Taxonomy and Modern Distribution of Elphidiid Foraminifera in the Kara Sea, Arctic Russia

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INTRODUCTION

The Arctic Ocean is the focus of much scientific interest because of the growing awareness of the role of the Arctic in the Earth's climatic changes (Aagard, 1999). One of the most important climatic controls is related to the large quantities of freshwater input into the Arctic seas. This fresh water is a relatively new feature to affect the Arctic Ocean. Tectonic convergence of land features such as the Himalayas helped to provide major sources of river-runoff around 15 million years B.P. (Kennett, 1982). The increased freshwater influx lowered the salinity of the Arctic Ocean and facilitated the formation of a sea-ice cover, which became one of the major regulators of climate in the Northern Hemisphere.

Two voluminous rivers, the Ob' and the Yenisey, input a Mississippi size amount of freshwater into the Kara Sea, the westernmost Siberian arctic sea (Fig. 1). Here, marine and fresh waters mix before entering the central Arctic Ocean. For this reason, the Kara Sea plays a significant role in affecting the sea-ice formation and the thermohaline circulation, which starts in the Nordic Seas and ultimately affects the global ocean circulation. Paleo-environmental record from the sediments of this sea can thus provide a valuable information on the environmental change taking place on a geographically much larger scale.

Foraminifera are one of the most important marine proxies used by geologists to interpret paleoenvironments. Stable isotope studies of oxygen and carbon obtained from the calcite tests of foraminifera can indicate the paleotemperatures, salinity and productivity. An understanding of modern foraminiferal living preferences, species relationships, and responses to environmental parameters is essential before understanding how they can be used to interpret past environments.

A large data set of foraminiferal assemblages from the surficial sediments of the Barents and Kara seas is being compiled by Dr. Leonid Polyak to be used as a modern analog for reconstructing Arctic marine paleoenvironments. This thesis contains a description of the calcareous benthic foraminifera from the Kara Sea, which constitute a part of Dr. Polyak's collection. A special effort was made to provide insight into the systematic of Elphidiid species, which are significant indicators of the high-latitude, river-proximal environments.

MATERIALS and METHODS

Systematic descriptions and graphical data in this thesis were obtained from pre-prepared sediment samples from the Kara Sea. Samples of surface sediments were collected from the Russian research vessel *Akademik Karpinski* in 1991 using a Peterson Grab Sampler. The top 1 cm of sediment ($20cm^2$) was kept in 70% ethanol stained with Rose Bengal and then washed and sieved for the fraction greater than 62.5μm. Light sediment fractions containing foraminifera were separated from the heavier sand fraction by using sodium polytungstate, a heavy liquid solution whose density was calibrated to approximately 1.6 g/ml. Light fractions were examined for foraminifera and other biogenic components (such as Ostracodes) using an Olympus SHZ10 Research Stereo binocular microscope. In addition, I have used foraminifera from downcore samples from the sediment core R-9, 1987 (Fig. 1). These samples were prepared as described above except without the utilization of the Rose Bengal staining.

Scanning Electron Microscopy (SEM) was used to illustrate the dominant species and to provide high resolution detail of selected Elphidiid foraminifera. The JEOL JSM-820 model at Mendenhall Laboratory was used in this project.

This supplemented the binocular microscope analysis and provided insight into reclarifying closely related Elphidiid species.

In order to facilitate the identification of Elphidiids, I have made chamber counts on four species from the R-9 core samples. 100 specimens of *Elphidium subarcticum*, *E. bartletti*, and *Haynesina orbiculare* and 50 specimens of less numerous *Elphidium incertum* were used for the counts of chambers in the last whorl (according to Murray, 1991); the counting results are presented as histograms (Fig. 2). In addition, the wall structure of each species was analyzed by examining portions of crushed test material under an Ortholux II POL-BK polarizing light microscope (after Towe and Cifelli, 1967).

The final part of this thesis includes maps of the distribution of Elphidiid species. This was accomplished by using Mapinfo 5.0, a Geographical Information Science computer program that integrates various types of data into multiple layer maps. The distributions are based on the foraminiferal data set compiled by Dr. Polyak for the Kara Sea from Karpinski '91 samples and other published and unpublished data (Paulsen, 1997).

OCEANOGRAPHY

The Kara Sea is the westernmost sea in the Siberian Arctic bounded by the Arctic Ocean to the north and by the Severnaya Zemlya and Novaya Zemlya archipelagos to the East and West, respectively (Fig. 1). This sea is ice covered for most of the year, but it is ice free in all but the northernmost regions for three months out of the year (Pavlov et al., 1996). Ice melting begins at the end of May in the south and progresses into more northern areas in July. By mid-October, the sea ice is completely frozen again.

The Kara Sea occupies an area of 883,000 km^2 and a volume of 98,000 km^3. The sea bottom is relatively shallow with depths averaging 110 m; the greatest depths of over 300m occur in the western part of the sea (Pavlov et al., 1996). Two Mississippi-size rivers, the Ob' and the Yenisey, discharge approximately 700 km^3 of freshwater during the months of May to September (Pavlov et al., 1996). Because of the relatively small extent of the sea, this fresh water discharge largely controls its environment.

KARA SEA FORAMINIFERA

The Kara Sea contains a diverse fauna of benthic foraminifera, having both calcareous and agglutinated species. Only one planktonic species, *Neogloboquadrina pachyderma*, occurs in the Kara Sea, mainly along its northern margin. Since the preservation of agglutinated species in down-core sediments is poor, calcareous benthic foraminifera are the most useful for reconstructing the sea's environment. Most of the calcareous benthic fauna is comprised of approximately 30 species. The most common systematic group, especially in the low-salinity, estuarine-proximal region is the Elphidiids. This group has been subject to much taxonomic confusion about closely related species, which causes problems with paleo-environmental interpretations. This work aims at elucidating the Kara Sea Elphidiid systematics to facilitate the Arctic paleoceanographic studies.

THE ELPHIDIID PROBLEM

The *Elphidiidae* family is an evolutionary advanced group of foraminifera with structurally complex designs (Buzas et al., 1985). This group contains species living in diverse, often extreme environments, including those with low temperatures and salinities. The genus *Elphidium* was erected by Montfort (1808) to include species that had a planispiral coiling, involute or evolute, bilaterally, symmetrical, and with or without retral processes. Buzas et al. (1985) examined 14 *Elphidium* species by means of canonical variate analysis. They used 8 biometric features measured on the foraminifera and tested their importance in distinguishing between morphologically similar species. As a result of this study, the species list was reduced in half and reorganized into 7 species groups. The authors suggested that redundant species names existed for the same morphological groups because of both geographic isolation of the researchers and the large amount of variety existing within the group.

In the Kara Sea, the common *Elphidium* species include *E. excavatum* forma *clavata* (*E. clavatum*), *E. incertum*, *E. subarcticum*, and *E. bartletti*. Some authors emend *E. subarcticum* and *E. bartletti* into a separate genus *Cribroelphidium* based on minor constructional features (Hansen and Anderson, 1976). Moreover, *E. incertum* has a granular-calcite wall instead of a radial calcite typical for other Elphidiids, which places this species into a genus *Cribrononion*, belonging to the closely related family *Nonionidae*. However, for the purposes of ease and common use, the generic name *Elphidium* will be used for these species. *Haynesina* (*Protelphidium*) *orbiculare* is another common Elphidiid species; I will keep its generic name *Haynesina* (Banner and Culver, 1978) to be consistent with the present-day foraminiferal literature.

