Foraminiferal stratigraphy in a marine Eemian-Weichselian sequence at Apholm, North Jutland

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Undisturbed core material is investigated for the first time from a marine Quaternary sequence through the Eemian of North Jutland. Core samples were examined from 86 m–190 m depth in a 202.6 m deep boring at Apholm. The marine sequence from that interval was subdivided into 4 biozones based on its foraminiferal content.

Zone AP3 (190–140 m) contains boreal and boreal-lusitanian faunas indicating a water depth of at least 60–100 m. This zone is referred to the Eemian Interglacial. The Late Saalian/Eemian transition is identified at 190.2 m depth (AP4). The faunas of zone AP2 (140–113 m) record the onset of a major deterioration in climate and a considerable shallowing of the marine environment. The climate is then seen to fluctuate between arctic and boreal-arctic in zone AP1 (113 m to at least 86 m). This indicates the succeeding stadial and interstadial periods. Zones AP2 and AP1 are referred to the Early and Middle Weichselian.

The foraminiferal zones at Apholm are compared with the marine sequence at Skærumhede. In addition, an attempt is made to relate these zones to the oxygen isotope chronology and to the Late Quaternary climatic regimes of the Norwegian Sea.

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The Quaternary stratigraphy of the Frederikshavn area was originally described by Jessen et al. (1910). They subdivided the marine sequence at Skærumhede using molluscs. More recently their material has been re-examined as more borehole material became available. A detailed examination of the foraminiferal assemblages, found in the boreholes at Skærumhede (fig. 1), has resulted in a well defined series of biozones being established in the succession (Konradi and Knudsen, 1974; Knudsen, 1976; Knudsen and Lykke-Andersen, 1982). One major drawback of these studies has however, been the lack of available undisturbed core material, and the risk of contamination could not therefore be easily overlooked.

This problem has now been alleviated by the Danish Geological Survey, who made available undisturbed core samples to the author. These came from a borehole put down in 1941 at Apholm, north of Frederikshavn (fig. 2). The borehole had a ground elevation of 3.5 m above present-day sea-level and penetrated 202.6 m of Quaternary deposits. The interval between 86.3 m and 190.2 m was cored, and the foraminiferal content of 57 core samples was examined from

this interval. As samples of this quality have not previously been studied from the present area, the results presented here establish a more satisfactory biostratigraphy, which may therefore also

Fig. 1. Locality map.

Fig. 2. The location of the Apholm boring 7.131b and of the Skærumhede borings.

act as a re-evaluation of the earlier investigations from Skærumhede.

In addition to the cored material at Apholm, three further samples from deeper levels in the same borehole (190.2–202.6 m) were available for analysis. These had already been washed, and only sediment greater than 0.1 mm remained. They have been included in the present study in order to complete the succession.

Methods

The samples from Apholm were treated for foraminiferal analyses according to the laboratory methods described by Feyling-Hanssen et al. (1971) and Meldgaard and Knudsen (1979). At least 300 specimens were counted where possible for quantitative purposes. The percentage frequencies of selected species are illustrated by symbols on the range chart, fig. 3a. In samples with few foraminifera the entire content was analysed. The actual number of tests for each species has been entered on the range chart, where this did not total 100 specimens.

The faunal diversity and dominance indices used on fig. 3b, were defined by Walton (1964). Faunal diversity is the number of ranked species that accounts for 95% of a counted fauna, and the faunal dominance is the percentage of the most common species in a fauna. These measures, together with the other parameters shown on fig. 3b, give an indication of the marine-ecolo-

gical conditions during deposition. The species, which were included in calculating boreal content of the faunas, are listed below. The actual percentage values of the species on fig. 3a are given on the diagram, fig. 3c. An outline of the lithology and the grain size distribution in Apholm 7.131b is shown on the left sides of figs. 3a and 3b.

