FORAMINIFERA FROM THE OLDER *YOLDIA* CLAY AT HIRTSHALS

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Hirtshals coast cliff was mentioned in the geological literature as early as 1828 by Pingel. Later, Forchhammer (1863) and Johnstrup (1882) dealt with the locality. Madsen (1895) examined a sample of Older *Yoldia* Clay from Hirtshals coast cliff for its content of foraminifera and found 26 species belonging to 11 genera.

A more detailed description of Hirtshals coast cliff is due to A. Jessen (1899, 1918 and 1936). He stated that the Older *Yoldia* Clay is not a uniform formation, but that it is composed of clay in which irregular patches and "pockets" of sand and gravel occur. The clay contains stones partly scattered, partly accumulated as bars. In the Older *Yoldia* Clay in Hirtshals coast cliff shells of *Portlandia arctica* (Gray), *Cyprina islandica* (= *Arctica islandica* (Linné)), *Tellina baltica* (= *Macoma baltica* (Linné)), *Mya truncata* Linné, *Saxicava rugosa* (= *Hiatella arctica* (Linné)), *Zirfaea crispata* (Linné), *Natica* sp., ?*Buccinum groenlandicum* Chemnitz, and *Balanus* sp. were found. A. Jessen considered this to be a mixed arctic and boreal fauna. The arctic fauna with *Portlandia arctica* is found in the clay, whereas the boreal fauna with *Zirfaea crispata* and *Arctica islandica* is found, often as rolled shells, in the gravelly parts of the Older *Yoldia* Clay. A. Jessen believed that the boreal fauna is not indigenous in the Older *Yoldia* Clay, but brought in by drift-ice. The boreal fauna was thought to originate from coastal sediments of the *Turritella terebra* Zone and the *Abra nitida* Zone of the Skærumhede sequence (A. Jessen, 1918 and 1936). Well-preserved but fragmentary specimens of *Zirfaea crispata* found in the upper part of the Older *Yoldia* Clay were considered as Lateglacial (A. Jessen, 1936). A. Jessen (1918 and 1936) thought that boulders found on top of the Older *Yoldia* Clay had been washed out of the Older *Yoldia* Clay, although he (1899) among these found a considerable number of indicator-boulders which does not occur in the Older *Yoldia* Clay. In 1936 he has described how in Hirtshals coast cliff the Older *Yoldia* Clay with the cover of boulders is overlain by Postglacial stratified gravel and sand together with wind-blown sand.

The Older *Yoldia* Clay was correlated with the *Portlandia arctica* Zone, the uppermost marine zone of the Skærumhede sequence (A. Jessen et al., 1910). Nordmann (in A. Jessen et al., 1910) placed the Older *Yoldia* Clay

together with the *Portlandia arctica* Zone at the beginning of the Weichselian in direct continuation of the other marine zones (the *Turritella terebra* Zone and the *Abra nitida* Zone) of the last interglacial (Eemian). He pointed out that the Eemian deposits found in the southern part of Denmark are quite different from the Skærumhede deposits.

Since then there has been some disagreement about the stratigraphical position of the Skærumhede sequence, but the reason for the different interpretations depends to a certain extent on the definition of terms. The Skærumhede sequence was placed in the last interglacial (Eemian) (i.a. A. Jessen, 1918 and 1936; K. Jessen & Milthers, 1928; Hansen, 1965). It was placed in an interstadial of the Weichselian (i.a. Wennberg, 1949; Rasmussen, 1966). S. A. Andersen (1966) placed the Skærumhede deposits in two interstadials of the Weichselian. S. T. Andersen (1967) suggested that the Skærumhede sequence represented deposits both from an interglacial (the *Turritella terebra* Zone) and from the following glacial stage (the *Abra nitida* and *Portlandia arctica* Zone). Mörner (1969) placed the *Turritella terebra* Zone and the *Abra nitida* Zone in the Brørup Interstadial, the lowermost c. 23 m of the *Portlandia arctica* Zone in the so-called Anholt Stadial (= the Lower Pleniglacial of the Netherlands) and the uppermost c. 17 m of the *Portlandia arctica* Zone in the so-called Glumslöv Interstadial (= the Göta Älv Interstadial = the Interpleniglacial of the Netherlands).

The purpose of the present study has been to register the species, subspecies and forms of foraminifera found in the Older *Yoldia* Clay in the coast cliff at Hirtshals and to attempt an ecological and stratigraphical interpretation of the assemblages. This has involved a short description of the sediments and their structural setting in the cliff. In addition, the molluscs found in the deposit were identified.

Sediments and structures in the cliff

Hirtshals coast cliff is situated about 1 km southwest of Hirtshals. The present exposure is about 300 m long and 6–7 m high and the trend is northeast to southwest (fig. 28). The main part of the cliff is composed of Older *Yoldia* Clay, which has a well-defined limit at the top against a deposit consisting of horizontally stratified sand and gravel – Postglacial littoral deposits – with a thickness varying from about two metres in the northeastern part to less than one metre in the southwestern part of the cliff. Between the Older *Yoldia* Clay and the Postglacial sand and gravel there is an abundance of boulders. On top of the cliff, and normally somewhat recessed, there is a cover of wind-blown sand. The cliff is rather irregular

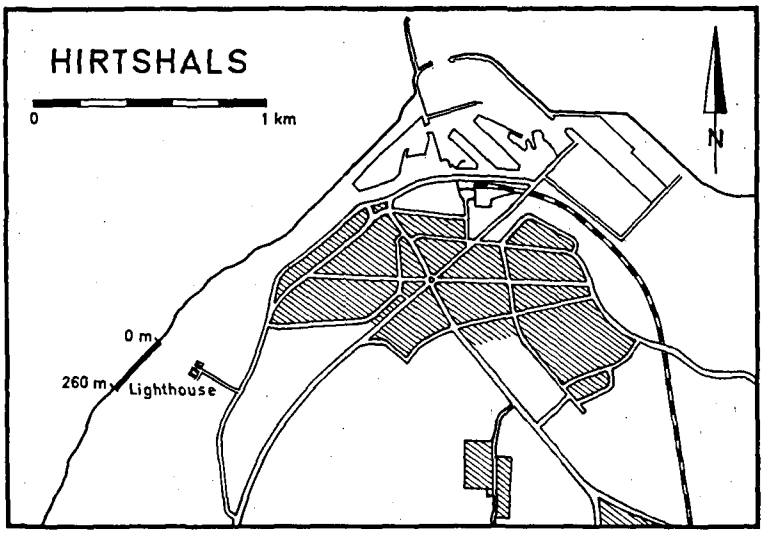

Fig. 28. The town of Hirtshals, northern Jutland. Hirtshals coast cliff is situated in front of the lighthouse.

with projecting parts alternating with embayments which are often partly covered by loose material. The beach is densely covered by boulders in front of the cliff (fig. 29).

The sediments

The Older *Yoldia* Clay in Hirtshals coast cliff is a very complex deposit which cannot be described adequately – in sedimentological and structural respects – within the framework of this study.

In the following description of the Older *Yoldia* Clay reference is made to the uppermost profile on plate 27. The profile, which only includes the Older *Yoldia* Clay of the cliff, is constructed partly from direct measurements and partly from a series of photographs.

The main part of the Older *Yoldia* Clay consists of solid bluish grey to grey clay, in some places with a few scattered stones. On plate 27 this sediment is called "clay". The deposit which is called "sandy clay" is a rather dark bluish grey to grey, sandy and silty clay (fig. 30). In this sandy clay there are scattered stones. The term "sand" includes two types of sandy material, viz.: *a*) Yellowish grey to greyish white, fine to medium-grained sand and silt which is stratified and has a tendency to rhytmic variation in grain size (fig. 31). Small pieces of amber and twigs are found in the sand. In some places sand of this type also contains irregular schlieren of clay (fig. 32). *b*) Unstratified yellowish grey, medium to coarse-grained sand, which

Fig. 29. A section of Hirtshals coast cliff. The lowermost part of the cliff contains Older *Yoldia* Clay. On the top of the Older *Yoldia* Clay is a frequent occurrence of boulders, which are overlain by Postglacial, horizontally stratified sand and gravel. Abundance of boulders on the beach.

here and there contains much plant material. Layers of clay and shelly gravel are found in this sand. In several places there is a characteristic sandy

Fig. 30. Fissured, sandy and silty clay. Attention is drawn to *Zirfaea crispata* with united valves to the left of the speed-marker. (Hirtshals coast cliff at 130 m).

Fig. 31. Folded layers of fine-grained sand and silt. (Hirtshals coast cliff at 220 m).