The above Elphidiid species can make up to 100% of the calcareous benthic fauna in some parts of the Kara Sea, especially in the areas proximal to the Ob' and the Yenisey River estuaries. There has been confusion about the distinction between some Elphidiid species from low-salinity environments, particularly between *E. incertum* and *E. subarcticum*. In the adult stage, there are differing morphological characteristics but these are not as clear in the juvenile stage. In order to clarify this confusion, three methods of study were incorporated: SEM studies of high resolution detail, optical wall analysis, and chamber counts. In order to illustrate the ecological significance of the Elphidiid species, I present their spatial distributions in the Kara Sea.

RESULTS AND DISCUSSION

SEM

The most insightful of all the methods is the use of the SEM. The high resolution provides much more detail than the binocular microscope observations. Minute details of the foraminiferal test structure, such as fine striations and sutural pores and depressions are seen much clearer under SEM. The results of the SEM study are reported in the Systematic Paleontology section and the plates in the appendices.

Optical Wall Structure

There is no agreement between various authors about the systematic significance of the structural properties of calcitic foraminiferal test walls (radial vs. granular calcite structure). Loeblich and Tappan (1964) considered the wall structure differences to be a cornerstone of the foraminiferal systematics. In contrast, Towe and Cifelli (1967) point out the fact that there is little difference in the calcification of granular versus radiate type. The radiate calcite forms have the c-axis of the calcite crystal perpendicular to the test wall; in granular calcite, the c-axis does not seem to follow any preferred orientation. The radiate calcite forms by laying down a hexagonal crystal base on the polysacharide organic lining of the cytoplasm. The granular calcite forms by laying down an orthorhombic base. Towe and Cifelli (1967) hypothesized that nothing seems to prevent the possibility of both granular and radiate calcite from forming in the same test.

This work does not seek to solve the problem of the systematic significance of the foraminiferal calcite structure; however, wall compositions of selected Elphidiid species was examined using a polarizing microscope in order to test the systematic divisions within this group (Plate 4). The radiate wall structure of the *E. clavatum, E. subarcticum,* and *H. orbiculare* is readily visible even under low magnification (63x). The isogyres show the uniaxial negative interference figure when the gypsum plate was inserted. The high birefringence causes the creamy high-order colors seen in plane polarized light. Some tests of *E. subarcticum* appear opaque and not transcluccent typical of radiate calcite. *E. bartletti,* in comparison with the previous species, had a much less obvious radiate calcite structure. The isogyres were blurred and showed no clear uniaxial interference figure. This is probably due to additional layers of calcite typical for this species. In contrast to other examined species, *E. incertum* clearly showed the appearance of granular calcite. Dark lines are present along the sutured margins of calcite grains.

<u>Chamber Counts</u>

The amount of chambers in the last whorl is commonly used to facilitate distinguishing between closely related foraminiferal species (Murray, 1991). To get statistically significant numbers of Elphidiids for the counts, specimens were picked from Holocene sediment samples in the R-9 core. As no evolutionary changes during the Holocene are recognized for foraminifers, it is justified to use these counts for characterizing modern assemblages. Each counting test contained 100 tests, except in the case of *E. incertum* in which only 50 tests could be picked. *E. bartletti* and *E. subarcticim* tests were picked at 1.45-1.5 m core depth. *E. incertum* counts included tests from 0.15-0.20, 0.30-0.35, and 0.4-0.45 m intervals. *H. orbiculare* tests were picked from 0.75-0.80 m depth. *E. clavatum* was not used in this analysis because its morphology is distinct enough not to be confused with other species.

The last whorls of *E. incertum* and *E. subarcticum* typically contain 10 and 7 chambers, respectively (Fig. 2). This large gap highlights the systematic difference between these two species. When *E. incertum* adds as many as 11 to 12 chambers, this represents either the fully grown adult or the microspheric generation, while the tests with as few as 7 are probably the juvenile or megalospheric generation. It was difficult to accurately determine whether or not two generations were present, based on breaking open tests as the prolocular chambers were always crushed in the process of breaking. This information is therefore not available and is a direction for future work. Although 50% of *E. subarcticum* specimens have 7 chambers, 45% have 8 chambers. In assemblages where *E. subarcticum* is the dominant species, there seems to be more variation in the number of chambers.

40-50% of *E. bartletti* and *H. orbiculare* populations contain 9 and 8 chambers, respectively. These species seem to be less variable with respect to chamber numbers than *E. incertum* and *E. subarcticum*. Again, the spread in the number of chambers (6-11 in *E. bartletti* and 7-11 in *H. orbiculare*) can be tentatively attributed to sexual dimorphism.

Foraminiferal Distributions

Elphidium subarcticum (Fig. 3) is typically found in areas with relatively coarse sediment and can have an epifaunal mode of life, being frequentley attached to immobile benthic organisms (Korsun and Polyak, 1989). In contrast to other Elphidiids, in the Kara Sea this species mostly prefers the areas, which are not significantly affected by riverine inputs.

Elphidium incertum (Fig. 3) is mostly found in the coastal areas proximal to the Ob' and Yenisey Rivers, where it commonly co-occurs with *H. orbiculare*. This distribution makes *E. incertum* to be an important indicator of near-estuarine environments.

Haynesina orbiculare (Fig. 4) has a distribution similar to that of *E. incertum*, but is also common further into the central Kara Sea, distal to the rivers.

Elphidium bartletti (Fig. 4) has maximum concentrations in the zone that is intermediate between river-proximal and river-distal environments. Although the ecological meaning of this distribution is not quite understood, it can be a useful proxy for the positions of past riverine fronts.

E. clavatum (Fig. 5) is abundant all over the Kara Sea. This is a highly abundant and opportunistic species that commonly lives in extreme environments, including heavy sea-ice cover and proximity to glacier fronts (Hald et al., 1994).

SYSTEMATIC PALEONTOLOGY

This section provides the descriptions of selected Elphidiid species. The descriptions are arranged in the order they are presented in the plates. Suprageneric classification is beyond the scope of this work and only generic and species level taxonomy, which is most important for practical paleoenvironmental purposes, is included.

Genus *Haynesina* Banner and Culver, 1978
Haynesina orbiculare Brady, 1881
Pl. 1, figs. 1-3

Synonomy—*Nonionina orbicularis* Brady, 1881: p. 415, pl. 21, fig. 5. Feyling Hansen, 1964: p.349, pl. 21, fig. 3.

Dimensions—Specimens have a maximum diameter of approximately 0.60mm and a minimum of 0.30mm.

Discussion—The genus *Haynesina* was constructed to include foraminifera like Elphidiids but lacking sutural bridges and pores (Buzas et al., 1985). This species is planispiral, involute, and has a radiate calcite test. The sutures are thin and depressed. The aperture contains multiple equatorial openings as seen in fig. 2 of pl.1. *H. orbiculare* can be distinguished from the other similar Elphidiids by the transparency of the test wall and its inflated body. The apertural face is narrow and wraps tightly around the whorl. Granulations are present in both the umbilical area and around the aperture. Fig. 3 shows a magnification of the apertures and granulations.

Genus *Elphidium* Montfort, 1808
Elphidium subarcticum Cushman, 1944
Pl. 1, figs. 4-5

Synonomy—*Elphidium subarcticum* Cushman, 1944: p. 27, pl. 3, figs. 34-35. Buzas, 1966: p.585-594, pl. 92, figs. 7-10. *E. magellanicum* Heron-Allen & Earland, 1932: p. 440, pl.16, figs. 26-28.

Dimensions—The maximum diameter is approximately 0.65 to 0.75mm, minimum diameter is approximately 0.3 to 0.35mm.

Discussion—Test planispiral and involute, radial calcite wall. The juvenile specimens are very similar in appearance to those of *E. incertum* when observed under a binocular microscope. In the adult forms, opaque bands of calcite appear on both sides of the sutures and continue along the periphery, tapering slightly. Sutural pores, which are circular to elongated, occur in some tests. The wall can be either transparent or opaque. Under SEM, the granulations and sutural pores are well defined in the juvenile and the adult form of *E. subarcticum*. In the juvenile, granulations cover most of the test and the sutural pores are either completely obscured, or not developed at all.