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

Foraminiferal zonation and palaeoecology

The marine sequence of Apholm boring 7.131b is subdivided into four foraminiferal biozones, viz. zones AP4, AP3, AP2 and AP1. The three samples mentioned above from the bottom of the borehole (200–202 m depth) contained very few foraminifera (figs. 3a and 3b). One of the samples included a large number of bryozoan fragments. These lowermost samples are considered here to represent a non-marine Quaternary deposit.

The foraminiferal zone AP4 is represented by only one sample of stiff clay from 190.15–190.25 m depth. The fauna is in fact a mixture of an arctic and a boreal fauna, but with arctic species as the dominant component (fig. 3a). The most common arctic species are *Islandiella helenae*, *Stainforthia loeblichii*, *Cassidulina reniforme*, *Elphidium excavatum* and *Islandiella norcrossi*. A common boreal species is *Cassidulina laevigata*. The admixing of these two faunas may have resulted from a transition from colder to more temperate conditions during deposition. Presumably the assemblage does not represent an indigenous living fauna. Each sample covers a certain time interval, this one may cover both the final arctic and the beginning of a warmer period. Bioturbation is also a factor, which may result in a considerable mixing of sediments, but even so the arctic components in zone AP4 show that a marine environment had already been introduced into the area, before warmer conditions were fully established.

The clay sequence from 190 to 140 m depth is included in the foraminiferal zone AP3. *Bulimina*

marginata and *Cassidulina laevigata* are dominant species, and normally *Hyalinea balthica* is frequent too. *Nonion barleeianum*, *Cassidulina ob-tusa* and *Epistominella exigua* are especially common in the lower part of the zone. *Pullenia osloensis*, *Gyroidina umbonatus*, *Uvigerina peregrina* and *Globobulimina turgida* also become important faunal elements within certain intervals of zone AP3 (figs. 3a and 3c).

The most common miliolid species in zone AP3 are *Quinqueloculina seminulum*, *Miliolinella subrotunda*, *Pyrgo williamsoni*, *Sigmoilopsis schlumbergeri*, *Sigmoilopsis tenuis* and *Quinqueloculina padana*. The total content of miliolids in each of the samples is shown on fig. 3b. It is initially low, but levels off at between 5 and 10% of the fauna in most of the zone, peaking at 147 m (25%).

The faunal diversity index usually varies from 10 to 20 in most of the samples from zone AP3, and the number of benthonic species is normally between 35 and 45. Planktonic foraminifera are largely restricted to a few samples between 167 m and 147 m, rising to 7.5% of the total counted assemblage at 165.5 m.

In general the present zone AP3 faunas reflect boreal to boreal-lusitanian marine-ecological conditions, water depths of at least 60–100 m and normal marine salinities of at least 33‰ (Höglund, 1947; Lange, 1956; Jarke, 1961; Risdal, 1964; Gevirtz et al., 1971; Thiede et al., 1981; van Weering and Qvale, 1983). The presence of planktonic foraminifera in a few samples may be an indication of more open connection to the Norwegian Sea at these levels in the borehole.

In the upper part of zone AP3 there are some drastic changes in dominance. In one sample (no. 30) *Stainforthia fusiformis* is the most frequent species instead of the usual dominance of *Bulimina marginata* or *Cassidulina laevigata*. In the overlying sample *Bolivina spathulata* reaches a peak, and the fauna is subsequently dominated by miliolids. The gaps between these samples are unfortunately too large (5 m) to give any detailed information about the environmental significance of these variations. All the important species here belong in water depths of up to about 100 m, while a relatively large number of miliolids could indicate increased salinities (Murray, 1973). More closely spaced sampling from the upper part of zone AP3 might lead to a better under-

standing of the apparently changing conditions reflected in the foraminifera towards the end of that warm period.

The lusitanian species *Quinqueloculina padana*, which is common in recent Mediterranean faunas (Giunta, 1954) but not found in the Recent Skagerrak (see also Knudsen and Lykke-Andersen, 1982), occurs throughout most of zone AP3 (figs. 3a and 3c). The faunas indicate a period of true interglacial conditions, when the environment must have been warmer than in the present Kattegatt and Skagerrak.

