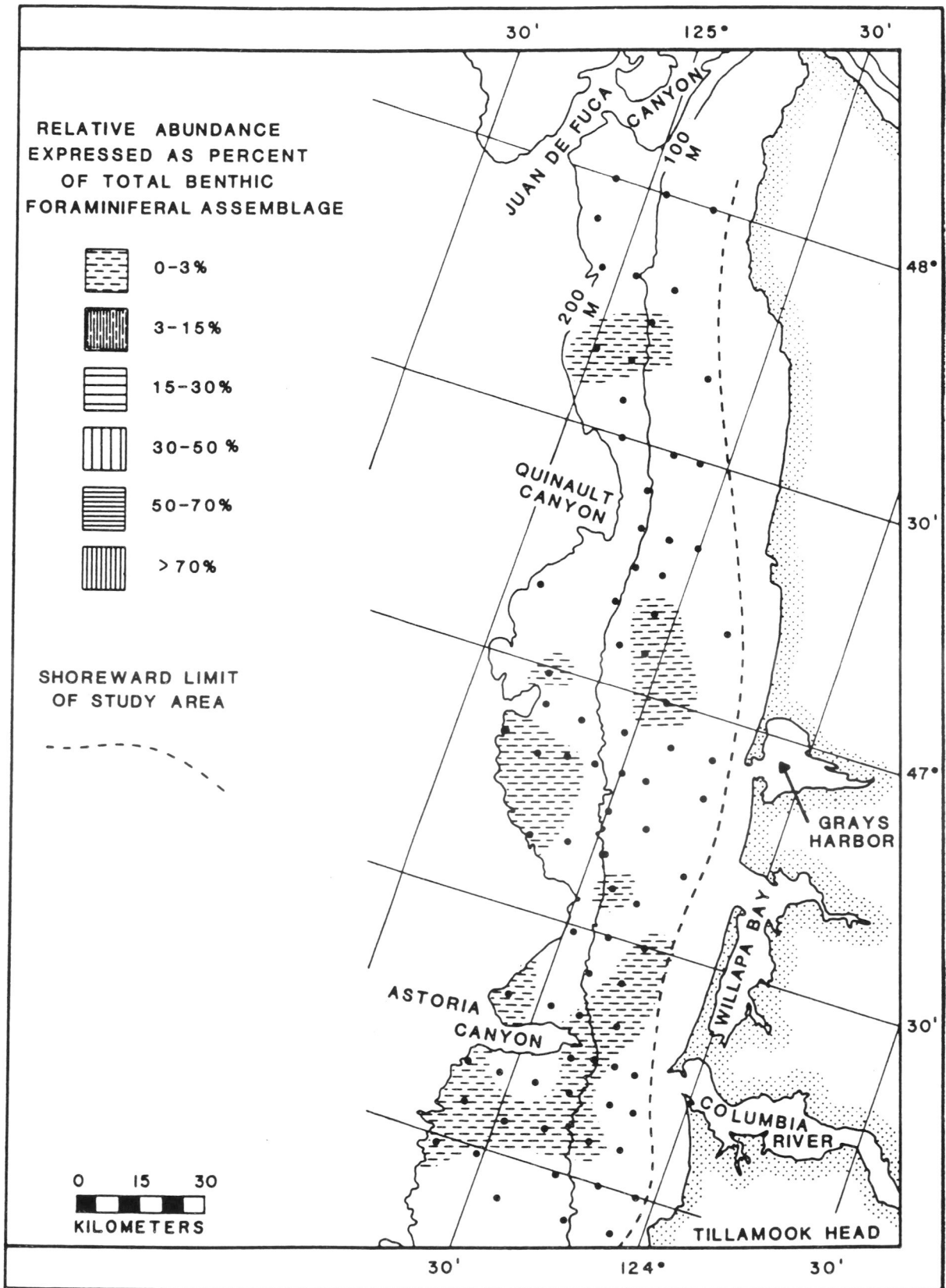


Figure 3A.

Distribution pattern of Alveolophragmium jeffreysi

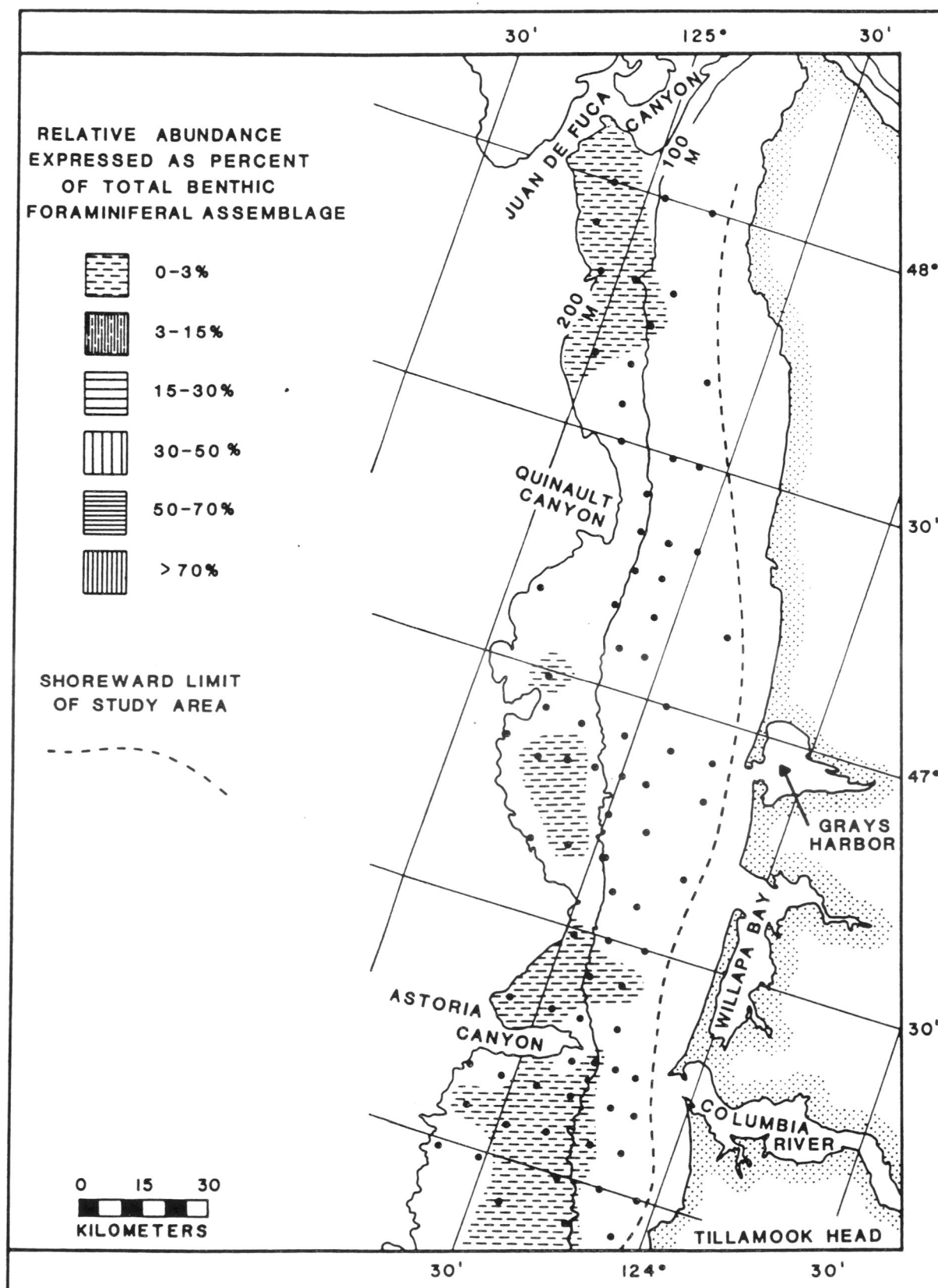


Figure 4A.

Distribution pattern of *Bolivina pacifica*

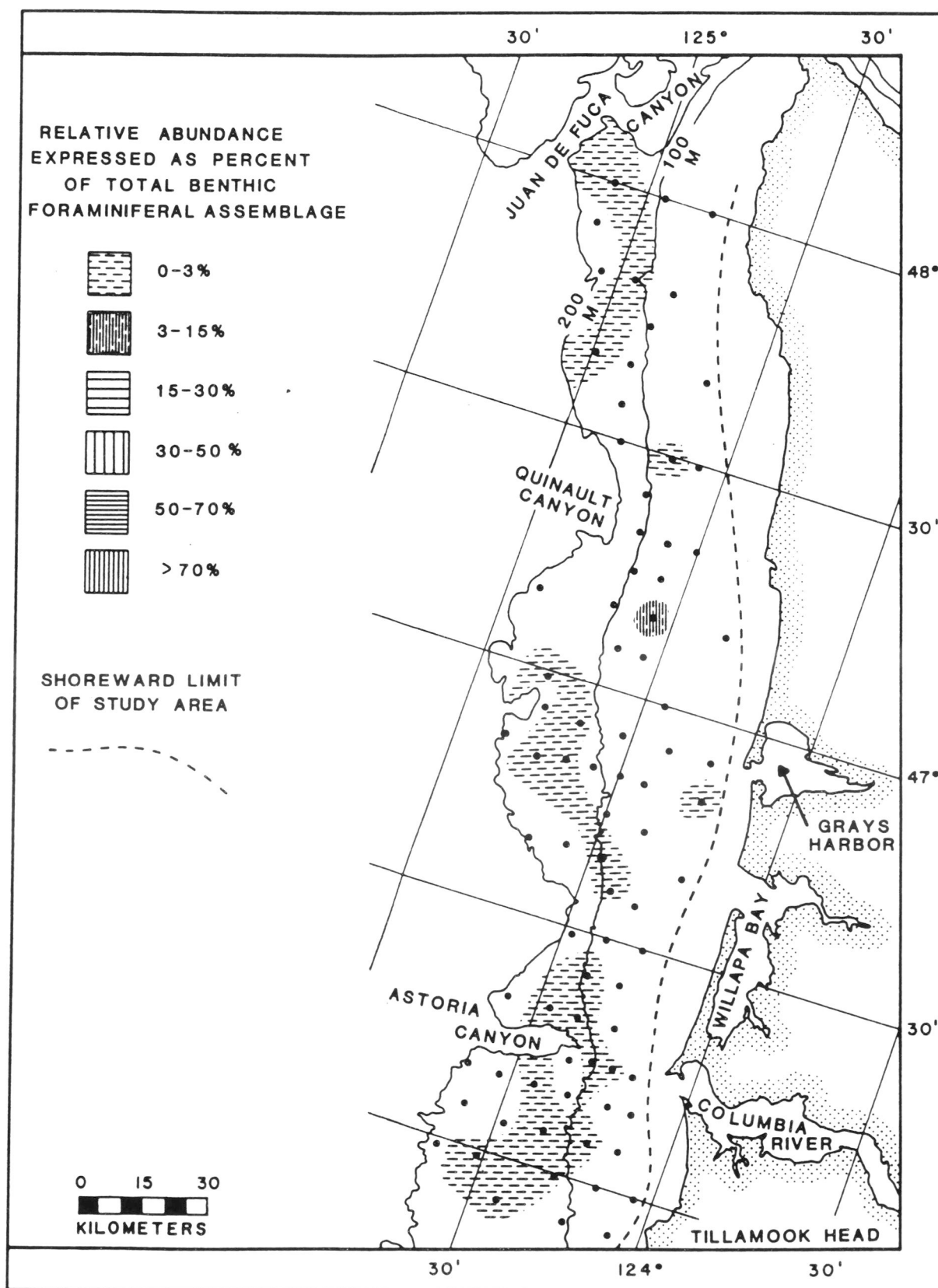


Figure 5A.

Distribution pattern of Buccella angulata

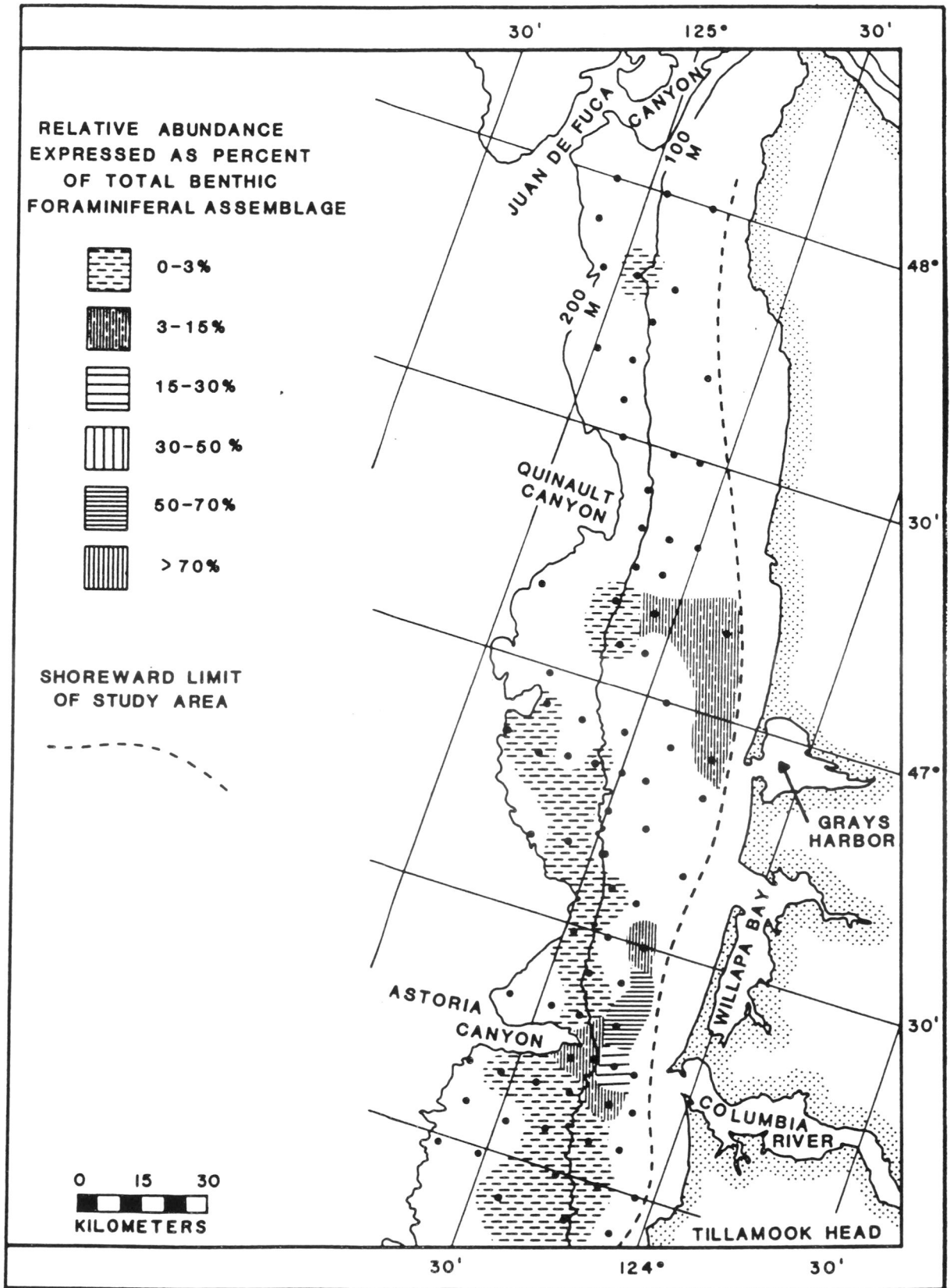


Figure 6A.