The aperture is not well defined even under SEM. Granulations cover most of both the apertural face and the basal aperture. The chambers are inflated, typically number between 7 to 8. This contrasts with that of *E. incertum* which has 10 chambers that are not inflated. *E. subarcticum* doesn't have many visible pores except when observed under SEM.

Elphidium incertum Williamson, 1858
Pl. 2, figs. 1-2

Synonomy—*E. incertum* Buzas, 1966: p. 585-594, pl. 72, figs. 1-6.
E. asklundi Knudsen in Feyling-Hanssen et al., 1971:p. 270, pl. 10, figs., 20-21.

Dimensions—Specimens have a maximum diameter of up to 0.9mm and a minimum of 0.45mm.

Discussion—Tests planispiral and involute. Chambers are not inflated and are tightly curved towards the outer periphery. Test wall is made of granular calcite but can appear translucent to opaque. *E. incertum* can be distinguished by having 10 chambers in the last whorl and deep elongated slits in the sutures. The umbilicus is usually granulated and depressed. The aperture is not clear even under SEM because granulations cover the basal slit.

Elphidium bartletti Cushman, 1933
Pl.2, figs. 3-4

Synonomy—*Elphidium bartletti* Cushman, 1933: p. 4, pl. 1, fig. 9.
Knudsen in Feyling-Hanssen et al., 1971: p. 271, pl. 20, figs. 1-4.

Dimensions—Specimens have a maximum diameter of approximately 0.95mm and a minimum diameter of 0.40mm.

Description—Tests planispiral and involute, radiate calcite test wall. Adult tests have 9 chambers and well developed sutural pores. Granulations occur in the umbilical region and along the sutures. In the adult, the umbilicus is depressed. This species is distinguished from the other Elphidiid species by having regularly spaced sutural fossettes and 9 chambers in the last whorl. Overall, the tests are larger than the other species. An important distinguishing characteristic in the juveniles is the broad and inflated apertural face.

Elphidium clavatum Cushman, 1930
PL. 3, figs 1-3

Synonomy—*Elphidium incertum* Cushman, 1930: p. 18-19, pl. 7, figs. 8-9. Feyling-Hanssen, 1964: p. 345, pl. 20, figs. 11-15.

Dimensions—Specimens have a maximum diameter of approximately 0.50mm and a minimum of 0.32mm.

Discussion—This is a species which has many variate forms and as a result, several subspecies have been described (Feyling-Hanssen, 1972). In the Kara Sea, different morphotypes are difficult to identify and are therefore not used for our purposes.

Tests are planispiral and involute with radiate calcite wall material. This specimen has very distinct retral processes and sutural pores. In broken chambers such as in pl. 3 fig. 3, the retral processes, which penetrate the chamber and connect to the inter-sutural cavities, are readily visible.

CONCLUSIONS

The Kara Sea plays an important role in our understanding of the Arctic climate system. Foraminifera can be the central instrument with which we can improve our understanding of Arctic paleoceanography. In particular, the Elphidiid group is especially important for reconstructing the paleoenvironments of the Kara Sea affected by riverine discharge. While the complexity of this group remains large, this thesis has provided some new insight into the taxonomic characteristics and distributions of 5 problematic elphidiids, which are dominant in the Kara Sea

E. subarcticum, E. incertum, H. orbiculare and *E. bartletti* differ from each other mostly by the total number chambers they posses, as well as by their test shape and suture differences. The distributions show *E. incertum, H. orbiculare, and E. bartletti* to be mostly river proximal, while *E. subarcticum* is mostly river distal. *E. clavatum* occurs throughout the entire Kara Sea, which is affected by sea ice.

This thesis is part of a larger collaborative effort, organized by Leonid Polyak, which will provide much more knowledge about the distributions of all recent foraminifera in the Kara and Barents Sea. This will be in the form of a modern analog database to be used for Arctic paleoceanographic studies.

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FIGURE DESCRIPTIONS

Figure 1—Map of the Kara Sea with bathymetric contours. Note the location of the Ob′ and the Yenisey Rivers emptying into the Kara Sea. Arrows indicate suface water circulation. Filled circles show Karpinski 91 samples, a double circle shows location of the sediment core R-9. Other symbols show surface sediment samples from various other sources used in Leonid Polyak's compilation of foraminiferal distributions.

Figure 2—Histogram plots of chamber counts for selected Elphidiid species. The number of individuals used in the plots are recorded under the x-axis.

Figures 3-5—Mapped distributions for *E. subarcticum, E. incertum, H. orbiculare, E. bartletti,* and *E. clavatum*. The circles represent the percentage of the species in the fauna at each individual site. The stars represent sample locations with zero or near zero percentages.

PLATE DESCRIPTIONS

*note, unless otherwise noted the scale bars equal 100μm.
*unless otherwise stated, all samples are from Karpinski 91 stations.

Plate 1

Figure 1—*Haynesina orbiculare,* side view. This specimen is from Station 19. X190

Figure 2—Same species as above, edge view showing the equatorial aperture. This specimen is also from station. 19. X160

Figure 3—Magnified sectioned outlined in figure 2. X800.

Figure 4—*Elphidium subarcticum,* side view. This is a juvenile form being mostly covered by granulations. Specimen is from station 27-3 X500. Note the scale bar equals 10μm.

Figure 5—Same species as above. This is an adult form also from station Station 27-3. X180.

Plate 2

Figure 1—*Elphidium incertum,* side view. Specimen is an adult form from the interval 0.50-0.60 in core R-9. X100.

Figure 2—Same species as above. This is an apertural view of the same specimen in figure 1. X170.

Figure 3—*Elphidium bartletti,* side view of an adult form. Specimen from Station 21-2. X120.

Figure 4—Same species as above. This is an edge view of an adult from station 21-2. X120.

Plate 3

Figure 1—*Elphidium clavatum,* side view. Specimen is an adult from station 27-4. Note the retral processes and sutural pores. X200.

Figure 2—Same specimen as above. This is a magnified view of the retral, or sutural bridges, tructures. Scale bar equals 10μm, X600.

Figure 3—This is a broken test of the same species as in figures 1-2. The view shows the interior pores (ponticulli) that connect the chamber with the subsutural canal. Test from 1.45-1.50 in core R-9. Scale bar equals 10µm, X650.

Plate 4

Figure 1—*E. subarcticum.* Note the isogyres visible at low magnification (63X).

Figure 2—*E. clavatum.* Note the obvious uniaxial interference figure in plane polarized light. The gypsum plate was inserted for the picture next to it giving the uniaxial negative interfence figure typical of calcite. X160.

Figure 3—*H. orbiculare.* Note the uniaxial image with the analyzer in and uniaxial negative figure with the gypsum plate in. X400.

Figure 4—*E. bartletti.* This image should show isogyres like the other radiate calcite species, but additional layers of calcite have distorted the expected view. X400.

Figure 5—*E. incertum.* This is the typical view of granular calcite in which the isogyres for a uniaxial interference figure are not visible. Dark lines separate crystals of calcite giving the sutured appearance of the grains. X400.