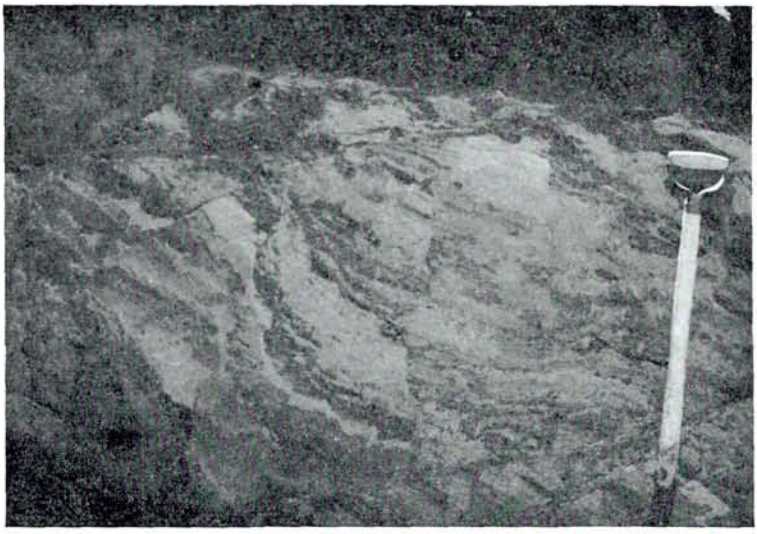

Fig. 32. Faulted layers of sand with irregular schlieren of clay. Between the sand and the overlying sandy clay there is a thrustplane (Hirtshals coast cliff at 135 m).

clay with a rather high content of boulders. The boulders are up to half a metre in diameter giving the sediment a till-like appearence (fig. 33). On plate 27 this sediment is called "stony and sandy clay". As subordinate layers there are decimeter-thick layers composed almost exclusively of plant material (fig. 34) and are indicated as "peat". In these layers there is a distinct schistosity and the planes of schistosity are covered by mica.

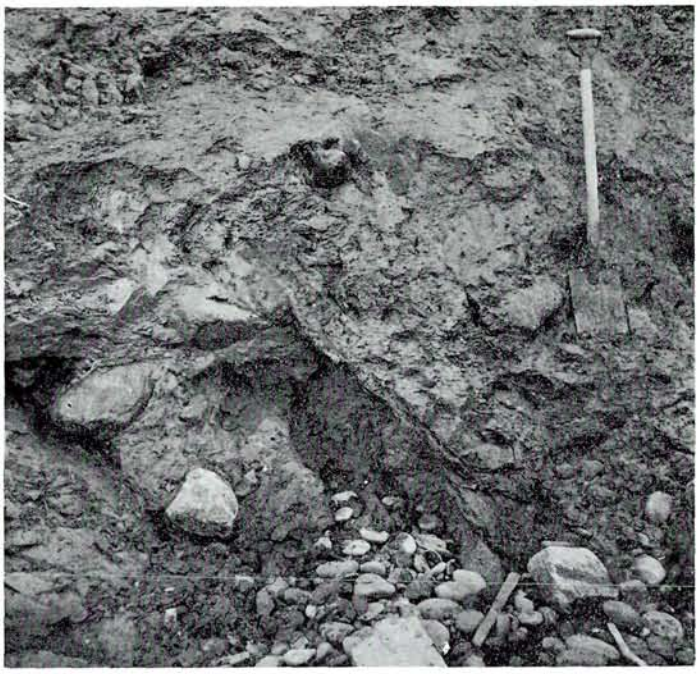

Fig. 33. Sandy clay rich in boulders. (Hirtshals coast cliff at 153 m).

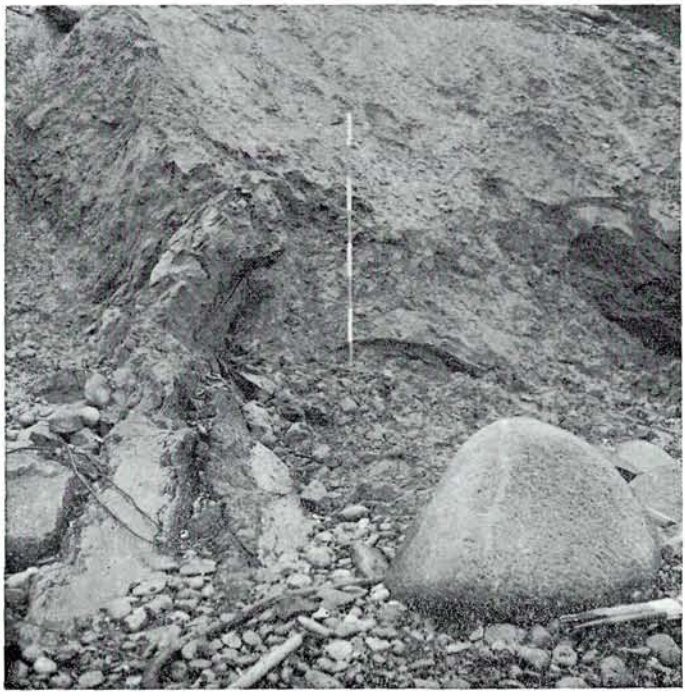

Fig. 34. Almost vertical layer of compressed plant material. (Hirtshals coast cliff at 143 m).

The structures

The structures of the Older *Yoldia* Clay are exhibited by the sandy layers in the clay. The clay often has a fissured appearence and most of the shells are crushed. The structure of the deposit is characterised by faulting and folding. The folding appears partly as small internal foldstructures in the sand, some times in connection with faulting (fig. 32), and partly as folds on a bigger scale, see fig. 31. The orientation of the fold axes is measured directly in the small-scale folds, and in the big-scale folds the orientation is found by construction from measurements of the orientation of the bedding-planes. It appears that the fold axes, with a few exceptions, have a north to south direction. This direction is also characteristic of the strike of vertical or almost vertical bedding planes. As the main direction of the structures in the Older *Yoldia* Clay seems to be north to south, it is assumed that the dislocations are due to ice-pressure from the east. The direction of the structures in the Older *Yoldia* Clay forms an angle of about 45° to the main trend of the cliff. This, together with the fact that the cliff is more or less vertical and the main part covered by loose material, is a severe hindrance to a reliable reconstruction of the original stratigraphy and the correlation of the successions of the foraminifera faunas with successions from other localities.

The Foraminifera

For the foraminiferal analyses 255 samples of Older *Yoldia* Clay have been collected over a distance of 250 m in the coast cliff at Hirtshals (plate 27). As the cliff is extensively covered by loose material the collection of samples has to some extent been concentrated in the least covered parts. In the central, most dislocated part of the cliff the density of sampling is greatest.

The treatment of the samples (all of which had a dry weight of 100 g), is described on p. 70. The statistical record of the foraminifera was transferred to distribution charts which show the percentage distribution of the most common and important species. Symbols indicating percentage frequency of specimens of each species are used for plotting the counts. If less than 100 specimens are present in a sample, the number of specimens is given directly. The legend for the distribution chart is given on p. 71.

Zonation

The Older *Yoldia* Clay of Hirtshals coast cliff has yielded 126 species, subspecies and forms of foraminifera belonging to 53 genera and 17 families. When the total number of foraminiferal analyses are considered, it appears

that a limited number of characteristic foraminiferal assemblages occur in the Older *Yoldia* Clay.

These foraminiferal assemblages define what here are called "zones". "Zone" is not a completely adequate term, but is used as a stratigraphic interpretation of faunal assemblages which are ecologically conditioned. Such a stratigraphy has, of course, a limited regional applicability. For the purpose of brevity, the zones are symbolised by letters from A to F.

Zone A, the *labradoricum-norcrossi* zone, has a rather frequent and characteristic occurrence of *Nonion labradoricum* and *Islandiella norcrossi. Virgulina loeblichi,* and *Trifarina fluens* are common. A sporadic occurrence of *Elphidium asklundi, E. groenlandicum, Uvigerina peregrina, Nonion barleeanum* and *Hyalinea baltica* is noteworthy. The zone is dominated by *Elphidium clavatum* and *Cassidulina crassa.* They are almost equal in frequency and together normally account for 85–90 % of the fauna. The faunal diversity is rather low, normally 6–9, and the number of species is moderate, about 20. The number of specimens is rather small, normally 200–1,000 specimens in 100 g sediment. The foraminiferal analysis of sample no. 2 G is presented here to show the faunal composition of zone A; the foraminiferal content in half of the sample was counted:

Species	Frequency	Percentage
Cassidulina crassa	222	45
Elphidium clavatum	195	40
Nonion labradoricum	11	2
Islandiella norcrossi	10	2
Virgulina loeblichi	7	1
Cibicides lobatulus	7	1
Bulimina marginata	6	1
Trifarina fluens	4	1
Astrononion gallowayi	4	1
Uvigerina peregrina	3	1
Islandiella teretis	3	1
Fissurina danica	2	<1
Buccella frigida	2	<1
Nonionella auricula	2	<1
Elphidium asklundi	2	<1
Trifarina angulosa	1	<1
Islandiella islandica	1	<1
Epistominella takayanagii	1	<1
Nonion umbilicatulum	1	<1
Elphidium albiumbilicatum	1	<1
Elphidium groenlandicum	1	<1
Protelphidium orbiculare	1	<1
Indeterminate species	1	<1
Total	488	

Zone B, the zone with scattered specimens, often contains only *Elphidium clavatum* and *Cassidulina crassa*. The number of species is low, as is the number of specimens in 100 g sediment.