Environmental conditions are totally altered in zone AP2 (140–113 m depth). The sediment is still largely a clay, but with a gradual increase in sand-sized material upwards. The deep, warm-water indicator-species such as *Bulimina marginata*, *Cassidulina laevigata*, *Hyalinea balthica* and many others disappear in this zone and are replaced by a shallower water assemblage, viz. *Elphidium excavatum*, *E. margaritaceum*, *E. gerthi*, *E. albiumbilicatum* and *Nonion depressulum*. Both *Elphidium gerthi* and *E. excavatum* began to appear in the upper part of zone AP3, a possible indication that a slight shallowing of the water had already commenced, but a significant drop in sea-level must have occurred at the transition between zone AP3 and zone AP2. At the beginning of zone AP2 the water depth was probably less than 20 m, but there seems to have been a return to slightly deeper water again in the upper part of the zone. The shallow water indicator-species become relatively less frequent, and some of the deeper water species known from zone AP3 return in low frequencies to the faunas.

Indicators of cooler marine conditions are first introduced at the bottom of zone AP2 and increase in importance upwards through the zone. An increase of the arctic *Cassidulina reniforme* also supports the suggestion of deeper water in the upper part of zone AP2, because *C. reniforme* prefers normal marine salinities, and it only occurs in large numbers at water depths of more than about 20 m (Buzas, 1965; Nagy, 1965).

Both the number of species and the number of benthonic specimens are extremely high in the upper part of this zone. The reduction in specimen numbers during the shallower period at the base of the zone may be an indication of a higher rate of sedimentation. No planktonic specimens are found in zone AP2, and the content of mili-

Fig. 3a. Range chart for Apholm boring 7.131b with frequency distribution of selected foraminiferal taxa. Legend on fig. 4. The samples from 35 to 52 are all from the interval between 165 and 170 m.

Fig. 3b. Apholm boring 7.131b, palaeoenvironmental indices and correlations. Isotope stages are those established by Shackleton and Opdyke (1973), and climatic regimes are according to Belanger (1982). Legend for grainsize distribution on fig. 4.

