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A COMPARISON OF FOURTEEN ELPHIDIID (FORAMINIFERIDA) TAXA

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ABSTRACT—Eleven morphological variables were measured or scored on 12 groups belonging to *Elphidium* and two belonging to *Haynesina.* The 14 groups were compared along canonical axes. The mean canonical variates for the groups *E.* cf. *mexicanum* and *E. mexicanum* are so close we consider them conspecific. *E. discoidale, E. gunteri, E. advenum,* and *E. mexicanum* are clearly discriminated from the other groups. *E. margaritaceum, E. excavatum,* and *H. orbiculare* are fairly well discriminated from the others. The remaining six groups form two overlapping sets. One set contains *E. bartletti, E. frigidum,* and *E. subarcticum,* while the other contains *E. williamsoni, E. excavatum* (deep), and *H. germanica.*

Two more analyses were made on these overlapping sets and the results indicate each of the groups can be discriminated. We conclude each group is a separate species, with the exception of *E. excavatum* (deep) which we regard as conspecific with *E. excavatum.*

The specimens from 1,530 m depth simply do not exhibit as much variation as the specimens from shallower water used in the group *E. excavatum.* This suggests that not only species, but also some morphological groups can be used as ecological indicators.

INTRODUCTION

THE FORAMINIFERAL genus *Elphidium* de Montfort is a diverse and abundant taxon in modern and Cenozoic shelf sediments. Although many constituent species have been studicd in great detail over the past 50 or so years, disagreement still exists over the spccific names given to various morphological groups (see Cushman, 1930, 1939; Loeblich and Tappan, 1953; Buzas 1965a, 1965b, 1966; Feyling-Hanssen, 1972; Haynes, 1973; Hansen and Lykke-Anderson, 1976; Banner and Culver, 1978; Poag, 1978; Wilkinson, 1979; Miller et al., 1982; Rodrigues and Hooper, 1982). Geographic isolation of various researchers and problems of communication are obvious reasons for identification problems, but we consider the main factor involved is the very great inherent morphological variation within the elphidiids.

In a study dealing with all published records of modern benthic foraminifera on the Atlantic continental margin of North America, Culver and Buzas (1980) found that approximately 40 names have been used to subdivide the genus *Elphidium.* Examination of type and figured specimens in the U.S. National Museum of Natural History, the British Museum (Natural History), and various smaller collections enabled us to reduce this figure by about one half. This was not a simple task, however, and some specific designations were more certain than others.

The first purpose of this paper is to statistically evaluate several troublesome elphidiid morphological groups to determine their relationship to onc another, and, at the same time, provide further information on a reasonable scheme for designating species. We chose 14 morphological groups that are commonly recorded on the North American Atlantic continental margin. These groups and the names we gave them are listed in Table 1. Twelve of these elphidiids we placed in the genus *Elphidium,* and two in the genus *Haynesina* (elphidiids lacking sutural bridges and pores and often assigned to the genus *Protelphidium,* see Banner and Culver, 1978).

The second purpose of this paper is to reillustrate several holotypes and additional carefully chosen specimens. We do this because many of the original illustrations do not allow a researcher to see the characters clearly.

MATERIALS AND METHODS

We examined the primary types of *Elphidium advenum* (Cushman), *E. bartletti* Cushman, *E. frigidum* Cushman, *E. margaritaceum* Cushman, *E. mexicanum* Kornfeld, *E. subarcticum* Cushman, *E. william-*

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TABLE 4—Group means for variables. (See Tables 1 and 2 for key.)

	Variables										
Species	A	B	C	D	E	F	G	H	I	J	K
1	0.4	0.3	0.2	10.9	3.0	3.0	3.7	0.6	0.0	0.0	2.2
2	0.7	0.6	0.3	9.2	1.0	2.0	3.6	0.0	0.3	0.0	1.1
3	0.6	0.5	0.3	15.5	2.0	1.0	3.6	1.0	0.0	0.0	3.0
4	0.5	0.4	0.2	10.6	1.2	1.9	1.9	2.7	0.0	0.0	2.1
5	0.6	0.6	0.2	7.7	1.0	2.0	4.2	0.0	0.2	0.4	1.8
6	0.3	0.3	0.2	10.9	1.1	1.0	2.7	3.8	0.0	0.0	2.2
7	0.4	0.4	0.2	10.8	2.2	2.0	3.7	0.0	0.0	0.0	1.8
8	0.4	0.3	0.2	9.9	1.0	3.0	2.5	1.0	0.0	0.0	2.0
9	0.3	0.3	0.2	9.9	1.0	3.0	1.8	4.2	0.0	0.0	1.8
10	0.6	0.5	0.2	7.9	1.0	2.0	3.9	0.0	1.0	0.0	1.8
11	0.4	0.4	0.2	10.2	1.0	2.0	4.0	0.5	0.0	0.0	2.0
12	0.3	0.3	0.1	7.5	1.0	2.0	0.0	0.0	0.1	0.0	2.0
13	0.5	0.5	0.3	9.3	1.0	2.0	0.0	0.0	0.1	0.0	2.0
14	0.4	0.3	0.2	8.7	1.0	2.0	2.3	0.6	0.0	0.0	2.0

give us some idea of strong similarities among groups. Figures 1 and 3 indicate a strong similarity between *E. bartletti* (2), *E. frigidum* (5), and *E. subarcticum* (10). Figures 1 and 3 also indicate a close similarity between *E. mexicanum* (8), and *E.* cf. *mexicanum* (9). Figures 2 and 3 indicate once again a close relationship between *E. frigidum* (5) and *E. subarcticum* (10). In addition *E. williamsoni* (11), *E. excavatum* (deep) (14), and *Haynesina germanica* (12) show a close relationship.