Zone C, the *asklundi-orbiculare* zone, has a characteristic constituent in *Elphidium asklundi* which is second or third in frequency in the faunas. In addition a fairly frequent occurrence of *Protelphidium orbiculare, Buccella frigida* and *Elphidium subarcticum* should be mentioned. The Polymorphinidae and the Miliolidae are common, and *Silicosigmoilina groenlandica* is found only in this zone. Furthermore, *Nonion labradoricum* and *Islandiella teretis* may be quite frequent. *Elphidium clavatum* dominates in this zone, normally accounting for 65–80 % of the fauna. *Cassidulina crassa* seldom makes more than 15 % of the fauna. The faunal diversity is often very low, normally 2–6, and the number of species is in most cases rather low. The number of specimens varies from very few to 13,000 specimens in 100 g sediment.

The foraminiferal analysis of sample no. 45 A is presented to show the faunal composition of zone C; the foraminiferal content of 11 % of the sample was counted:

Species	Frequency	Percentage
Elphidium clavatum	326	67
Cassidulina crassa	52	11
Elphidium asklundi	50	10
Protelphidium orbiculare	19	4
Buccella frigida	12	2
Elphidium subarcticum	12	2
Islandiella teretis	3	1
Guttulina glacialis	2	<1
Nonion labradoricum	2	<1
Silicosigmoilina groenlandica	1	<1
Guttulina austriaca	1	<1
Guttulina lactea	1	<1
Esosyrinx curta	1	<1
Oolina lineata	1	<1
Oolina melo	1	<1
Bulimina marginata	1	<1
Virgulina loeblichi	1	<1
Virgulina schreibersiana	1	<1
Islandiella norcrossi	1	<1
Nonion barleeanum	1	<1
Indeterminate species	1	<1
Total	490	

Zone D, the *crassa-norcrossi* zone, has *Islandiella norcrossi* as a frequent and diagnostic constituent. *Nonion labradoricum, Virgulina loeblichi, Trifarina fluens, Bulimina marginata* and *Elphidium albiumbilicatum* are also frequent. Characteristic and constant members of the fauna are *Nonion barleeanum, Hyalinea baltica, Uvigerina peregrina* and *Elphidium groenlandicum*. Normally *Cassidulina crassa* dominates, accounting for 40–60 % and *Elphidium clavatum* is next in frequency with 20–40 %. The zone D fauna resembles the zone A fauna, but within zone D the faunal diversity is rather high, normally 13–17, the number of species per sample great, normally 2,000–4,000 in 100 g sediment.

The foraminiferal analysis of sample no. 6 G shows the composition of zone D; the foraminiferal content of 16 % of the sample was counted:

Species	Frequency	Percentage
Cassidulina crassa	218	43
Elphidium clavatum	162	32
Islandiella norcrossi	28	6
Nonion labradoricum	15	3
Elphidium albiumbilicatum	14	3
Virgulina loeblichi	8	2
Nonion barleeanum	7	1
Bulimina marginata	5	1
Uvigerina peregrina	5	1
Buccella frigida	5	1
Astrononion gallowayi	5	1
Elphidium groenlandicum	4	1
Quinqueloculina seminulum	3	1
Pyrgo williamsoni	3	1
Fissurina danica	3	1
Islandiella islandica	3	1
Islandiella teretis	3	1
Ammonia batavus	3	1
Cibicides lobatulus	2	<1
Pullenia bulloides	2	<1
Elphidium umbilicatulum	2	<1
Protelphidium orbiculare	2	<1
Dentalina frobisherensis	1	<1
Globulina inaequalis	1	<1
Planulina ariminensis	1	<1
Hyalinea baltica	1	<1
Elphidium asklundi	1	<1
Elphidium bartletti	1	<1
Elphidium margaritaceum	1	<1
Total	509	

Zone E, the *albiumbilicatum-umbilicatulum* zone, is dominated by *Elphidium albiumbilicatum* together with *E. clavatum*. *Elphidium umbilicatulum* is a characteristic and frequent constituent. Other common species are *Buccella frigida* and *Cassidulina crassa*. *Bulimina marginata* may also be common. *Ammonia batavus* is also found. The faunal diversity is rather low, normally 5–7, the number of species per sample is small, normally 10–20, and the number of specimens varies from a few to 3,000 specimens in 100 g sediment.

As an example of the foraminiferal assemblage of zone E, the analysis of sample no. 22 A is presented below; the foraminiferal content of 12.5 % of the sample was counted:

Species	Frequency	Percentage
Elphidium albiumbilicatum	160	46
Elphidium clavatum	126	36
Cassidulina crassa	22	6
Elphidium umbilicatulum	17	5
Bulimina marginata	5	1
Buccella frigida	5	1
Protelphidium orbiculare	3	1
Guttulina glacialis	1	<1
Guttulina lactea	1	<1
Virgulina loeblichi	1	<1
Uvigerina peregrina	1	<1
Trifarina fluens	1	<1
Buccella tenerrima	1	<1
Nonion barleeanum	1	<1
Nonionella auricula	1	<1
Ammonia batavus	1	<1
Total	347	

Zone F, the *albiumbilicatum-marginata* zone, has *Elphidium albiumbilicatum*, *Bulimina marginata* and *Buccella frigida* as common and characteristic elements. *Elphidium clavatum* dominates the fauna and *Cassidulina crassa* is second in abundance. The faunal diversity is often about 10, the number of species per sample is normally 20–30 and the number of specimens 500–1,500 in 100 g sediment. Strong contamination with pre-Quaternary foraminifera is characteristic.

The foraminiferal analysis of sample no. 13 C is given to show the faunal composition of zone F; the foraminiferal content of 40 % the sample was counted:

Species	Frequency	Percentage
Elphidium clavatum	163	48
Cassidulina crassa	79	23
Elphidium albiumbilicatum	38	11
Bulimina marginata	15	4
Buccella frigida	13	4
Virgulina loeblichi	3	1
Trifarina fluens	3	1
Astrononion gallowayi	3	1
Elphidium umbilicatulum	3	1
Fissurina danica	2	1
Nonion labradoricum	2	1
Nonionella auricula	2	1
Pseudopolymorphina soldanii	1	<1
Oolina acuticosta	1	<1
Oolina borealis	1	<1
Oolina hexagona	1	<1
Parafissurina tectulostoma	1	<1
Virgulina fusiformis	1	<1
Trifarina angulosa	1	<1
Bolivina cf. *robusta*	1	<1
Cassidulina laevigata	1	<1
Islandiella teretis	1	<1
Elphidium margaritaceum	1	<1
Protelphidium orbiculare	1	<1
Indeterminate species	2	1
Total	340	

In addition to these zones there is zone E_0, the zone without foraminifera.

Interpretation of the zonation

The investigations of recent foraminifera, which are mentioned in the systematic part of the present paper (p. 185) form the basis for the ecological interpretation of the foraminiferal assemblages in the Older *Yoldia* Clay in the coast cliff at Hirtshals.