Distribution pattern of Buliminella elegantissima

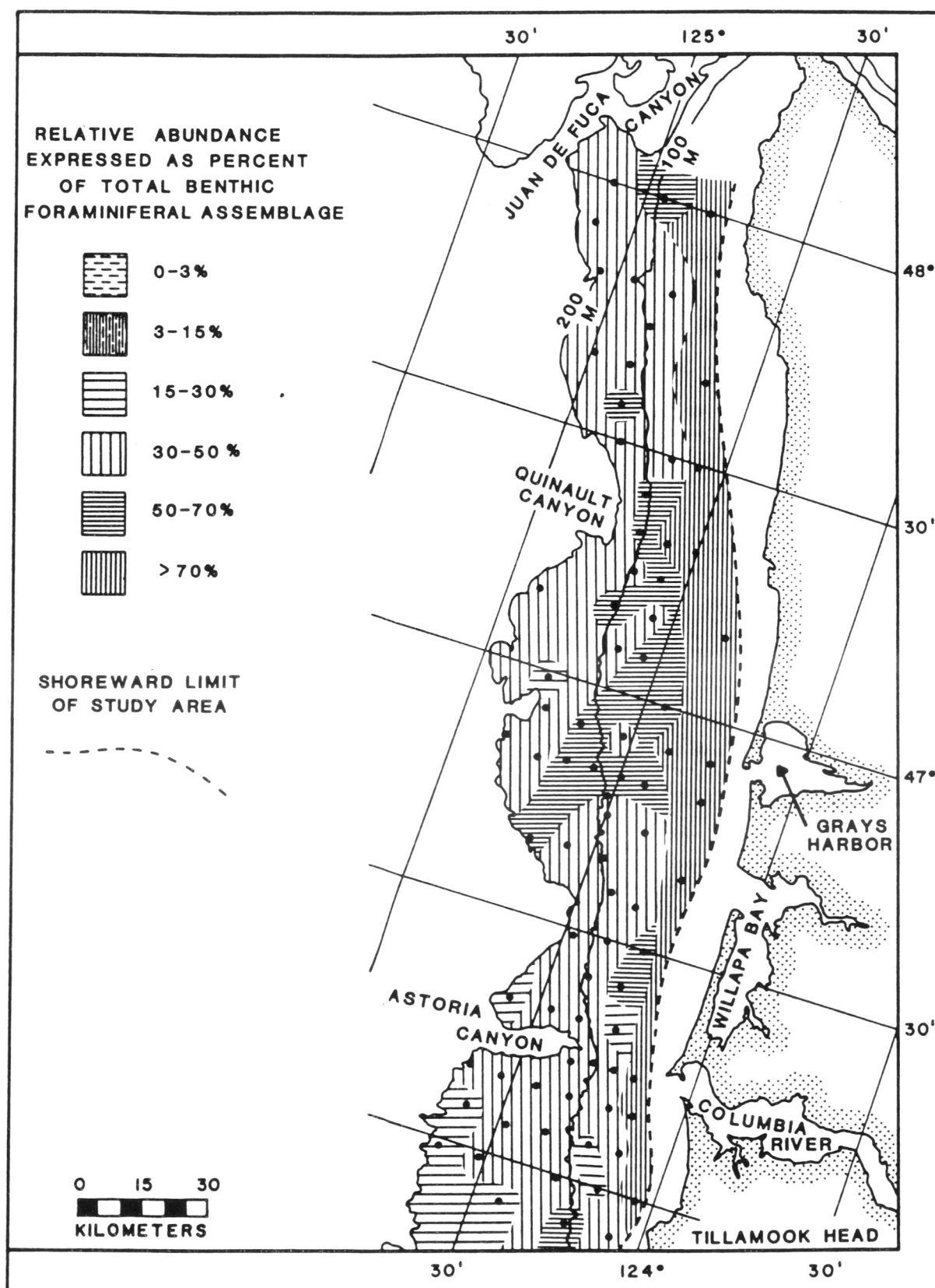


Figure 7A.

Distribution pattern of *Eggerella advena*

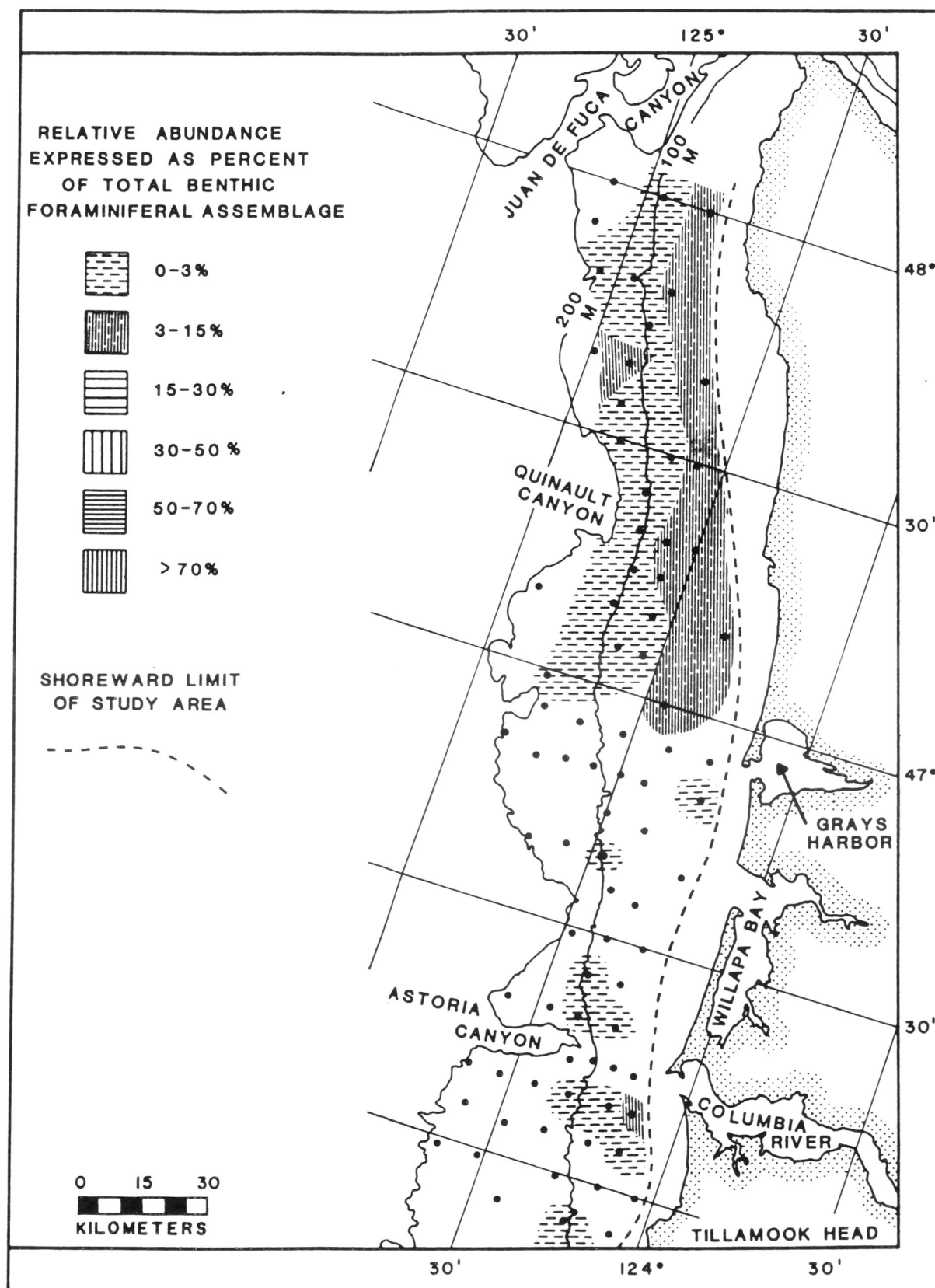


Figure 8A.

Distribution pattern of *Eggerella humboldti*

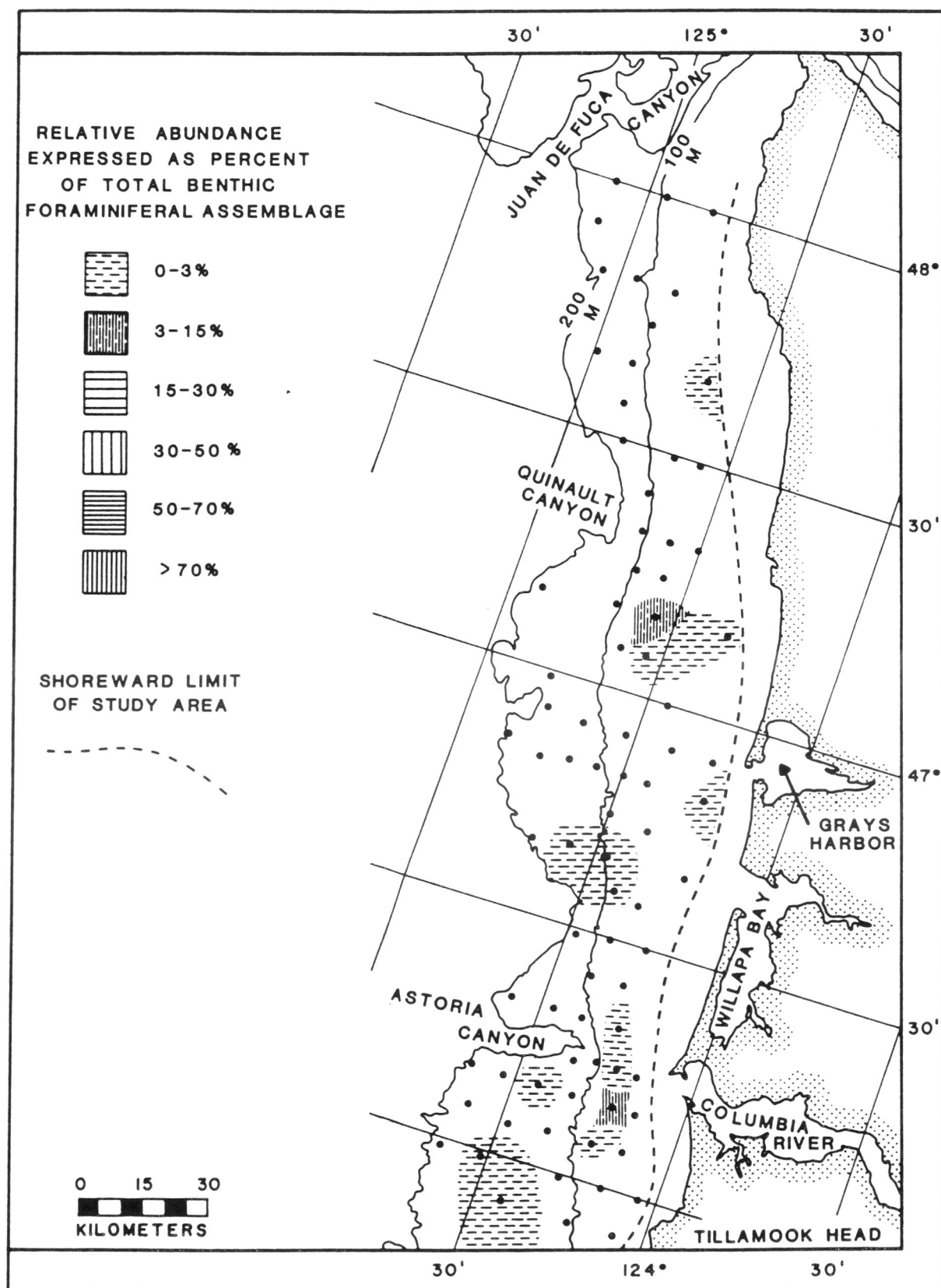


Figure 9A.

Distribution pattern of *Elphidium excavatum* forma *clavatum*

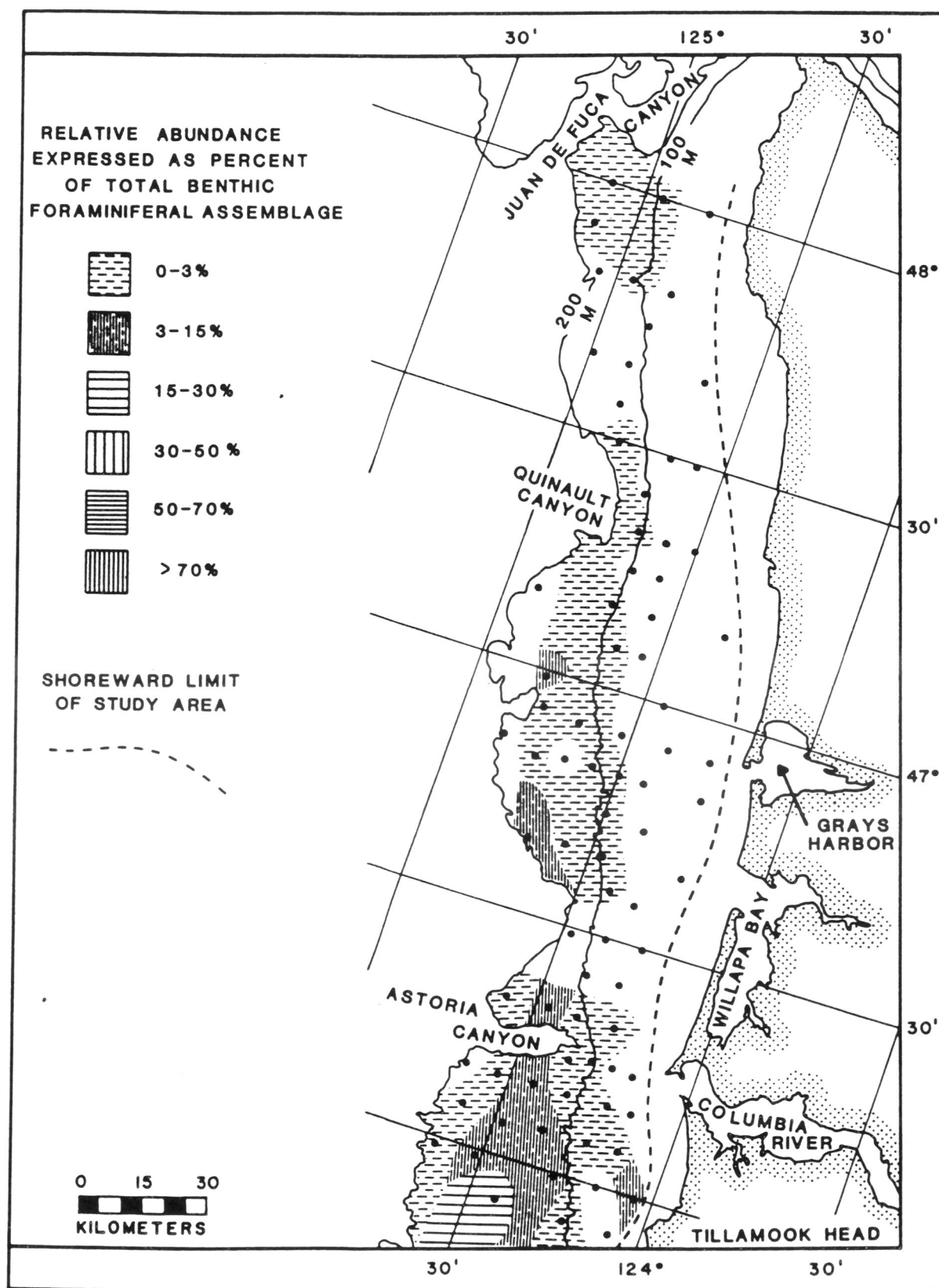


Figure 10A.