An option of the SPSS package is a listing of the predicted group membership of every observation. In this case each specimen of every morphological group is assigned to the group with the highest probability of membership. In the present analysis, 93% of the 420 specimens were correctly classified. The great variability of *E. excavatum* is shown by its assignment to six different groups. Only 63% were correctly classified.

In summary, the analysis allows the placement of the 14 groups into three sets: those groups which are clearly discriminated from the rest, those groups which are fairly well discriminated from the rest, those groups which show a good deal of overlap with other groups. The first set contains *E. discoidale* (3), *E. gunteri* (6), *E. advenum* (1), *E. mexicanum* (8), and *E.* cf. *mexicanum* (9). The second category consists of *E. margaritaceum* (7), *E. excavatum* (4), and *Haynesina orbiculare* (13). The third set consists of two subsets each containing three groups. These are *Elphidium bartletti* (2), *E. frigidum* (5), *E. subarcticum* (10), and *E. williamsoni* (11), *E. excavatum* (deep) (14), *Haynesina germanica* (12).

Because of the large amount of overlap of these last two subsets, we decided to run a canonical variate analysis on each of the subsets.

The canonical variate analysis for *Elphidium bartletti, E. frigidum,* and *E. subarcticum* has $N = 90$ individuals, $h = 3$ groups, and $p = 8$ variables. Angularity of margin, porosity, and umbilical boss development were deleted as variables because for these three groups they are constants. Because $p > h$ there are only $h - 1$ or two possible canonical variates. Table 8 lists the eigenvalues and the percent of the variability they account for. Both eigenvalues are statistically significant. The mean canonical variates are listed in Table 9 and are plotted in Figure 4.

The first canonical variate, accounting for 78% of the variability, clearly separates the three groups. The standardized canonical discriminant function coefficients shown in Table 10 indicate that length (thickness) of the test is the most discriminating variable followed by the spiral diameter at 90 degrees to gsd.

TABLE 5—The first three eigenvalues with the percentage of variability accounted for: analysis of the 14 groups.

Eigenvalue	Percent of variability	Cumulative percent
28.11	46.88	46.88
13.22	22.05	68.93
7.97	13.30	82.22

TABLE 6—Mean canonical variates for the first three canonical variates: analysis of the 14 groups.

Species No.	Species Name	Mean CV1	Mean CV2	Mean CV3
1	*Elphidium advenum*	9.11	7.51	2.23
2	*E. bartletti*	−1.40	−2.88	2.64
3	*E. discoidale*	−9.45	5.72	−0.15
4	*E. excavatum*	−1.42	−0.55	−2.46
5	*E. frigidum*	−0.94	−2.30	3.99
6	*E. gunteri*	−7.98	1.92	−4.95
7	*E. margaritaceum*	0.40	4.99	2.00
8	*E. mexicanum*	8.00	−1.32	−1.28
9	*E.* cf. *mexicanum*	8.37	−1.37	−5.19
10	*E. subarcticum*	−1.23	−2.85	4.05
11	*E. williamsoni*	−0.32	0.66	−0.04
12	*Haynesina germanica*	−0.57	−3.45	−0.49
13	*H. orbiculare*	−1.61	−4.60	0.11
14	*Elphidium excavatum* (d)	−0.96	−1.48	−0.45

The second canonical variate discriminates *E. subarcticum* from the other two groups. In keeping with such a separation Table 10 shows the presence of an opaque white band along the sutures was the most important variable.

The classification of each individual into one of the three groups correctly classified 92% of the cases. We conclude that these three groups can be discriminated.

The canonical variate analysis for the groups *E. excavatum* (deep), *E. williamsoni,* and *Haynesina germanica* has N = 90 individuals, h = 3 groups and p = 8 variables. Angularity of margin, groove across chamber, and depression of umbilicus were deleted as variables because they are constants.

Table 11 lists the eigenvalues and the percent of the variability they account for. Both eigenvalues are statistically significant, but the first one accounts for 92% of the variability. The first canonical variate (Table 12, Figure 5) separates the three groups equally. Reference to Table 13 indicates sutural bridge development is the most important variable and the number of chambers in the last whorl is the second most important (see Table 4).

The second canonical variate separates *E. excavatum* (deep) from the remaining two (Table 12, Figure 5). The length (thickness) of the test is the most important variable while umbilical boss development and spiral diameter at 90 degrees to gsd also contribute substantially.

Our confidence in the discreteness of the three groups is enhanced by the results of the classification of each of the 90 individuals. One hundred percent of the specimens were correctly classified.

DISCUSSION

In the analysis of the 14 morphological groups, *Elphidium mexicanum* and *E.* cf. *mexicanum* are not discriminated along the first two canonical axes (Figure 1). Along the third axis, however, the two groups are sep-

TABLE 7—Standardized canonical discriminant function coefficients: analysis of the 14 groups.