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FIGURES

FIGURE 1

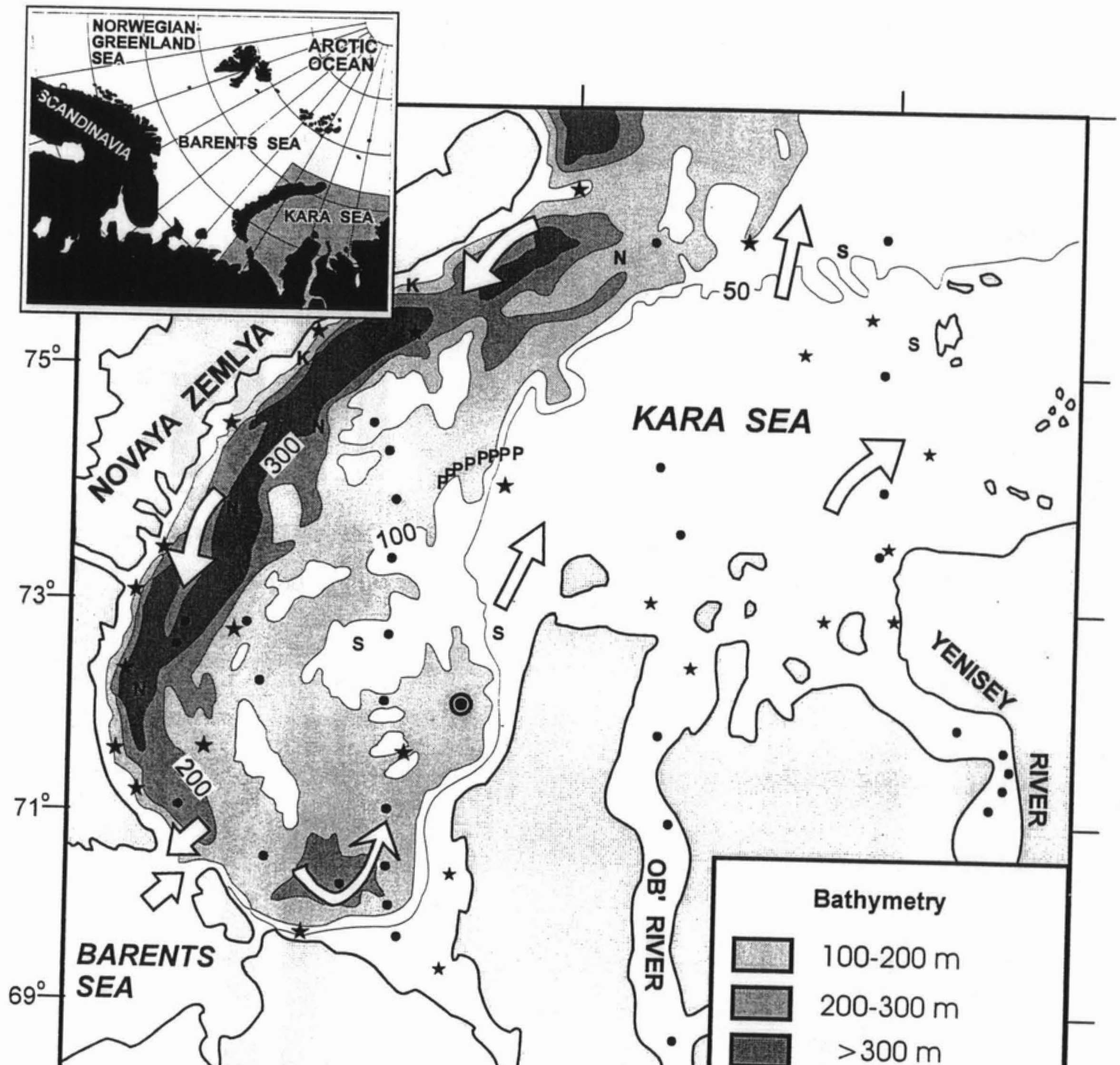

NORWEGIAN-GREENLAND SEA
ARCTIC OCEAN
SCANDINAVIA
BARENTS SEA
KARA SEA
NOVAYA ZEMLYA
KARA SEA
BARENTS SEA
OB' RIVER
YENISEY RIVER
300
200
100
50
75°
73°
71°
69°
60°
70°
80° E
Bathymetry
100-200 m
200-300 m
>300 m

