A COMPARISON OF FOURTEEN ELPHIDIID (FORAMINIFERIDA) TAXA

MARTIN A. BUZAS,1 STEPHEN J. CULVER2 AND LAWRENCE B. ISHAM1
1Department of Paleobiology, Smithsonian Institution, Washington, D.C. 20560
2Department of Geophysical Sciences, Old Dominion University, Norfolk, Virginia 23508

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 studied in great detail over the past 50 or so years, disagreement still exists over the specific 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 one 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-
give us some idea of strong similarities among
groups. Figures 1 and 3 indicate a strong simi-
larity 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 Haynes-
ina 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 mem-
bership. 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 place-
ment 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. mex-
icanum (8), and E. cf. mexicanum (9). The
second category consists of E. margarita-
ceum (7), E. excavatum (14), 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 ger-
manica (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 sub-
sets.

The canonical variate analysis for Elphi-
dium bartletti, E. frigidum, and E. subarcti-
cum 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 ca-
nonical variates. Table 8 lists the eigenvalues
and the percent of the variability they ac-
count 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 dis-
riminant function coefficients shown in Ta-
ble 10 indicate that length (thickness) of the
test is the most discriminating variable fol-
lowed by the spiral diameter at 90 degrees to
gsd.
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-
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. Komfeld'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-
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.

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

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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CENOZOIC ELPHIDIID FORAMINIFERA

front view, x85. 7, 8, Elphidium excavatum (Terquem) (Elphidium clavatum Cushman, holotype, Cushman Coll. 10403); 7, side view; 8, front view, x85. 9, 10, Elphidium excavatum (Terquem), topotype, USNM 365943; 9, side view; 10, front view, x100.
Figure 7—1, 2, Elphidium excavatum (Terquem), hypotype, USNM 365944, 1, side view; 2, front view, x85. 3, 6, Elphidium frigidum Cushman, holotype, USNM 26143, 3, side view; 6, front view, x65. 4, 5, Elphidium gunteri Cole, hypotype, USNM 365945, 4, side view; 5, front view, x160. 7.


Elphidium 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, fgs. 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, while *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 KORNFIELD, 1931, p. 89, Pl. 16, fgs. 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 lodged in the U.S.N.M. collections and identified as *E. discoïdale*. The misidentification probably occurred because the specimens have a single umbilical boss. *E. discoïdale*, 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, fgs. 34a, 3b, 35.

Remarks.—Most of the specimens used in this study have the characteristic opaque band on either side of the sutures. The only other species that occasionally exhibit this feature 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, PI. 24, fig. 7, Pl. 25, fgs. 6, 9, Pl. 27, fgs. 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 have 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
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 labeled *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 texture.

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.


*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. orbicularare* are the only two species studied here that lack sutural bridges. *H. germanica* can be confused with *H. orbicularare*, 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, Quebec.

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