14. FORAMINIFERS

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METHODS

Samples from the borings Solberga, Moltemyr, and Brastad were treated for foraminiferal analysis mainly according to the laboratory methods described by Feyling-Hanssen *et al.* (1971) and by Meldgaard and Knudsen (1979). Between 10 and 100 g sediment (dry weight) were distintegrated in a 5–10% solution of hydrogen peroxide (H_2O_2). The disintegrated samples were washed through two sieves with mesh diameters of 0.1 and 1.0 mm. Foraminifera in the size fraction 0.1 to 1.0 mm were concentrated by means of a heavy liquid made of ethylene dibromide ($C_2H_4Br_2$) mixed with absolute alcohol (C_2H_5OH) to a specific gravity of 1.75 g/ccm.

For quantitative analyses of foraminiferal faunas at least 300 specimens were counted from each sample when possible, and the percentage frequencies of selected taxa of foraminifers are illustrated by symbols in the range charts. In samples with few foraminifers the entire content was analysed. When a sample contained less than 100 specimens the percentages were not calculated, and the occurrences of species are entered in the range chart by their actual number.

The faunal diversities, defined by Walton (1964) as the number of ranked species that accounts for 95% of a counted fauna, are shown to the right in the range chart together with the number of species in the samples and the number of specimens in 100 g sediment.

For the diagrams showing percentages of Boreal elements in the faunas, the following species are included: *Ammonia batavus* (Hofker), *Buccella frigida* (Cushman), var. *calida* (Cushman & Cole), *Bulimina marginata* d'Orbigny, *Buliminella elegantissima* (d'Orbigny), *Cassidulina laevigata* d'Orbigny, *Eggerella scabra* (Williamson), *Elphidium albiumbilicatum* (Weiss), *E. gerthi* van Voorthuysen, *E. guntheri* Cole, *E. incertum* (Williamson), *E. magellanicum* Heron-Allen & Earland, *E. margaritaceum* Cushman, *E. voorthuyseni* Haake, *E. williamsoni* Haynes, *Jadammina polystoma* Bartenstein & Brand, *Nonion germanicum* (Ehrenberg), *Trochammina ochracea* (Williamson), *Uvigerina peregrina* Cushman and *Virgulina fusiformis* (Williamson).

The three forms of *Elphidium excavatum* (Terquem), the mainly Arctic forma *clavata* Cushman, the Boreal-Arctic forma *alba* Feyling-Hanssen and the mainly Boreal forma *selseyensis* (Heron-Allen & Earland), (see Feyling-Hanssen 1972a), are not counted separately in the present faunas. The dominance of one of these forms in proportion to the others in the faunas is estimated and shown by symbols in the frequency column, and the Boreal element represented by *E. excavatum,* forma *selseyensis* is therefore not included in the diagrams.

The foraminiferal "zones" described in the present work are assemblage zones, according to the definition given by Hedberg (1976). The term "zone" is used for the purpose of brevity.

FORAMINIFERAL ZONES AND PALAEOECOLOGY

SOLBERGA

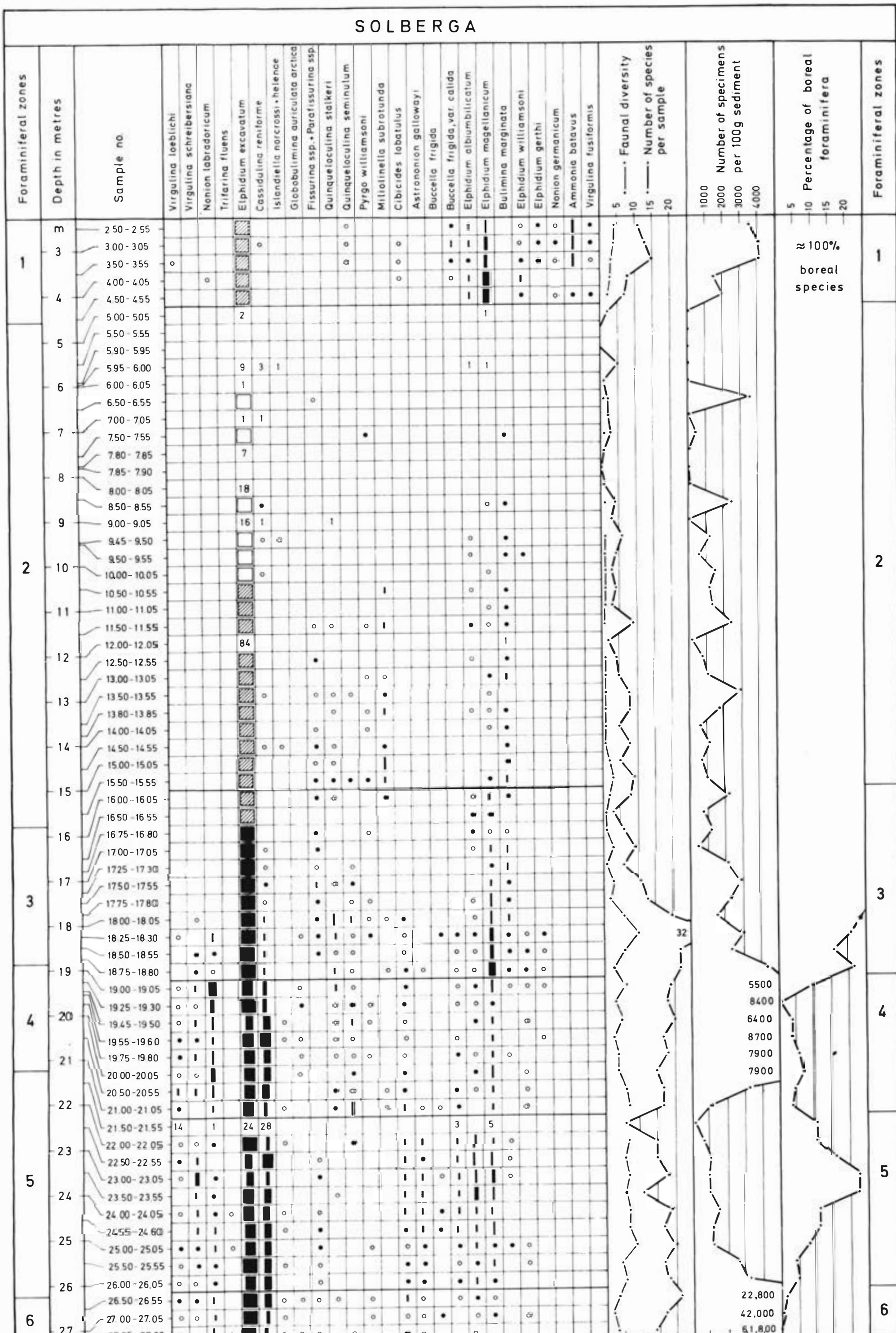
The marine sequence of the Solberga core is subdivided into 6 foraminiferal faunal zones shown in Fig. 14:1.

In the three lowest zones (zones 6, 5 and 4) the two dominant species are *Elphidium excavatum* and *Cassidulina reniforme.* Most specimens of *Elphidium excavatum* occur as the Arctic forma *clavata,* (see Feyling-Hanssen 1972a), but specimens of the mainly Boreal forma *selseyensis* are also found. The composition of these faunas indicates mainly arctic marine-ecological conditions, but there is a varying content of Boreal species. The dominance of *Elphidium excavatum* in all the faunas indicates that the water was ice-free, at least during the summer (Vilks 1970, Vilks and Mudie 1978).

The foraminiferal faunas of zone 6 indicate high-arctic marine-ecological conditions. The content of Boreal species does not exeed 2% and the faunal diversity is low (2–4). The very high number of specimens per 100 g sediment presumably indicates a low rate of sedimentation.

In zone 5 there is a pronounced increase in faunal diversity (5–9) and in content of Boreal species compared to zone 6. In two samples the percentages of Boreal species are as high as 23% of the total faunas. The most common Boreal species in zone 5 are *Elphidium albiumbilicatum, Elphidium magellanicum* and the Boreal forma *calida* of *Buccella frigida.* The decrease in number of specimens per 100 g sediment through zone 5 is suggested to reflect a higher rate of sedimentation during the milder period. A foraminiferal fauna from zone 5 is shown in Fig. 14:3.

In zone 4 the faunal diversity is slightly lower than in zone 5, and the influence of Boreal species in the faunas has decreased to between 1 and 7%. There is, however, an increase to 10% of boreal species in the uppermost sample. The most common boreal species in zone 4 is *Elphidium*


SOLBERGA
Foraminiferal zones
Depth in metres
Sample no.
Virgulina loeblichi
Virgulina schreibersiana
Nonion labradoricum
Trifarina fluens
Elphidium excavatum
Cassidulina reniforme
Islandiella norcrossi + helenae
Globobulimina auriculata arctica
Fissurina ssp. + Parafissurina ssp.
Quinqueloculina stalkeri
Quinqueloculina seminulum
Pyrgo williamsoni
Miliolinella subrotunda
Cibicides lobatulus
Astrononion gallowayi
Buccella frigida
Buccella frigida, var. calida
Elphidium albiumbilicatum
Elphidium magellanicum
Bulimina marginata
Elphidium williamsoni
Elphidium gerthi
Nonion germanicum
Ammonia batavus
Virgulina fusiformis
Faunal diversity
Number of species per sample
Number of specimens per 100g sediment
Percentage of boreal foraminifera
≈100% boreal species
m
2.50-2.55
3.00-3.05
3.50-3.55
4.00-4.05
4.50-4.55
5.00-5.05
5.50-5.55
5.90-5.95
5.95-6.00
6.00-6.05
6.50-6.55
7.00-7.05
7.50-7.55
7.80-7.85
7.85-7.90
8.00-8.05
8.50-8.55
9.00-9.05
9.45-9.50
9.50-9.55
10.00-10.05
10.50-10.55
11.00-11.05
11.50-11.55
12.00-12.05
12.50-12.55
13.00-13.05
13.50-13.55
13.80-13.85
14.00-14.05
14.50-14.55
15.00-15.05
15.50-15.55
16.00-16.05
16.50-16.55
16.75-16.80
17.00-17.05
17.25-17.30
17.50-17.55
17.75-17.80
18.00-18.05
18.25-18.30
18.50-18.55
18.75-18.80
19.00-19.05
19.25-19.30
19.45-19.50
19.55-19.60
19.75-19.80
20.00-20.05
20.50-20.55
21.00-21.05
21.50-21.55
22.00-22.05
22.50-22.55
23.00-23.05
23.50-23.55
24.00-24.05
24.55-24.60
25.00-25.05
25.50-25.55
26.00-26.05
26.50-26.55
27.00-27.05
27.25-27.30
32
5500
8400
6400
8700
7900
7900
22,800
42,000
61,800

magellanicum. The faunas of zone 4 thus indicate colder marine-ecological conditions than in zone 5. The high frequencies of *Nonion labradoricum*, especially in the upper part of zone 4, together with high frequencies of *Cassidulina reniforme* indicate normal marine salinity conditions during deposition. These two species do not tolerate lowered salinity, and they are usually infrequent with water depths of less than about 20 m (Nagy 1965, Buzas 1965). An increased number of specimens per 100 g sediment in zone 4 compared to zone 5 may be a result of lower sedimentation rate during the colder period.