The distribution chart (fig. 35) shows one of the profiles containing foraminiferal assemblages of zone A. The fauna of zone A with the high frequency of *Elphidium clavatum* and *Cassidulina crassa* indicates arctic conditions. *Nonion labradoricum* and *Islandiella norcrossi* are normally found in arctic faunas at depths between 20 and 100 m. Also *Virgulina loeblichi* and *Trifarina fluens* are found at moderate depths. *Uvigerina peregrina, Hyalinea baltica,* and Nonion barleeanum constitute a boreal element in

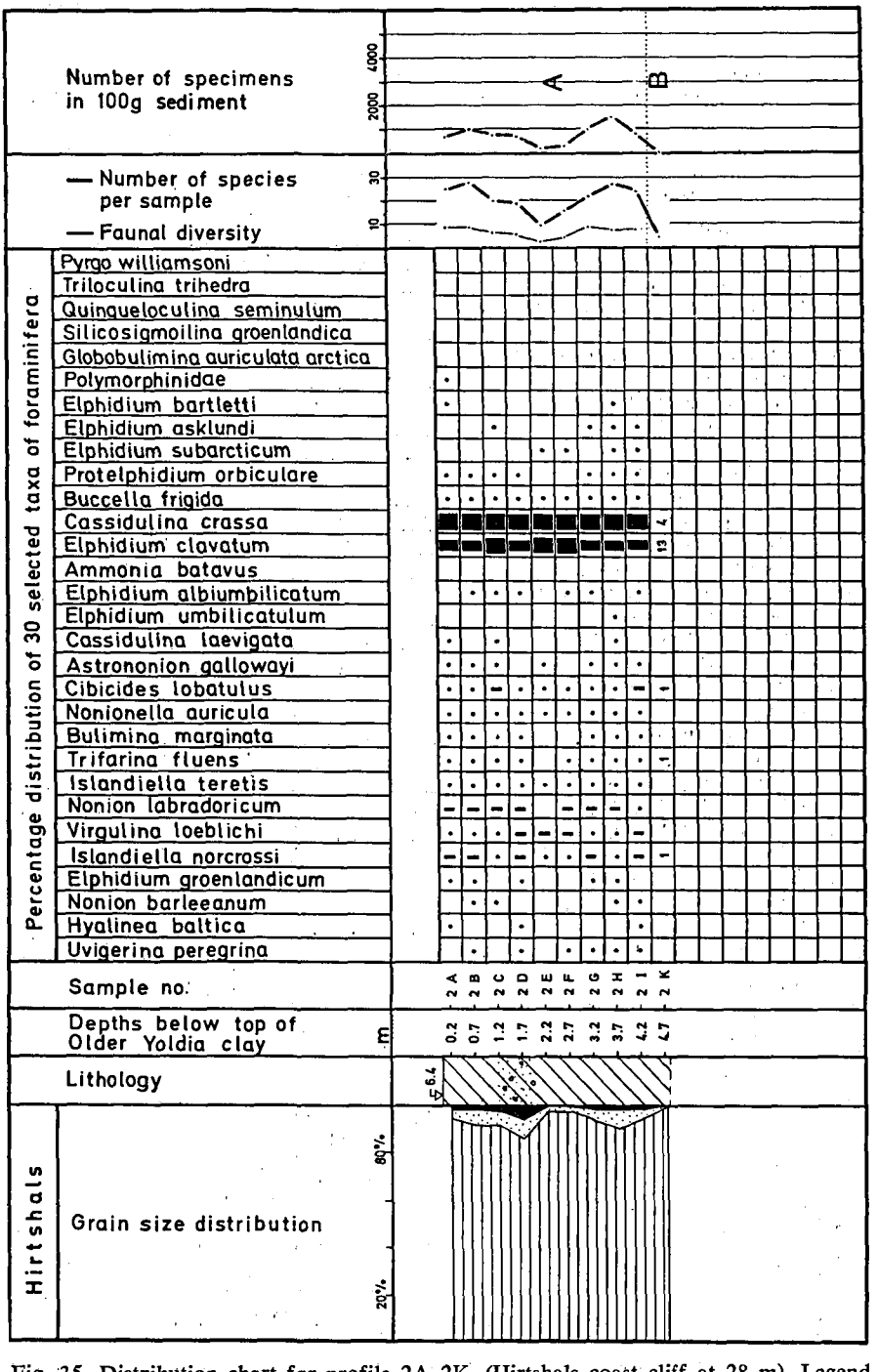

Fig. 35. Distribution chart for profile 2A–2K. (Hirtshals coast cliff at 28 m). Legend p. 71.

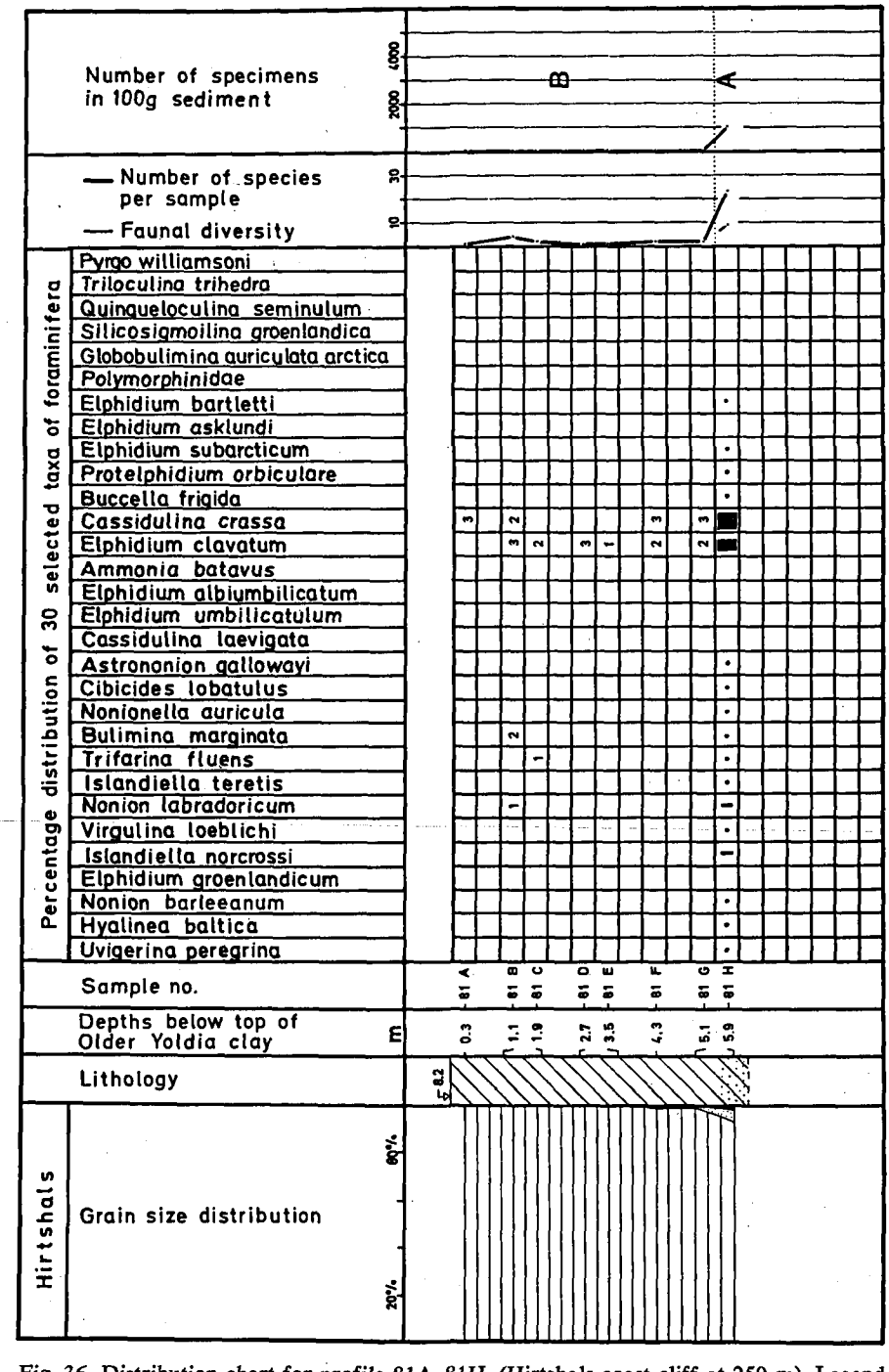

Fig. 36. Distribution chart for profile 81A–81H. (Hirtshals coast cliff at 250 m). Legend p. 71.

the fauna and also indicate moderate depths. The faunal diversity is rather low, the limiting factor here is believed to be rather low temperature. The zone A fauna thus seems to be arctic with a boreal element from moderate water depths with a minimum depth of about 20 m. The zone A fauna is generally found in bluish grey to grey sometimes sandy clay, containing a few small angular stones, some very small and indeterminate shell fragments and some plant material. However, the zone A fauna is also found in fine-bedded, fine-grained sand and silt with small angular stones, very small shell fragments and pieces of amber and twigs. Only one mollusc specimen found in the sand was fairly well preserved, namely a *Turritella* sp. (probably the arctic species *Turritella erosa* Couthouy).

The zone B fauna is found underlying the zone A fauna in the cliff. On the distribution chart (fig. 35) the lowermost sample contains a zone B fauna, whereas the rest of the samples contain faunas belonging to zone A. On the distribution chart (fig. 36) zone B apparently overlies zone A, whereas, in fact, the opposite is the case. The zone B fauna is found in bluish grey to grey clay. No shell debris occurred, only some plant material. The few species of foraminifera found in zone B indicate arctic conditions. The number of specimens and species in zone B is small, but the specimens are well-preserved, so that secondary solution of the tests can hardly be the reason for the very poor fauna. A possible explanation is that the environment was unfavorable due to decreased salinity and decreased transparancy of the water, with deterioration of food supply. Melt-water rich in suspended clay may have caused these conditions. The pure clay in which the zone B is found supports this interpretation.