FIGURE 2

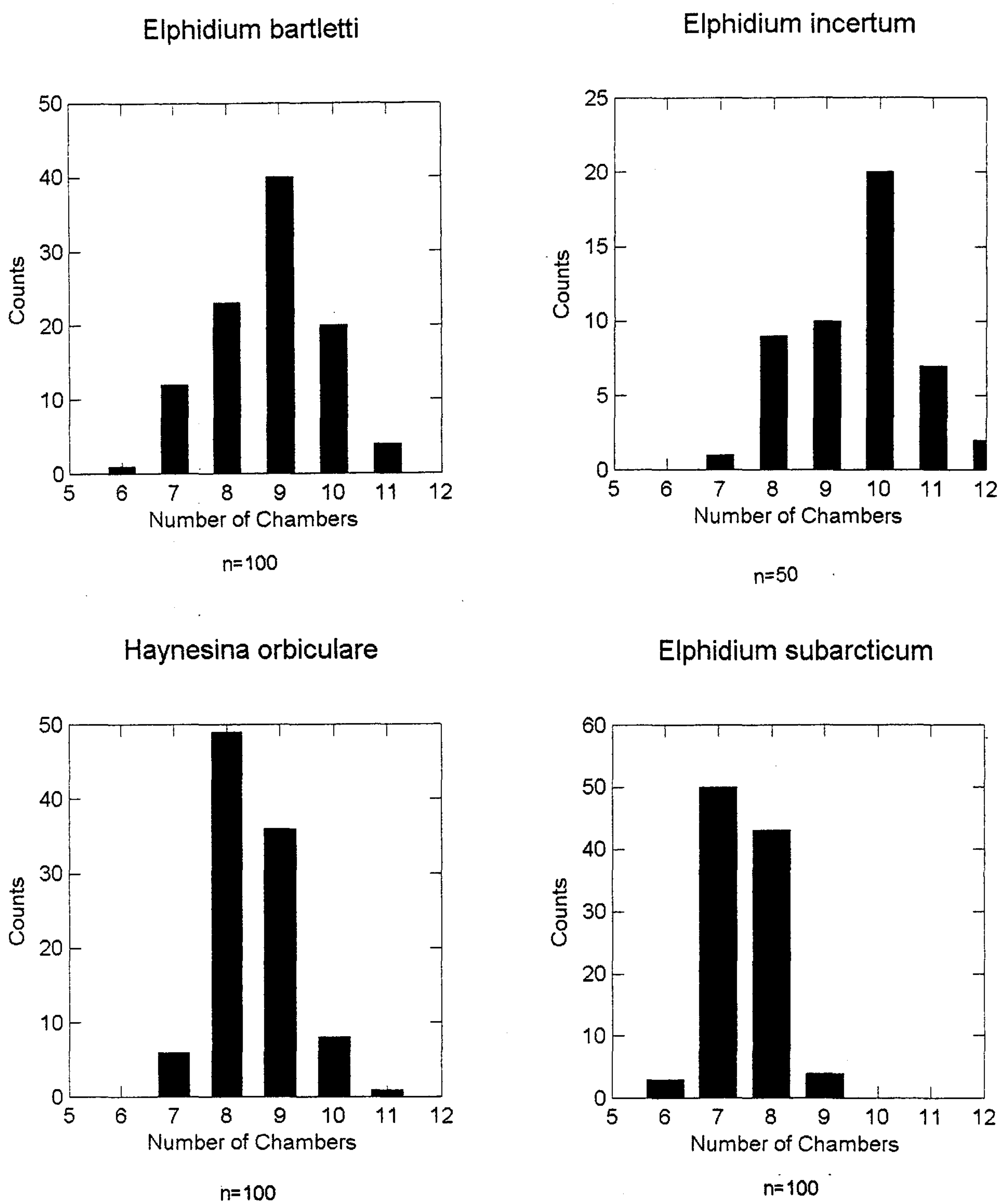
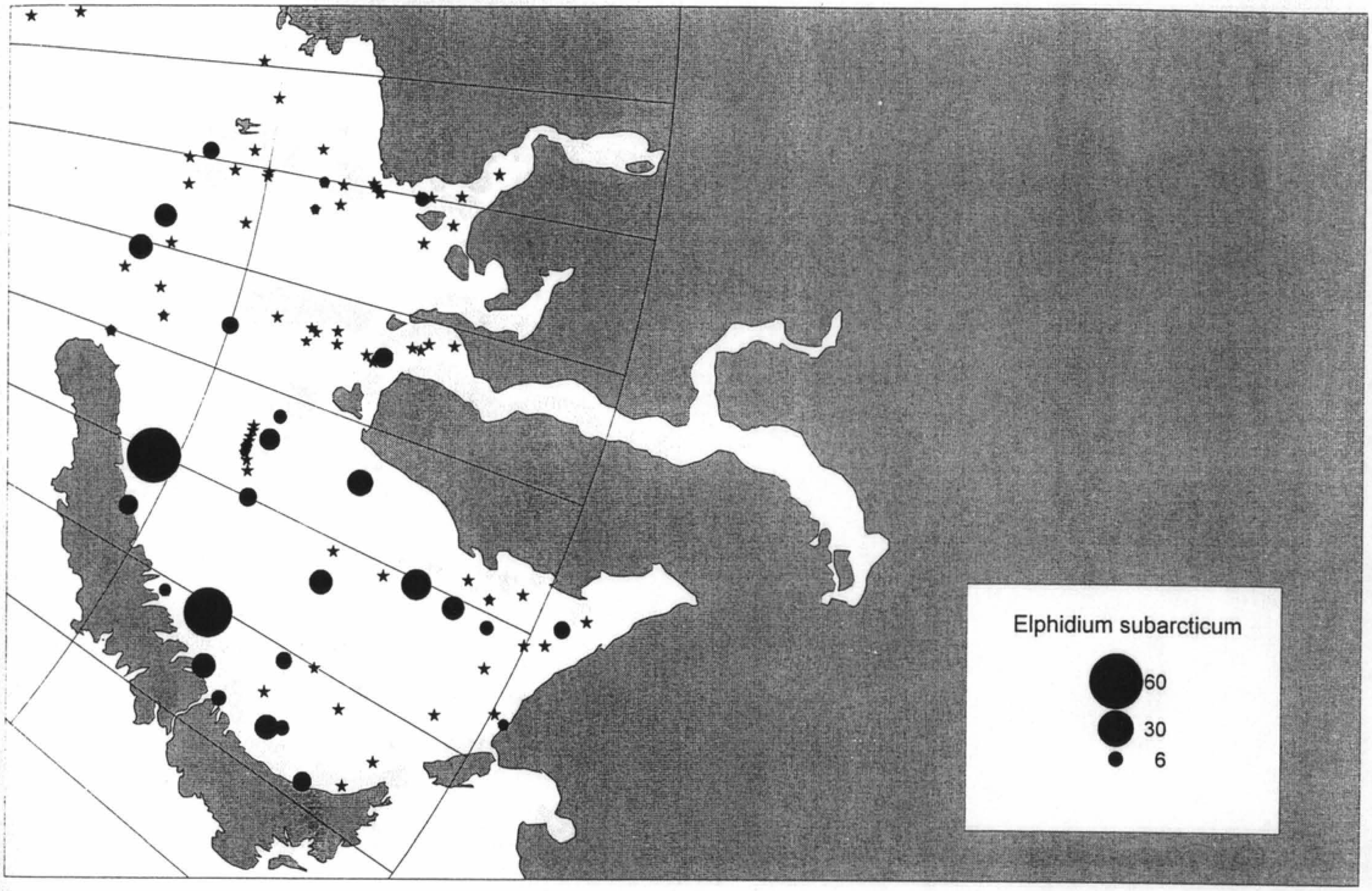
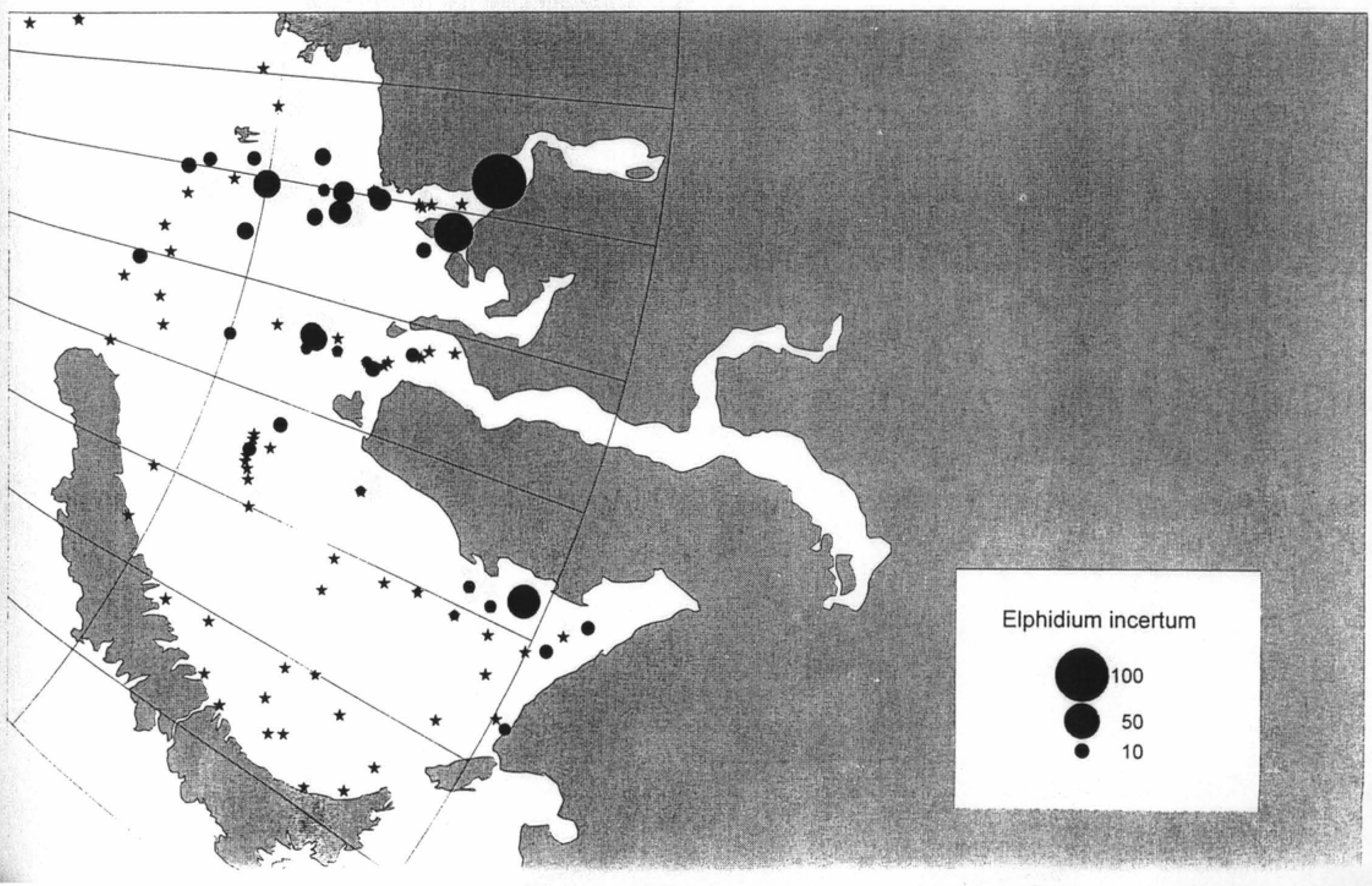