Variables	Function 1	Function 2	Function 3
Greatest spiral diameter (gsd)	−0.14	−0.49	0.51
Spiral diameter at 90° to gsd	0.07	−0.01	0.25
Length (thickness)	−0.24	−0.14	−0.21
Number of chambers in last whorl	0.03	0.48	−0.43
Angularity of margin	0.10	0.74	0.29
Porosity	0.97	−0.12	0.01
Sutural bridge development	0.06	0.52	0.18
Umbilical boss development	0.06	0.09	−0.66
Opaque white band along suture	−0.03	−0.16	0.28
Groove across chamber	0.02	−0.03	0.14
Depression of umbilicus	−0.10	0.08	−0.00

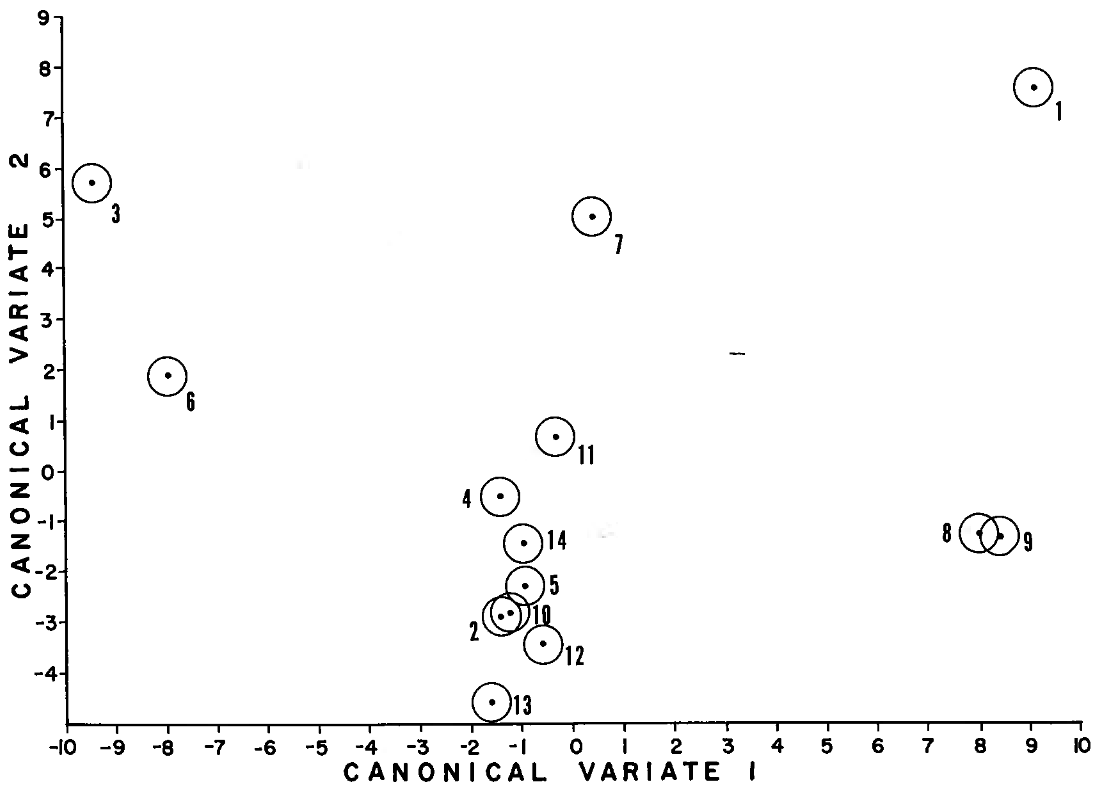

FIGURE *1*—Mean canonical variates 1 and 2 with 95% confidence circles for 14 groups.

arated (Figure 2). One of the most important contributing variables for the third canonical variate is umbilical boss development (Tables 4, 7). We examined the types of *E. mexicanum* and believe the specimens called *E.* cf. *mexicanum* from the Indian River, have a wider more depressed umbilical area. In addition these specimens have several small individual bosses while the type has only one. Kornfeld's (1931) description, however, stated "... umbilical region multiple or central" indicating, perhaps, that some of the specimens he examined had multiple umbilical bosses. Given the variability in boss development on the specimens from the Indian River, and the high degree of overlap of confidence circles for the first two canonical axes, we believe it is best to follow Buzas and Severin (1982) and consider these two morphological groups as conspecific.

The analyses indicate the remaining 12 morphological groups are all distinct. Nevertheless, we believe they represent only 11 species. While *E. excavatum* is clearly discriminated from *E. excavatum* (deep), we believe the two groups belong to the same highly variable species (the variant that dominates the "deep" group is also present, although less commonly, in the "shallow" group). The specimens measured for *E. excavatum* exhibit the wide range of variation so typical of this species. On the other hand, the specimens referred to *E. excavatum* (deep) are all opaque and have one or no umbilical boss. This latter group was called *E. excavatum* forma *alba* by Feyling-Hanssen (1972), *E. clavatum album* by Wilkinson (1979), and *E. excavatum* forma *clavata* by Miller et al. (1982). Regardless of the name used, we have demonstrated that populations of the morphological group found in relatively deep water off Newfoundland can be distinguished from shallow dwelling members of the species.