The zone C fauna which is presented in the distribution chart of figure 37, contains species of foraminifera which indicate arctic conditions. *Protelphidium orbiculare, Buccella frigida* and also to some extent *Elphidium subarcticum* are known from arctic shallow-water assemblages. The Polymorphinidae and the Miliolidae are also common at low depths. The diagnostic *Elphidium asklundi* has not been recorded from recent faunas. Characteristic of the zone C faunas is the relatively large size of the specimens, which is another indication of arctic conditions. The low faunal diversity is here thought to have been caused by low temperature as well as shallow water.

The zone C fauna is found in solid, bluish grey clay, which often is a little sandy. In the clay, layers with many shell fragments and some stones are found, together with some plant material. Fragments of the barnacle *Balanus crenatus* Bruguière are very common. The molluscs *Macoma calcarea* (Chemnitz) and *Hiatella arctica* are common both as intact shells and as fragments. A few fragments of *Portlandia arctica* and *Mya truncata* also occurred. All these species are found in modern arctic shallow-water assemblages as are the foraminifera species. The zone C is assumed to be older

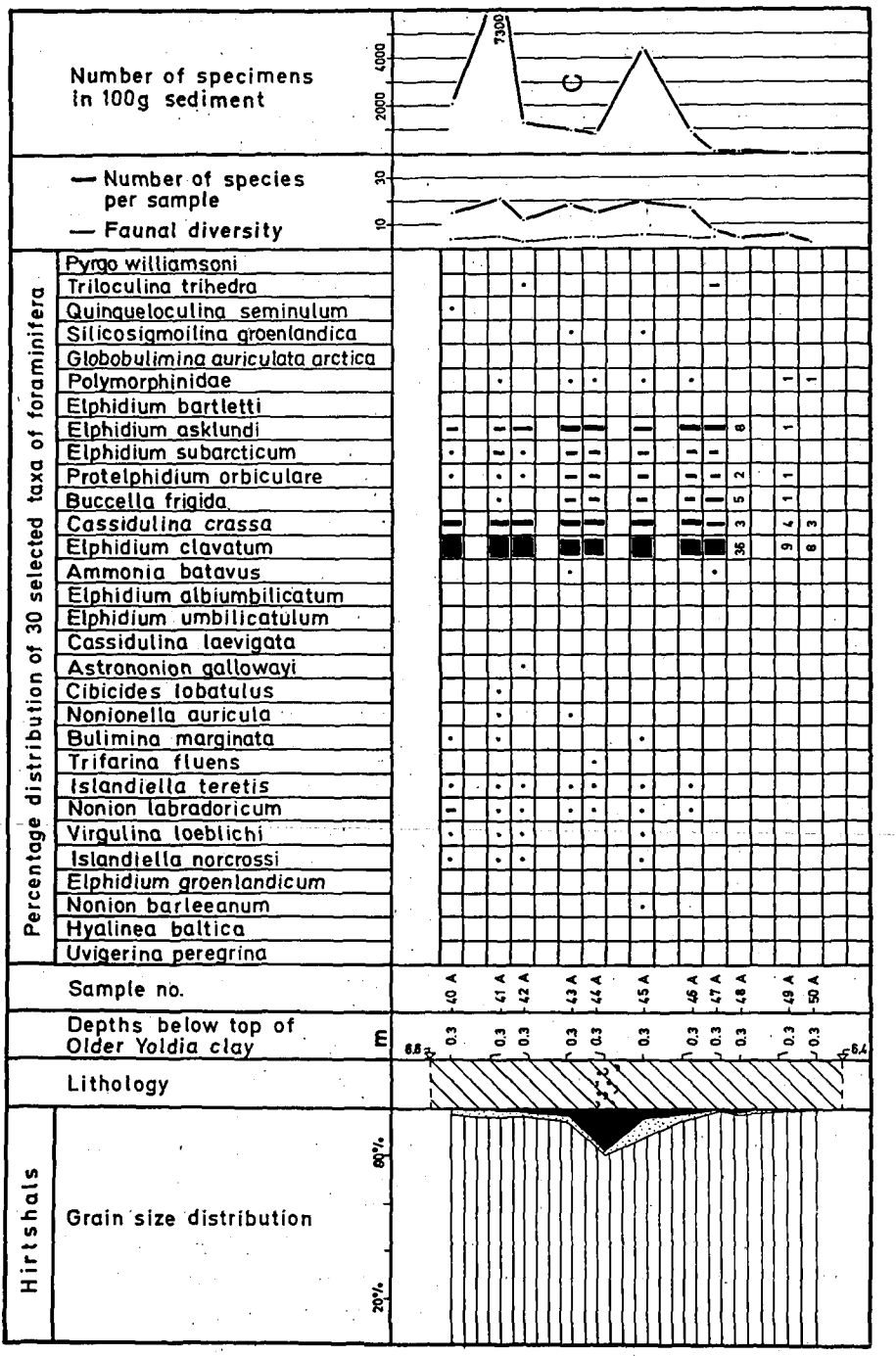

Fig. 37. Distribution chart for profile 40A–50A. (Hirtshals coast cliff at 161–168.5 m). Legend p. 71.

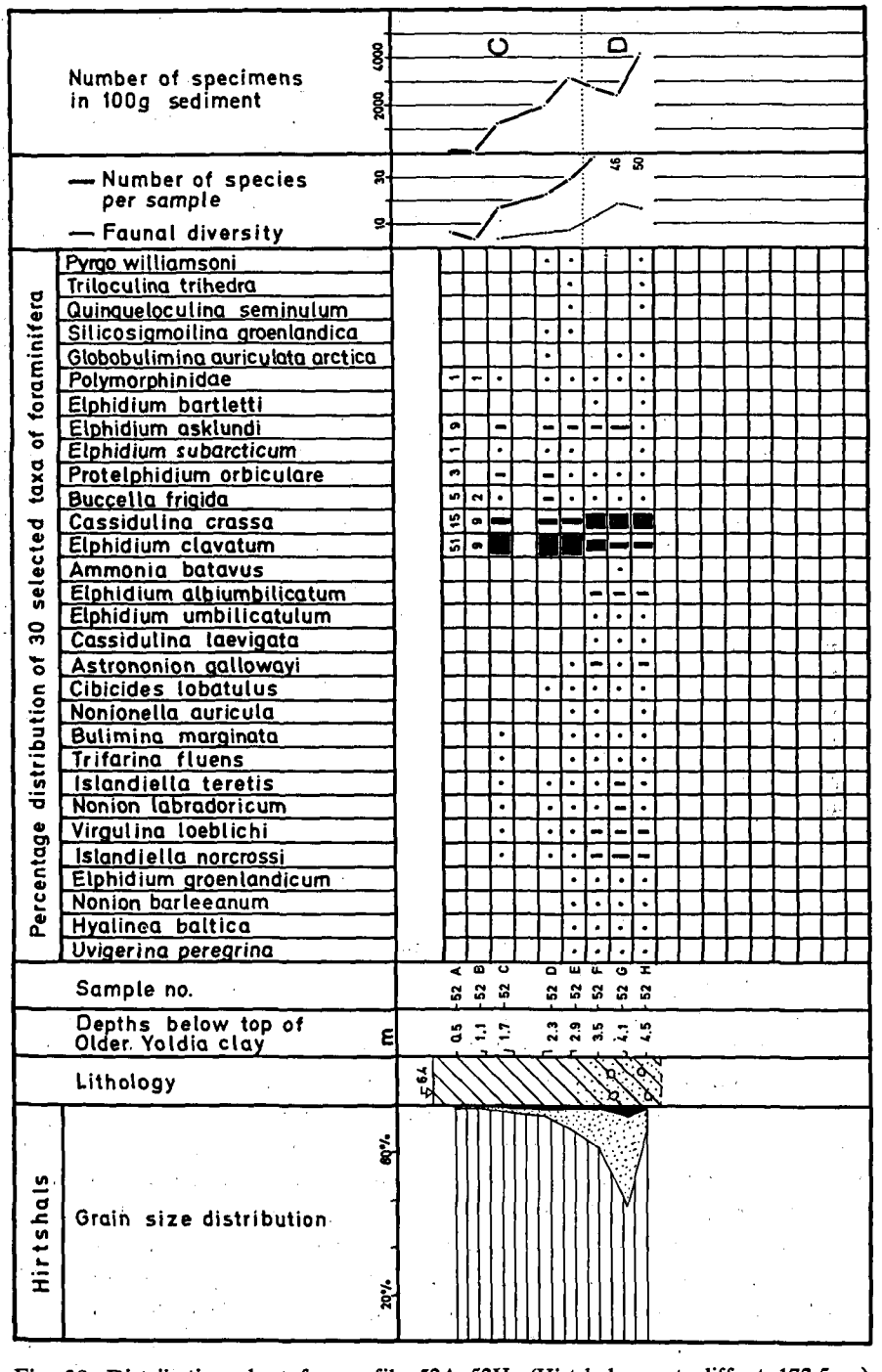

Fig. 38. Distribution chart for profile 52A–52H. (Hirtshals coast cliff at 172.5 m). Legend p. 71.

than zone B. A thinning out of the fauna in the upper part of zone C supports this assumption.