Distribution pattern of Epistominella vitrea

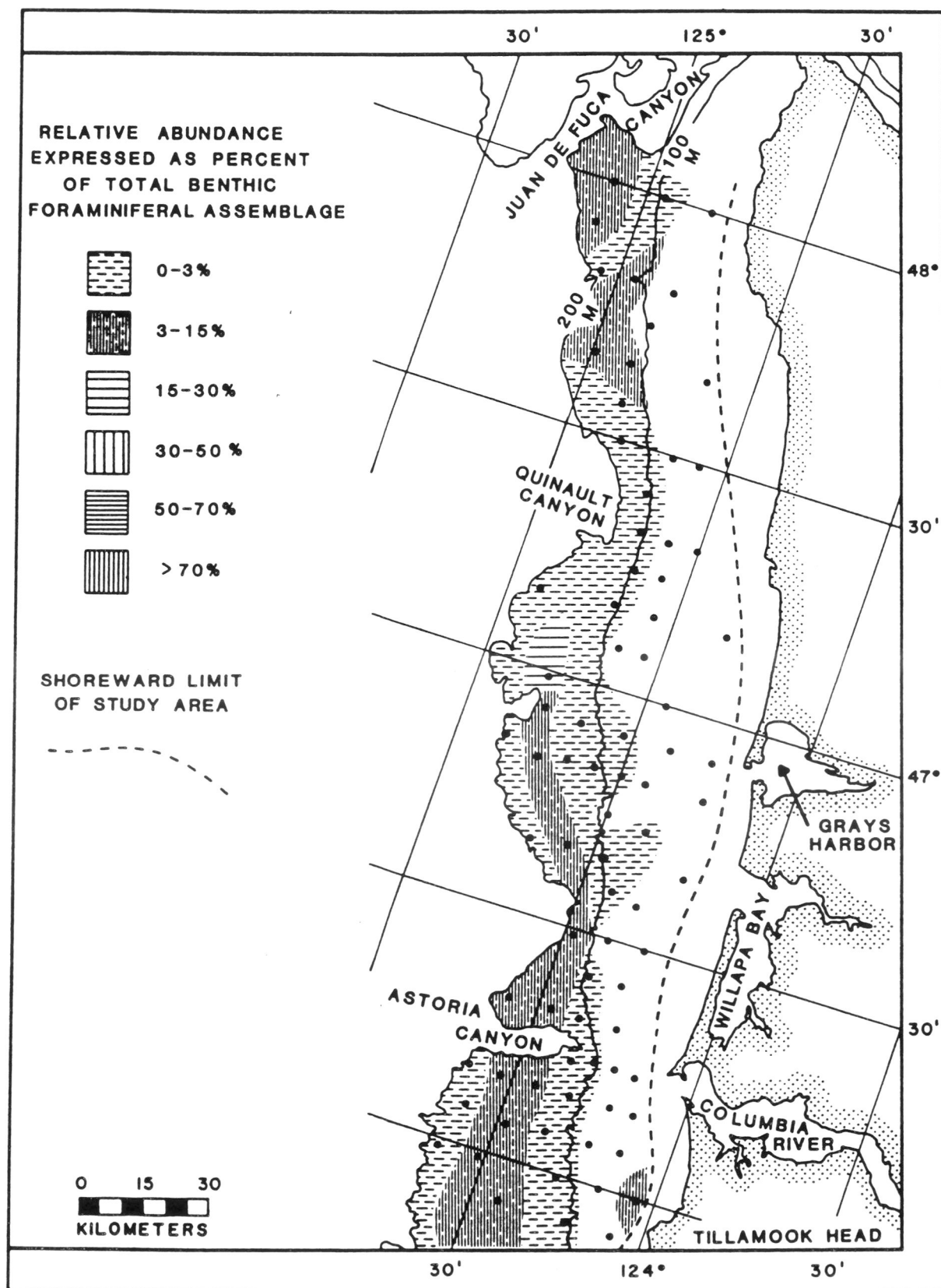


Figure 11A.

Distribution pattern of Eponides leviculus

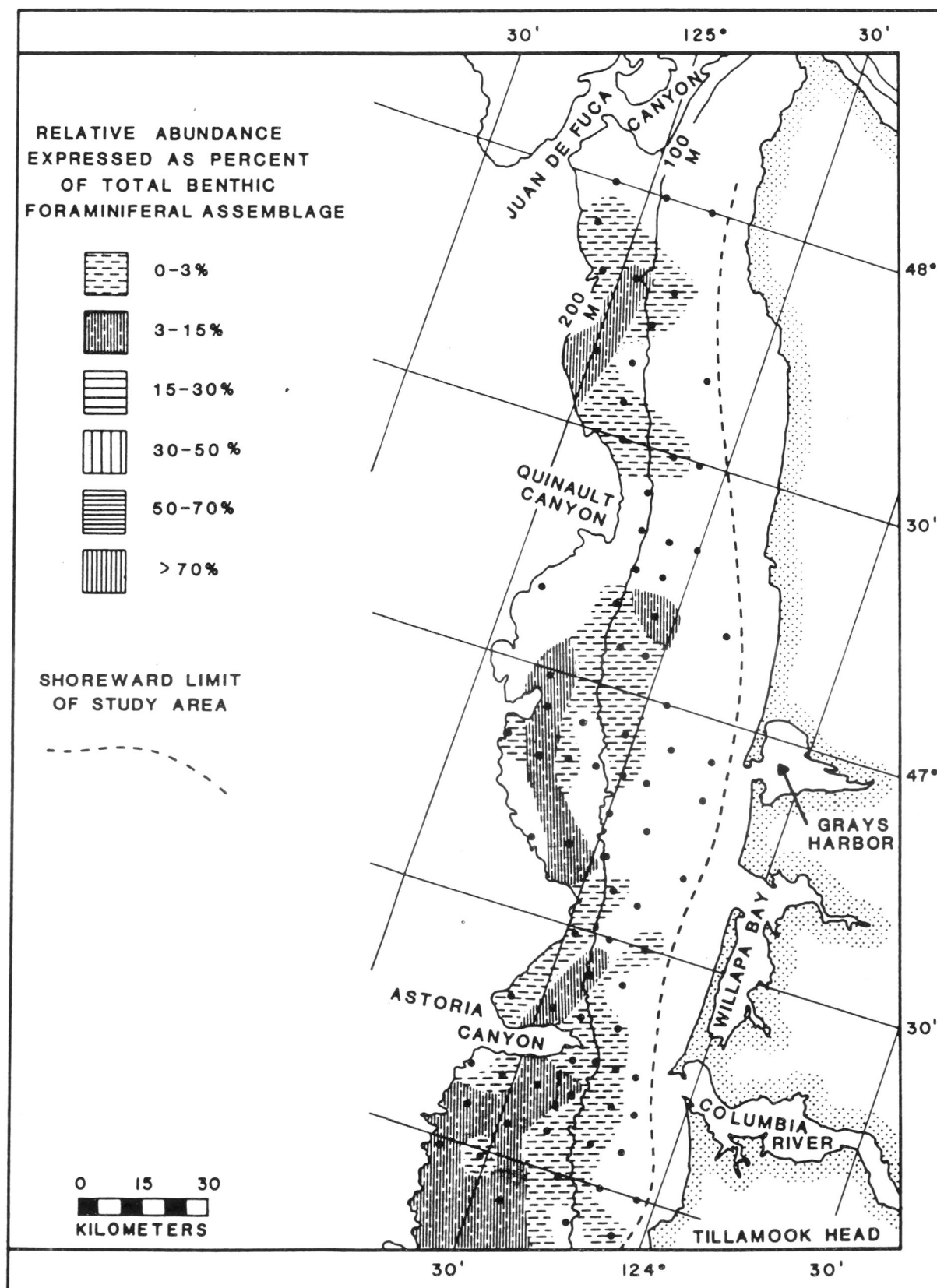


Figure 12A.

Distribution pattern of *Florilus auriculus*

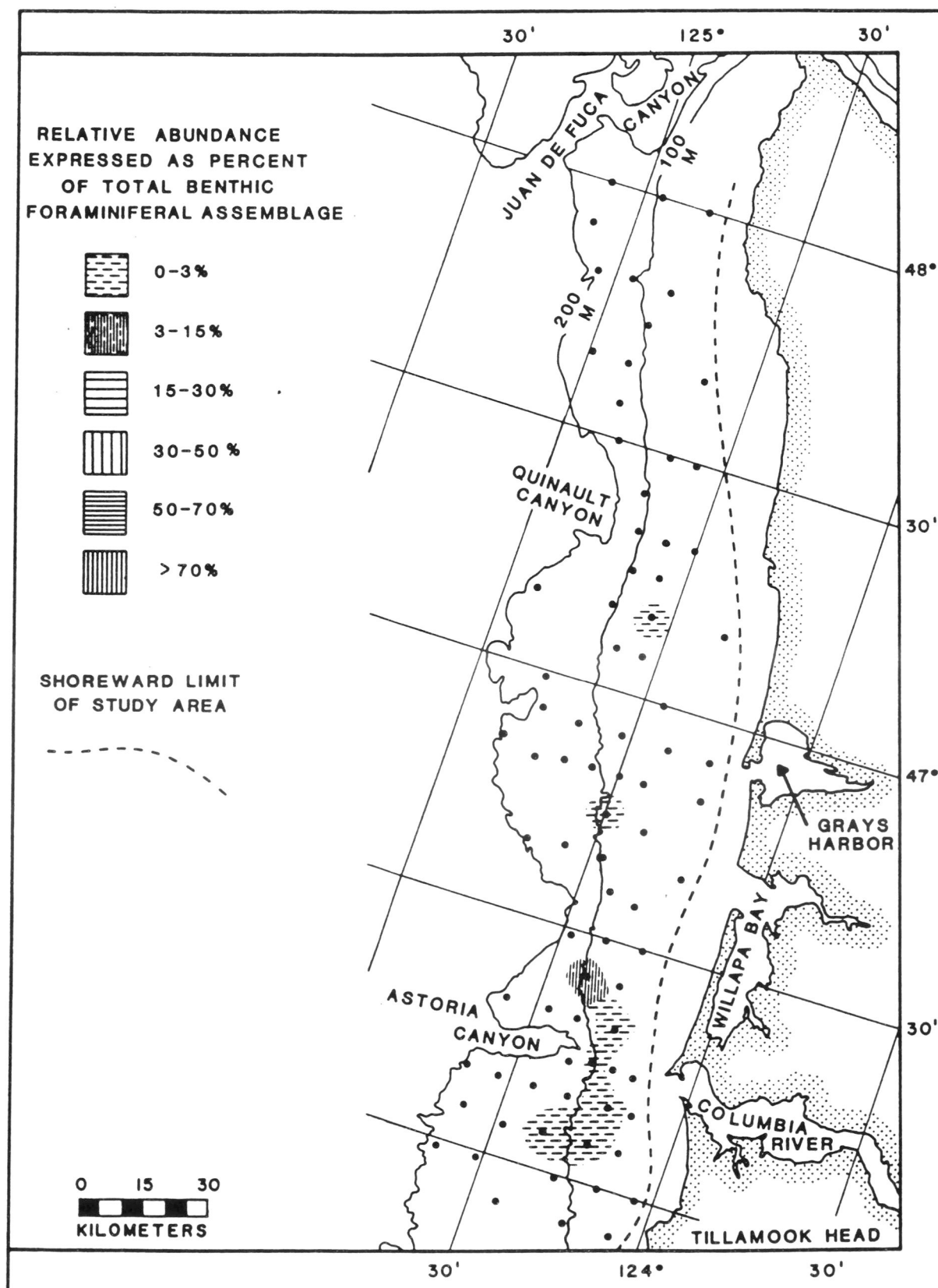


Figure 13A.

Distribution pattern of Florilus basispinatus

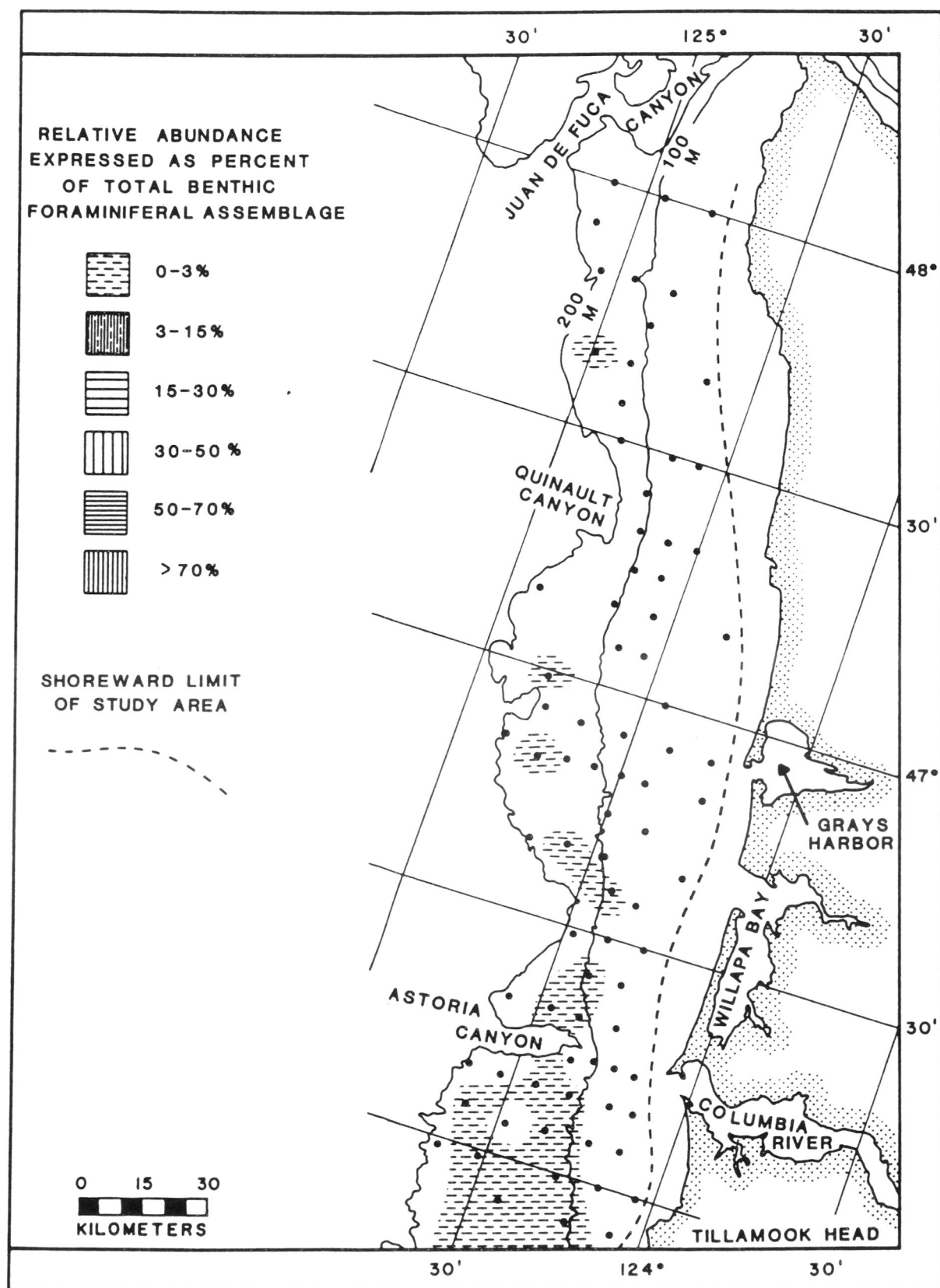


Figure 14A.