Elphidium bartletti
Counts
Number of Chambers
n=100
Elphidium incertum
Counts
Number of Chambers
n=50
Haynesina orbiculare
Counts
Number of Chambers
n=100
Elphidium subarcticum
Counts
Number of Chambers
n=100

FIGURE 3





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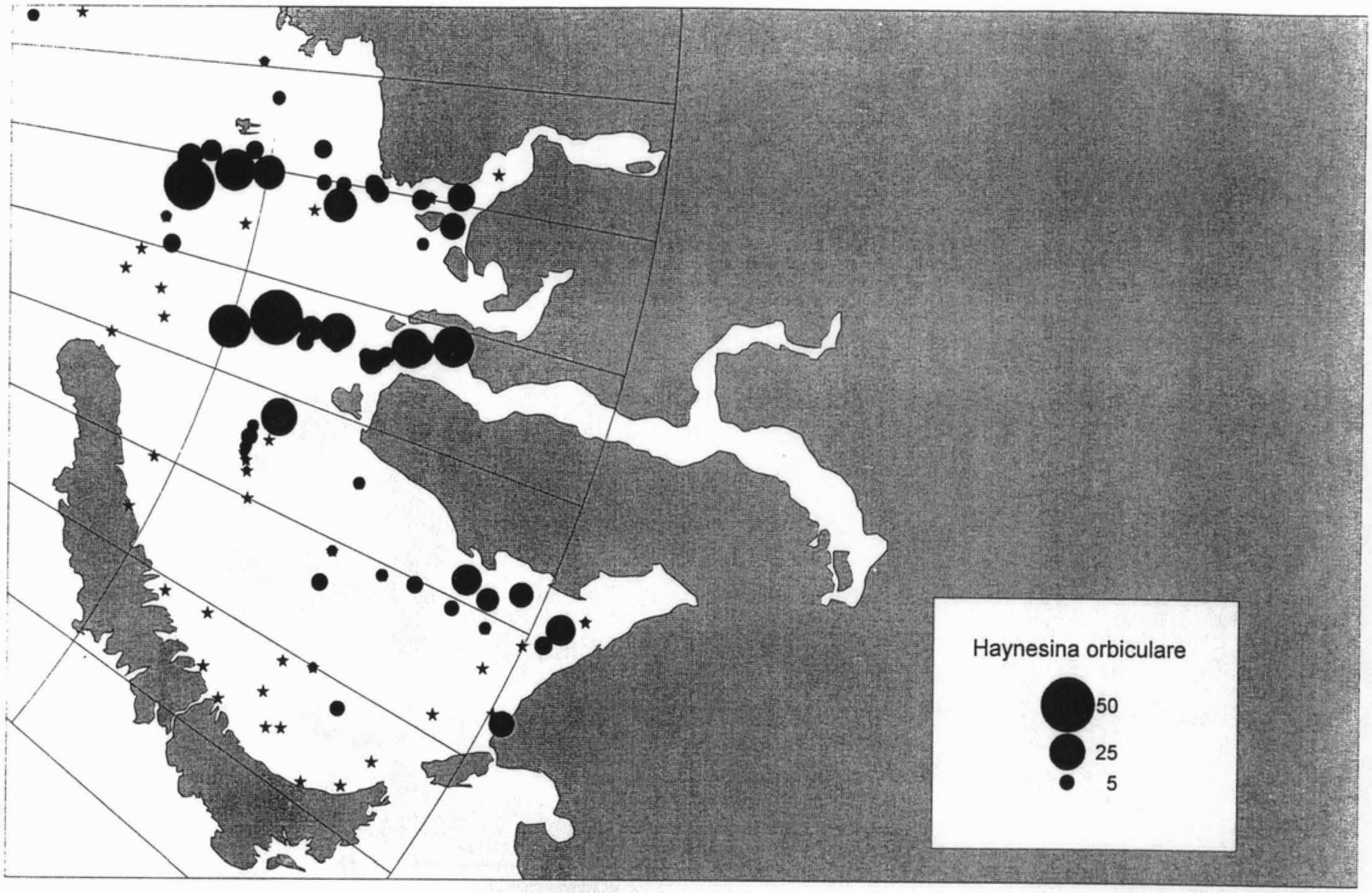