There is a remarkable and sudden change in faunal composition from zone 4 into zone 3, *i.e.* between the samples 19.00–19.05 m and 18.75–18.80 m. The frequency of *Nonion labradoricum* decreases from 21% in the uppermost sample of zone 4 to <0.5–2% in the lower part of zone 3. At the same level the percentages of *Cassidulina reniforme* also decrease distinctly to about 2–4% in the lower part of zone 3. These two species are absent in the upper part of zone 3. At the transition from zone 4 to zone 3 there is a pronounced increase in content of Boreal species, especially of *Elphidium magellanicum*. The faunal change can be interpreted as reflecting a climatic amelioration which caused a sudden increase in the supply of fresh meltwater to the area. The normal marine species disappear from the faunas, and the boreal *Elphidium magellanicum*, which seems to tolerate lowered salinity, takes over. A foraminiferal fauna from the lower part of zone 3 is shown in Fig. 14:4.

The faunal diversity and the number of species decrease towards the

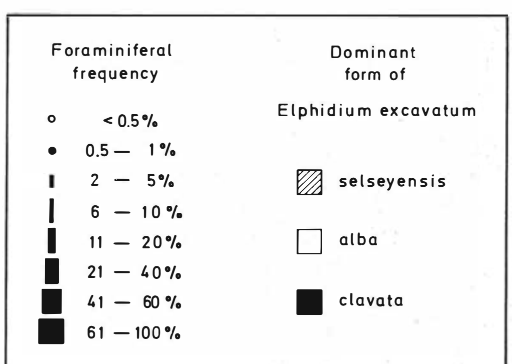


Fig. 14:2. Legend for the range charts in Figs. 14:1, 6 and 7.

Fig. 14:1. Range chart for Solberga core. Legend for foraminiferal frequencies and for forms of *Elphidium excavatum* in Fig. 14:2.

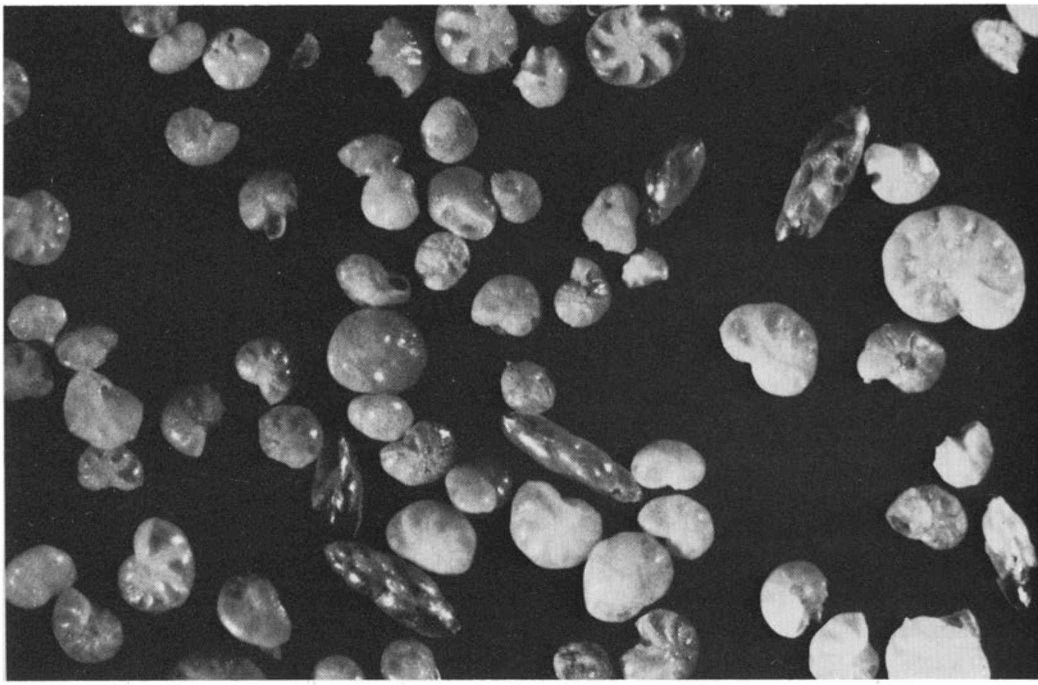


Fig. 14:3. Foraminiferal fauna from Solberga zone 5 (23.00–23.05 m). This is a mainly Arctic fauna with *Elphidium excavatum,* f. *clavata, Cassidulina reniforme* and *Virgulina schreibersiana* as the most common species, but there is a strong influence of Boreal species as *Elphidium albiumbilicatum* and *E. magellanicum* in the fauna. x 40.

upper part of zone 3, and in this part of the zone *E. excavatum* becomes extremely dominant. A change in dominant form of *E. excavatum* from the Arctic forma *clavata* to the Boreal forma *selseyensis* in the upper part of zone 3 suggests a continuing rise in temperature during deposition of this zone. As the different forms of *E. excavatum* are not included in the calculation of Boreal content in faunas, it has not been possible to indicate Boreal content for the faunas of zones 3 and 2 in Fig. 14:1.

The most common accessory species in zone 3 besides *Elphidium magellanicum* are the Boreal *Bulimina marginata* (<0.5–4%) and also *Quinqueloculina stalkeri* in the lower part of the zone. A decreasing number of specimens per 100 g sediment through zone 3 probably indicates an increasing rate of sedimentation during deposition.

The extreme ecological conditions indicated by the faunas in the upper part of zone 3 continued during deposition of zone 2, where the dominance of *Elphidium excavatum* is between 90 and 100%. The lower boundary of zone 2 is defined by the appearance of a few per cent of Miliolidae in the faunas. *Bulimina marginata* occurs in most faunas, but it usually only makes

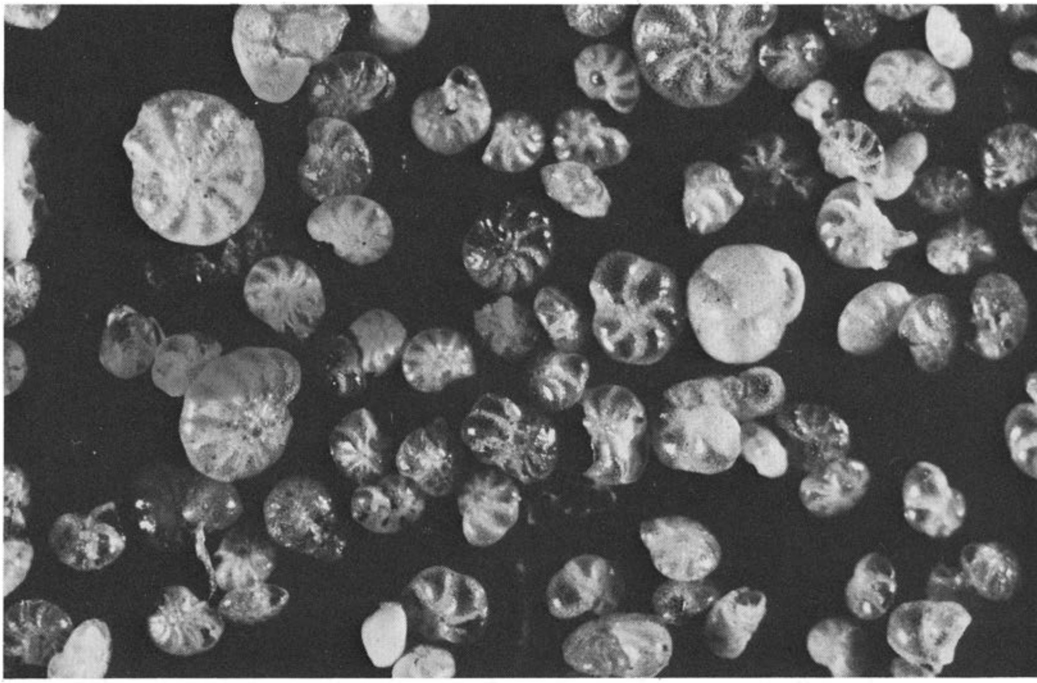


Fig. 14:4. Foraminiferal fauna from the lowermost sample of zone 3 in Solberga (18.75–18.80 m). The boreal species *Elphidium magellanicum* is frequent in this sample and dominates the fauna together with *Elphidium excavatum*, f. *clavata*. x 40.

up about 1% of the faunas. In the lower part of zone 2, *E. excavatum* occurs mainly as forma *selseyensis*, but specimens of forma *clavata* are also present. In a few samples in the upper part forma *alba* (Feyling-Hanssen 1972a) is the dominant form. The number of species and specimens is very low in the upper part of zone 2, and objective ecological interpretation is hardly possible although a continuing high rate of sedimentation seems probable. A great deal of the foraminiferal tests in the upper part of zone 2 are badly preserved and are often etched on the surface. Therefore the poor representation of foraminifers in samples from this part of the sequence may partly be due to postdepositional dissolution of shells in the sediment. A foraminiferal fauna from zone 2 is shown in Fig. 14:5.

The zone 1 faunas are typical Boreal shallow water faunas. *Elphidium excavatum,* forma *selseyensis* dominates, and the most important accessory species *Elphidium magellanicum, E. albiumbilicatum, E. williamsoni,* and *Ammonia batavus* all occur in Boreal shallow water areas. The low faunal diversity (2–4) indicates extreme ecological conditions during deposition, and the limiting factor for these faunas was presumably shallow water.

Fig. 14:5. Foraminiferal fauna from Solberga zone 2 (13.80–13.85 m) with a very high dominance of one species, *Elphidium excavatum*. It occurs mainly as forma *selseyensis*, but also as forma *clavata*. x 40.

MOLTEMYR

The marine sequence of the Moltemyr core is subdivided into 4 foraminiferal faunal zones, zones K, L, M, and N (Fig. 14:6). *Elphidium excavatum* is the dominant species in most samples. In the two lower zones this species occurs mainly as the arctic forma *clavata*, but specimens of the mainly Boreal forma *selseyensis* also occur, especially in zone M. The *selseyensis* form of *E. excavatum* is the most frequent one in zones L and K.

The foraminiferal faunas of zone N indicate high-arctic marine-climatic conditions. There is a very high dominance of the Arctic forma *clavata* of the species *Elphidium excavatum* together with frequent occurrences of *Cassidulina reniforme*, and a faunal diversity of only 3 indicates severe conditions. The content of Boreal specimens is less than 1% in zone N.

In zone M there is a pronounced increase in Boreal content of the faunas, the most common Boreal species being *Elphidium magellanicum, E. albiumbilicatum, E. williamsoni*, and *Nonion germanicum*. The maximum percentage of Boreal specimens is 41 in sample 430 cm from the middle part of the zone, and in the upper part the boreal content decreases again to 13–19% of the total faunas. Faunal diversities also reach maximum values in the middle part of this zone. The marine-climatic indication of foraminiferal faunas in zone M thus suggests a change from the high-arctic conditions of zone N to a relatively mild period with gradually increasing temperatures and a return to cooler conditions in the later part. All the faunas of zone M must be characterized as Boreal-Arctic.