The value of a statistical analysis is depen-

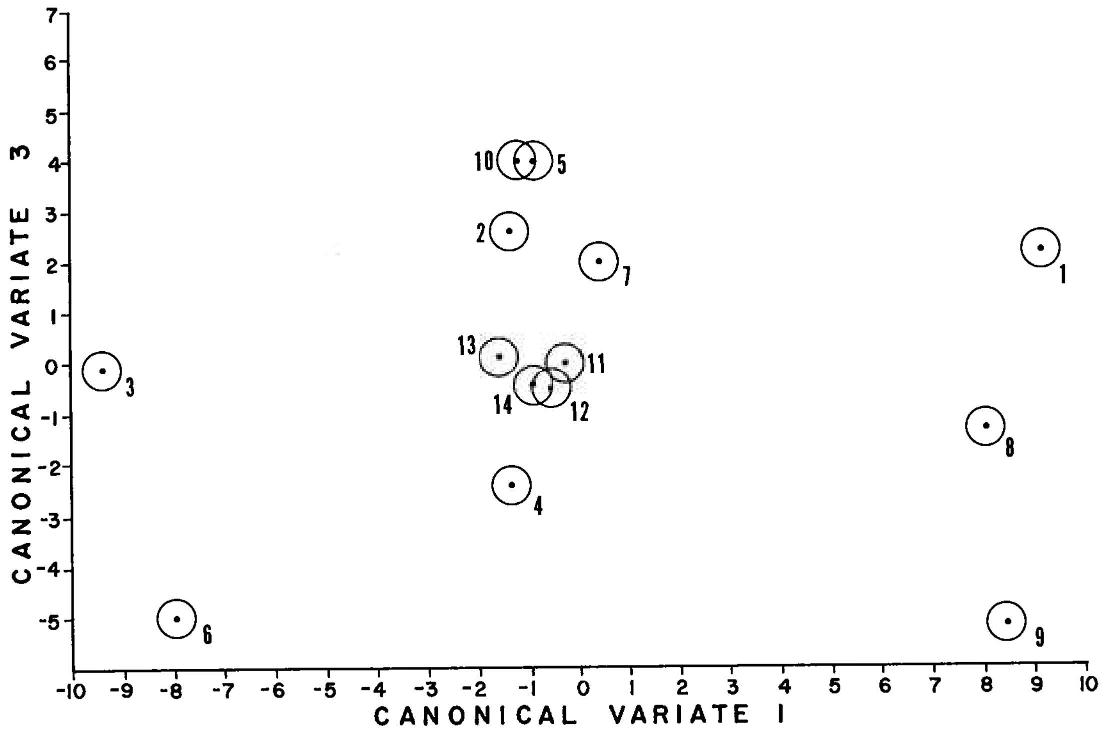

FIGURE 2—Mean canonical variates 1 and 3 with 95% confidence circles for 14 groups.

dent on the significance of the variables chosen for the analysis. In this study, eleven subjectively selected morphological variables were measured or scored. Other possible variables readily come to mind, but decisions to include some and exclude others are necessary. Some characters that are important in foraminiferal classification, such as wall structure and apertural type, are invariant. Such variables have a zero variance and cannot be used in statistical analyses. Banner and Culver (1978) showed the aperture of *Haynesina germanica* differs from *Elphidium*. Had we been able to use this character, perhaps, *H. germanica* would have shown more discrimination from *Elphidium* spp. On the other hand, the lack of sutural bridges in *H. germanica* and *H. orbiculare* did not result in great discrimination of these two species from the other elphidiids in the present analysis. We must keep in mind that all characters are considered in a multiple discriminant analysis, not just one.

The conclusion to draw from this, although not novel, is that numerical taxonomic methods are useful tools, but they cannot be expected to totally replace the qualitative observations of an experienced taxonomist.

SYSTEMATIC PALEONTOLOGY

Order FORAMINIFERIDA Eichwald, 1830
Family ELPHIDIIDAE Galloway, 1933
Genus ELPHIDIUM de Montfort, 1808
ELPHIDIUM ADVENUM (Cushman, 1922)
Figures 6.1, 6.2

Polystomella advena CUSHMAN, 1922, p. 56, Pl. 9, figs. 11, 12.

Remarks.—In his description of this species Cushman (1922) noted the existence of a carina. While many specimens possess this character, some do not. The periphery, however, is always acute (Table 4). This species also has very fine pores and is optically granular. The only other species studied here that has fine porosity and is optically granular is *E. mexicanum.* The two are easily distinguished because *E. mexicanum* does not have

TABLE *13*—Standardized canonical discriminant function coefficients for analysis of *Elphidium excavatum* (deep), *E. williamsoni,* and *Haynesina germanica.*

Variables	Function 1	Function 2
Greatest spiral diameter (gsd)	−0.01	−0.10
Spiral diameter at 90° to gsd	−0.26	−0.48
Length (thickness)	−0.20	1.34
Number of chambers in last whorl	0.42	−0.22
Porosity	−0.26	−0.11
Sutural bridge development	1.12	−0.08
Umbilical boss development	0.09	0.52
Opaque white band along suture	0.04	−0.38

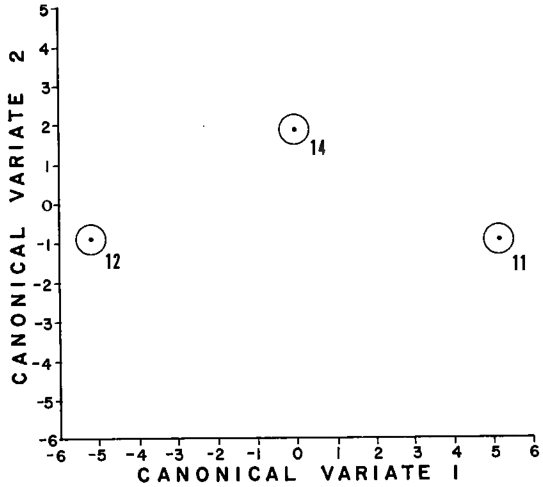

FIGURE *5*—Mean canonical variates 1 and 2 with 95% confidence circles for *Elphidium excavatum* (deep), *E. williamsoni,* and *Haynesina germanica.*

the classification procedure which correctly identified only 63% of the specimens. A researcher working with this species must spend many hours looking at thousands of specimens before he or she can be confident they have seen all of the many "faces" of *E. excavatum.*

Fifteen specimens of the shallow water group come from Vineyard Sound, Mass., seven from Newport, R.I., and eight from Casco Bay, Maine. All 30 of the deep water group come from 1,530 m depth off the coast of Newfoundland.