In the distribution chart (fig. 38), zone D occurs below zone C. The lowermost samples of zone C (figs. 38 and 39) contain more species and more specimens of foraminifera than normal for the zone. This, together with a more common occurrence of *Nonion labradoricum* and *Islandiella teretis,* seems to indicate a deepening of the water. The fauna in the lowermost part of zone C forms a gradual transition to the zone D fauna.

In the zone D fauna (fig. 38 and fig. 39) the dominance of *Cassidulina crassa* together with *Elphidium clavatum* indicates arctic conditions. *Islandiella norcrossi, Nonion labradoricum,* and *Virgulina loeblichi* commonly occur, all of which are found in arctic waters of moderate depths. *Uvigerina peregrina, Hyalinea baltica* and *Nonion barleeanum* constitute a stronger boreal element in this fauna than in the zone A fauna. The species also indicate moderate depths. The large number of specimens and the great number of species together with a rather high faunal diversity may indicate favourable conditions. The zone D fauna seems to be arctic with a strong boreal element. The minimum depth seems to have been about 20 m. The fauna belonging to zone D is only found in layers of sandy clay with a considerable content of boulders. None of the boulders are greater than half a metre in length. In this sediment there are fragments of *Balanus crenatus* and *B. hameri* (Ascanius), the latter is seldom found at depths less than 40 m. Shell fragments of *Hiatella arctica* and *Macoma calcarea* are frequent and a few fragments of *Mytilus edulis* Linné and *Portlandia arctica* also occur, together with some plant material. The sediment is almost a till in character, but because of the rich occurrence of very well-preserved foraminifera and the gradual transition from the zone D fauna to the overlying zone C fauna, the sediment is assumed to be of glacio-marine origin. This conclusion is supported by the fact that the enclosed boulders do not seem to have any preferred orientation.

The distribution chart (fig. 39) shows a horizontal profile which, besides the faunas mentioned earlier belonging to zone C and zone D, also contains a zone E fauna. Zone E seems to be older than zone D.

The zone E fauna contains species which are not, or only partly, represented in arctic faunas. *Elphidium albiumbilicatum,* which is very frequent in this zone, is known from boreal waters shallower than 20 m and of lowered salinity. *Elphidium umbilicatulum* occurs in boreo-lusitanian shallow-water faunas together with *Ammonia batavus,* but there they are normally much more frequent than in the present zone. The presence of *Buccella frigida* also indicates shallow-water. *Cassidulina crassa,* which is mainly of arctic habitat, is still a member of this fauna, but the relatively low numbers of this species may be due to shallow water, higher temperature and lowered salini-

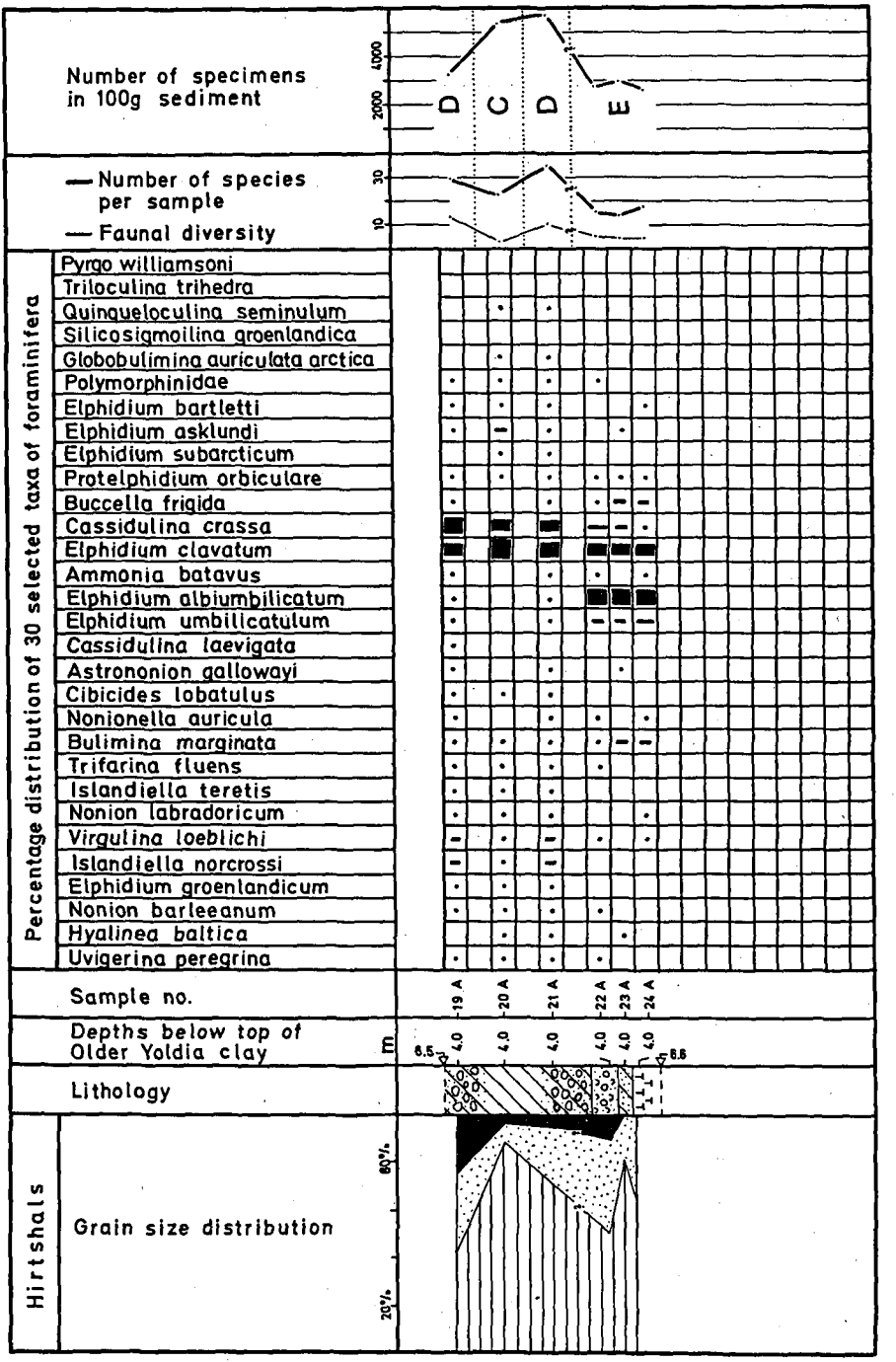

Fig. 39. Distribution chart for profile 19A–24A. (Hirtshals coast cliff at 140–144 m). Legend p. 71.

ty. In a few of the samples from this zone *Cassidulina crassa* did not occur. *Bulimina marginata* is not very frequent and the specimens are very small, which may be due to the fact that the environment was unfavourable for the species. *Bulimina marginata* is known to prefer temperate waters at depths greater than 15 m, when the species normally dominates the fauna. The faunal diversity is low in zone E, the limiting factor in this case probably being shallow water.

The zone E fauna is assumed to be boreo-arctic in shallow water, the water depth was certainly less than 20 m, probably less than 10 m. The salinity was relatively low. Foraminifera assemblages belonging to zone E are found in grey sandy and silty, often fissured clay, in shelly gravel, in peat and in sand containing much plant material. In the sandy and silty clay there are well-preserved fragments of *Zirfaea crispata,* in some places in abundance. *Z. crispata* is often with united valves (fig. 30). *Hiatella arctica, Macoma calcarea, Mya truncata, Macoma baltica,* and *Mytilus edulis* are also found in this sediment. Furthermore, fragments of *Balanus crenatus* and some plant material occur. In the shell gravel the same species are found together with a single fragment of *Arctica islandica.* Here the mollusc fragments are rolled to a greater or lesser extent. The mollusc fauna indicates boreo-arctic shallow-water conditions as does the foraminifera fauna of this zone. Two radio-carbon datings have been made on material from this zone. One on well-preserved shells of *Zirfaea crispata* (from sample no. 14 G) and one on plant material (from sample no. 24 A). Both of these datings gave ages $>$ 35,000 years B.P. A. Jessen (1899, 1918 and 1936) believed that these layers represented reworked material. The present investigation shows, however, that their occurrence in the cliff is very consistant and that they are a genuine part of the sequence and of the Older *Yoldia* Clay.