There is a marked change in faunal composition from zone M to zone L, all the typical Arctic species disappearing from the faunas. The most frequent form of the dominant species *Elphidium excavatum* is the Boreal forma *selseyensis,* and the most common accessory species are the Boreal *Elphidium magellanicum* and *Nonion germanicum,* a few *E. albiumbilicatum* and *E. williamsoni,* and, in the upper part of the zone, also *E. incertum.* The low faunal diversities suggest extreme marine-ecological conditions during deposition of zone L. The water was probably shallower, and the influence of freshwater was probably higher than in the two lower zones of the Moltemyr core. The conditions during deposition of zone L must be characterized as Boreal.

The foraminiferal faunas of zone K indicate boreal shallow and brackish water conditions. Typical species are *Elphidium excavatum* (as the Boreal forma *selseyensis*), *Nonion germanicum, E. williamsoni, E. incertum,* and *E. magellanicum,* and in the upper part of the zone other additional Boreal shallow water species such as *E. albiumbilicatum* and *Ammonia batavus.* The low faunal diversities in most of zone K indicate extreme marine-ecological conditions, the limiting factor in this case presumably being shallow and brackish water. The higher diversities of the uppermost samples seem to be due to reworking of foraminiferal tests from older sediments. One sample (255.4–258.1 cm) from zone K did not contain any foraminifers. This might indicate a temporary regression previous to the final regression of the area, but etching of the tests by acid ground water seems also to have occurred in the zone K faunas.

BRASTAD

The marine sequence of the Brastad core is subdivided into 4 foraminiferal faunal zones, zones A–D (Fig. 14:7). *Elphidium excavatum* is the dominant species through all the zones, and *Cassidulina reniforme* is second in number.

The faunal compositions of the Brastad core indicate mainly arctic marine-ecological conditions, but there is a varying content of Boreal species in the faunas. The dominant form of *Elphidium excavatum* is the Arctic forma *clavata* through all zones, but specimens of the mainly Boreal forma *selseyensis* also occur.

In zone D there is high dominance of *Elphidium excavatum,* forma

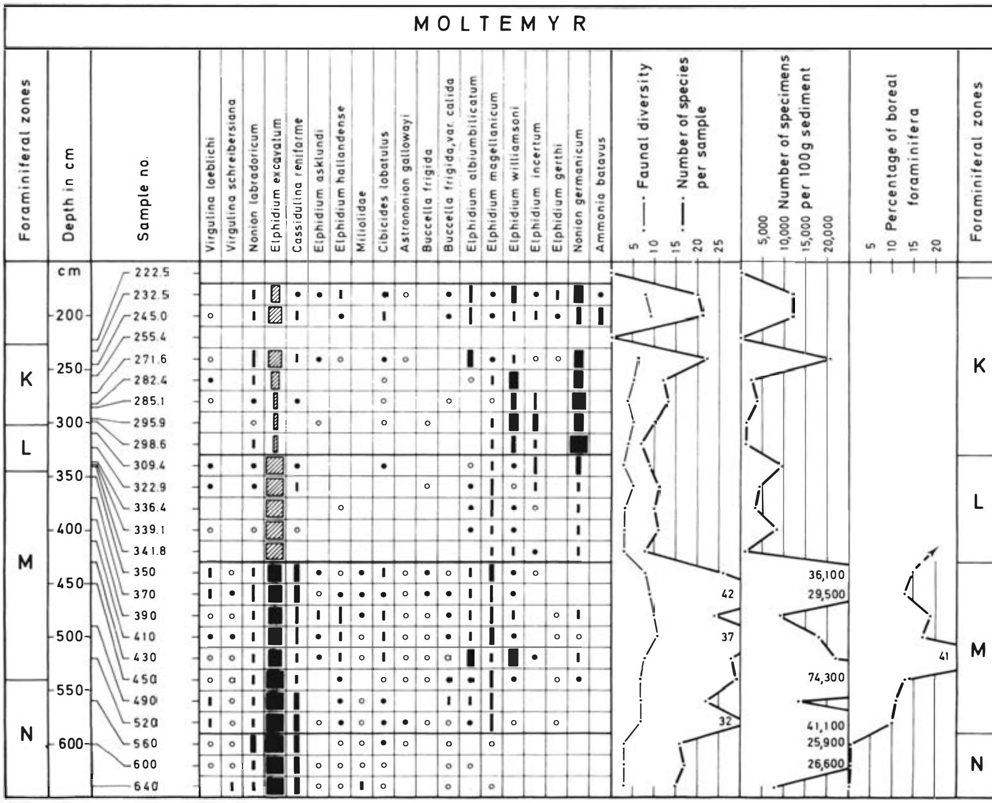


Fig. 14:6. Range chart for the Moltemyr boring. The sample numbers indicate the upper limits of sample intervals. These are about 2.5 cm in the upper part of the core, 5 cm for samples between 350 cm and 450 cm depth, and 10 cm in the lowermost part from 450 cm to 650 cm depth. Legend for foraminiferal frequencies and for forms of *Elphidium excavatum* in Fig. 14:2.

clavata, together with a varying amount of *Cassidulina reniforme.* The faunas indicate high-arctic environment, and the low faunal diversities (2–3) indicate extreme ecological conditions. The number of specimens per 100 g sediment is very low in the lower part of zone D, but increases upwards together with an increase in number of species and in percentages of *Cassidulina reniforme* and *Nonion labradoricum.* These faunal changes may demonstrate a transition to more normal marine conditions, and perhaps also to deeper water. The boreal influence in zone D faunas is very low. Only a few poor faunas in the lowermost part of the marine sequence contain some specimens of Boreal species, but the numbers of specimens in these samples are too low to allow reliable conclusions to be drawn. A foraminiferal fauna from zone D is shown in Fig. 14:8.

The faunal composition in zone C also indicates arctic marine-ecological conditions, but the rather high frequencies of *Nonion labradoricum* and

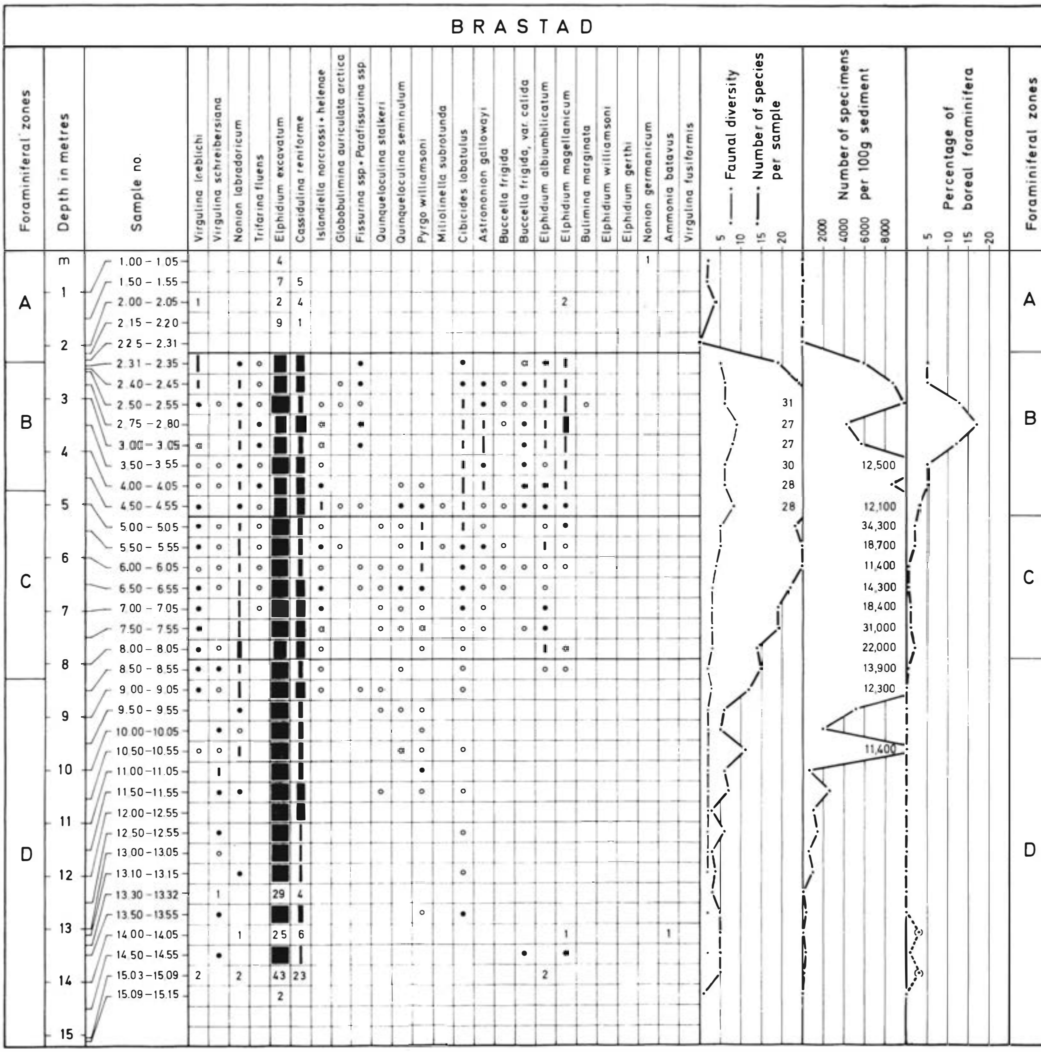


Fig. 14:7. Range chart for Brastad core. Legend for foraminiferal frequencies and for forms of *Elphidium excavatum* in Fig. 14:2.

Cassidulina reniforme in the faunas may indicate normal marine salinities during deposition in the area. Faunal diversities are low in zone C, but they increase slightly towards the upper part. The number of species also becomes gradually higher, and the uppermost samples contain a few per cent of Boreal species in addition to the Arctic ones. The high number of specimens per 100 g sediment in zone C probably indicates low rate of sedimentation during this cold period.

In zone B there is a distinct increase in faunal diversity and in number of species compared to zone C. The increase in content of Boreal species, which started in the uppermost part of zone C, continues in zone B to reach a maximum of 17% in sample 2.75–2.80 m. The boreal content decreases again to 5% in the upper two samples of zone B. The present faunal composition thus indicates amelioration during deposition of zone B. The most common Boreal species in the faunas are *Elphidium albiumbilicatum* and *E. magellanicum* and the Boreal forma *calida* of *Buccella frigida.* The lower number of specimens in zone B compared to zone C may indicate a higher rate of sedimentation during the milder period, and the decrease in frequency of *Nonion labradoricum,* together with an increase in *Elphidium albiumbilicatum* and *E. magellanicum,* probably also reflect a slight decrease in salinity. As mentioned, there are indications of cooling again in the uppermost part of zone B.