ELPHIDIUM FRIGIDUM Cushman, 1933
Figures 7.3, 7.6

Elphidium frigidum CUSHMAN, 1933, p. 5, Pl. 1, fig. 8.

Remarks.—Some specimens of this species can be confused with *E. subarcticum.* Indeed, Todd and Low (1967) were of the opinion that they are the same species. Perhaps they are, but the specimens available to us allow for a reasonable amount of discrimination. In the analysis of *E. bartletti, E. frigidum,* and *E. subarcticum,* 90% of the *E. frigidum* group was classified correctly. The remaining 10% were classified as *E. subarcticum.* Only 3% of the *E. subarcticum* group were classified incorrectly and assigned to *E. frigidum.* Consequently, we prefer, at this time, to treat the two groups as separate species.

E. frigidum can be distinguished from *E. subarcticum* by poorer development of opaque bands along the sutures, fine grooves (when present) on the last chamber, a broader depressed umbilical area, and a protruding last chamber.

Twenty-four of the specimens used in this study are from off Point Barrow, Alaska, and six are from near North Star Bay, Greenland.

ELPHIDIUM GUNTERI Cole, 1931
Figures 7.4, 7.5

Elphidium gunteri COLE, 1931, p. 34, Pl. 4, figs. 9, 10.

Remarks.—The type for this species has been lost. We have based our judgement of the morphology of this species on specimens deposited in the collection of the U.S. National Museum of Natural History. Some specimens of this species can be confused with

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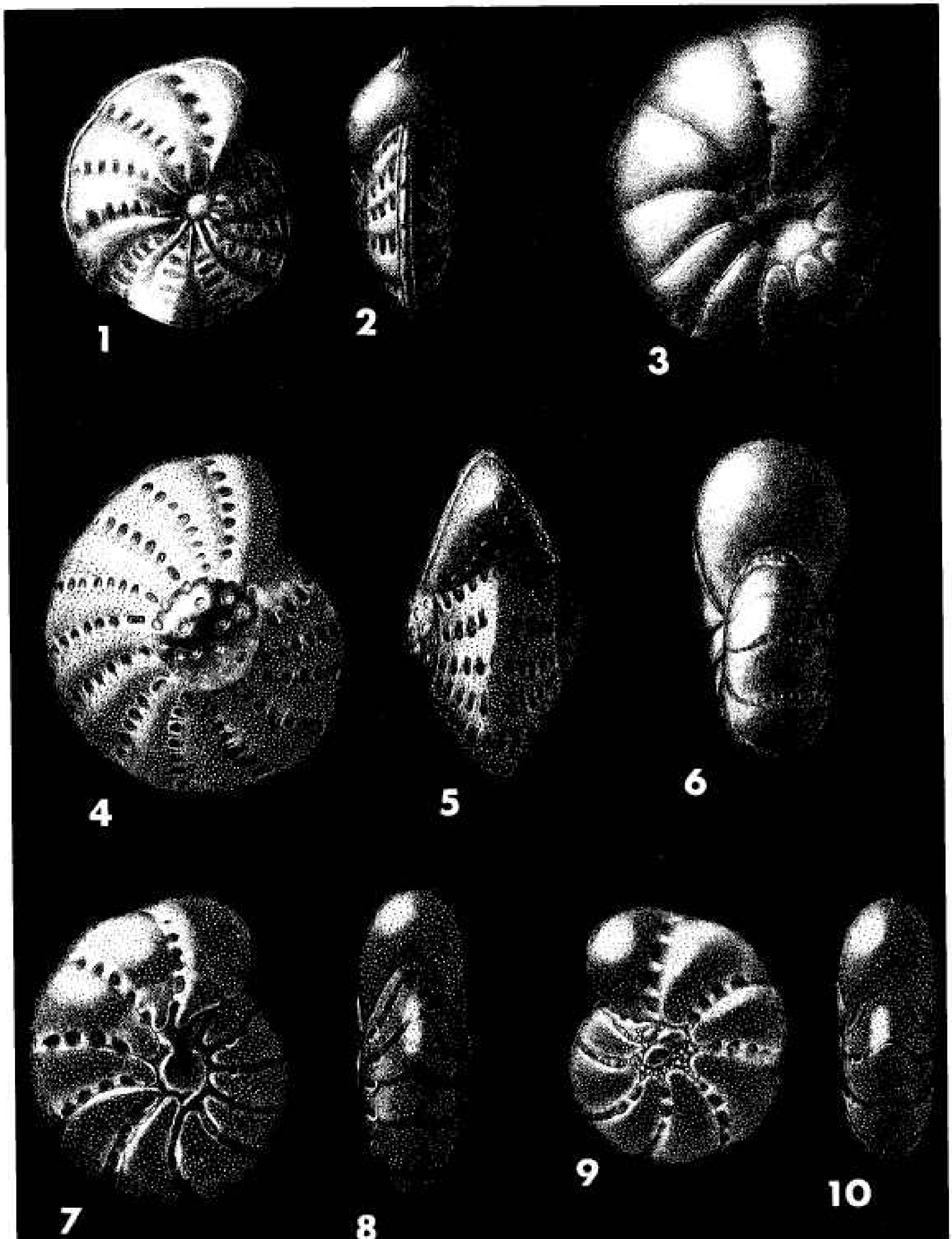
FIGURE *6*—*1, 2, Elphidium advenum* (Cushman), holotype, Cushman Coll. 3281a, *1,* side view, *2,* front view, ×85. *3, 6, Elphidium bartletti* Cushman, holotype, USNM 26142, *3,* side view; *6,* front view ×65. *4, 5, Elphidium discoidale* (d'Orbigny), hypotype, Cushman Coll. 22815, *4,* side view; *5,*