Distribution pattern of *Florilus labradoricus*

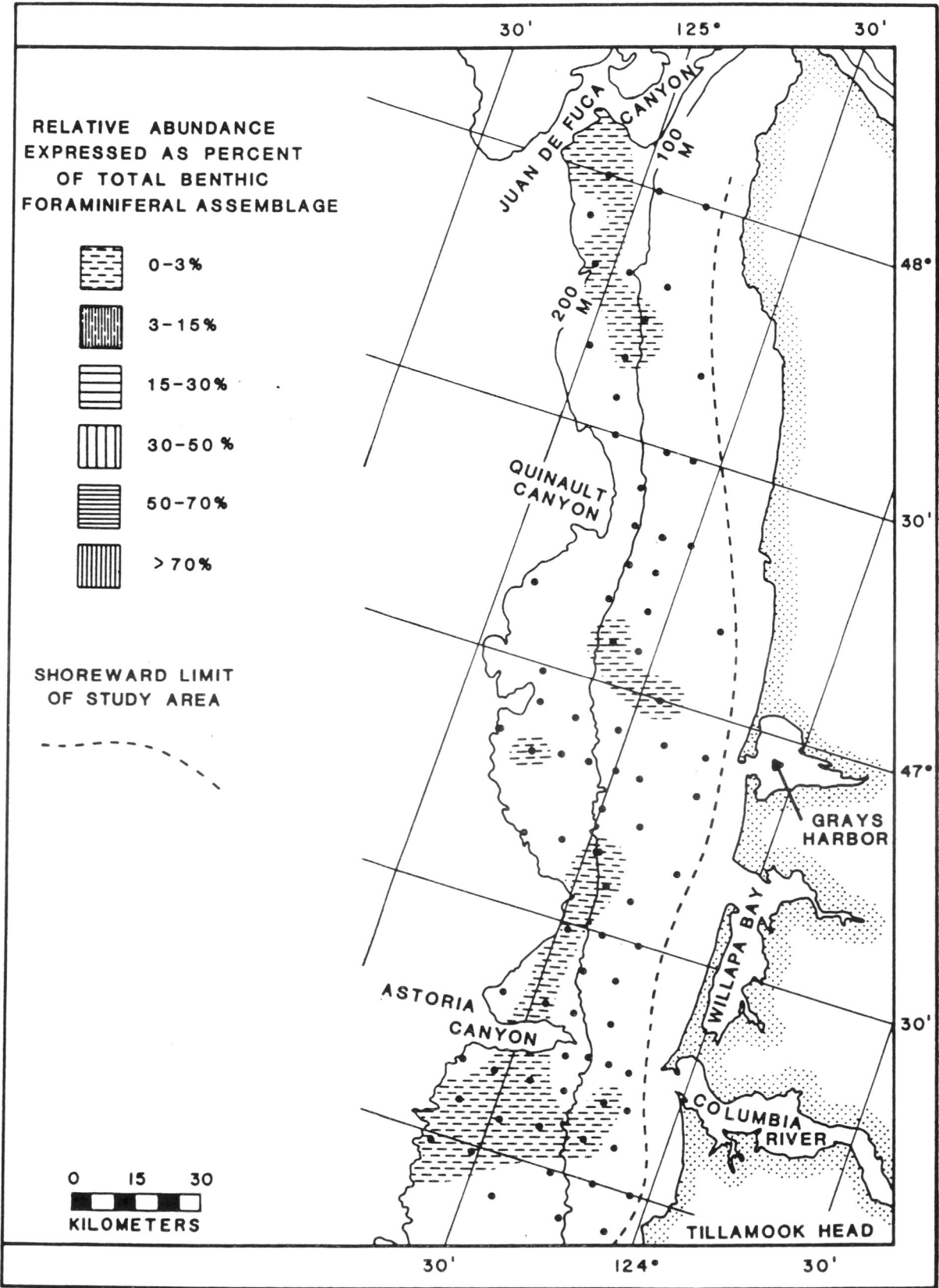


Figure 15A.

Distribution pattern of *Gaudryina arenaria*

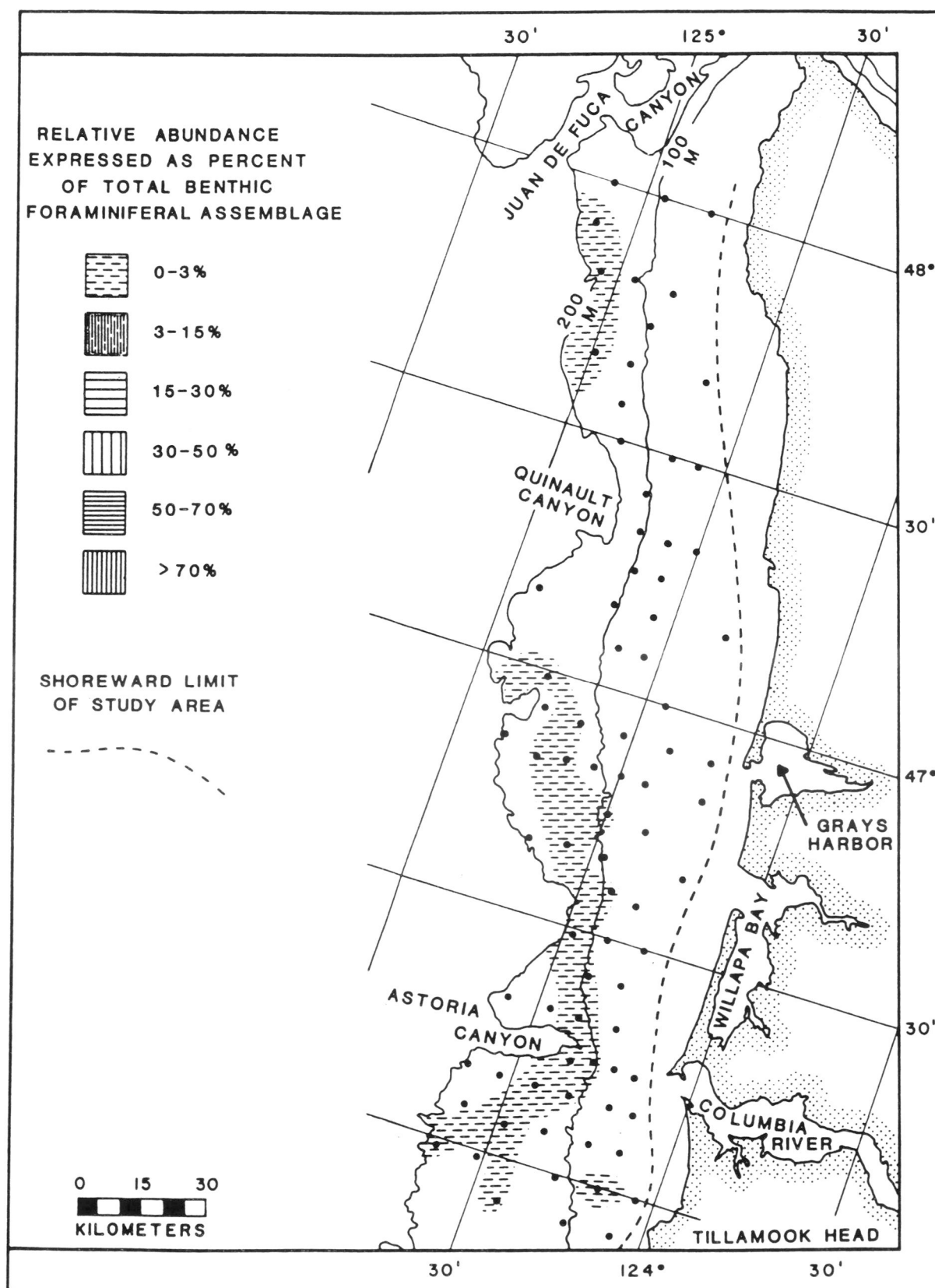


Figure 16A.

Distribution pattern of Globobulimina auriculata

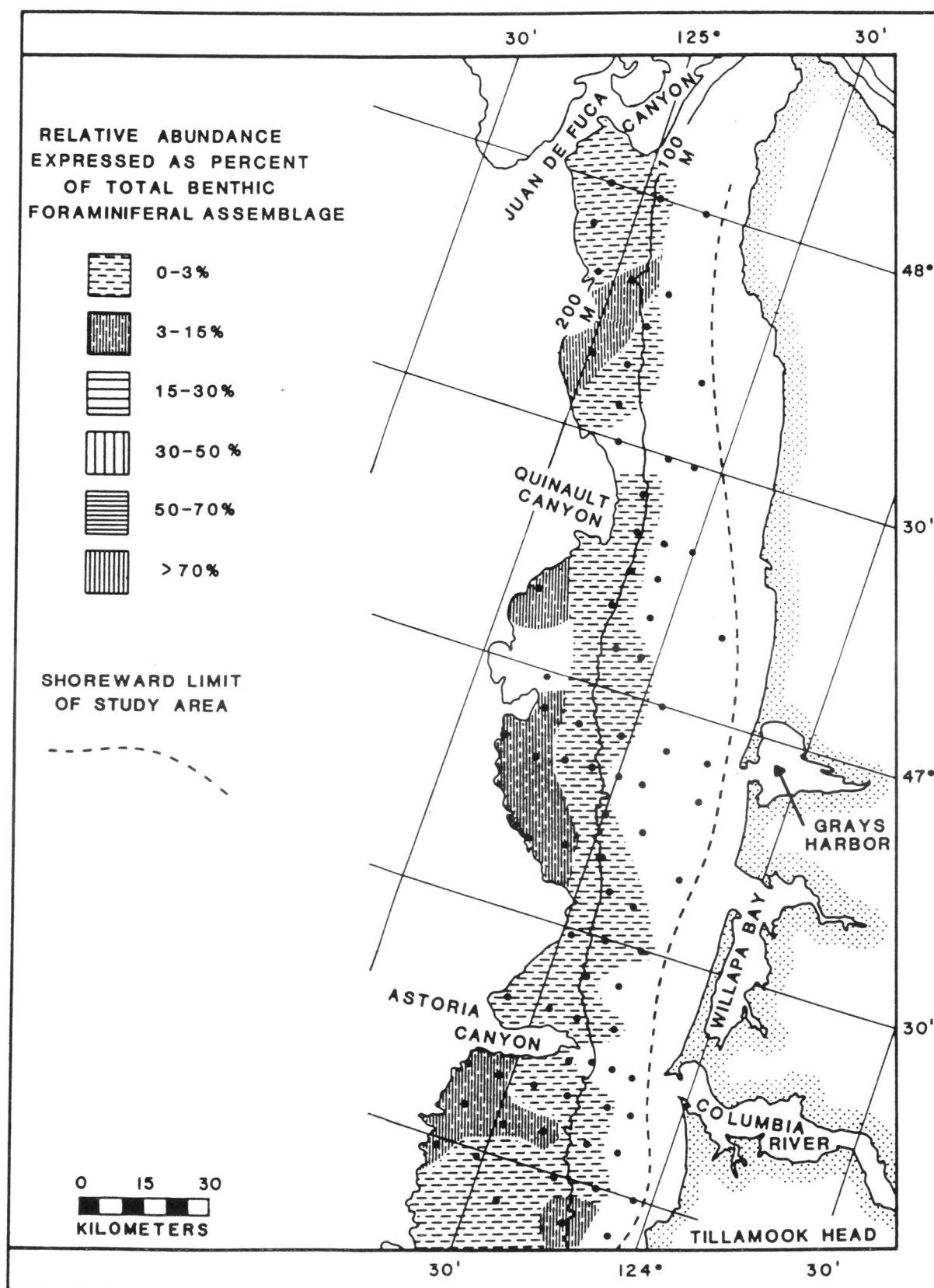


Figure 17A.

Distribution pattern of Haplophragmoides bradyi

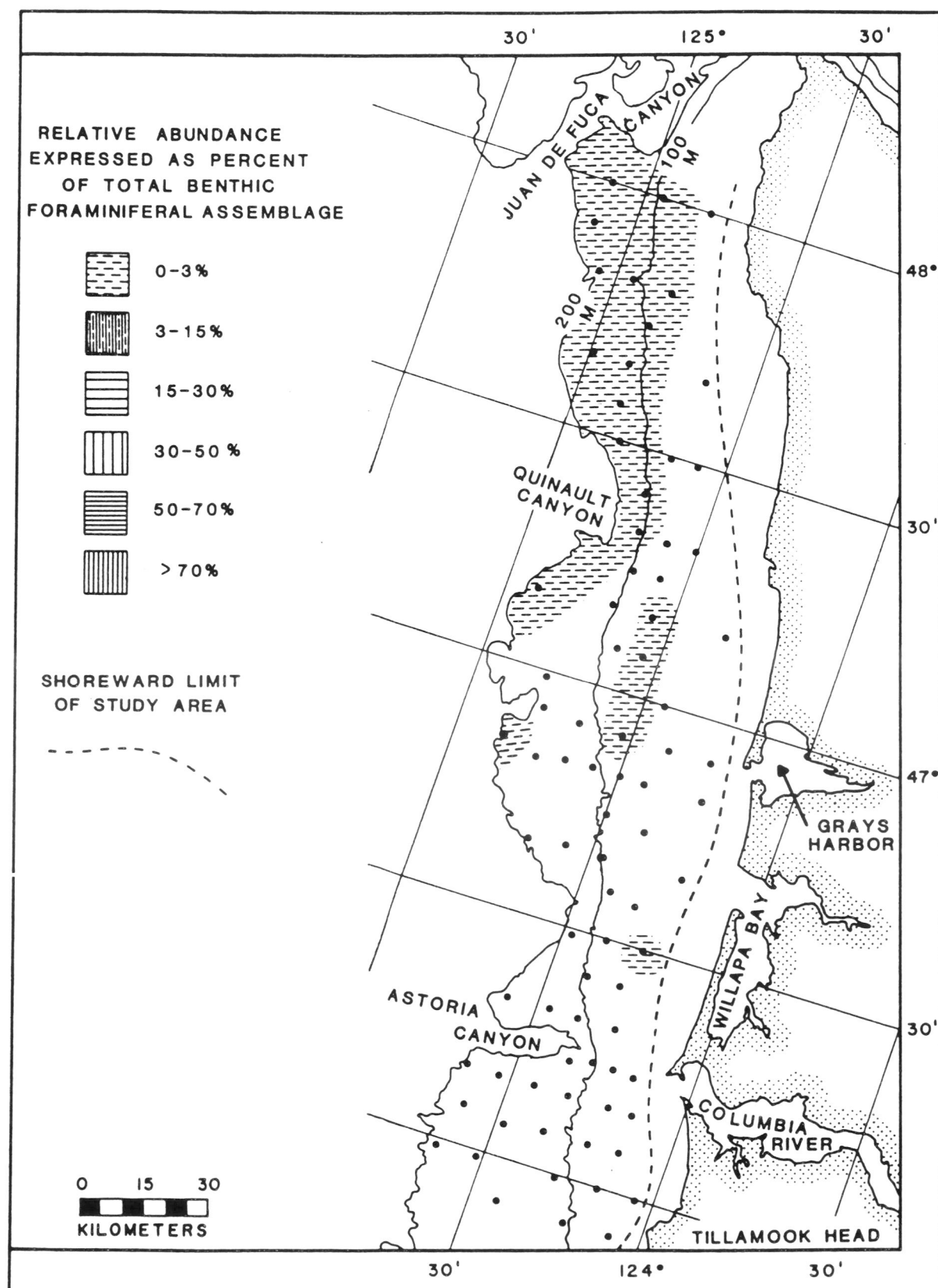


Figure 18A.