Zone A is very poor in foraminifers. The species are broadly the same as in the preceeding zones, but the faunas are much too poor to allow any attempt at ecological interpretations. The specimens may have been reworked from older marine deposits.

CORRELATIONS

A biostratigraphical correlation between the foraminiferal zones in Solberga, from the southern part of the area, and in Moltemyr and Brastad, from the northern part of the area, has been attempted (Fig. 14:9), and the faunas have been compared with corresponding faunas described from adjacent areas.

SOLBERGA, MOLTEMYR AND BRASTAD

Zone 6 in Solberga, which contains high-Arctic faunas, seems to be correlatable with zone N of the Moltemyr core and with the two high-Arctic zones C and D in Brastad. According to the palaeomagnetic results zone D in Brastad is probably not represented in Solberga (see Chapter 11).

In all three cores these zones with high-Arctic faunas are followed by zones with faunal indications of ameliorated conditions, viz., zone 5 in Solberga, zone M in Moltemyr and zone B in Brastad.

The Arctic zone 4 in Solberga is not represented in Brastad, except maybe in the uppermost part of zone B, where a colder period seems to have just set in. This suggested correlation implies that there was a break in sedimentation between zone B and zone A in Brastad.

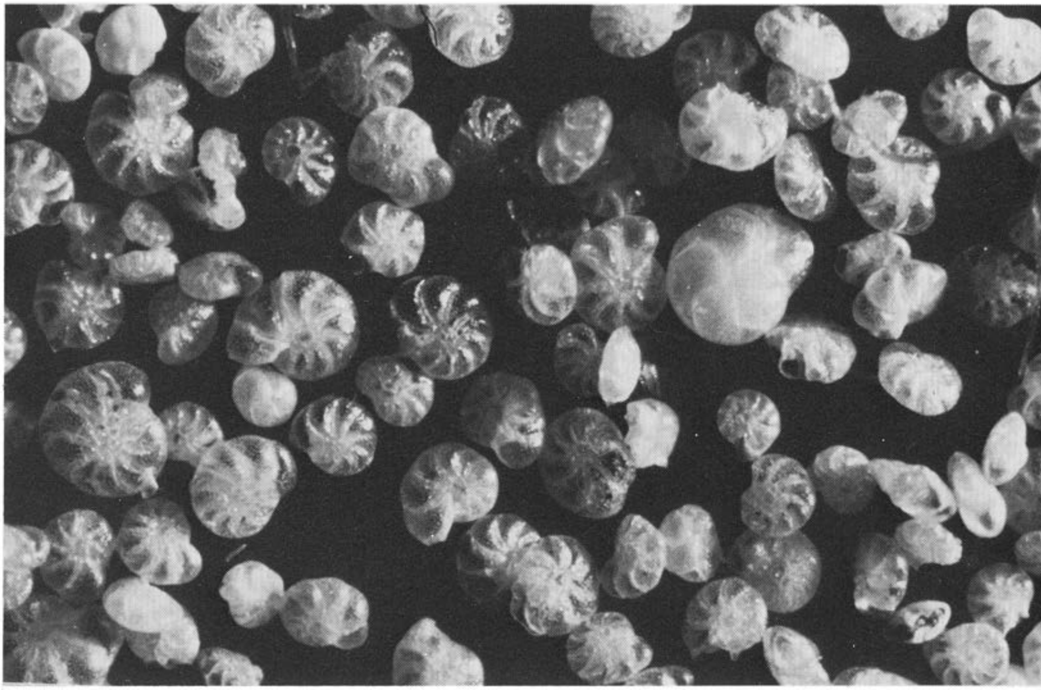


Fig. 14:8. Foraminiferal fauna from Brastad zone D (13.00–13.05 m). This high-Arctic fauna is dominated by only two species, *Elphidium excavatum*, f. *clavata* and *Cassidulina reniforme*. x 40.

The upper relatively cool part of zone M in the Moltemyr core may correspond to zone 4 in Solberga, but as a whole the faunas of zone M in Moltemyr seem to indicate milder conditions than zones 5 and 4 in Solberga. This may simply be a result of much shallower water at Moltemyr. Boreal foraminifers in the zone M faunas are also typical shallow water species.

Zone 3 in Solberga probably correlates with zone L in Moltemyr, and the later transition to real Boreal faunas with the *selseyensis* form of *Elphidium excavatum* at Solberga may also be explained as a consequence of deeper water in this area than in the Moltemyr area.

The faunal indication of the uppermost zone K in Moltemyr is close to that of zone 1 in Solberga. These faunas represent the shallowing of water preceeding the regressions in the respective areas.

The upper two zones at Moltemyr and the upper three zones of Solberga seem not to be represented in the Brastad core. Zone A in the Brastad core contains scarcely any foraminifers, and a biostratigraphical correlation with the Moltemyr and Solberga sequences is not possible.

ADJACENT AREAS

A comparison between the foraminiferal zones in Solberga, Moltemyr and Brastad and earlier described foraminiferal faunas from western Sweden has been made. It seems that a transition from the Arctic *Elphidium excavatum,* f. *clavata–Cassidulina reniforme* faunas to faunas without *C. reniforme* and some other Arctic species, but with an increasing amount of Boreal species, is characteristic for the whole area. This transition presumably represents the Pleistocene/Holocene boundary in this area.

A very uniform *E. excavatum* fauna is often found higher in the sequences, comparable with the upper part of zone 3 and zone 2 in Solberga. Such faunas indicate very extreme conditions and probably a high rate of sedimentation which might be a result of the high meltwater discharge into the Skagerrak.

TUVE

In Tuve core 18 there is a distinct faunal change at about 8 m depth (Fält 1981.) The Arctic *Elphidium excavatum–Cassidulina reniforme* faunas in the lower part of the core are followed by faunas with a pronounced increase in Boreal species. This faunal change can be correlated with the transition from zone 4 to zone 3 in Solberga, and the Pleistocene/Holocene boundary thus seems to be represented at 8 m depth in the Tuve 18 boring.

A corresponding change from *Elphidium excavatum–Cassidulina reniforme* faunas to Boreal faunas is also demonstrated by Fält (1977) in cores from Kattegat (about 80 m water depth) north-west of Gothenburg. The Pleistocene/Holocene boundary seems to be represented at about 3.5 m and 5.0 m depth in these borings.

BÄCKEBOL

In a core from Bäckebol the *Cassidulina reniforme* faunas are not represented at all (Klingberg 1977). The faunas with very high dominances of *Elphidium excavatum* in the lower part of the marine sequence at Bäckebol probably correlate with the zone 2 faunas of Solberga, and the Pleistocene/Holocene boundary is presumably not reached in that boring.

GOTHENBURG CORE B873

The foraminiferal faunas from core B873 in the Botanical Garden, Gothenburg show a remarkable change of faunal composition in the deeper part of the boring (Feyling-Hanssen and Knudsen 1976). After samples (113–111) with typical Arctic *Elphidium excavatum,* f. *clavata–Cassidulina*

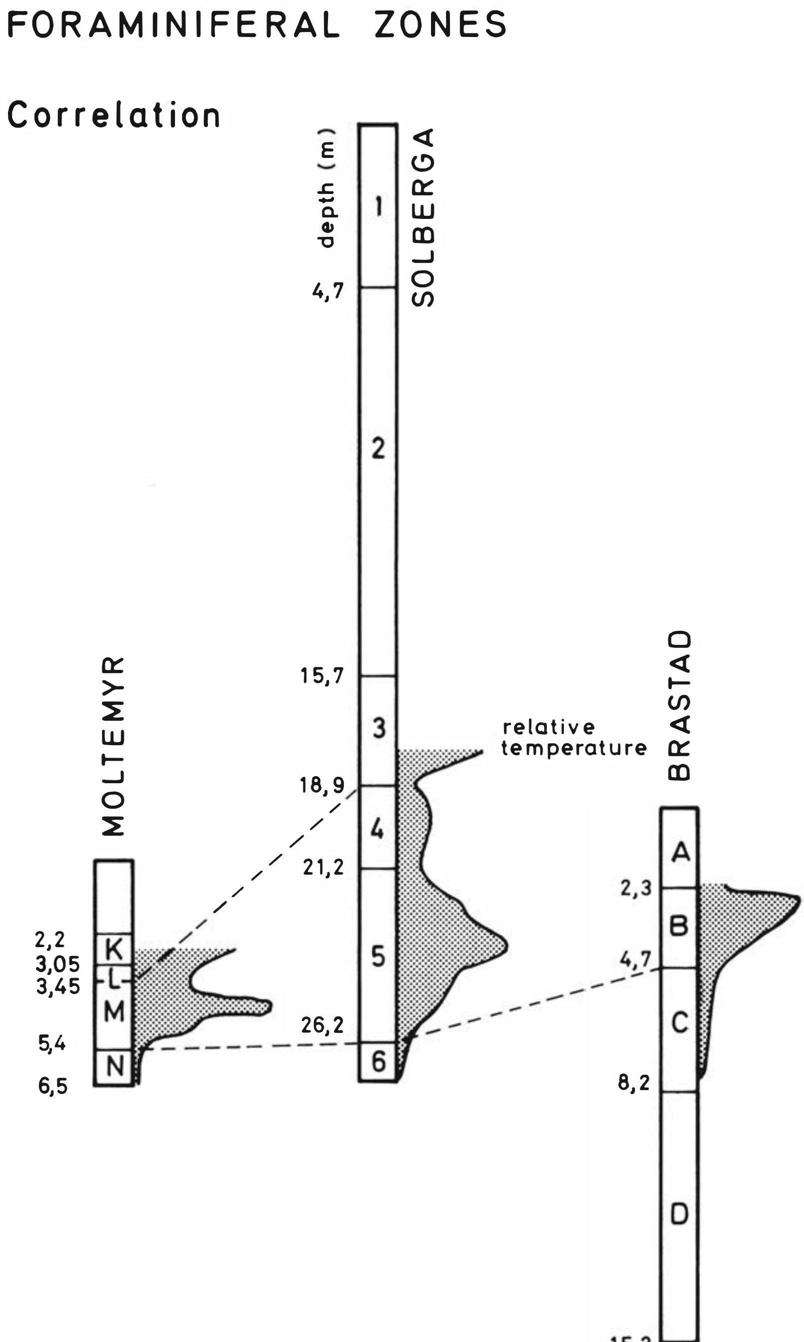


Fig. 14:9. Suggested biostratigraphical correlation between the foraminiferal zones in Solberga, Moltemyr and Brastad.

reniforme faunas follow two samples (110–109) with Boreal-Arctic to Boreal faunas above 13.5 m depth in the borehole. In 1976 this part of the sequence was placed in the Pleistocene, and the amelioration was suggested to represent an interstadial. The faunal indication could, however, just as well be interpreted as a late part of the Pleistocene, followed by the amelioration at the Pleistocene/Holocene boundary, as pointed out by Feyling-Hanssen and Knudsen (1976).