front view, ×85. *7, 8, Elphidium excavatum* (Terquem) (*Elphidium clavatum* Cushman, holotype, Cushman Coll. 10403), *7,* side view; *8,* front view, ×85. *9, 10, Elphidium excavatum* (Terquem), topotype, USNM 365943, *9,* side view; *10,* front view, ×100.

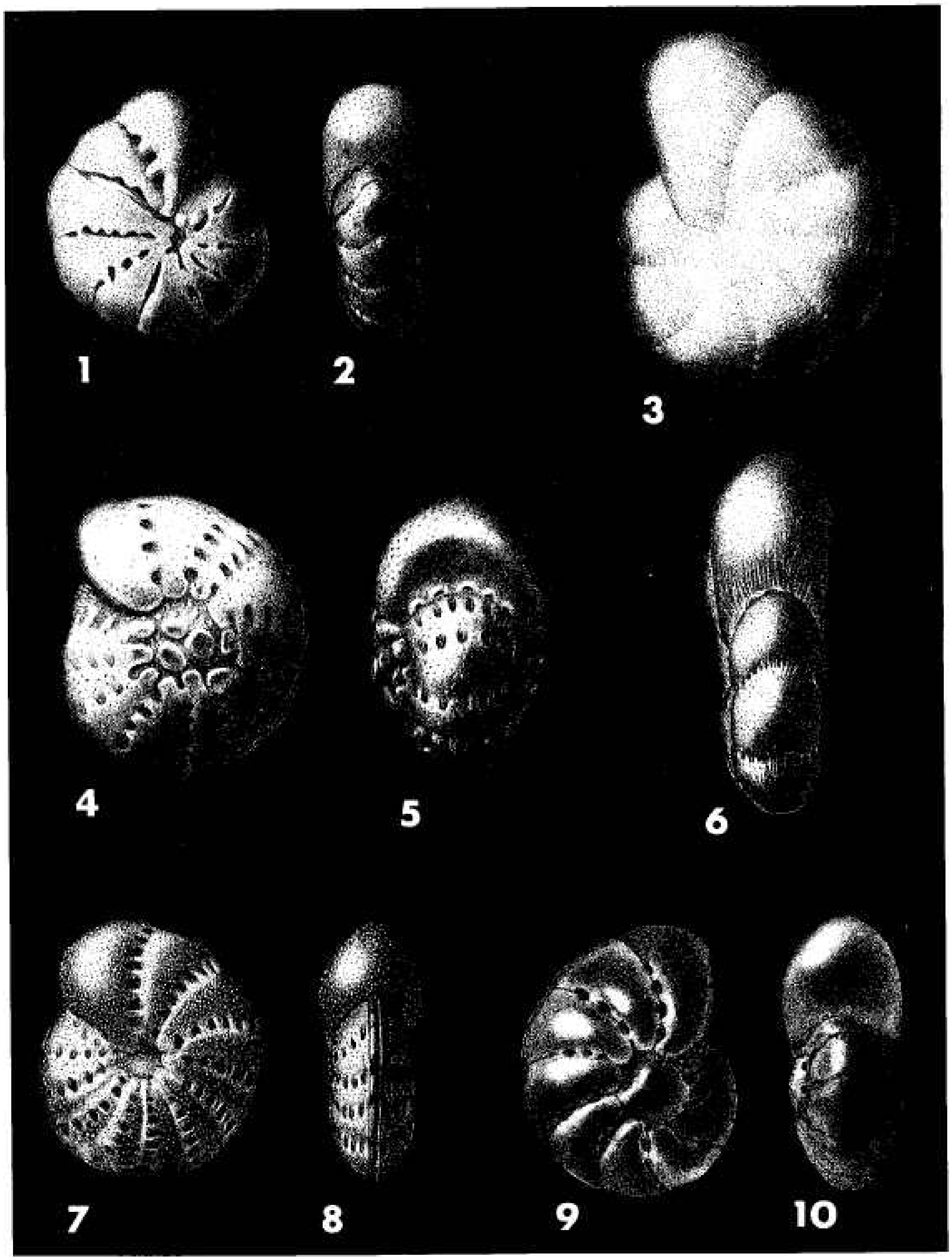


FIGURE 7—*1, 2, Elphidium excavatum* (Terquem), hypotype, USNM 365944, *1,* side view; *2,* front view, ×85. *3, 6, Elphidium frigidum* Cushman, holotype, USNM 26143, *3,* side view; *6,* front view, ×65. *4, 5, Elphidium gunteri* Cole, hypotype, USNM 365945, *4,* side view; *5,* front view, ×160. *7,*

E. excavatum. The classification procedure placed 3% of the specimens studied with *E. excavatum* from shallow water and 3% with *E. excavatum* from deep water. In general, *E. gunteri* has coarser pores than *E. excavatum,* better development of umbilical bosses, and a smaller gsd:l ratio (1.72:1 compared to 2.19:1 for *E. excavatum*).