The zone F fauna is shown in the distribution chart (fig. 40). One sample containing a zone E fauna is situated between the zone F faunas. The uppermost part of the profile containing zone F assemblages is thrusted over the zone E part, which is again underlain by zone F. It is evident from the cliff that zone F is older than zone E. The zone F fauna partly contains the same species as zone E, but with another frequency distribution. In addition, the zone F fauna contains a greater number of species and the faunal diversity is higher. This, together with the higher frequency of *Cassidulina crassa,* which together with *Elphidium clavatum* dominate the fauna, indicates deeper and colder water. It should be mentioned that the deeper-water species *Bulimina marginata,* which is rather frequent, and *Nonion labradoricum,* which is found as scattered specimens, are small. The lower frequency of *Elphidium albiumbilicatum* and the only scattered occurrence of *Elphidium umbilicatulum* supports the assumption of a deepening of the water

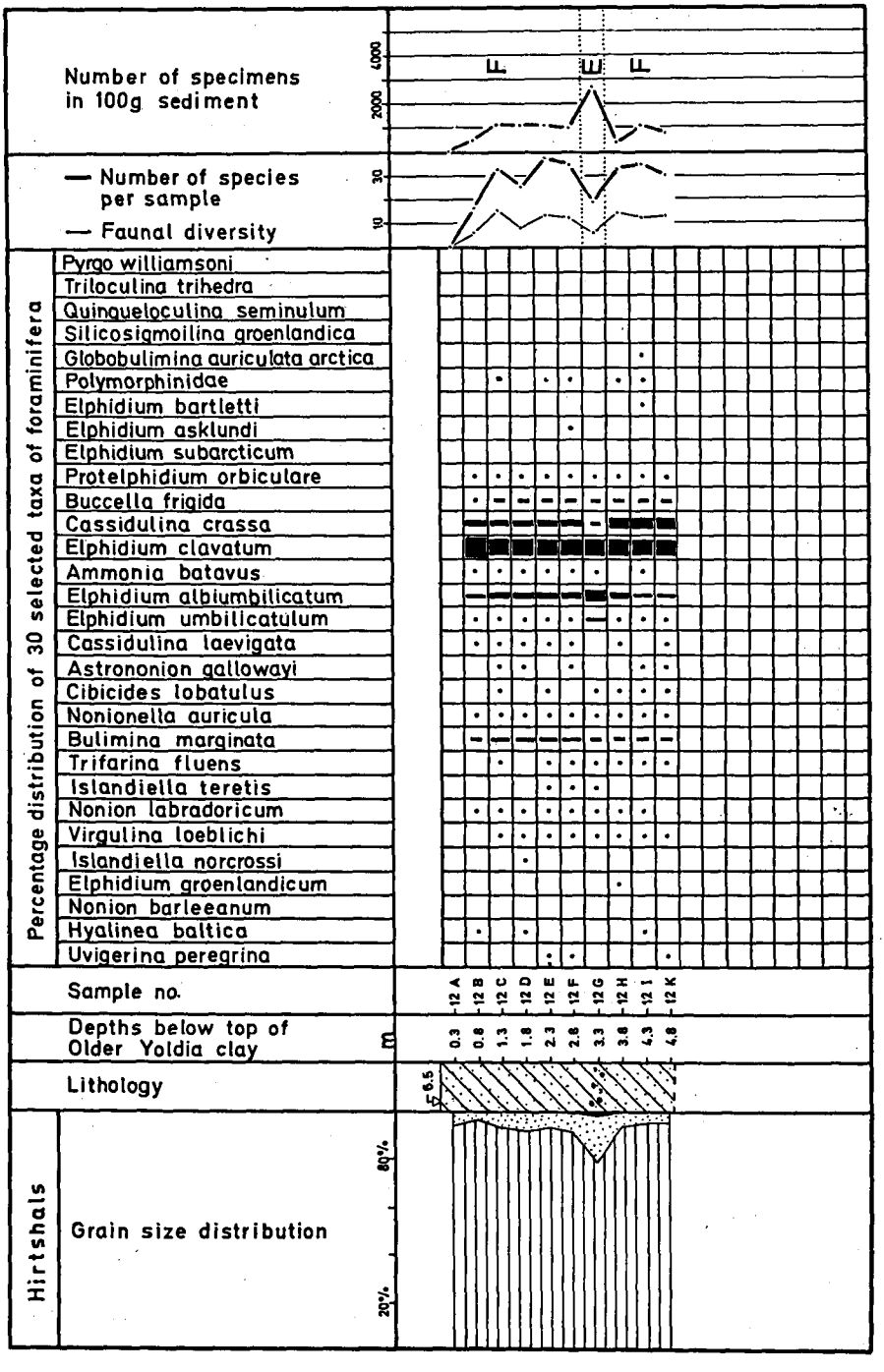

Fig. 40. Distribution chart for profile 12A–12K. (Hirtshals coast cliff at 129.5 m). Legend p. 71.

and a lowering of the temperature. The fact that these specimens are nevertheless members of the fauna indicates a lower salinity. The zone F fauna seems to be arctic with a boreal element, from depths of 10–30 m. The salinity of the water was probably a little lowered. The zone F fauna is found in a sandy and silty clay, which contains some plant material. Molluscs are normally rare in the sediment, but in some horizons there are many fragments of small specimens of *Portlandia arctica*. A few specimens of *Portlandia frigida* (Torell) are found together with *P. arctica*. These are the only molluscs found in zone F.

The zone E_0, which is here inserted for deposits without foraminifera, is only found in sand. Some plant material, but no molluscs occurred in the sediment. Sand belonging to zone E_0 occurs in the cliff between sediments containing the zone E fauna. Zone E_0 may represent a fresh-water deposit, or a deposit with a secondary solution of the tests of foraminifera.

Discussion

A synthesis of the distribution of foraminifera in the different zones of Older *Yoldia* Clay in Hirtshals coast cliff is presented in the chart (fig. 41). The lithology is generalised and the thicknesses approximate.

If the stratigraphical relations of the zones are as proposed, zone F is the oldest and zone A the youngest part of the Older *Yoldia* Clay in Hirtshals coast cliff. This means that zone F, the *albiumbilicatum-marginata* zone, which seems to indicate rather shallow water with a slighty lowered salinity and subarctic environment, is succeeded by zone E, the *albiumbilicatum-umbilicatulum* zone. The succession seems to indicate a transition to boreo-arctic conditions with very shallow water and lowered salinity. Zone E is succeeded by zone D, the *crassa-norcrossi* zone, indicating a deepening of the water, a lowering of the temperature and an increase in salinity. In addition the ice-rafted stones suggest an advancing ice-margin. From zone D there is a gradual transition to zone C, the *asklundi-orbiculare* zone, in which the water-depth mainly appears shallow and the climate has become arctic; perhaps this zone was formed just in front of a stationary ice-margin. In the upper part of zone C there is a thinning out of the fauna, which continues in zone B, the zone with scattered specimens. This is assumed to have been caused by the unfavourable influence of melt-water, possibly from a retreating ice-margin. Zone B is succeeded by zone A, the *labradoricum-norcrossi* zone. Here a boreal element enters into the arctic fauna and the water-depth has increased.

Within the zones of the Older *Yoldia* Clay in Hirtshals coast cliff, there thus seems to be two warmer intervals, viz. zone E and zone A, separated by a cold interval, zone C. Zone D and zone B appear to be zones of transition