A correlation of the faunal change at 13.5 m depth in Gothenburg core B873 with the zone 4–zone 3 boundary in Solberga would lead to a tentative correlation between zone 2 in Solberga with its poor and very extreme faunas and the sequence without any foraminifers from 13.2 m to 2.5 m depth in Gothenburg. These sequences might represent a period of very rapid sedimentation, giving poor faunas at Solberga and no foraminiferal fauna at all at Gothenburg, such as the drainage of the Baltic Ice Lake and the discharge of meltwater into Skagerrak during the Preboreal times.

INGEBÄCK

By comparing the unpublished foraminiferal diagrams made by Brotzen (see also Brotzen 1961) from Ingebäck with the Solberga sequence, it seems most likely that the boundary between Brotzen's "Late Glacial I" and "Late Glacial II" at 35 m depth should be correlated with the boundary between zone 4 and zone 3 in Solberga. At that level *Cassidulina reniforme* and other Arctic species disappear from the faunas, and the interval from 35 m to 30 m in the Ingebäck boring seems to be correlatable with zone 3 in Solberga. The very uniform *Elphidium excavatum* faunas from 30 m to 15 m depth in Ingebäck points to a correlation with zone 2 in Solberga, and the upper 15 m contain Boreal shallow water faunas similar to the zone 1 faunas in Solberga. This correlation implies a Pleistocene/Holocene boundary deeper in the Ingebäck sequence than originally suggested, *i.e.* between "Late Glacial I" and "Late Glacial II" in Brotzen's zonation.

SURTE

A foraminiferal zonation of the marine sequence at Surte has been made by Brotzen (1951). He found a transition from Lateglacial to Postglacial faunas at the boundary between zone 4 b and zone 5, at 16 m depth. A comparison with the Solberga sequence seems to suggest a correlation of the zone 4 a–zone 4 b boundary in Surte with the zone 4–zone 3 boundary in Solberga. Such a correlation would imply that the Pleistocene/Holocene boundary might be represented at a lower level than Brotzen's Lateglacial-Postglacial boundary, *i.e.* between zone 4 a and zone 4 b at about 20 m depth.

DENMARK

The Arctic faunas in Solberga and Brastad correlate closely with foraminiferal faunas in Lateglacial deposits from Læsø (Michelsen 1967) and from Vendsyssel (Jørgensen 1971, Knudsen 1971 and 1978, Abrahamsen and Knudsen 1979). In some places in Vendsyssel a transition from high-Arctic faunas to Boreal-Arctic faunas is demonstrated in the sections, and radiocarbon dates show that the Boreal-Arctic faunas represent the Bølling Interstadial. There are similarities between the foraminiferal faunas in these deposits and the Boreal-Arctic faunas in zone 5 of Solberga, zone M in Moltemyr and zone B of Brastad, but this may, however, indicate corresponding environments rather than corresponding age. The Pleistocene/Holocene boundary is not represented in marine deposits of Vendsyssel.

NORWAY

The faunal change from zone 4 to zone 3 in Solberga and from zone M to zone L in Moltemyr is characterized by the change from *Elphidium excavatum,* f. *clavata–Cassidulina reniforme* faunas to faunas with Boreal species instead of Arctic ones.

A similar faunal change is described from the Late Quaternary deposits of the outer Oslofjord area (Feyling-Hanssen 1964) going from subzone B_l into subzone B_u. Subzone B_l is interpreted as having been deposited during stagnation of the ice margin at the Ås-Ski position and the deposition of subzone B_u is connected with the subsequent rapid melting from the Ås-Ski stage. New interpretations of radiocarbon dates from the Oslofjord area (Sørensen 1979) suggest that both the Ra ridges and the Ås-Ski moraines were formed during the Younger Dryas, and that the melting from the Ås-Ski position corresponds to the transition Younger Dryas–Preboreal. This interpretation implies that the boundary between the foraminiferal subzones B_l and B_u corresponds to the Pleistocene/Holocene boundary and not, as earlier suggested (Feyling-Hanssen 1964, 1972b), the transition from subzone A_m to subzone A_u where a similar faunal succession is seen.

Ormaasen (1977) described corresponding Arctic foraminiferal faunas from Late Quaternary deposits of the Larvik-Porsgrunn area. The zones were compared closely with the Oslofjord zones of Feyling-Hanssen (1964), and the Pleistocene/Holocene boundary in the area was discussed. Late Pleistocene and Holocene foraminiferal zones from borings in the North Sea and Kattegat were described by Moyes *et al.* (1974), who also closely correlated their zones with the Oslofjord zones and discussed the Pleistocene/Holocene boundary in the area.

SUGGESTED AGE

Based on the palaeoecological interpretations and the biostratigraphical correlations with Late Quaternary deposits in adjacent areas, a possible age of the zones in Solberga, Moltemyr and Brastad is suggested.

Assuming continuous sedimentation during deposition of the marine sequence of Solberga, there are obvious reasons to believe that the faunal indication of milder marine-ecological conditions and increase in influence of fresh meltwater at the biostratigraphical boundary between zone 4 and zone 3 corresponds to the major amelioration of climate at the Pleistocene/Holocene boundary. This would imply that zone 4 represents the cold chronozone Younger Dryas (see Mangerud *et al.* 1974), a suggestion which is also supported by the biostratigraphical correlation with subzone B_1 in the Oslofjord area. As a consequence the Boreal-Arctic zone 5 of Solberga would represent the earlier amelioration of the climate, the Allerød Interstadial, and zone 6 would represent the Older Dryas Stadial.

According to the biostratigraphical correlations between Solberga and Moltemyr, the boundary between zones M and L in Moltemyr may correspond to the Pleistocene/Holocene boundary, and the amelioration in zone M is suggested to reflect interstadial conditions, most likely the Allerød Interstadial. The Younger Dryas would thus be represented only by the upper part of zone M, and the Older Dryas by zone N.

Another possibility is that the Pleistocene/Holocene boundary is represented by the first faunal indication of a milder climate in the Moltemyr core. This would lead to a correlation of the biostratigraphical boundary between zone N and zone M with the Pleistocene/Holocene boundary.

In Brastad the amelioration in zone B could represent the Allerød Interstadial. The uppermost cold spell of zone B may belong in the Younger Dryas, and the two arctic zones C and D below zone B may represent the Older Dryas. The poor faunas with only a few Boreal specimens in the lower part of zone D could probably indicate another mild period, *i.e.* Bølling Interstadial, but the faunas are too poor to allow any convincing interpretation.

Zones 3, 2 and 1 in Solberga and zones K and L in Moltemyr thus seem to belong in the Holocene epoch, but it is not possible to give any closer suggestions as to the age of these zones on the basis of foraminiferal faunas. The zone 1 faunas of Solberga and the zone K faunas of the Moltemyr core cannot, however, be much different from present day shallow water faunas in that area.

CONCLUSIONS

The marine sequence of Solberga is divided into 6 foraminiferal assemblage zones (1–6). The faunas of the lower three zones (6, 5 and 4) indicate mainly arctic marine-ecological conditions with a distinct influence of Boreal species in the zone 5 faunas. There is a remarkable change in faunal composition from zone 4 to zone 3, *i.e.* just above 19.00 m depth in Solberga. This faunal change is interpreted as a result of higher temperature and of increasing supply of fresh meltwater to the area, and the biostratigraphical boundary between zone 4 and zone 3 may correspond to the Pleistocene/Holocene boundary. The amelioration seen in zone 5 could thus represent the Allerød Interstadial, with the Arctic faunas of the Older Dryas age below (zone 6) and of the Younger Dryas age above (zone 4).

The foraminiferal faunas of zones 3, 2 and 1 in Solberga contain faunas which reflect increasing temperature during deposition. The faunas of zone 2 indicate very extreme conditions probably caused at least partly by a high rate of sedimentation, and zone 1 contains typical Boreal shallow water faunas.

The marine sequence of the Moltemyr core is divided into 4 foraminiferal assemblage zones (K, L, M and N). The two lower zones (M and N) are characterized by mainly Arctic faunas, but in zone M there is a gradual change to Boreal-Arctic faunas and indications of cooler conditions again in the upper part of this zone. In zone L the Arctic species are absent, and the faunas in this zone and in zone K are Boreal, indicating gradually shallower water through the sequence. The biostratigraphical boundary between zone M and zone L in Moltemyr is correlated with the boundary between zones 4 and 3 in Solberga, and this may correspond to the major amelioration of climate at the Pleistocene/Holocene boundary.

In Brastad the sequence is subdivided into 4 foraminiferal assemblage zones (A, B, C, and D). The faunas of the lower three zones (B, C and D) indicate mainly Arctic environments, but there is an indication of a gradual amelioration through zone B and a return to cooler conditions again in the upper part of that zone. This milder period may be correlatable with zone 5 in Solberga and with the amelioration of zone M in Moltemyr, and thus it may represent the Allerød Interstadial. Zone C in Brastad, which is biostratigraphically correlated with zone 6 in Solberga and with zone N in Moltemyr, would then be of Older Dryas age, and zone D, which seems not to be represented in Moltemyr and Solberga, probably belongs in the same Stadial. The minor influence of Boreal species in some of the poor faunas of the lower part of zone D could, however, be interpreted as a weak indication of another interstadial period, viz, the Bølling Interstadial.