All 30 of the specimens used in this study are from the Indian River, Florida. Although the primary types of this species are lost, erection of a neotype from the modern specimens used in this study would be inappropriate.

ELPHIDIUM MARGARITACEUM Cushman, 1930
Figures 7.7, 7.8

Elphidium advenum var. *margaritaceum* CUSHMAN, 1930, p. 25, Pl. 10, figs. 3a, 3b.

Remarks.—Cushman (1930) indicated that this species differs from *E. advenum* because it has coarser pores and a pearly appearance. The specimens used in this study do have coarser pores, and *E. margaritaceum* is optically radial, whilc *E. advenum* is optically granular.

Sixteen of the specimens used in this study come from Newport, R.I., nine are from Buzzards Bay, Mass., and five are from Vineyard Sound, Mass.

ELPHIDIUM MEXICANUM Kornfeld, 1931
Figures 7.9, 7.10

Elphidium incertum var. *mexicanum* KORNFELD, 1931, p. 89, Pl. 16, figs. 1, 2.

Remarks.—While the type material of this species has a single umbilical boss, Kornfeld (1931) stated the umbilicus was "... multiple or central." Most of the specimens used in the morphological group *E. mexicanum* have a single umbilical boss, while most of the specimens from the morphological group *E.* cf. *mexicanum* have several umbilical bosses. The umbilical area is also somewhat larger in the latter group. In other respects the two groups are quite similar, and we consider them to be the same species. Some of the specimens from the group *E. mexicanum* were on slides lodgcd in the U.S.N.M. collections and identified as *E. discoidale.* The misidentification probably occured because the specimens have a single umbilical boss. *E. discoidale,* however, has a much more angular periphery, coarser pores, and is optically radial, whereas *E. mexicanum* is optically granular.

Five of the specimens in the group *E. mexicanum* are from the Gulf of Mexico, 13 are from off Jacksonville, Florida, and 12 are from off Cape Canaveral, Fla. All 30 of the specimens in the group *E.* cf. *mexicanum* are from the Indian River, Florida.

ELPHIDIUM SUBARCTICUM Cushman, 1944
Figures 8.1, 8.2

Elphidium subarcticum CUSHMAN, 1944, p. 27, Pl. 3, figs. 34a, b, 35.

Remarks.—Most of the spccimens used in this study have the characteristic opaque band on either side of the sutures. The only other species that occasionally exhibit this fcature are *E. bartletti,* and *E. frigidum. E. bartletti,* however, has greater thickness, and *E. frigidum* has a protruding final chamber that sometimes has minute grooves.

Twenty-one specimens came from off Point Barrow, Alaska, one from Diska Island, Greenland, two from Lyon Inlet, Melville Peninsula, and six from Frobisher Bay, Baffin Island.

ELPHIDIUM WILLIAMSONI Haynes, 1973
Figures 8.3, 8.6

Elphidium williamsoni HAYNES, 1973, p. 207–209, Pl. 24, fig. 7, Pl. 25, figs. 6, 9, Pl. 27, figs. 1–3.

Remarks.—In the analysis of the 14 groups, *E. williamsoni*'s mean canonical variate on the third axis lies very close to *E. excavatum* (deep), and *Haynesina germanica.* This was surprising because these two species havc fewer chambers and fewer or no sutural bridges. Nevertheless, we performed another analysis on these three species which showed, as we expected, that these species are distinct. Many

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8, Elphidium margaritaceum Cushman, holotype, Cushman Coll. 10227, *7,* side view; *8,* front view, ×85. *9, 10, Elphidium mexicanum* Kornfeld, hypotype, Cushman Coll. 51269, *9,* side view; *10,* front view, ×160.