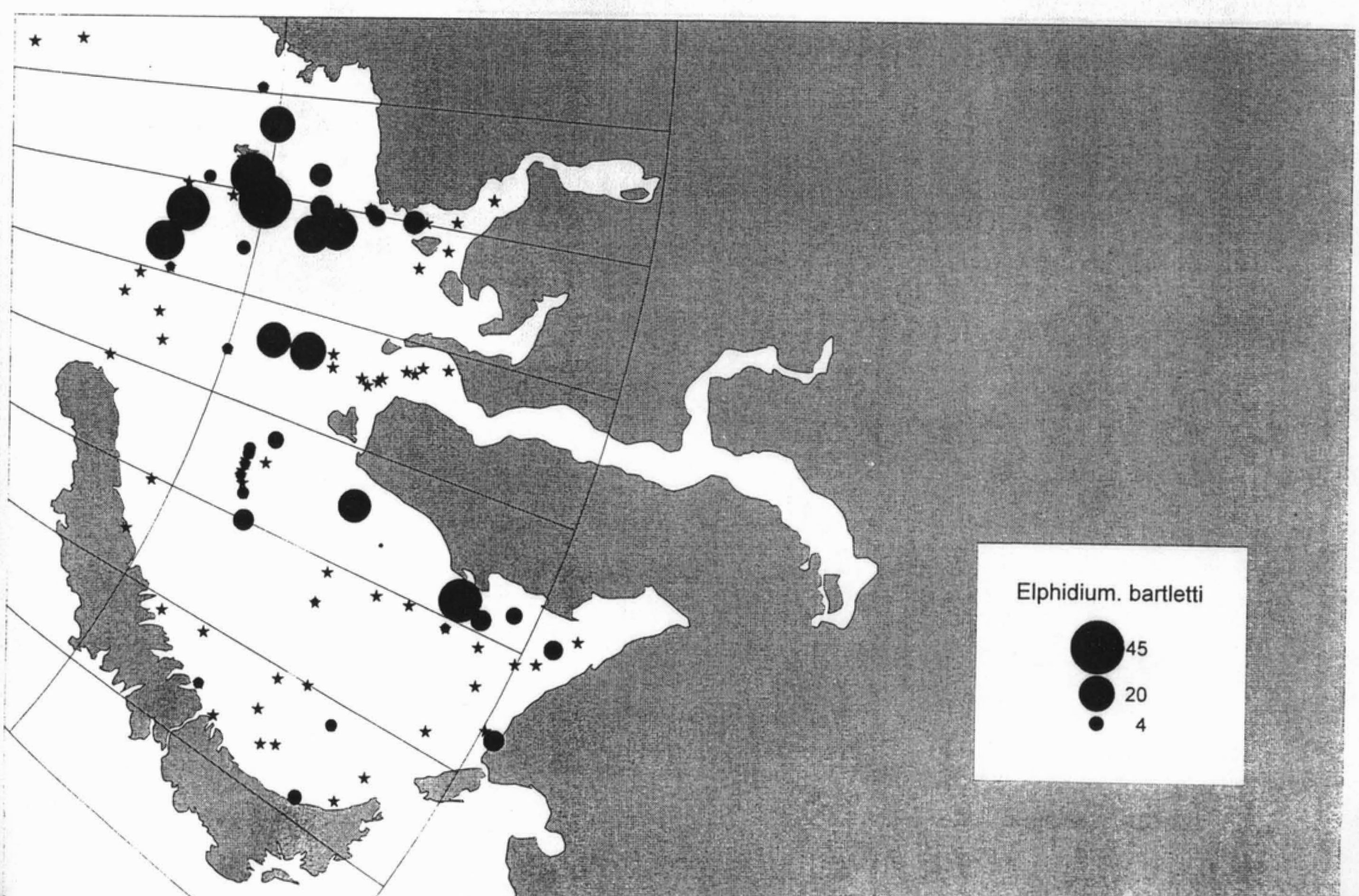

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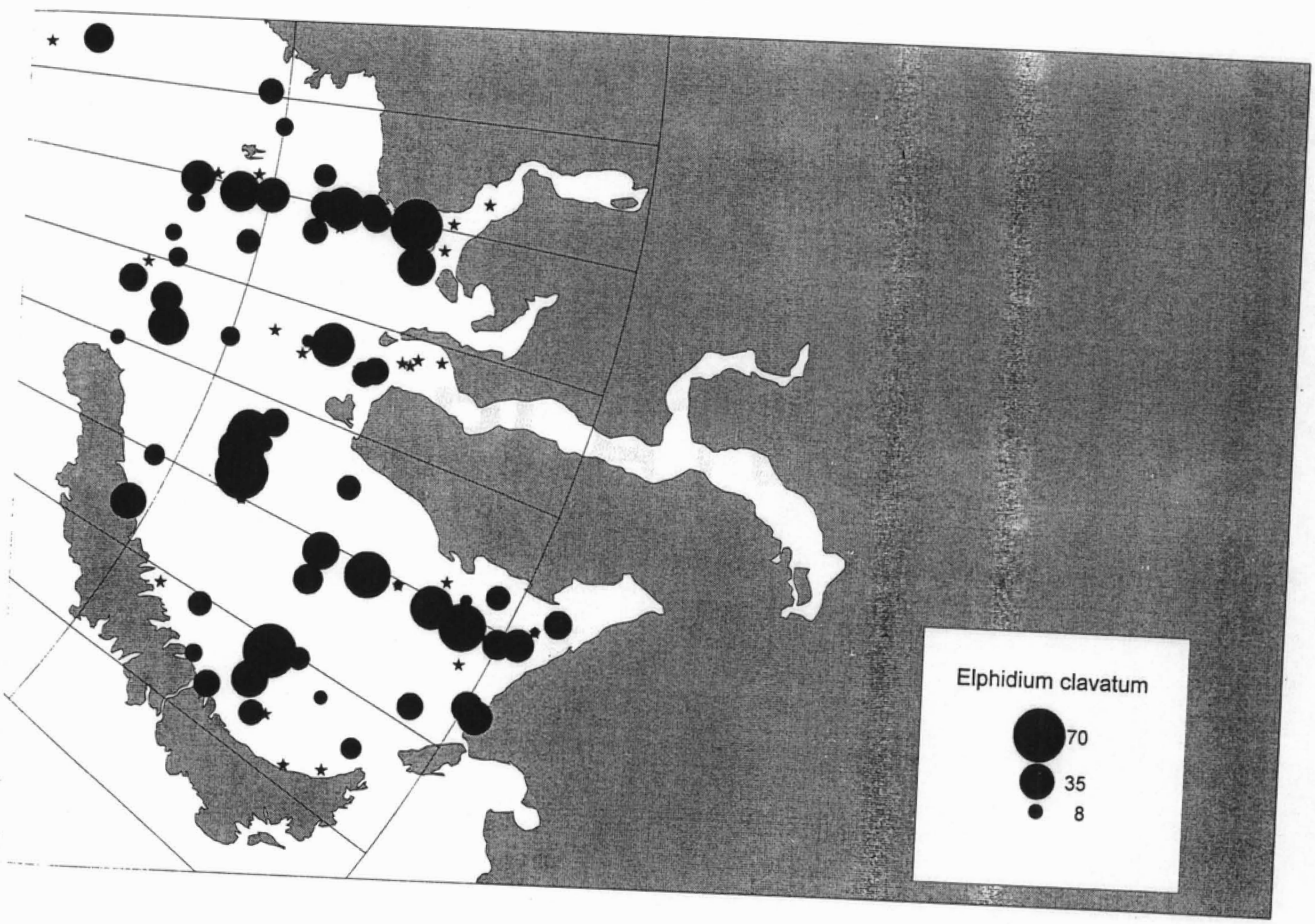

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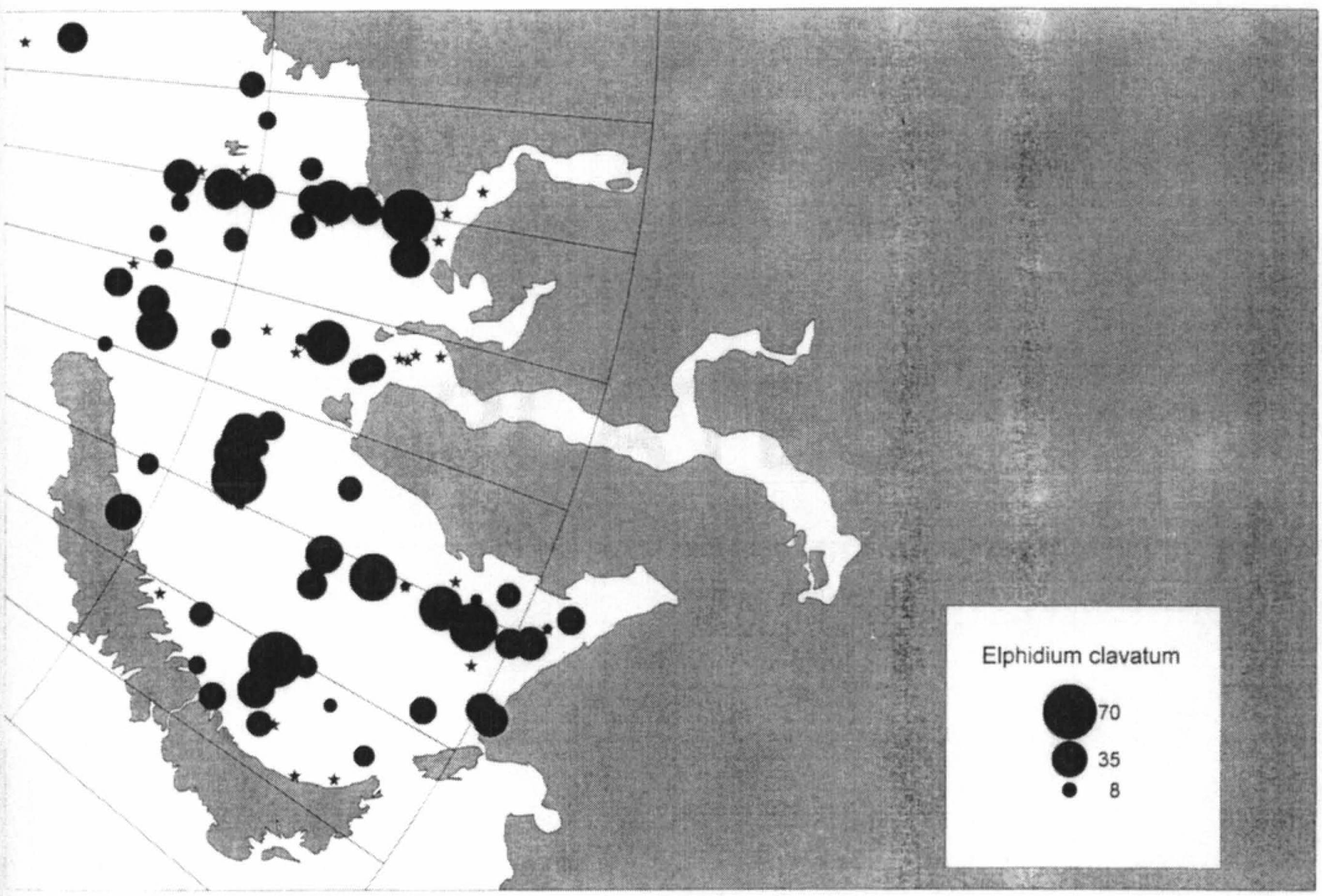