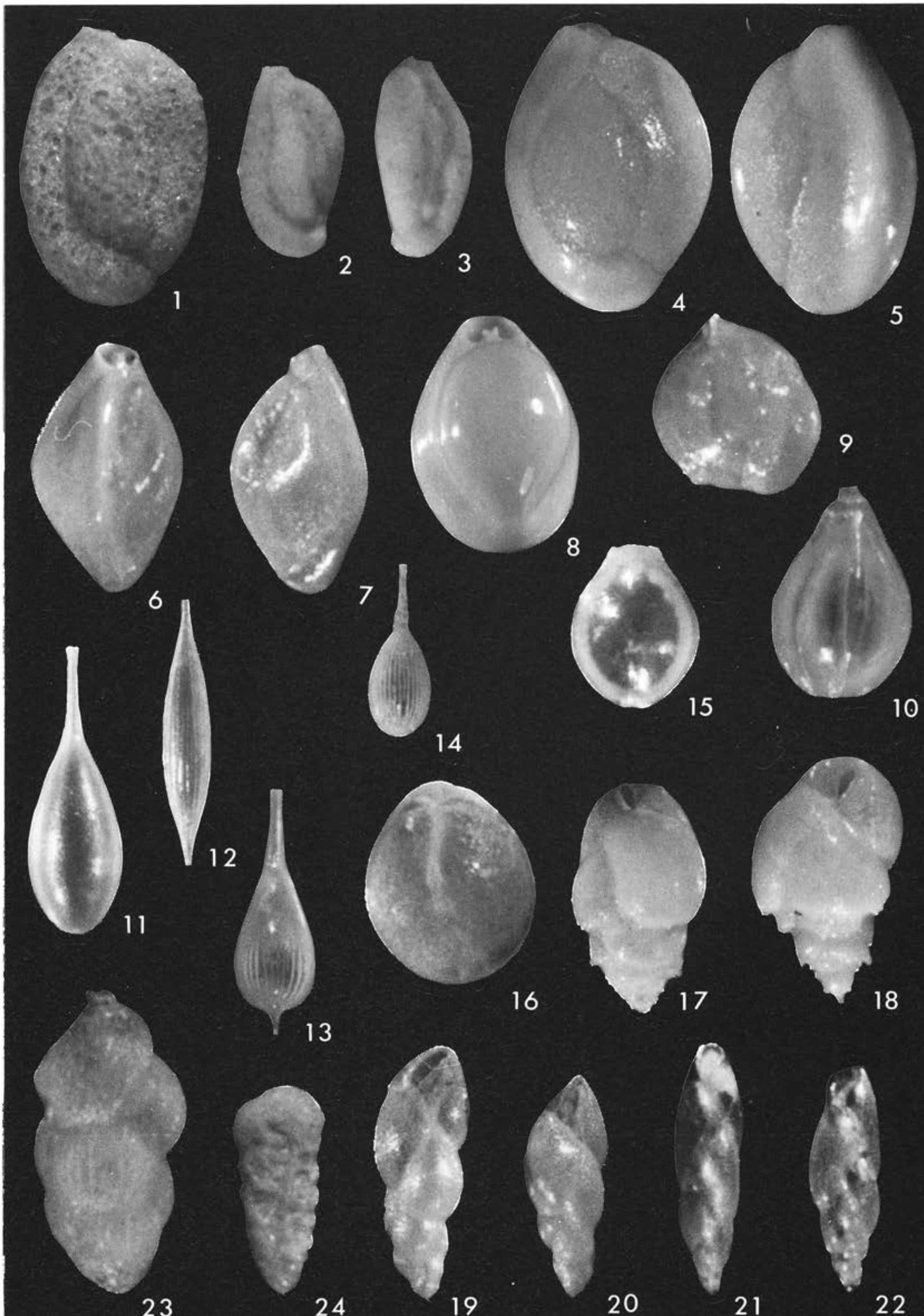
Zone A in Brastad contains very few foraminifers, probably reworked, and there seems to have been a break in sedimentation between zone B and zone A. The Pleistocene/Holocene boundary is probably not represented in Brastad.

FORAMINIFERA

The foraminiferal species found in the cores Solberga, Moltemyr and Brastad are arranged alphabetically in the following list. The most common species are illustrated by photographs and scanning electron micrographs in Figs. 14:10–14. For original references, synonymy lists, taxonomic remarks and additional illustrations of the species in the present material, the reader is referred to the systematic section by Knudsen (*in* Feyling-Hanssen *et al.* 1971), or to the more recent literature mentioned in the present work (e.g. Feyling-Hanssen 1972a, Hansen and Lykke-Andersen 1976, Knudsen 1978, 1980, Sejrup and Guilbault 1980).

In addition to the 78 listed species, different species within the family Polymorphinidae d'Orbigny, 1839 were found. Together these usually account for less than 0.5% of the fauna, and they have been counted as a single group in the present material.

Fig. 14:10.
1. *Quinqueloculina agglutinata* Cushman from Brastad zone C, spl. 6.00–6.05 m. x 75.
2, 3. *Quinqueloculina stalkeri* Loeblich & Tappan from Solberga zone 3, spl. 18.75–18.80 m. x 105.
4, 5. *Quinqueloculina seminulum* Linné from Solberga zone 3, spl. 18.00–18.05 m. x 75.
6, 7. *Triloculina trihedra* Loeblich & Tappan from Solberga zone 4, spl. 19.45–19.50 m. x 105.
8. *Pyrgo williamsoni* (Silvestri) from Brastad zone C, spl. 6.50–6.55 m. x 75.
9. *Miliolinella subrotunda* (Montagu) from Solberga zone 2, spl. 15.00–15.05 m. x 90.
10. *Lagena apiopleura* Loeblich & Tappan from Brastad zone B, spl. 4.00–4.05 m. x 90.
11. *Lagena laevis* (Montagu) from Brastad zone C, spl. 7.50–7.55 m. x 70.
12. *Lagena mollis* Cushman from Solberga zone 3, spl. 17.75–17.80 m. x 70.
13. *Lagena semilineata* Wright from Brastad zone C, spl. 5.00–5.05 m. x 70.
14. *Lagena striata* (d'Orbigny), f. *typica* from Solberga zone 3, spl. 18.75–18.80 m. x 70.
15. *Fissurina lucida* (Williamson) from Solberga zone 3, spl. 18.00–18.05 m. x 105.
16. *Fissurina marginata* (Montagu) from Solberga zone 5, spl. 25.50–25.55 m. x 105.
17, 18. *Bulimina marginata* d'Orbigny. 17. From Solberga zone 3, spl. 17.25–17.30 m. x 75. 18. From Solberga zone 3, spl. 18.50–18.55 m. x 75.
19, 20. *Virgulina loeblichi* Feyling-Hanssen. 19. From Solberga zone 4, spl. 19.25–19.30 m. x 75. 20. From Solberga zone 4, spl. 19.75–19.80 m. x 75.
21, 22. *Virgulina schreibersiana* Czjzek. 21. From Solberga zone 4, spl. 19.55–19.60 m. x 90. 22. From Solberga zone 4, spl. 19.75–19.80 m. x 90.
23. *Trifarina fluens* (Todd) from Brastad zone C, spl. 5.00–5.05 m. x 105.
24. *Bolivina pseudoplicata* Höglund from Solberga zone 3, spl. 18.25–18.30 m. x 105.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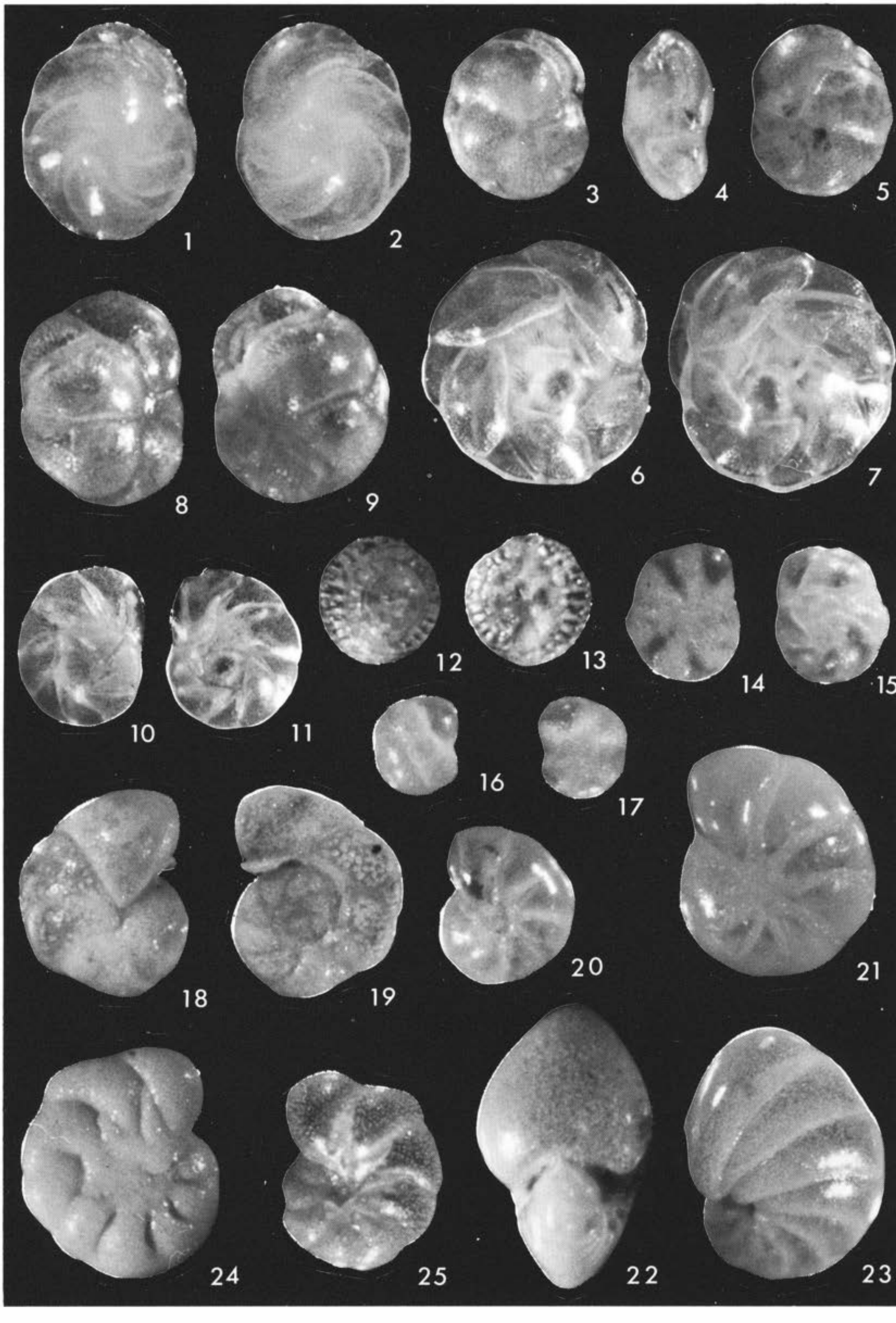
The frequencies of the most common and characteristical species in the deposits are shown in the range charts (Figs. 14:1, 6 and 7). Other species in the list only occur scattered in the deposits, and usually they account for 1 or less than 1% of the faunas.

The figured specimens, Catalogue No. 1981-KLK-1 to 1981-KLK-67, are kept in the Department of Micropalaeontology, Geological Institute, University of Aarhus, 8000 Aarhus C, Denmark.