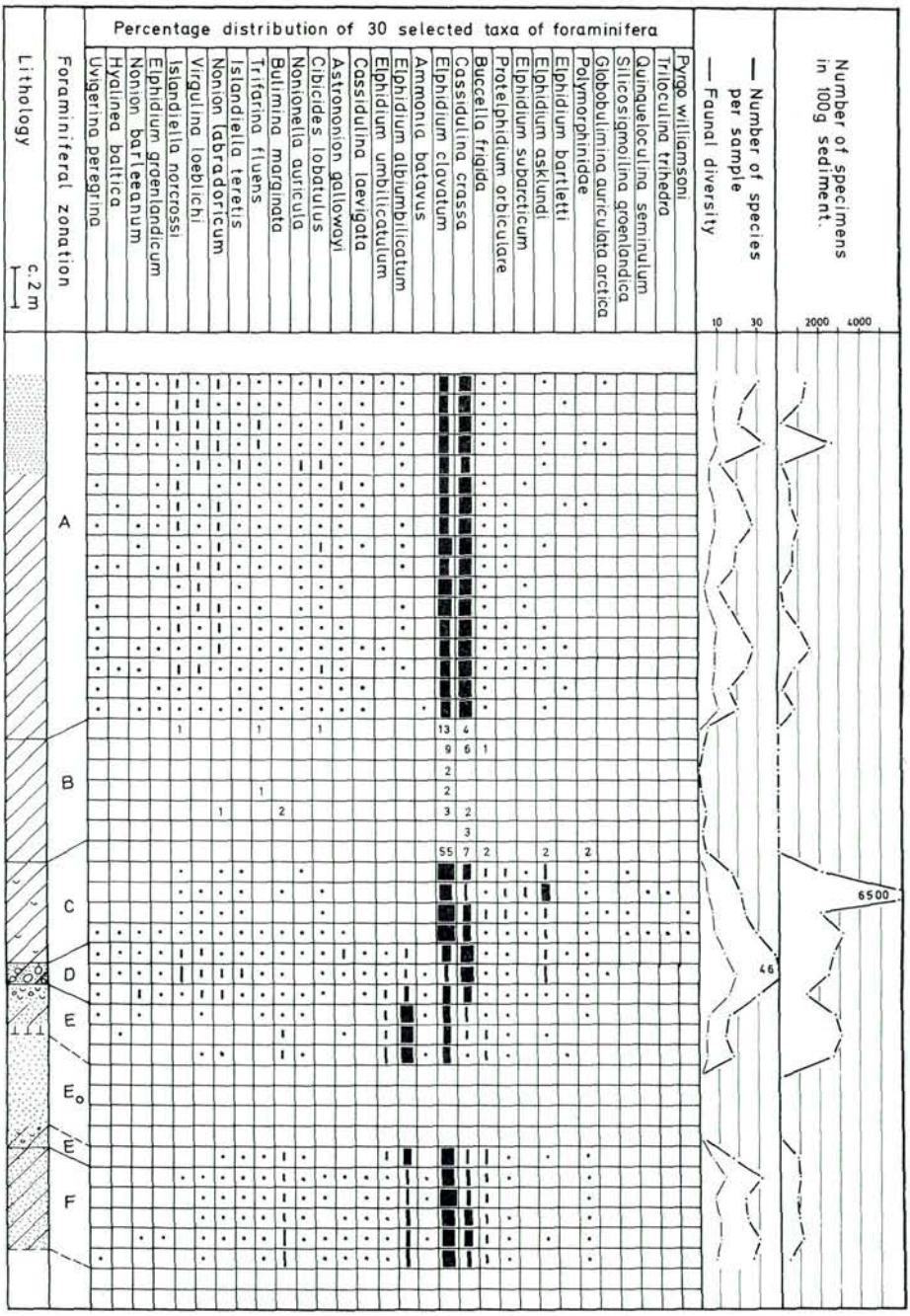

Fig. 41. Synoptic distribution chart of the Older *Yoldia* Clay in Hirtshals coast cliff. Legend p. 71.

between the cold interval and the warm ones. Zone F is probably also a zone of transition. Because of the relatively low temperature of all the zones, they are considered as belonging to a glacial stage. The warmer intervals indicate interstadials, in the sense of minor warm intervals within a glacial stage. The cold interval may represent a stadial. No inland-ice seems to have overridden the area during the deposition of the Older *Yoldia* Clay.

The Older *Yoldia* Clay has later been dislocated by ice, which probably moved in a westerly direction at this place. The cover of boulders on top of the Older *Yoldia* Clay is assumed to be partly a remnant of outwashed Older *Yoldia* Clay, and partly remains of an outwashed till deposit left by the above-mentioned ice. This latter point of view is based on the fact, that there is a huge number of very large boulders in this deposit, including many indicator-boulders (e.g. rhomb-porphyry and larvikite), whereas in the Older *Yoldia* Clay there are no boulders greater than half a metre in length, none of them being sure indicator-boulders.

Correlation

A correlation of the foraminifera assemblages of the Older *Yoldia* Clay in Hirtshals coast cliff with the foraminifera faunas of the *Portlandia arctica* Zone in the Skærumhede sequence would be of great interest. For this purpose the foraminifera from the Skærumhede sequence, which was examined, but not published by the late Dr. Nørvang, were placed at our disposal. Unfortunately, the material is rather inadequate from the *Portlandia arctica* Zone, as part of this zone is not represented at all. Furthermore, there seems to be an overrepresentation of the larger species of foraminifera. Nevertheless, a consideration of the foraminiferal content seems to confirm the well established correlation between the Older *Yoldia* Clay and the *Portlandia arctica* Zone. However, it is not possible on the basis of the foraminifera faunas to find out to what extent the *Portlandia arctica* Zone is represented in Hirtshals coast cliff. Therefore, a correlation with the *Portlandia arctica* Zone based also upon the sediments and their content of molluscs, is attempted. In the Skærumhede sequence the *Portlandia arctica* Zone occurs from 57.4 to 97.9 m below the surface, which is at 23.3 m above sea level. From 75.0 to 88.2 m below the surface alternating layers of gravel, sand and clay occur. In the lowermost section (82.7–88.2 m) of this interval *Portlandia arctica* is frequent. This section might be correlated with zone F in Hirtshals. The four samples of foraminifera (Nørvang's material) from this interval of the *Portlandia arctica* Zone contained only two or three specimens each. In the upper section (75.0–82.7 m) shells, i.a. of *Macoma calcarea, Hiatella arctica, Mya truncata, Mytilus edulis, Macoma*

baltica, and *Zirfaea crispata* are found. Within a part of this section *Portlandia arctica* is absent. This upper section may be correlated with zone E, though some of the molluscs (*Zirfaea crispata, Mytilus edulis,* and *Macoma baltica*) have been (A. Jessen et al., 1910) considered to be reworked and not belonging to the *Portlandia arctica* Zone. From this interval of the *Portlandia arctica* Zone there is only one sample containing one specimen of *Elphidium clavatum* (Nørvang's material). From 74.4 to 75.0 m a layer described as stones, gravel, coarse-grained sand and clay occurs. This layer with shells including *Macoma calcarea, Hiatella arctica, Mytilus edulis,* and *Portlandia arctica* recalls zone D in Hirtshals. There are no foraminifera samples from this interval of the *Portlandia arctica* Zone. From 70.9 to 74.4 m solid clay with a content of sand and scattered stones occurs. This interval may be correlated with zone C. It should be mentioned that the foraminifera in the two samples (Nørvang's material) from this interval of the *Portlandia arctica* Zone show a good resemblance to the zone C Fauna. Zone C probably also includes the lowermost part of the clay, which is found in the uppermost interval (from 57.4 to 70.9 m) of the *Portlandia arctica* Zone. The rest of this interval, possibly together with a part of the glacifluvial clay and sand overlying the *Portlandia arctica* Zone, may be correlated with zone A and B. Each of the five samples (Nørvang's material) from the uppermost part of the *Portlandia arctica* Zone contained only a very few foraminifera.

This correlation seems to show that the Older *Yoldia* Clay of Hirtshals coast cliff corresponds to the upper c. 30 m of the *Portlandia arctica* Zone together with the lowermost part of the glacifluvial deposits overlying this zone in the Skærumhede sequence. In addition, it should be mentioned that plant material, which is found in all the zones of the Older *Yoldia* Clay, is only found in the upper 29 m of the *Portlandia arctica* Zone and in the overlying glacifluvial deposits.

The Older *Yoldia* Clay from different localities in Vendsyssel, discussed by Jørgensen and Knudsen (the present paper), resembles partly zone A and partly zone C of the Older *Yoldia* Clay at Hirtshals.

Feyling-Hanssen (1966 and the present paper) has investigated the foraminifera faunas of the Sandnes Clay. Some of the faunas found in Older *Yoldia* Clay at Hirtshals have a pronounced resemblance to faunas found in the Sandnes Clay. These faunas seem to be identical both in ecological and in stratigraphical respects (Feyling-Hanssen, the present paper). Therefore, zone A is correlated with zone 1 of the Sandnes Clay, zone B is correlated with zone 2 and zone C is correlated with zone 3. The Sandnes Clay does not contain zones resembling the zones D, E and F in the Older *Yoldia* Clay at Hirtshals.

Feyling-Hanssen (in the present paper) believes that the Sandnes Clay belongs to an extended interstadial of Middle Weichselian age, which he

calls the Sandnes Interstadial. Therefore the upper zones of the Older *Yoldia* Clay at Hirtshals may be of Middle Weichselian age. The lower zones of the Older *Yoldia* Clay, of which the age of zone E is greater than 35,000 years B.P., may belong to an older part of the Middle Weichselian. Another possibility is that zone E is essentially older and belongs to the Brørup Interstadial at about 58,000 years B.P. (S.T. Andersen, 1961), but the temperature indication of zone E is probably too low. Such a correlation would indicate that inland-ice did not reach Hirtshals between the early and the middle part of the Weichselian.