PLATES

PLATE 1

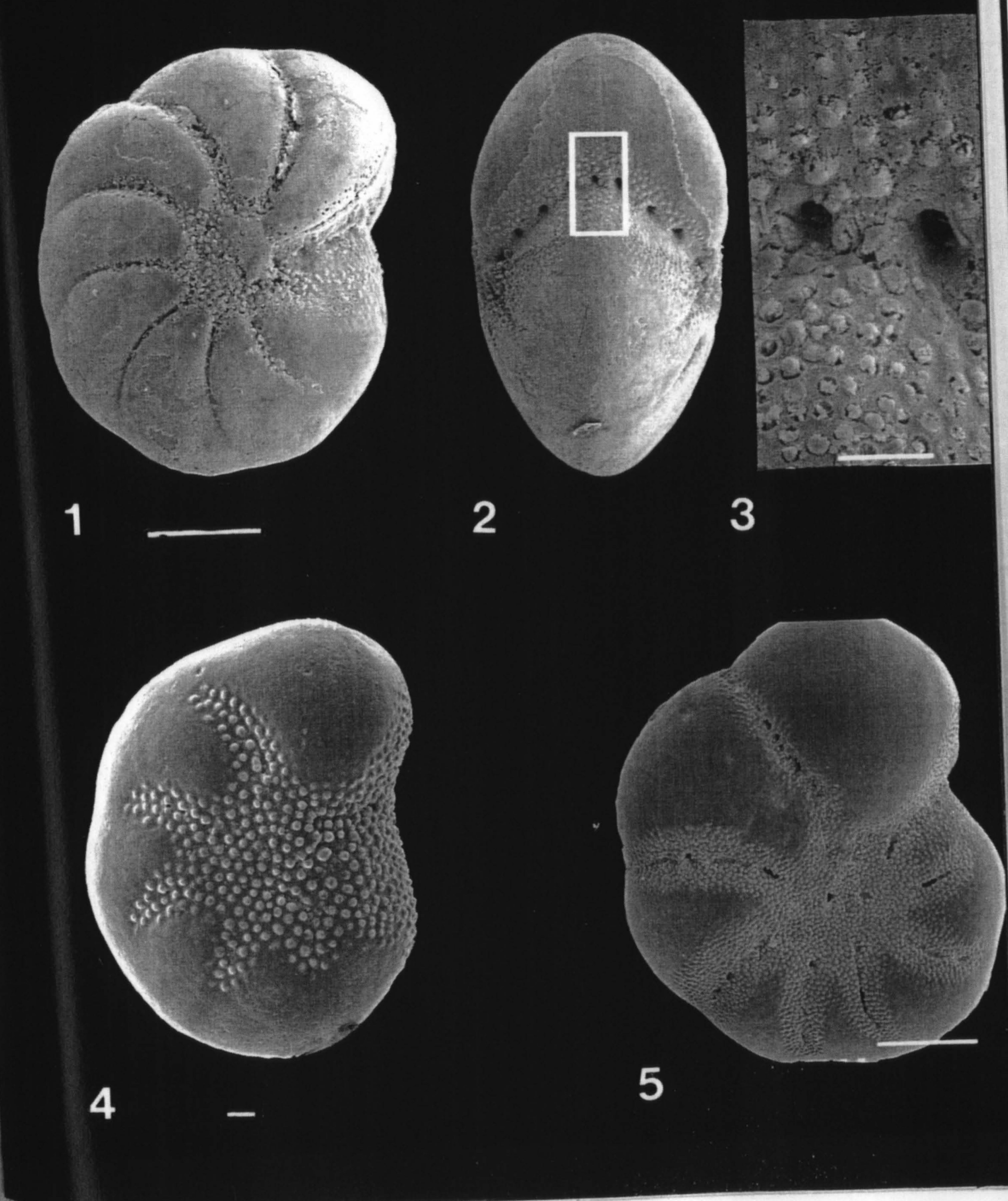
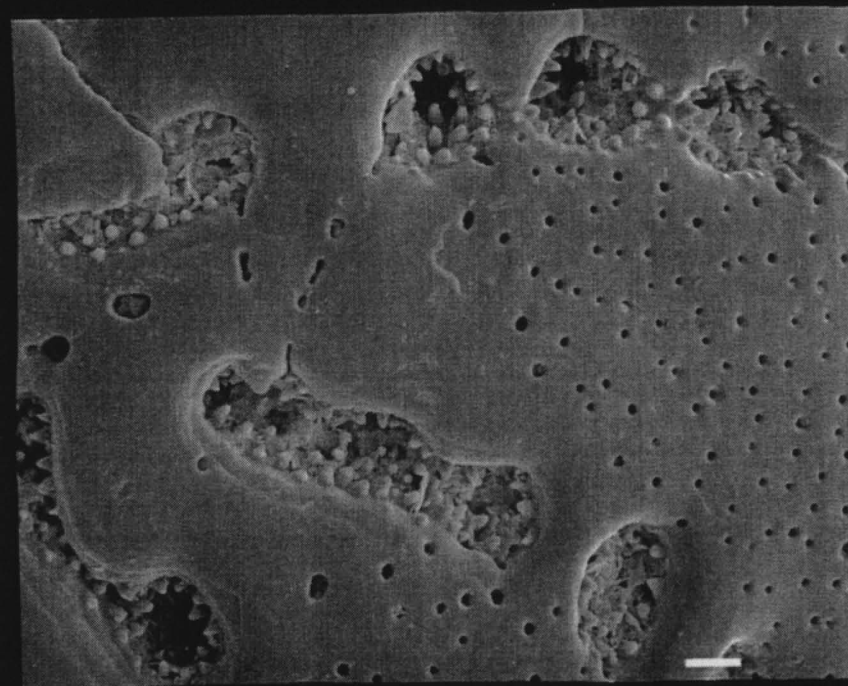


PLATE 2

PLATE 3

1



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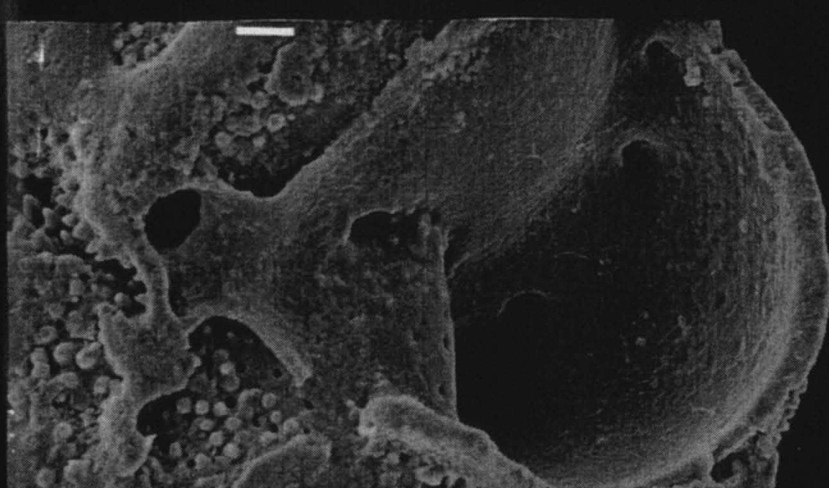

3

PLATE 4