Distribution pattern of *Lagenammina atlantica*

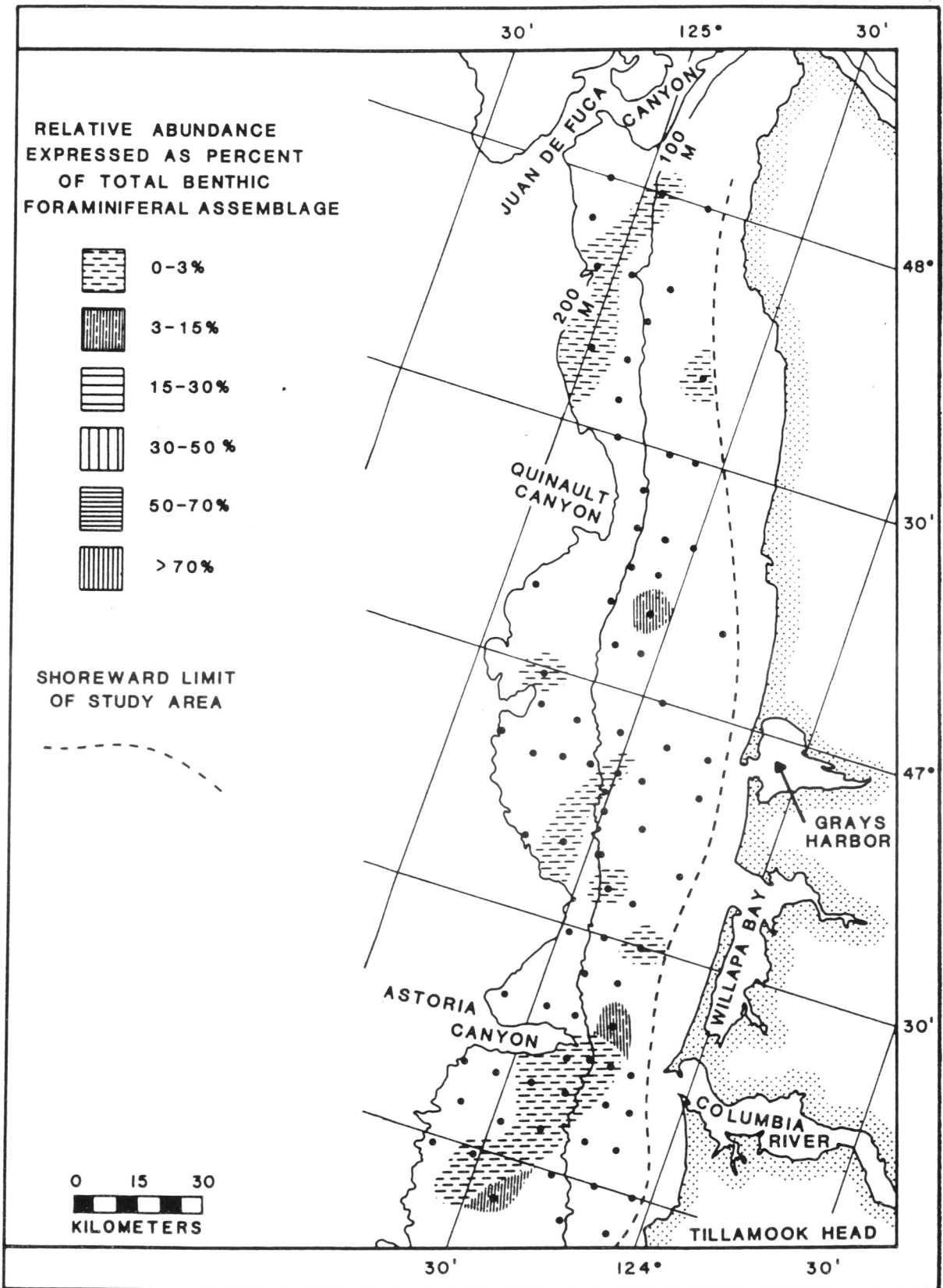


Figure 19A.

Distribution pattern of Nonionella miocenica

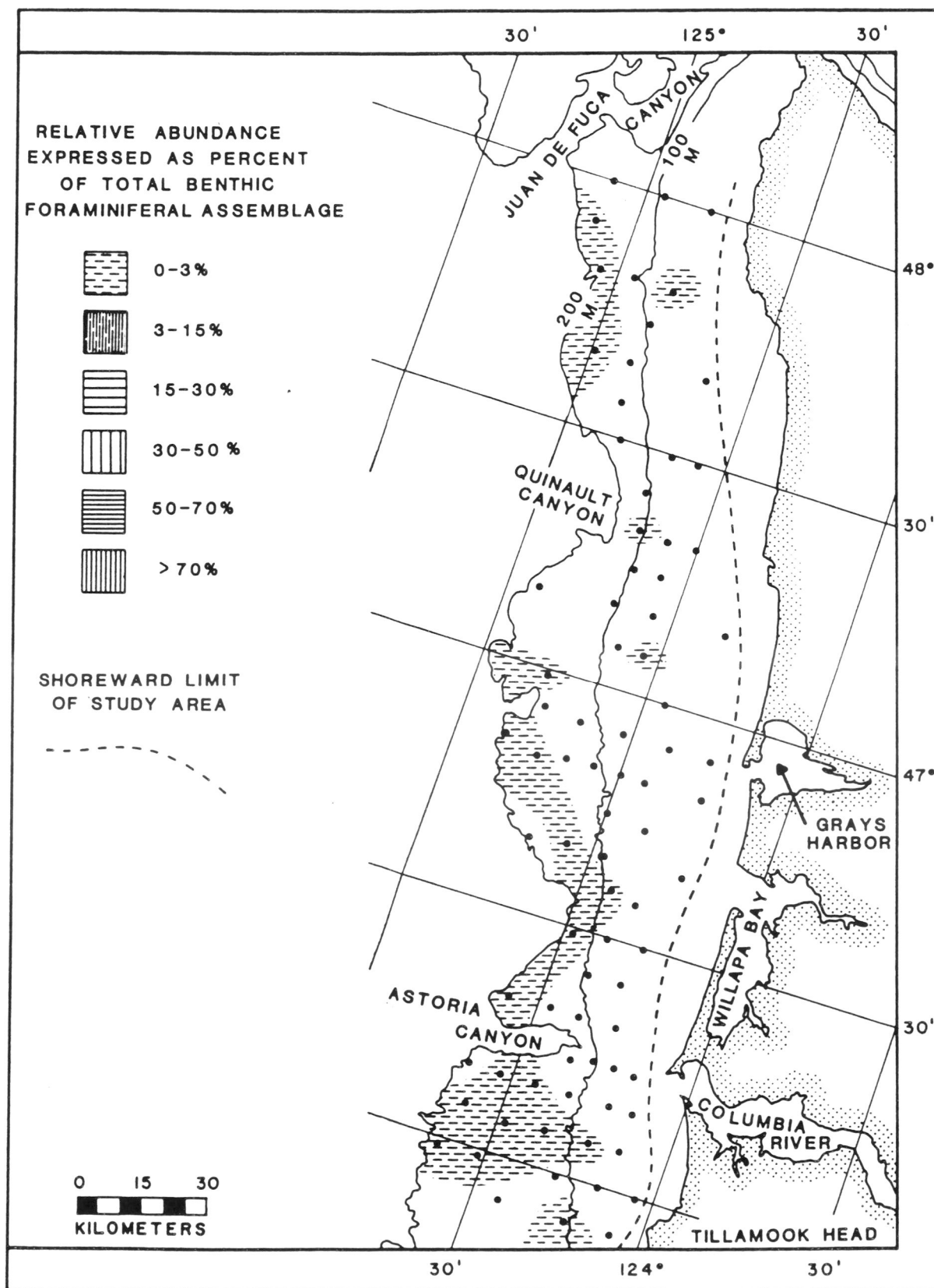


Figure 20A.

Distribution pattern of *Pullenia salisburyi*

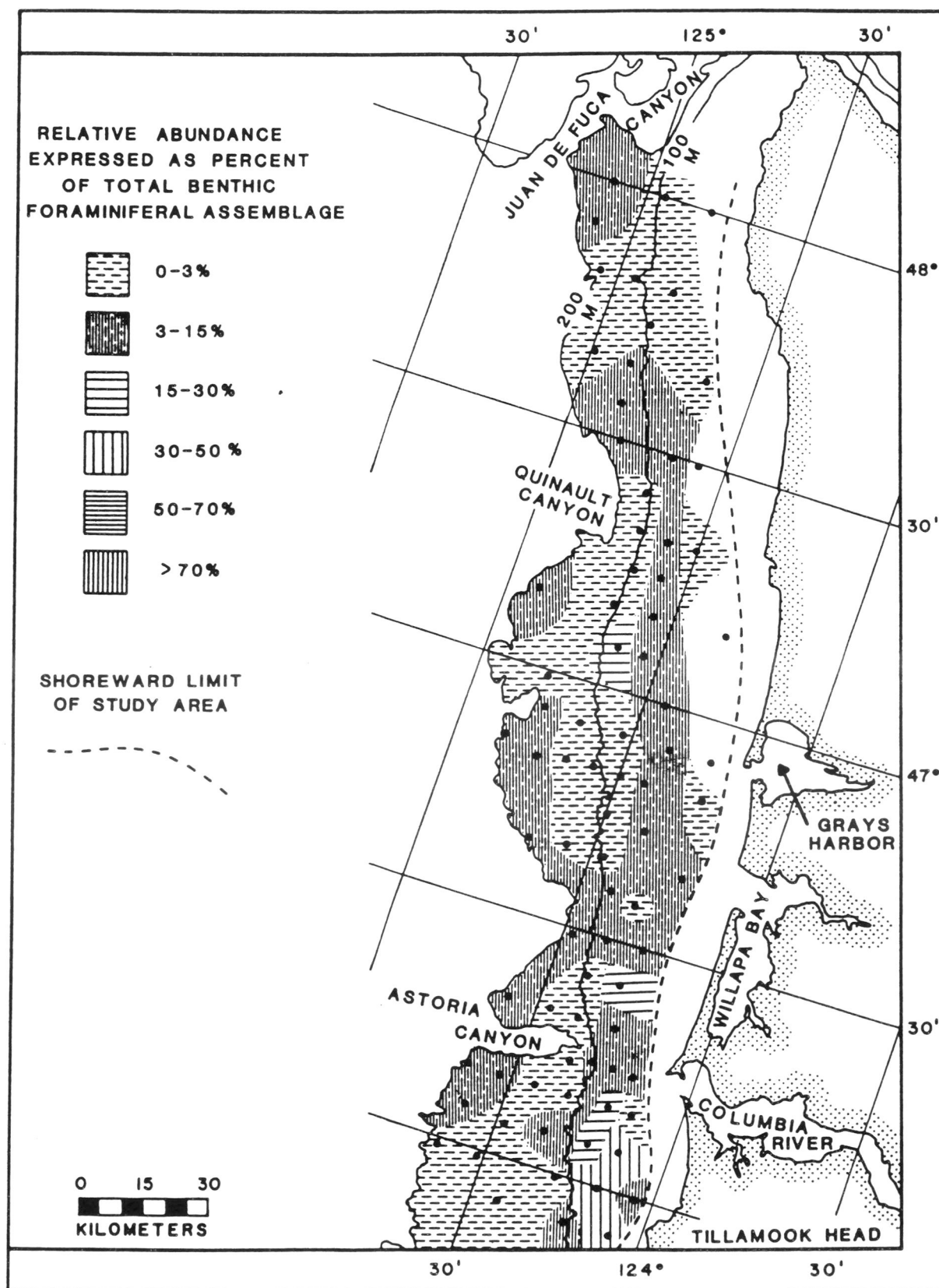


Figure 21A.

Distribution pattern of Recurvoides turbinatus

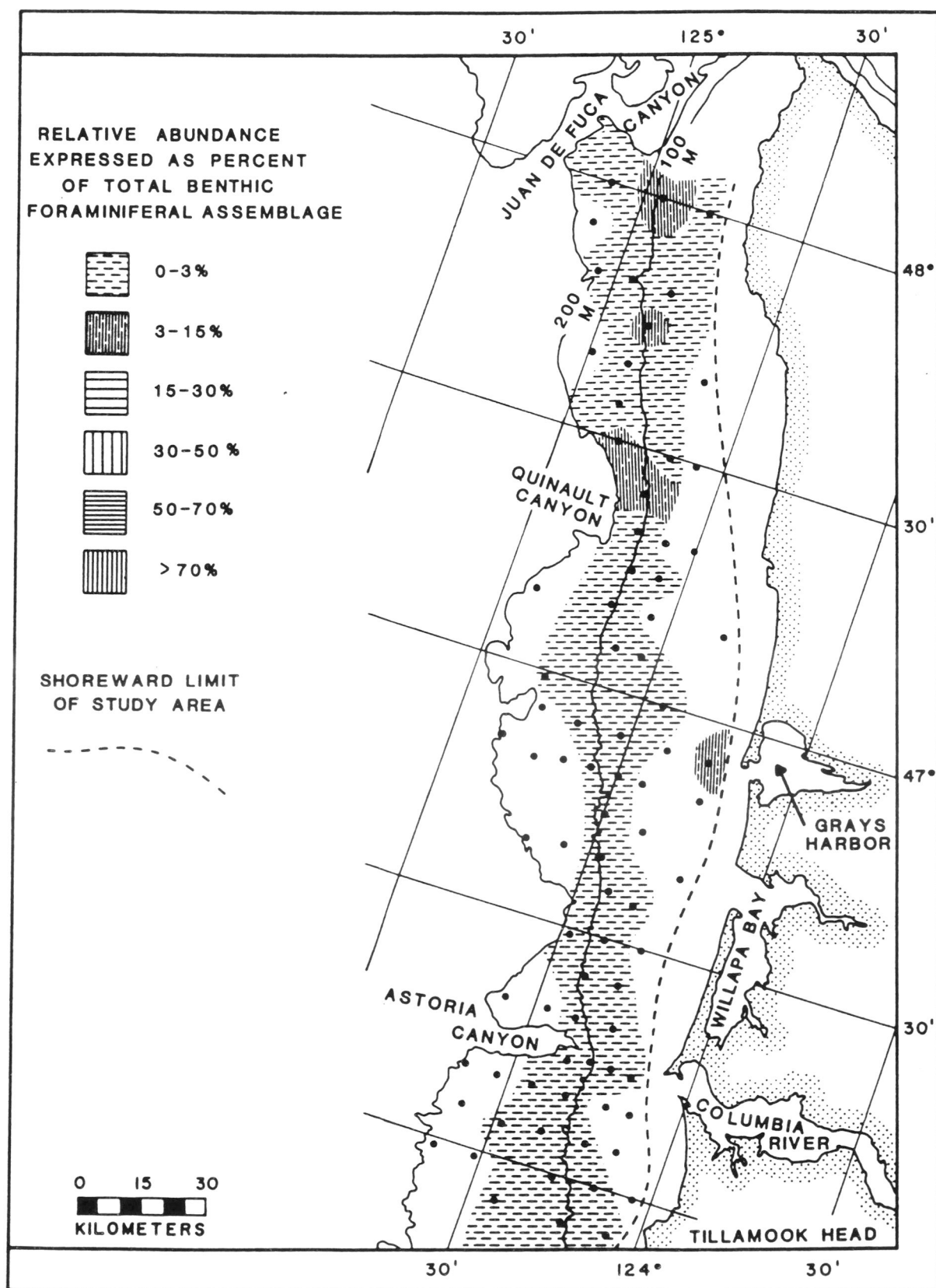


Figure 22A.