Ammonia batavus (Hofker, 1951)
Fig. 12:20–23
Astacolus hyalacrurus Loeblich & Tappan, 1953
Astrononion gallowayi Loeblich & Tappan, 1953
Fig. 11:24, 25; Fig. 13:3
Bolivina minima Phleger & Parker, 1951
Bolivina pseudoplicata Heron-Allen & Earland, 1930
Fig. 10:24
Bolivina pseudopunctata Höglund, 1947
Bolivina robusta Brady, 1884
Buccella frigida (Cushman, 1922)
Fig. 11:14, 15
Buccella frigida (Cushman), var. *calida* (Cushman & Cole, 1930)
Fig. 11:16, 17; Fig. 13:2
Bulimina marginata d'Orbigny, 1826
Fig. 10:17, 18
Buliminella elegantissima (d'Orbigny, 1839)
Cassidulina laevigata d'Orbigny, 1826
Fig. 11:1, 2
Cassidulina reniforme Nørvang, 1945
Fig. 11:3–5

Fig. 14:11.
1, 2. *Cassidulina laevigata* d'Orbigny from Solberga zone 3, spl. 18.00–18.05 m. x 75.
3–5. *Cassidulina reniforme* Nørvang from Solberga zone 4, spl. 19.25–19.30 m. x 75.
6, 7. *Islandiella helenae* Feyling-Hanssen & Buzas from Brastad zone B, spl. 4.00–4.05 m. x 60.
8, 9. *Islandiella islandica* (Nørvang) from Brastad zone B, spl. 4.00–4.05 m. x 90.
10, 11. *Islandiella norcrossi* (Cushman) from Brastad zone C, spl. 6.50–6.55 m. x 75.
12, 13. *Patellina corrugata* Williamson from Solberga zone 5, spl. 24.00–24.05 m. x 75.
14, 15. *Buccella frigida* (Cushman) from Solberga zone 4, spl. 21.00–21.05 m. x 100.
16, 17. *Buccella frigida* (Cushman), var. *calida* (Cushman & Cole) from Solberga zone 4, spl. 21.00–21.05 m. x 100.
18, 19. *Cibicides lobatulus* (Walker & Jacob) from Solberga zone 1, spl. 3.00–3.05 m. x 75.
20. *Nonion germanicum* (Ehrenberg) from Solberga zone 1, spl. 2.50–2.55 m. x 75.
21. *Nonion orbiculare* (Brady) from Brastad zone B, spl. 3.50–3.55 m. x 75.
22, 23. *Nonion labradoricum* (Dawson). 22. From Solberga zone 4, spl. 19.25–19.30 m. x 75. 23. From Solberga zone 4, spl. 19.25–19.30 m. x 60.
24, 25. *Astrononion gallowayi* Loeblich & Tappan. 24. From Brastad zone B, spl. 2.75–2.80 m. x 75. 25. From Solberga zone 6, spl. 26.50–26.55 m. x 75.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Cibicides lobatulus (Walker & Jacob, 1798)
Fig. 11:18, 19
Cyclogyra involvens (Reuss, 1850)
Dentalina ittai Loeblich & Tappan, 1953
Eggerella scabra (Williamson, 1858)
Elphidium albiumbilicatum (Weiss, 1954)
Fig. 12:3, 4; Fig. 13:6, 7
Elphidium asklundi Brotzen, 1943
Fig. 12:1, 2
Elphidium excavatum (Terquem), forma *alba* Feyling-Hanssen, 1972
Fig. 12:5; Fig. 14:8, 9
Elphidium excavatum (Terquem), forma *clavata* Cushman, 1930
Fig. 12:6–8; Fig. 14:1–4
Elphidium excavatum (Terquem), forma *selseyensis* (Heron-Allen & Earland, 1911)
Fig. 12:9–12; Fig. 14:5–7
Elphidium gerthi van Voorthuysen, 1957
Fig. 12:13, 14
Elphidium guntheri Cole, 1931
Elphidium hallandense Brotzen, 1943
Fig. 12:15
Elphidium incertum (Williamson, 1858)
Fig. 12:16
Elphidium magellanicum Heron-Allen & Earland, 1932
Fig. 12:17, 18; Fig. 13:4, 5
Elphidium margaritaceum Cushman, 1930
Elphidium voorthuyseni Haake, 1962
Elphidium williamsoni Haynes, 1973
Fig. 12:19; Fig. 14:10, 11

Fig. 14:12.

1, 2. *Elphidium asklundi* Brotzen. 1. From Solberga zone 6, spl. 26.50–26.55 m. x 60. 2. From Brastad zone D, spl. 8.50–8.55 m. x 60.

3, 4. *Elphidium albiumbilicatum* (Weiss). 3. From Brastad zone C, spl. 6.50–6.55 m. x 90. 4. From Solberga zone 3, spl. 18.00–18.05 m. x 75.

5. *Elphidium excavatum* (Terquem), forma *alba* Feyling-Hanssen from Solberga zone 2, spl. 8.50–8.55 m. x 75.

6–8. *Elphidium excavatum* (Terquem), forma *clavata* Cushman. 6. From Solberga zone 3, spl. 16.00–16.05 m. x 75. 7, 8. From Solberga zone 3, spl. 18.75–18.80 m. x 75.

9–12. *Elphidium excavatum* (Terquem), forma *selseyensis* (Heron-Allen & Earland). 9. From Solberga zone 3, spl. 16.00–16.05 m. x 75. 10. From Solberga zone 2, spl. 11.00–11.05 m. x 75. 11. From Solberga zone 2, spl. 11.50–11.55 m. x 75. 12. From Solberga zone 1, spl. 4.00–4.05 m. x 90.

13, 14. *Elphidium gerthi* van Voorthuysen. 13. From Solberga zone 1, spl. 3.50–3.55 m. x 90. 14. From Solberga zone 1, spl. 3.00–3.05 m. x 90.

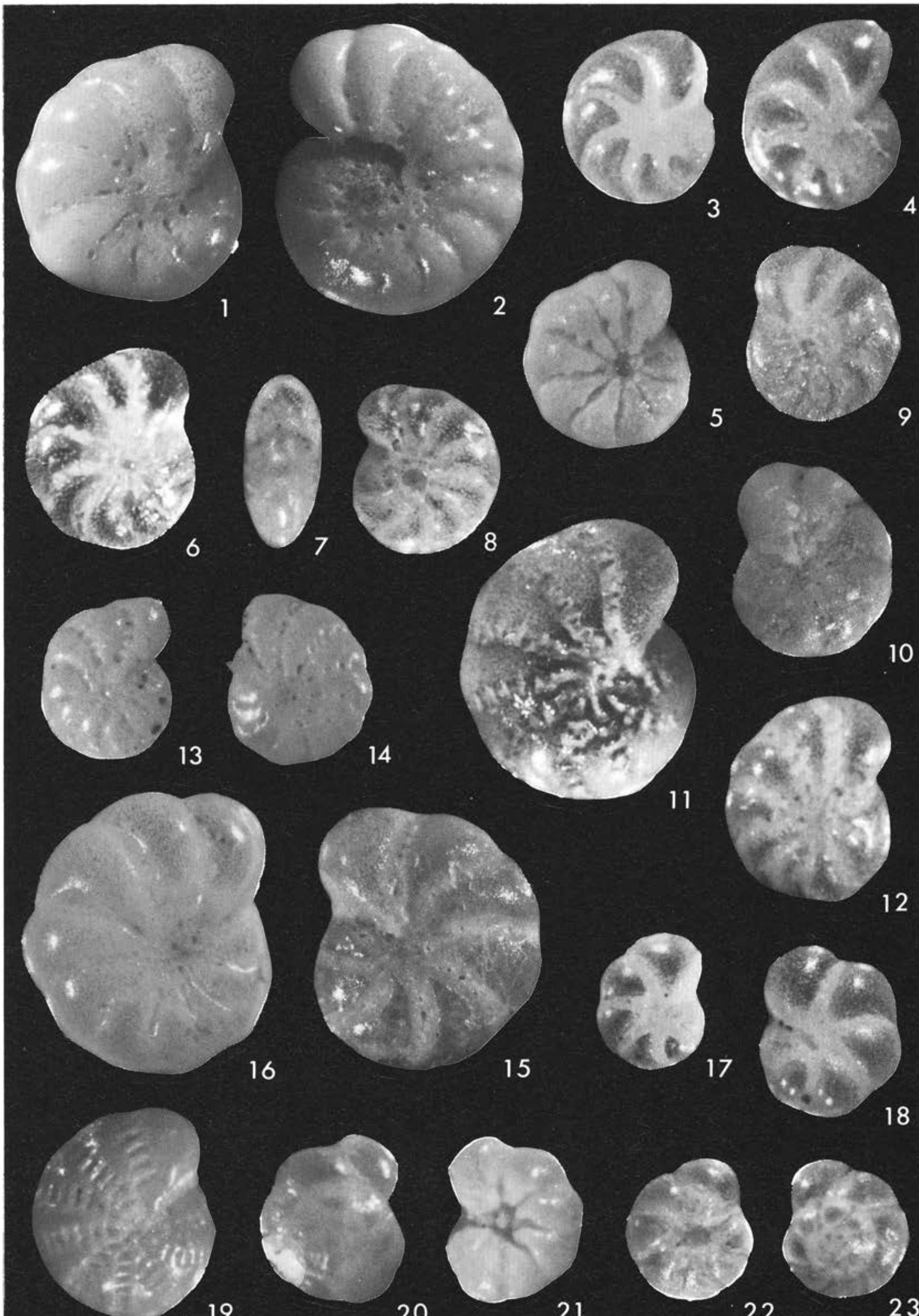
15. *Elphidium hallandense* Brotzen from Solberga zone 3, spl. 18.00–18.05 m. x 60.

16. *Elphidium incertum* (Williamson) from Moltemyr zone K, spl. 295.9–298.6 cm. x 60.

17, 18. *Elphidium magellanicum* Heron-Allen & Earland. 17. From Solberga zone 3, spl. 18.75–18.80 m. x 75. 18. From Solberga zone 3, spl. 18.75–18.80 m. x 90.

19. *Elphidium williamsoni* Haynes from Solberga zone 4, spl. 20.00–20.05 m. x 75.