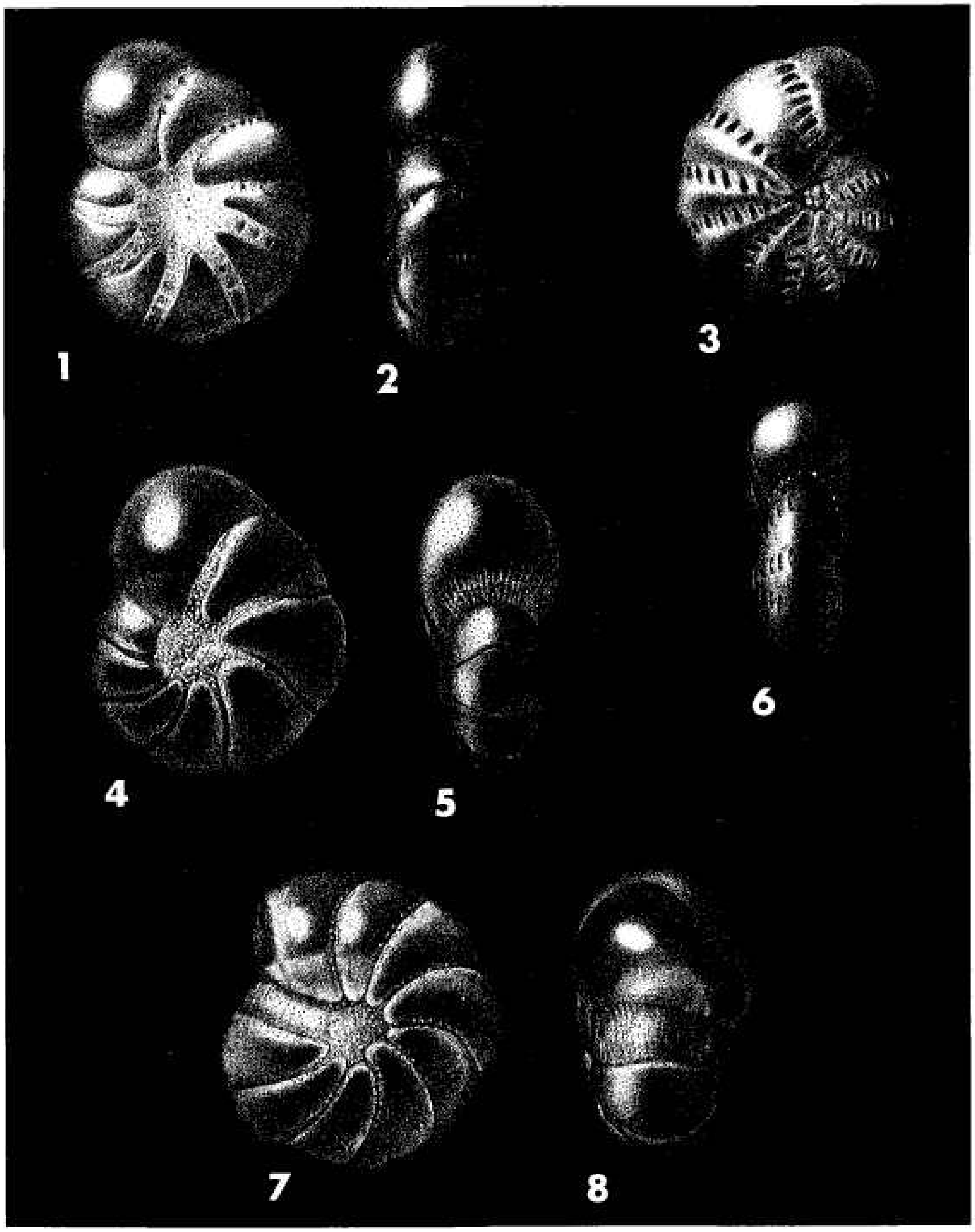

FIGURE 8—*1, 2, Elphidium subarcticum* Cushman, holotype, Cushman Coll. 40995, *1,* side view; *2,* front view, ×65. *3, 6, Elphidium williamsoni* Haynes, hypotype, USNM 365946, *3,* side view; *6,* front view, ×85. *4, 5, Haynesina germanica* (Ehrenberg), hypotype, USNM 365947, *4,* side view; *5,* front view, ×135. *7, 8, Haynesina orbiculare* (Brady), hypotype, USNM 365948, *7,* side view; *8,* front view, ×85.

of the specimens labelcd *E. excavatum* in the collections of the U.S. National Museum of Natural History are actually *E. williamsoni.* This is so because researchers were unaware that *E. excavatum* is what was commonly called *E. clavatum* in the U.S.A. Of the groups studied here *E. williamsoni* is probably most easily confused with *E. margaritaceum.* The latter, however, has a more angular periphery and often has a sugary texturc.

All 30 of the specimens used in this study are from Hommocks Marsh, Long Island.

HAYNESINA GERMANICA (Ehrenberg, 1840)
Figures 8.4, 8.5

Nonionina germanica EHRENBERG, 1840, p. 23; EHRENBERG, 1841, Pl. 2, figs. 1a–g.
Nonion tisburyensis BUTCHER, 1948, p. 22. figs. 1–3.
Protelphidium anglicum MURRAY, 1965, p. 149–150, Pl. 26, figs. 1–6.
Haynesina germanica (Ehrenberg), BANNER AND CULVER, 1978, p. 191–195, Pl. 4, figs. 1–6, Pl. 5, figs. 1–8, Pl. 6, figs. 1–7, Pl. 7, figs. 1–6, Pl. 8, figs. 1–10, Pl. 9, figs. 1–11, 15, 18.

Remarks.—*H. germanica* and *H. orbiculare* are the only two species studied here that lack sutural bridges. *H. germanica* can be confused with *H. orbiculare,* but the latter has a much greater thickness.

All 30 of the specimens used in this study are from subrecent sediments from Swansea Bay, South Wales, U.K.

HAYNESINA ORBICULARE (Brady, 1881)
Figures 8.7, 8.8

Nonionina orbicularis BRADY, 1881a, p. 105, Pl. 2, figs. 5a, b; BRADY, 1881b, p. 415, Pl. 21, figs. 5a, b; BRADY, 1884, p. 727, Pl. 109, figs. 20a, b, 21.

Remarks.—Like *H. germanica,* this species lacks sutural bridges. Its rounded profile and great thickness makes it aptly named. The considerable development of granular material on the first chamber of the final whorl is typical of this species, and is well shown by the specimen figured by Brady (1884, Pl. 109, figs. 20a, b) and designated as the lectotype of this species by Banner and Culver (1978).

All 30 of the specimens studied are from Ungava Bay, Qucbec.

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