Distribution pattern of *Reophax arctica*

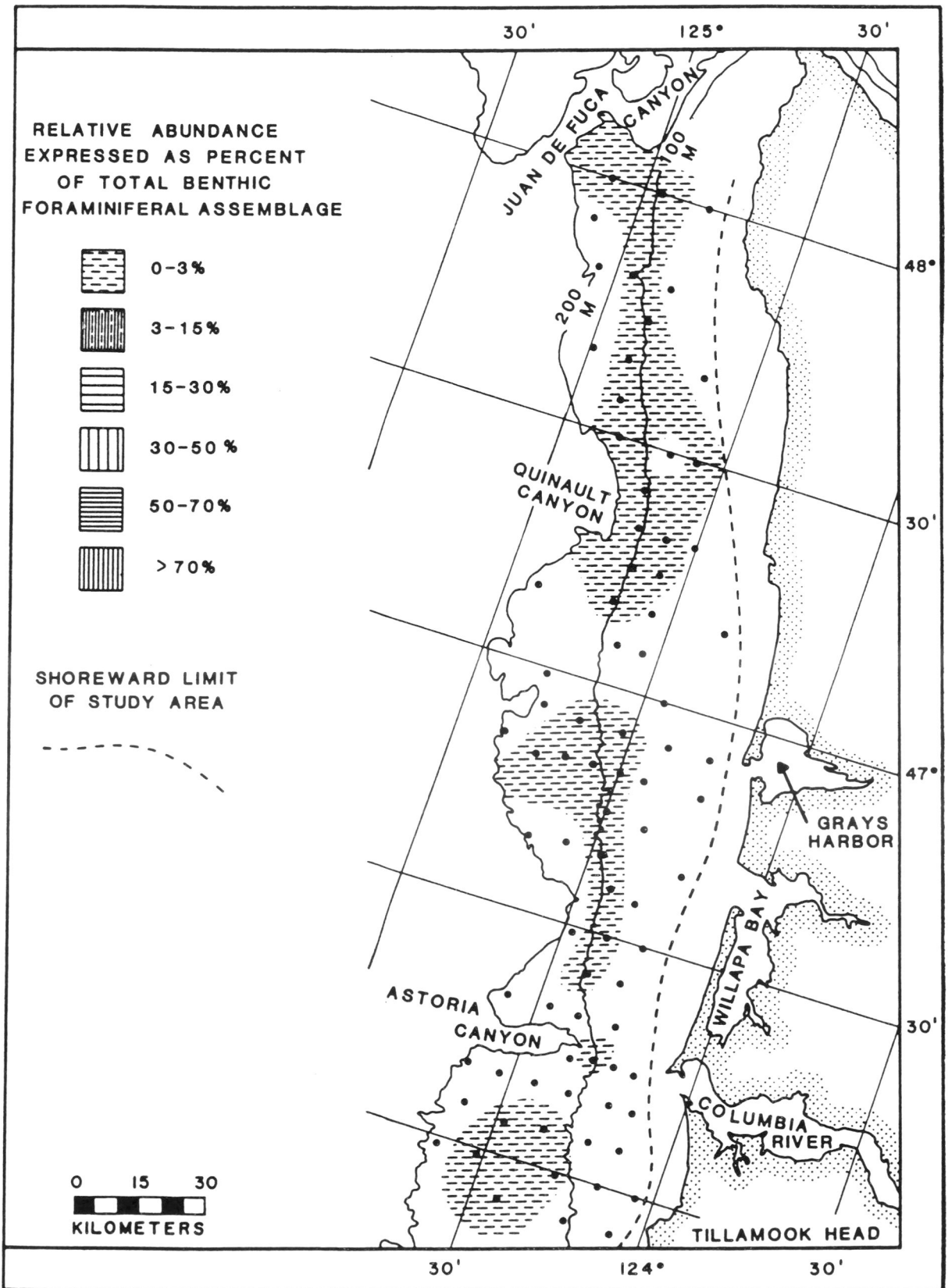


Figure 23A.

Distribution pattern of Reophax scorpiurus

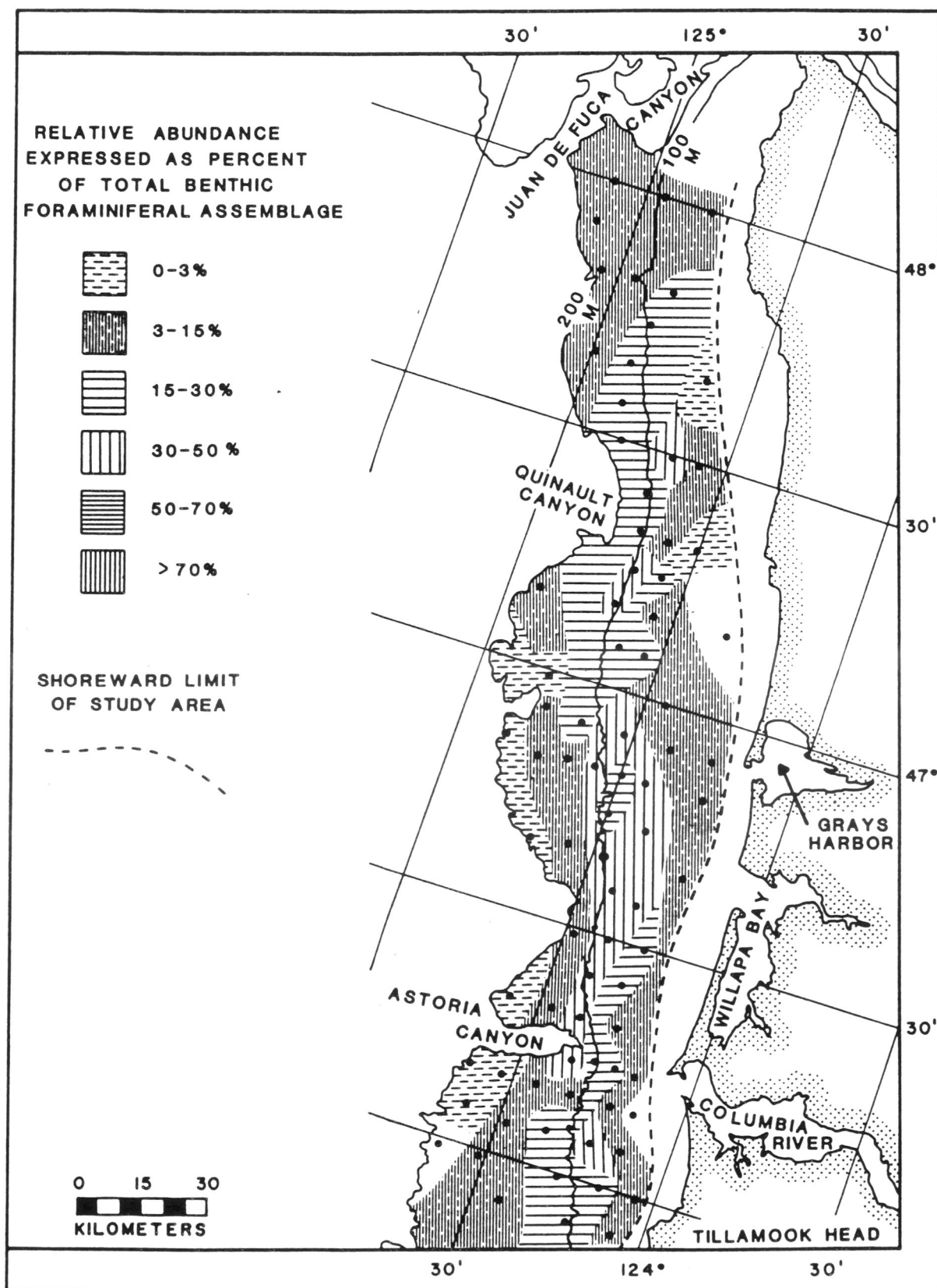


Figure 24A.

Distribution pattern of *Spiroplectammina biformis*

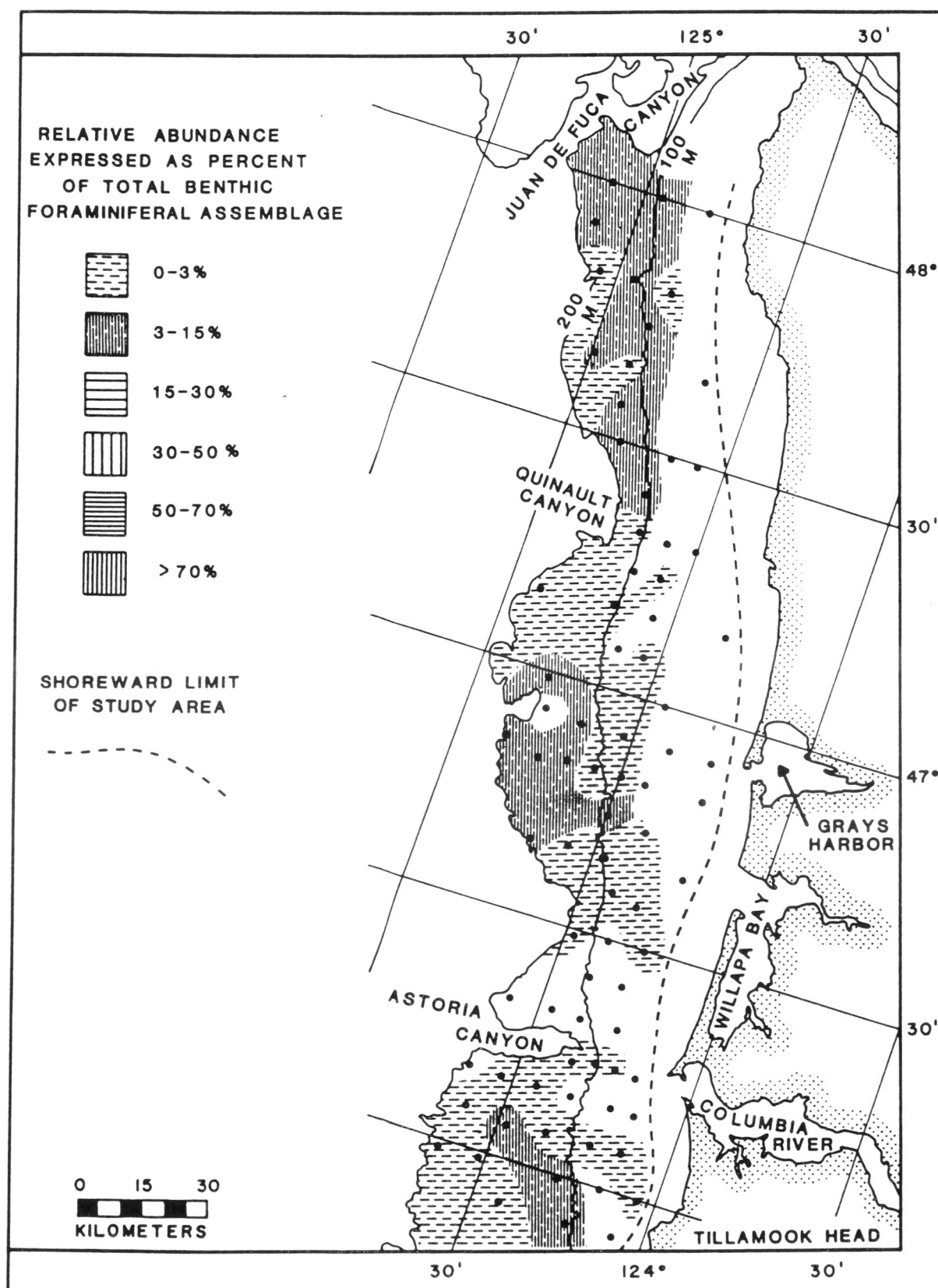


Figure 25A.

Distribution pattern of *Textularia earlandi*

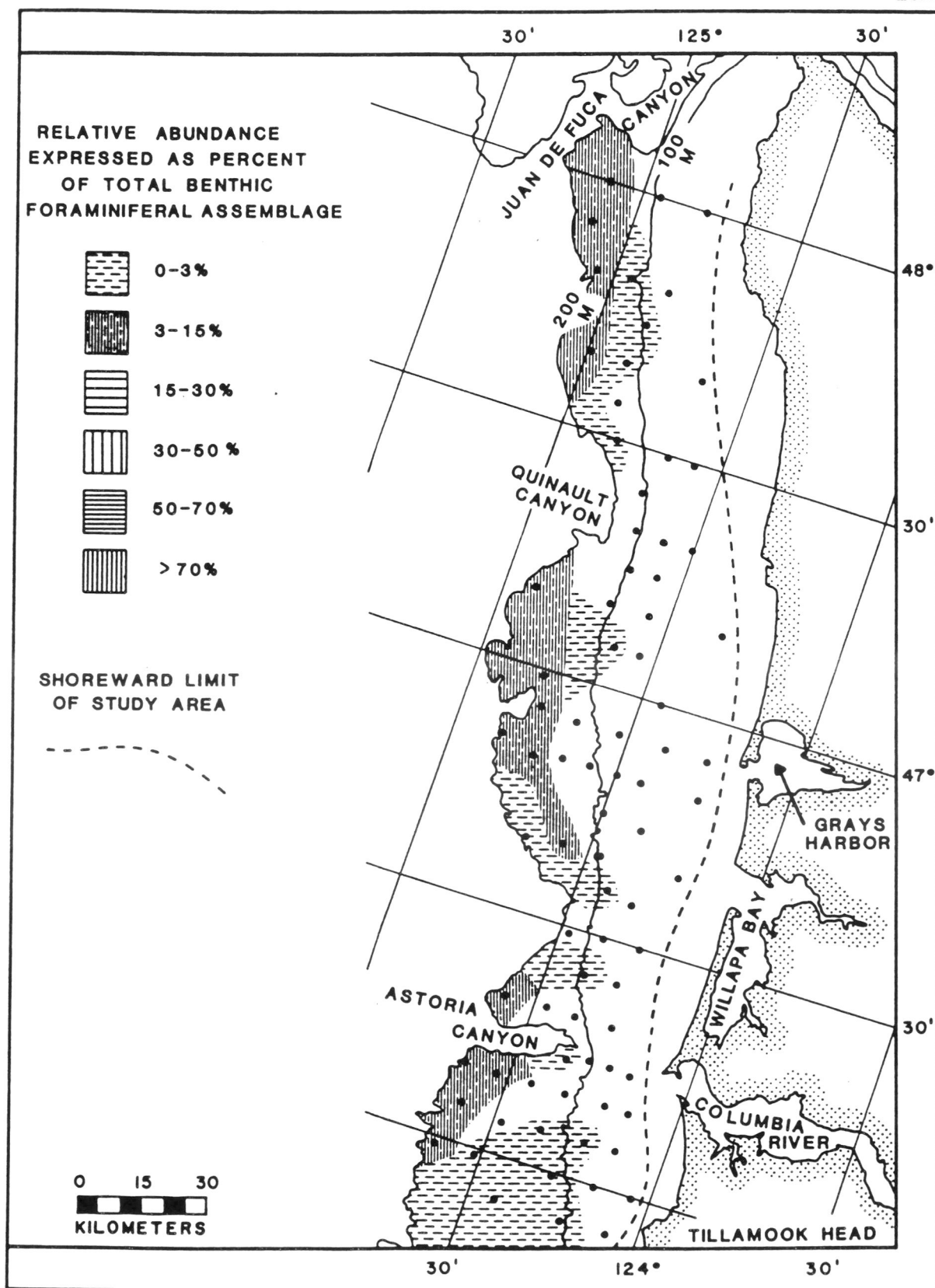


Figure 26A.

Distribution pattern of *Trifarina angulosa*

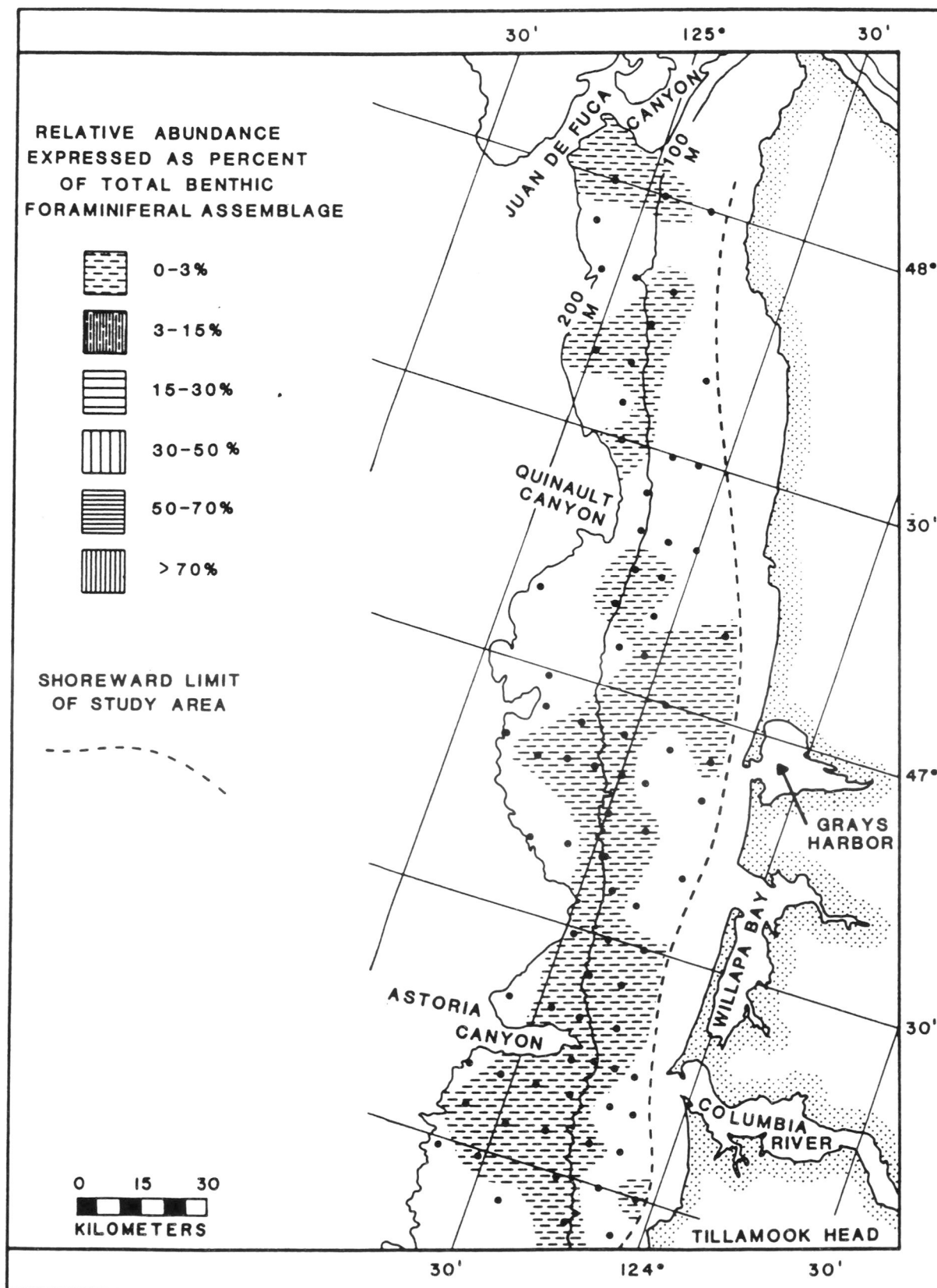


Figure 27A.