20–23. *Ammonia batavus* (Hofker). 20, 21. From Solberga zone 1, spl. 3.00–3.05 m. x 75. 22, 23. From Solberga zone 1, spl. 3.00–3.05 m. x 75.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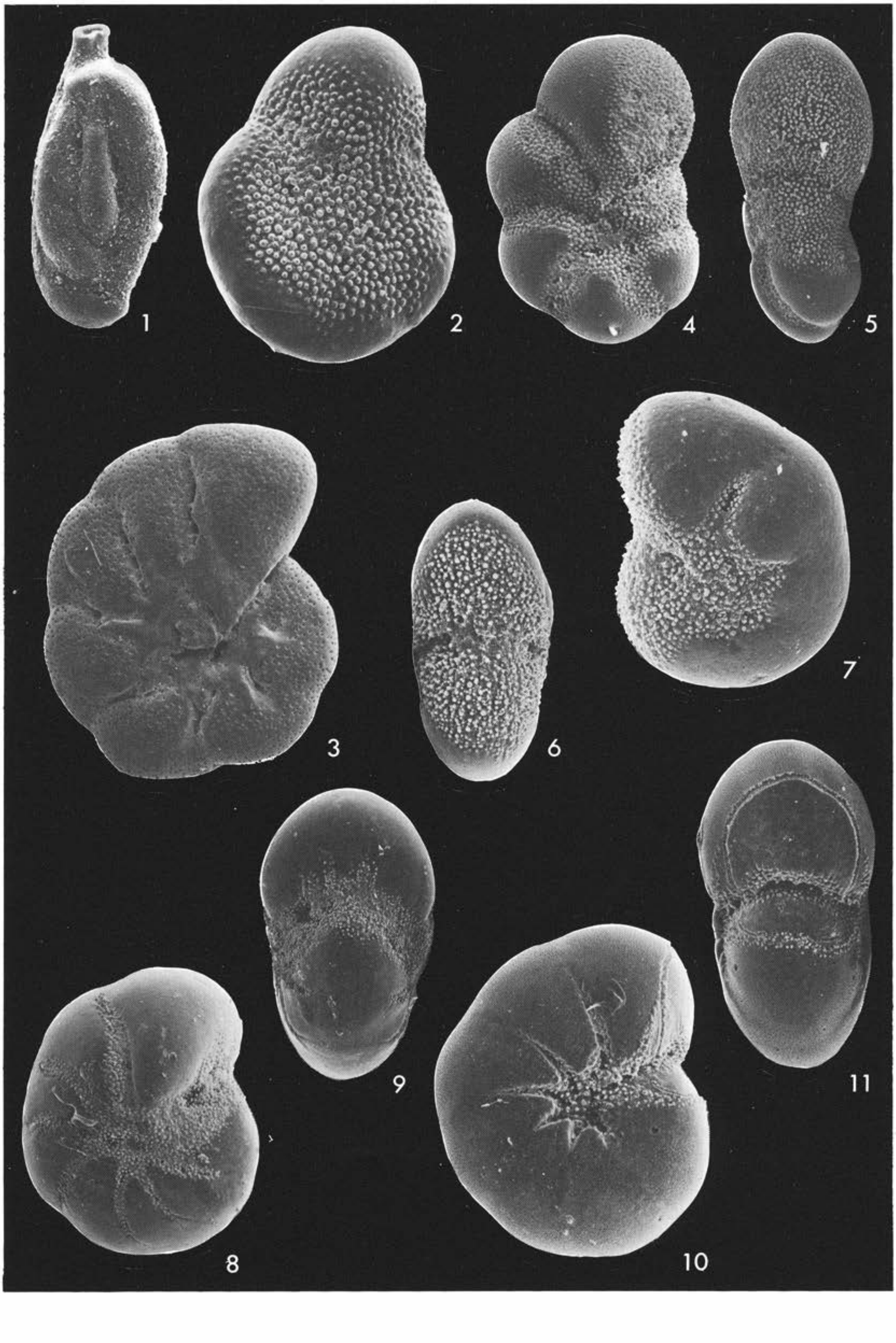
Eoeponidella laesoeensis Michelsen, 1967
Epistominella takayanagii Iwasa, 1955
Fissurina laevigata Reuss, 1850
Fissurina lucida (Williamson, 1848)
Fig. 10:15
Fissurina marginata (Montagu, 1803)
Fig. 10:16
Fissurina serrata (Schlumberger, 1894)
Globobulimina auriculata (Bailey), forma *arctica* Höglund, 1947
Islandiella helenae Feyling-Hanssen & Buzas, 1976
Fig. 11:6, 7
Islandiella islandica (Nørvang, 1945)
Fig. 11:8, 9
Islandiella norcrossi (Cushman, 1933)
Fig. 11:10, 11
Jadammina polystoma Bartenstein & Brand, 1938
Lagena apiopleura Loeblich & Tappan, 1953
Fig. 10:10
Lagena hirtshalsensis Andersen, 1971
Lagena gracillima (Seguenza, 1862)
Lagena laevis (Montagu, 1803)
Fig. 10:11
Lagena mollis Cushman, 1944
Fig. 10:12
Lagena semilineata Wright, 1886
Fig. 10:13
Lagena striata (d'Orbigny), forma *substriata* Williamson, 1848
Lagena striata (d'Orbigny, 1839) forma *typica*
Fig. 10:14
Lamarckina haliotidea (Heron-Allen & Earland, 1911)
Laryngosigma hyalascidia Loeblich & Tappan, 1953
Lenticulina cf. *angulata* (Reuss, 1851)
Lenticulina gibba (d'Orbigny, 1839)
Lenticulina limbosus (Reuss, 1863)
Miliolinella subrotunda (Montagu, 1803)
Fig. 10:9

Fig. 14:13. (SEM).
1. *Quinqueloculina stalkeri* Loeblich & Tappan from Solberga zone 3, spl. 18.25–18.30 m. x 190.
2. *Buccella frigida* (Cushman), var. *calida* (Cushman & Cole) from Solberga zone 3, spl. 18.25–18.30 m. x 340.
3. *Astrononion gallowayi* Loeblich & Tappan from Solberga zone 5, spl. 26.00–26.05 m. x 140.
4, 5. *Elphidium magellanicum* Heron-Allen & Earland from Solberga zone 1, spl. 3.00–3.05 m. x 180.
6, 7. *Elphidium albiumbilicatum* (Weiss) from Solberga zone 5, spl. 24.00–24.05 m. x 280.
8, 9. *Nonion orbiculare* (Brady) from Brastad zone B, spl. 3.50–3.55 m. x 100.
10, 11. *Nonion germanicum* (Ehrenberg) from Solberga zone 1, spl. 2.50–2.55 m. x 170.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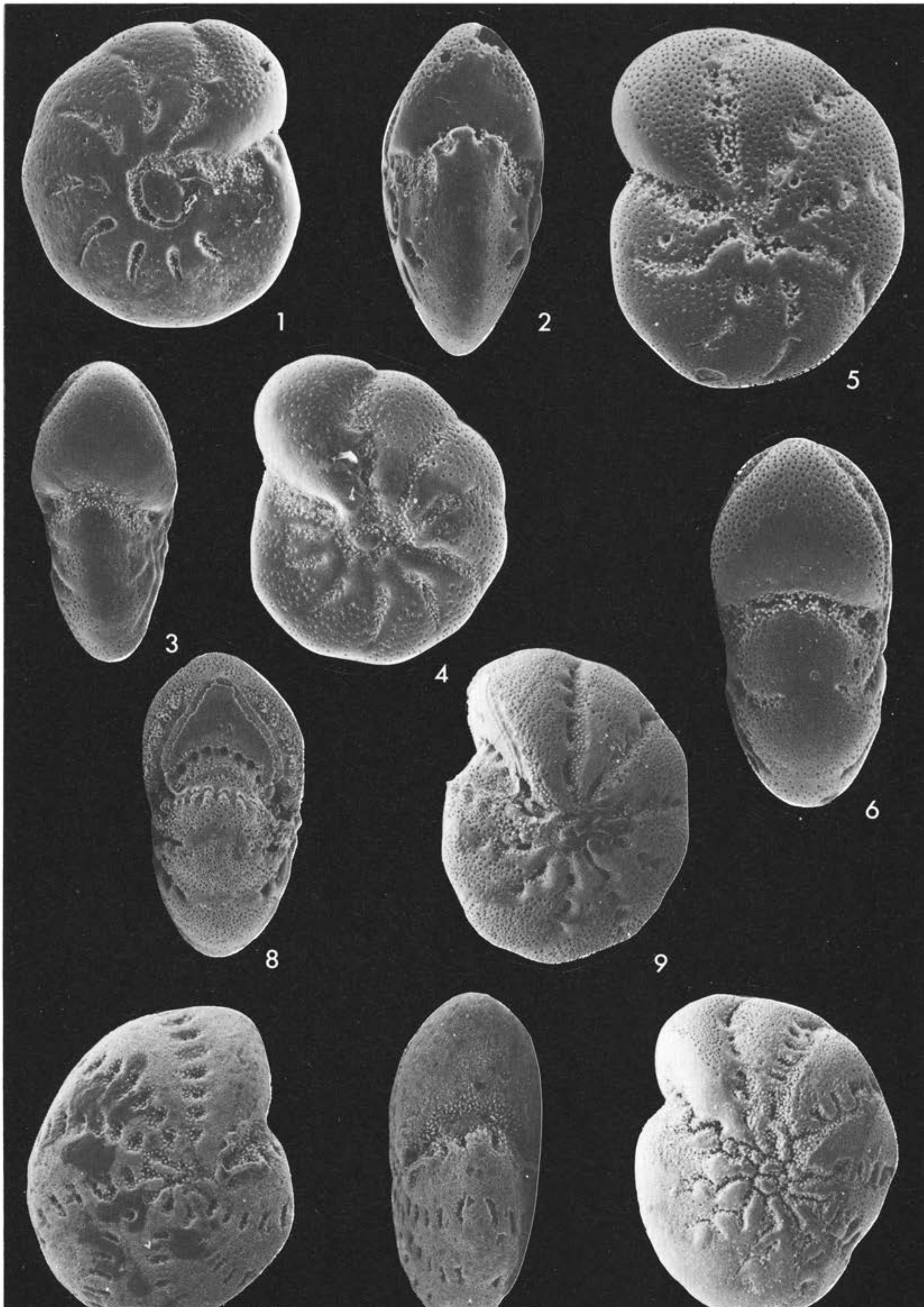
Nonion germanicum (Ehrenberg, 1840)
Fig. 11:20; Fig. 13:10, 11
Nonion labradoricum (Dawson, 1960)
Fig. 11:22, 23
Nonion orbiculare (Brady, 1881)
Fig. 11:21; Fig. 13:8, 9
Nonionella auricula Heron-Allen & Earland, 1930
Oolina hexagona (Williamson, 1848)
Oolina lineata (Williamson, 1848)
Oolina melo d'Orbigny, 1839
Oolina williamsoni (Alcock, 1865)
Parafissurina tectulostoma Loeblich & Tappan, 1953
Patellina corrugata Williamson, 1858
Fig. 11:12, 13
Pullenia bulloides (d'Orbigny, 1826)
Pullenia osloensis Feyling-Hanssen, 1954
Pyrgo williamsoni (Silvestri, 1923)
Fig. 10:8
Quinqueloculina agglutinata Cushman, 1917
Fig. 10:1
Quinqueloculina seminulum (Linné, 1758)
Fig. 10:4, 5
Quinqueloculina stalkeri Loeblich & Tappan, 1953
Fig. 10:2, 3; Fig. 13:1
Rosalina praegeri (Heron-Allen & Earland, 1913)
Sigmoilopsis schlumbergeri (Silvestri, 1904)
Trifarina fluens (Todd, 1947)
Fig. 10:23
Triloculina trigonula (Lamarck, 1804)
Triloculina trihedra Loeblich & Tappan, 1953
Fig. 10:6, 7
Trochammina ochracea (Williamson, 1858)
Uvigerina peregrina Cushman, 1923
Virgulina fusiformis (Williamson, 1858)
Virgulina loeblichi Feyling-Hanssen, 1954
Fig. 10:19, 20
Virgulina schreibersiana Czjzek, 1848
Fig. 10:21, 22

Fig. 14:14. (SEM).
1–4. *Elphidium excavatum* (Terquem), forma *clavata* Cushman. 1, 2. From Solberga zone 6, spl. 27.00–27.05 m. x 180. 3, 4. From Solberga zone 6, spl. 27.00–27.05 m. x 190.
5–7. *Elphidium excavatum* (Terquem), forma *selseyensis* (Heron-Allen & Earland). 5, 6. From Solberga zone 1, spl. 3.00–3.05 m. x 210. 7. From Solberga zone 2, spl. 11.00–11.05 m. x 110.
8, 9. *Elphidium excavatum* (Terquem), forma *alba* Feyling-Hanssen from Solberga zone 2, spl. 6.50–6.55 m. x 135.
10, 11. *Elphidium williamsoni* Haynes from Solberga zone 1, spl. 4.50–4.55 m. x 140.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