Distribution pattern of Trochammina kelletiae

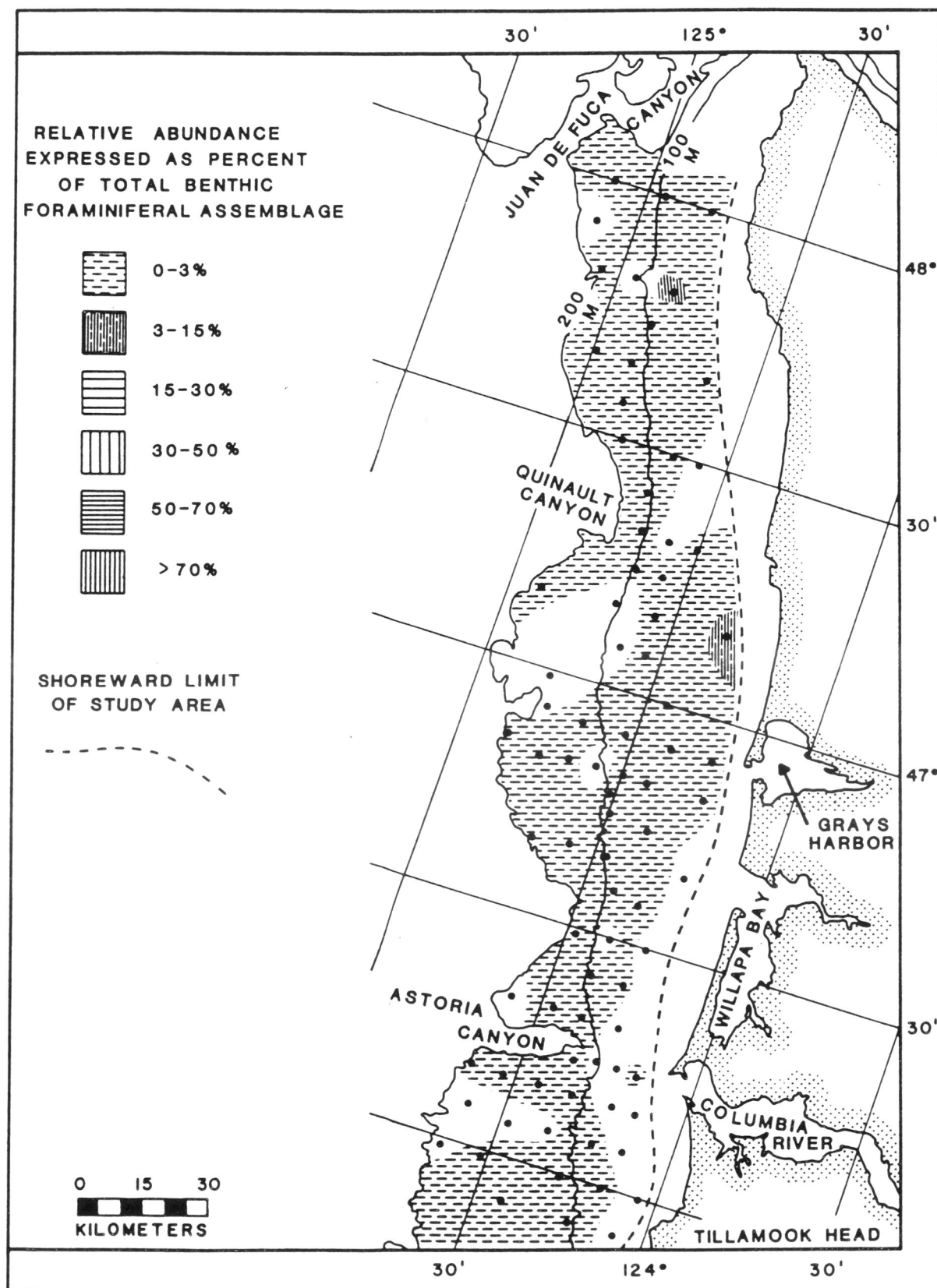


Figure 28A.

Distribution pattern of *Trochammina nitida*

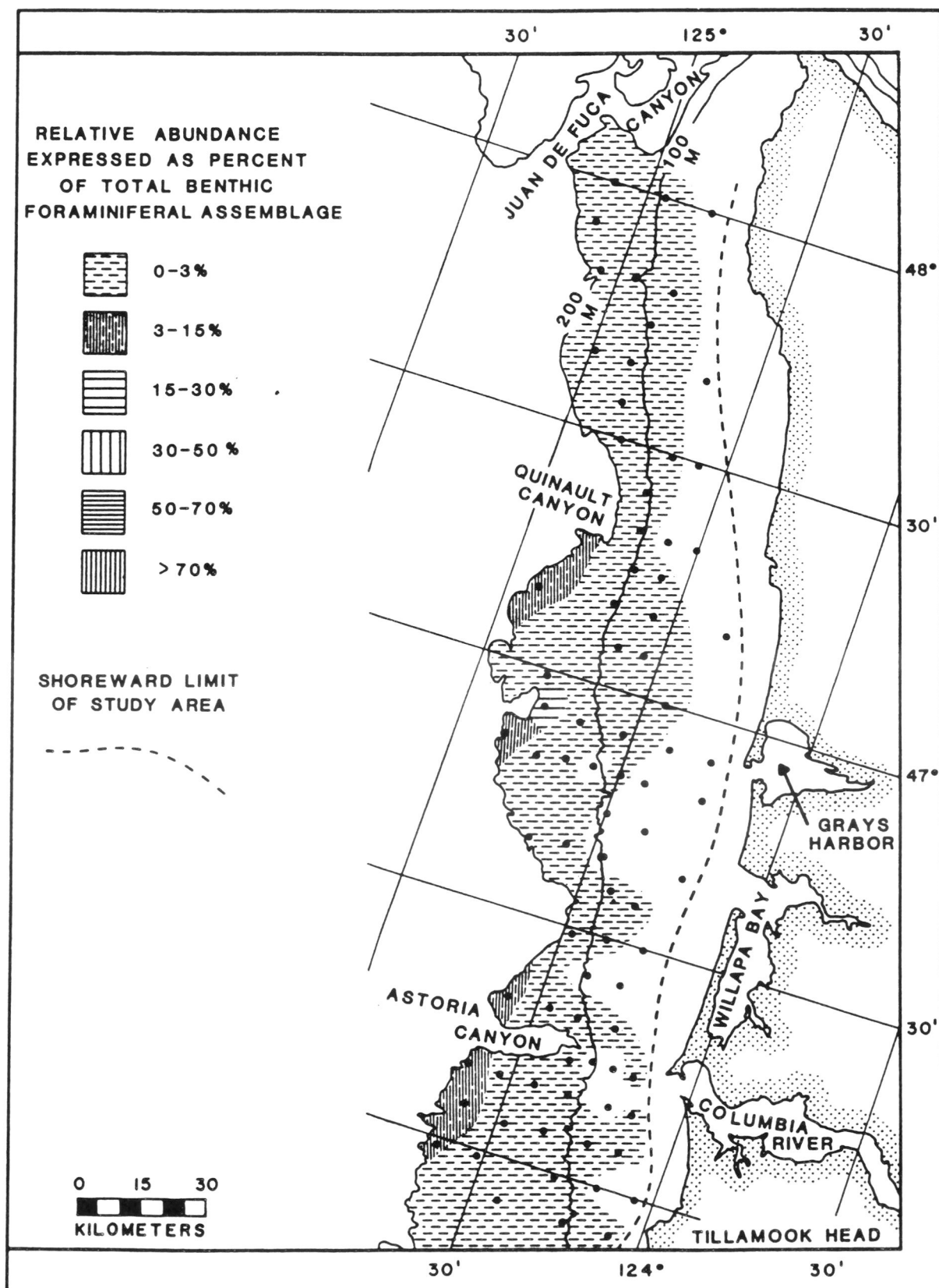


Figure 29A.

Distribution pattern of *Trochammina pacifica*

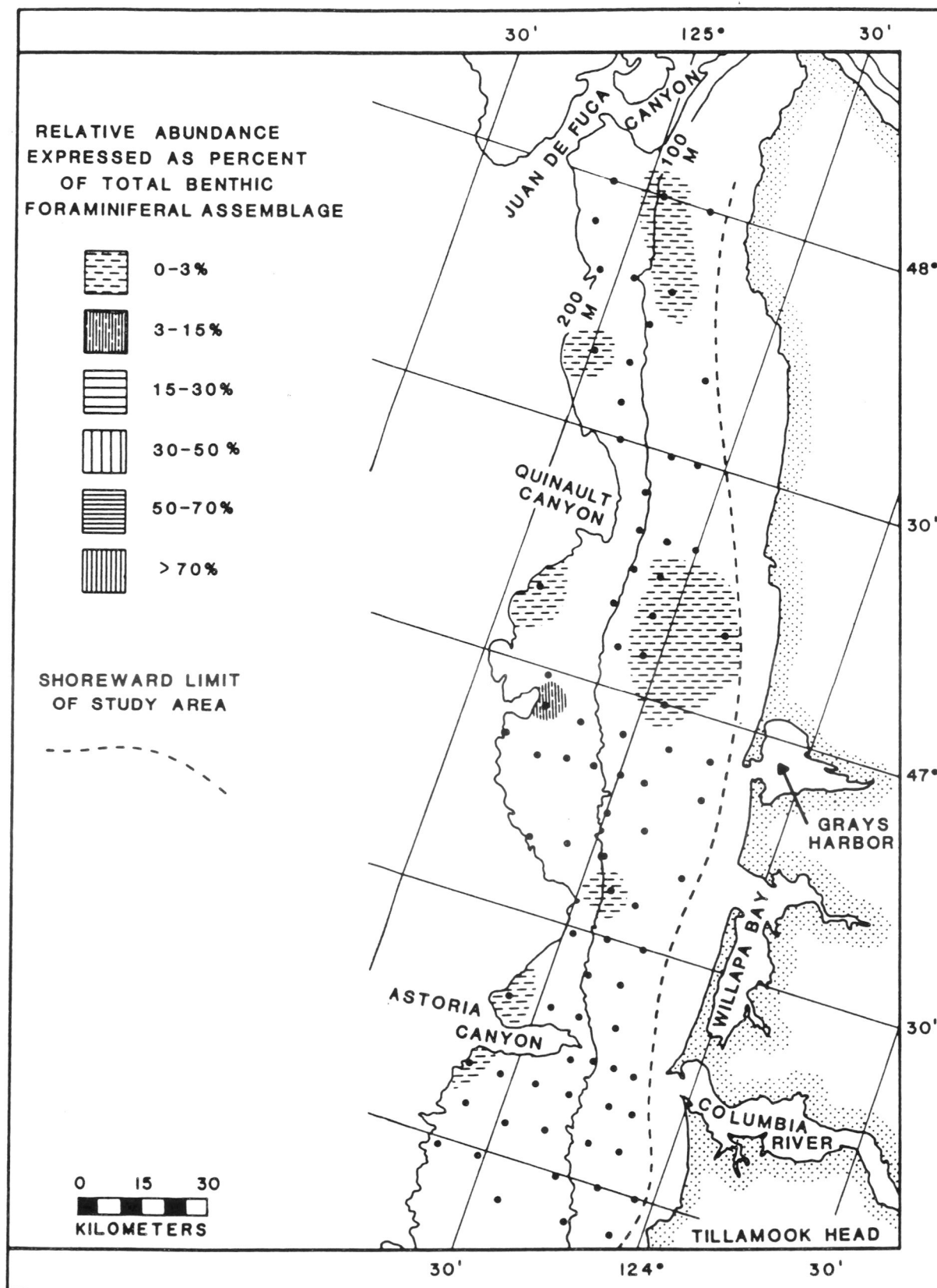


Figure 30A.

Distribution pattern of *Trochammina rotaliformis*

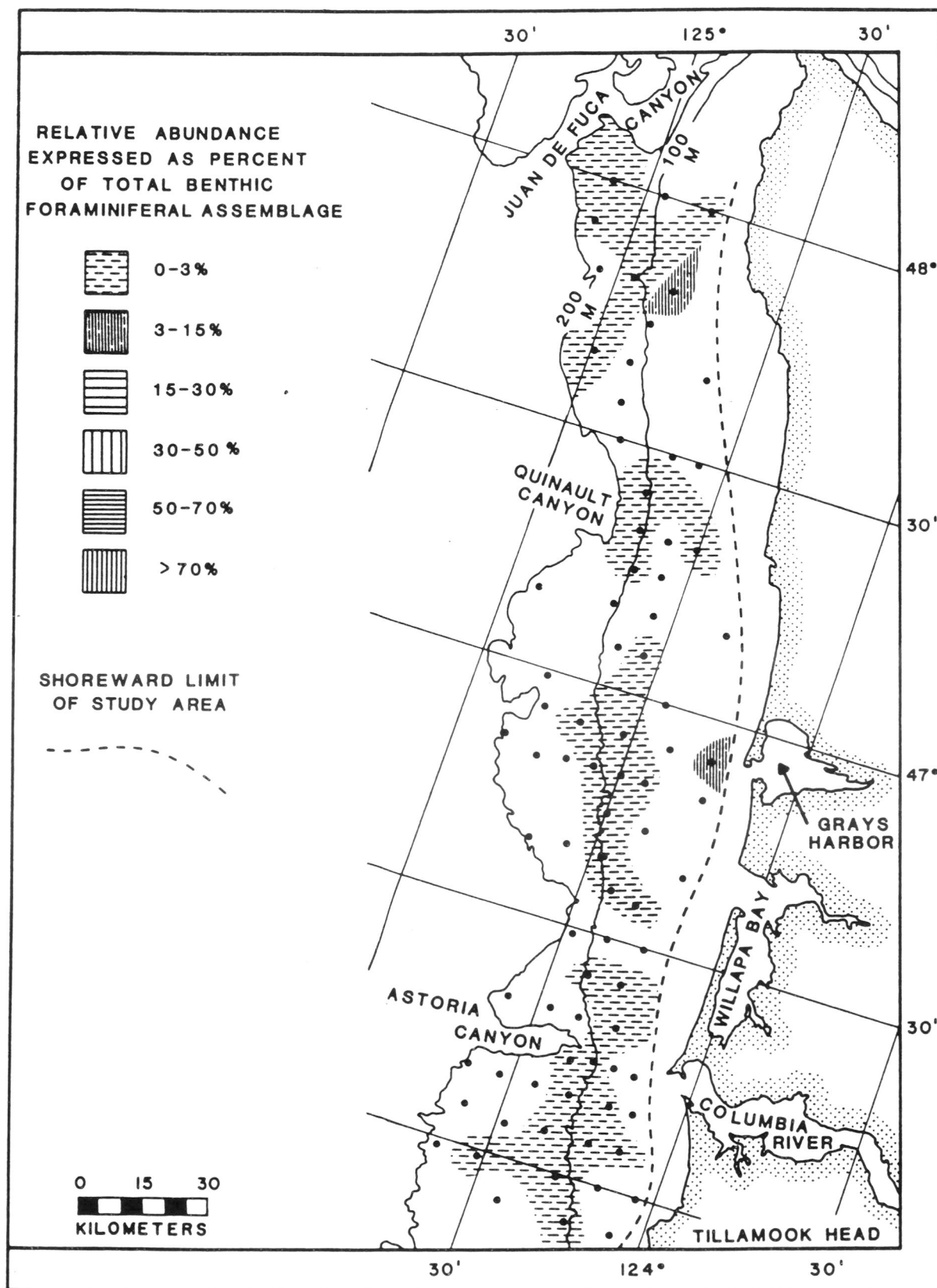


Figure 31A.

Distribution pattern of *Trochammina squamata*

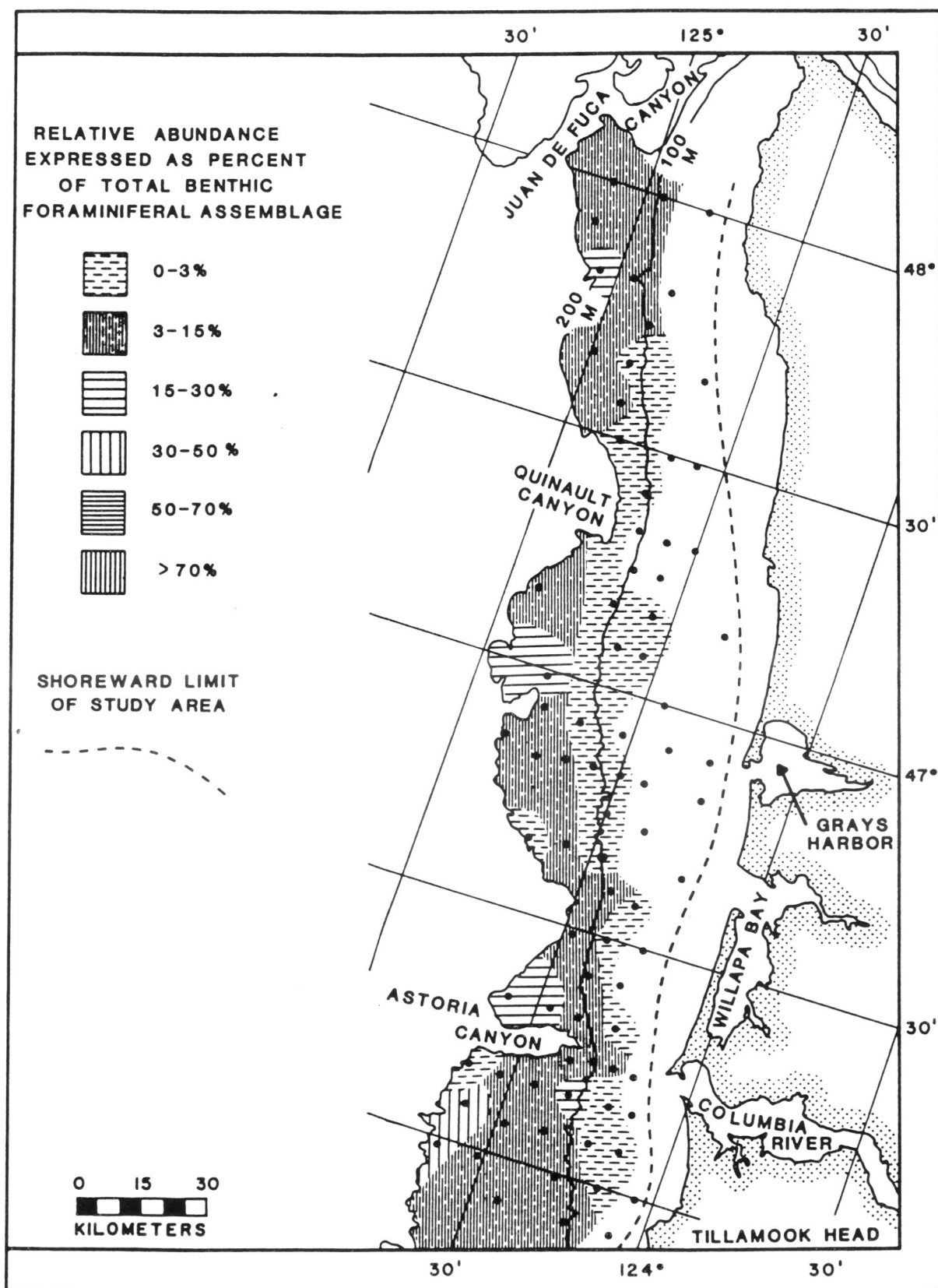


Figure 32A.

Distribution pattern of *Uvigerina juncea*

APPENDIX 3

APPLE BASIC PROGRAM FOR SCHEFFE'S METHOD
SPECIES-TO-SPECIES COMPARISON

```

50 DIM N$(150)
60 DIM Y(150)
70 DIM T2(150)
80 DIM AV(150)
90 DIM V(150)
95 PR# 3
100 INPUT "NUMBER OF GROUPS OF DATA? ";K
107 NN = 0
108 SM = 0
109 TT = 0
110 FOR X = 1 TO K
114 T2 = 0
115 T = 0
116 A$ = "Q"
120 PRINT
130 PRINT "INPUT NAME OF DATA GROUP ";X
131 INPUT "? ";N$(X)
140 PRINT "ENTER -1 AFTER LAST SAMPLE VALUE IS ENTERED"
145 Y(X) = 0
150 PRINT "GIVE VALUES FOR EACH SAMPLE"
180 INPUT "? ";V(Z)
181 IF V(Z) = - 1 THEN 3000
185 T = T + V(Z)
186 T2 = T2 + V(Z) * V(Z)
187 T2(X) = T2
188 NN = NN + 1
189 Y(X) = Y(X) + 1
190 GOTO 180
195 TT = TT + T2(X)
200 AV(X) = T / Y(X)
204 PR# 1
205 SM = SM + AV(X) * T
206 PRINT
207 PRINT "DATA FOR GROUP ";N$(X)
210 PRINT "MEAN = ";AV(X)
211 PRINT "NUMBER OF DATA ENTRIES = ";Y(X)
215 PR# 0
216 PR# 3
220 NEXT X
230 SS = TT - SM
240 SW2 = SS / (NN - K)
245 PR# 1
246 PRINT "-----"
      PRINT "-----"
247 PRINT "DATA FOR ALL GROUPS"
248 PRINT
250 PRINT "SUM OF SQUARES = ";SS
260 PRINT "DEGREES FREEDOM WITHIN = ";NN - K
270 PRINT "VARIANCE ESTIMATE = ";SW2
271 NU = K - 1
272 DE = NN - K
273 PRINT "-----"
      PRINT "-----"

```



```

274 PR# 0
275 PR# 3
280 PRINT "CONSULT A TABLE OF F VALUES, (IN THE BACK OF MOST STATISTICS
      BOOKS).
281 PRINT "DEGREES OF FREEDOM FOR GREATER MEAN SQUARE, (ALSO CALLED BEET
      WEEN"
282 PRINT "GROUP DEGREES FREEDOM, DF1, OR NUMERATOR = ";NU
283 PRINT
284 PRINT "DEGREES OF FREEDOM FOR LESSER MEAN SQUARE, (ALSO CALLED WITHI
      N"
286 PRINT "GROUP DEGREES FREEDOM, DF2, OR DENOMINATOR = ";DE
290 PRINT
300 INPUT "AT WHAT SIGNIFICANCE LEVEL DO YOU WISH TO WORK? ";S$
310 INPUT "WHAT IS THE CRITICAL VALUE OF F AT THAT LEVEL? ";FF
320 FP = FF * NU
400 REM FIND F RATIO, SS = SUM OF SQUARES W/IN Y = N(j)
450 B = 1
455 C = 2
456 H = C
460 PR# 1
489 PRINT
490 PRINT "GROUPS COMPARED";: HTAB (27): PRINT "SIG. DIFFERENCE AT ";S$;
      " LEVEL          F RATIO"
491 PRINT "-----"
      "-----"
500 FOR D = C TO K
550 F = (AV(B) - AV(C)) * (AV(B) - AV(C)) / (SW2 / Y(B) + SW2 / Y(C))
560 IF F > = FP THEN SC$ = "YES"
570 IF F < FP THEN SC$ = "NO"
580 PRINT B;") ";N$(B);: HTAB (35): PRINT SC$;"
      ";F
590 PRINT C;") ";N$(C)
600 PRINT "-----"
      "-----"
870 IF D = K THEN 890
875 C = C + 1
880 NEXT D
890 IF K - B = 1 THEN 2000
900 B = B + 1
910 C = H + 1
911 H = H + 1
920 GOTO 500
2000 PR# 0
2100 PR# 3
2200 END
3000 INPUT "CHECK DATA; DO YOU WISH TO RE-ENTER? (Y/N) ";A$
3010 IF A$ = "Y" THEN GOTO 3099
3020 IF A$ = "N" THEN GOTO 195
3025 PRINT
3030 PRINT "Y OR N"
3040 GOTO 3000
3099 PRINT
3100 PRINT "RE-ENTER CORRECT DATA FOR GROUP ";N$(X)
3105 A$ = "Q"
3110 T2 = 0
3115 NN = NN - Y(X)
3117 Y(X) = 0
3120 T = 0
3130 PRINT
3140 GOTO 140

```

APPENDIX 4

TABLE OF NUMERICAL VALUES FOR VARIOUS MAP PATTERNS

Explanation:

N = Total number of specimens counted

S = Number of species identified

H(S) = Shannon-Weiner Information function (expression of diversity)

E = Equitability

SPEC/GM = Estimated number of specimens per gram of unwashed sediment

%AGGLUT = Percentage of the sample composed of agglutinated specimens

(SPEC/GM and %AGGLUT are figured only for stations represented on the distribution maps.)

SAMPLE	N	S	H(S)	E	SPEC/GM	%AGGLUT
WA-1B	220	9	1.35	0.43	35	98.7
WA-2A	54	6	0.52	0.28	9	100.0
WA-2B	75	2	0.07	0.54	--	---
WA-3	91	15	1.99	0.49	15	77.0
WA-4	412	25	1.86	0.26	72	71.8
WA-5	411	32	2.26	0.30	60+	57.8
WA-6	336	18	1.97	0.40	52+	77.7
WA-7	321	15	1.75	0.38	56	98.1
WA-8	376	26	2.47	0.46	132	70.2
WA-9	315	19	2.02	0.40	50+	56.9
WA-10	558	21	1.50	0.21	196	91.4
WA-11	336	19	1.59	0.26	106+	36.3
WA-13	29	4	0.86	0.59	--	---
WA-14	309	15	1.49	0.30	54	96.5
WA-15	329	11	1.20	0.30	26	86.1
WA-16	518	24	2.03	0.32	46	67.5
WA-17	427	12	1.45	0.36	34	97.0
WA-18B	238	22	2.18	0.40	38	54.6
WA-19C	325	18	1.36	0.22	52+	93.4
WA-21	75	5	0.62	0.37	6	98.7
WA-22SH	57	6	0.66	0.32	--	---
WA-22	179	10	0.48	0.16	14	98.0
WA-23A	19	3	0.41	0.50	--	---
WA-24A	92	6	1.09	0.50	4	100.0
WA-25	245	18	1.54	0.26	39	93.0
WA-26C	353	16	1.41	0.26	56	94.8
WA-27	332	19	1.68	0.28	53	91.5
WA-28A	654	26	2.25	0.36	105	70.6
WA-28C	747	22	1.61	0.23	--	---
WA-29B	402	21	2.14	0.41	129	91.4
WA-30	56	7	1.12	0.44	9	94.6
WA-31	55	4	0.51	0.42	18	100.0
WA-32	526	15	1.11	0.20	23	100.0
WA-33	304	21	1.53	0.22	49	90.1
WA-34	52	20	2.62	0.68	--	---
WA-34SH	306	19	1.94	0.37	98	69.2
WA-36SH	381	28	2.25	0.34	122	41.9

SAMPLE	N	S	H(S)	E	SPEC/GM	%AGGLUT
WA-39	277	16	1.47	0.27	44	99.2
WA-41	86	13	1.40	0.31	14	86.1
WA-43	217	24	2.24	0.39	38	65.4
WA-44	355	20	1.43	0.21	57	96.7
WA-46	299	17	2.03	0.45	24	93.6
WA-47	375	17	1.39	0.24	33	99.2
WA-48	130	6	0.76	0.35	21	100.0
WA-49	124	8	0.71	0.25	20	99.2
WA-51	68	6	0.65	0.32	22	98.5
WA-52	155	12	1.48	0.37	25	98.0
WA-54	373	20	1.89	0.33	113	92.5
WA-55	433	10	0.52	0.17	69	99.0
WA-57	252	19	1.76	0.30	20	99.6
WA-58	559	33	2.39	0.33	197	65.1
WA-59	724	26	1.89	0.25	127	77.7
WA-60	195	21	2.32	0.49	69	78.4
WA-61(1)	143	18	1.75	0.32	23	99.0
WA-61(2)	135	14	2.08	0.57	--	---
WA-62	37	3	0.64	0.63	--	---
WA-63	68	8	0.99	0.34	5	100.0
WA-64	603	22	1.51	0.21	53	95.2
WA-65	272	22	2.23	0.42	48	83.3
WA-67	360	25	2.33	0.41	63	73.9
WA-68	235	24	2.27	0.40	68	83.4
WA-69	385	16	1.67	0.33	68	90.1
WA-70	757	22	1.59	0.22	266	97.5
WA-71	324	14	1.29	0.26	47	99.7
WA-72	284	14	1.35	0.27	45	100.0
WA-73	380	22	1.42	0.19	67	98.1
WA-74	278	17	1.46	0.25	24	97.5
WA-75	332	8	1.24	0.43	58	99.7
WA-76	276	16	1.53	0.29	42+	95.1
WA-77	640	35	2.15	0.24	113	85.2
WA-78	473	12	1.23	0.29	42	99.8
WA-79	217	22	2.06	0.36	35	72.3
WA-80	126	12	1.41	0.34	5	96.0
WA-81A	192	8	0.93	0.32	31	100.0
WA-81B	2	1	0.00	1.00	--	---
WA-82	318	15	1.57	0.32	51	77.7
WA-83	299	24	1.94	0.29	46+	78.4
WA-84	212	17	1.52	0.27	16+	94.3
WA-85	227	11	1.41	0.37	36	97.4
WA-86	395	27	2.00	0.27	62+	90.0
WA-87	971	36	2.19	0.25	171	75.6
WA-88	551	24	2.11	0.34	88+	71.7
WA-89	550	22	2.03	0.34	44+	56.5
WA-90	307	18	2.02	0.42	49	61.4
WA-91	932	28	1.97	0.21	75	62.6
WA-93	674	25	1.96	0.28	106+	79.7
WA-94	123	7	0.89	0.35	20	89.4

SAMPLE	N	S	H(S)	E	SPEC/GM	%AGGLUT
WA-95	164	9	1.30	0.41	26	99.4
WA-96	790	27	1.87	0.24	139	91.8
WA-97	719	31	2.34	0.34	127	29.2