A P H O L M 7.131 ^b																																											
FORAMIN. ZONES		DEPTH (m below surface)	SAMPLE NO.	ELPHIDIUM GREENLANDICUM	NONION ORBICULARE	ELPHIDIUM ASKUNDI	ELPHIDIUM EXCAVATUM	CASSIDULINA RENIFORME	ISLANDIELLA HELENAE	ISLANDIELLA NORCROSSI	NONION LABRADORICUM	STAINFORTHIA LOEBLICHII	BUCCELLA FRIGIDA	BUCCELLA FRIGIDA var. CALIDA	CIBICIDES LOBATULUS	QUINQUELOC. SEMINULUM	PYRGO WILLIAMSONI	MILIOINELLA SUBROTUNDA	SIGMOIOPSIS SCHLUMBERGERI	SIGMOIOPSIS TENNIS	QUINQUELOCULINA PADANA	CASSIDULINA OBTUSA	PULLENIA OSLOENSIS	BULIMINA MARGINATA	CASSIDULINA LAEVIGATA	HYALINEA BALTICA	NONION BARLEEANUM	UVIGERINA PEREGRINA	GLOBOBULIMINA TURGIDA	PLANULINA ARMINENSIS	GYRODINA UMBONATUS	ANGULGERINA ANGULOSA	BOLIVINA SPATHULATA	STAINFORTHIA FUSIFORMIS	AMMONIA BATAYUS	ELPHIDIUM MAGELLANICUM	ELPH. ALBIUMBILICATUM	ELPH. MARGARITACEUM	NONION DEPRESSULUM	ELPHIDIUM GERTHII			
AP 1a	86.3	1		*	1	71	5	*	*	*			7	1	*	*	*						2													1	9						
	86.4	2	*	*	1	70	6	*		1			7	1	*	*	*						*										*			2	8						
	88.0	3			1	73	6	1	*	*			8	1	*	*	1																		3	5							
	88.6	4	*	1	5	73	15	1	1	*	*	3				1		*					*	*									*	2									
	89.8	5	1	9	37	31	6	5				2																						4	6								
	90.8	6		2	9	72	9	1	1	*	1	1	*		*			*					*											1	1	2							
	91.8	7	*		1	88	8	*	*			1	*										*	*							*			*	*			*		*			
	92.5	8	*	*	1	87	8	*	*	*		1	*		*	*							*	*									*	*		*		*		*			
	93.8	9	*	*	*	79	13	*	2			3	*		1								*	*									*	*		*		*		*			
	94.6	10	1	*	1	70	18	1	2	*	3	1	1	*				*					1	*	*	*						*	*	1	*		*		*		*		
AP 1b	95.9	11	1	1	1	76	16	*	1	*	1	*		*	*	1						*	*				*	*	*	*	*	*	*	1	*		*		1		*		
	97.0	12	*	*	1	74	16	1	1	*	3	1	*		*							1	*	*	*	*						*	*	1	*		1	*		*			
	97.7	13	*	*	1	71	24	1	*		2	*										*	*									*	*	1	*		*		*				
	98.8	14	*	*		81	13	1	1	*	1	*	*	*	1							*	*									*	*	1	*		*		1		*		
	100.2	15				80	5	*		1		2	3		*		*					*	*							*	*		1	3	4								
	101.3	16				79	1	*	*			2	5	*	*	*	*					1	*		*					*	*		*	3	7	1							
	104.0	17		1	6	70	19	*	1	*	*	*										*	*									*	*		*								
	105.4	18	*	*	1	75	18		1	*	2	*	*	*	*	*						*	*		*	*						*	*	1	*		*		*				
	108.6	19	1	2	4	69	10	1	1	1	1	3	*	*	*	*						2									*	1	5	*									
	111.1	20			2	79	13	*	*		*					*																	*	2	2								
AP 2	115.1	21	1	*	28	47	3	4	2	1	2		1	*	*	*	*	*	*	*	*	1	*	*	*	1	*	*	*	*	*	*	*	*	1	*	1	1	1	1	1	1	1
	117.5	22	*	*	*	26	38	5	9	1	1	2	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3	1	1	1	1	1	1	1	1	
	121.4	23	1	2	*	49	13	6	4	2	*	3	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	6	3	2	1	1	1	1	1	1		
	126.9	24	*	*		22	21	5	7	1	1	*	7	1	*	*	*	1				1	*								*	1	10	1	5	5	6						
	132.8	25			33	2						5	1									1	2	1							1	2	1	1	1	1	1	1	1	1	1		
	137.4	26		1	1	25	2					5	1	3	1							3	1								3	12	3	11	5	15							
AP 3	142.8	27				1			1				1	8	2	3		3			2	20	40	8								1									3		
	147.3	28				3					1	*		15	1	2	*	4	3		6	23	10	4								1	1	*	*			1	1	4			
	152.6	29			14								*	2	*	*	*	*	*	*	4	36	14	7	*	1	*	1	*	17	*	*	*	*	*	*	*	*	*	*	*	*	
	157.6	30			5								1	3	1	*	1	1	*	11	17	17	5	1	*	*	1	*	1	23	*	*	*	*	*	*	*	*	*	*	*		
	159.9	31			1	*							2	1	1	*	1	1		10	43	5	20	*	4	*	*	1	*	1	1	*	1	1	*	*	*	*	*	*	*		
	162.5	32											*	4	1	1	1	3	1		9	44	10	13	1	1	1	*	*	1		*	*	*	*	*	*	*	*	*	*		
	164.9	33											1	1	*	*	*	5	1	*	4	25	43	13	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
	165.3	34			*			*					1	*	*	*	3			3	45	24	12	3	1	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
	165.5	35											1	3	*	1	1	4	1	*	11	19	23	19	1	*	1	*	2	1		1	1			*	*	*	*	*			
	165.7	36			*								3	*	*	1	2	1	*	6	27	35	15	*	*	1	*	2	1	*	*	*	*	*	*	*	*	*	*	*	*		
	166.0	37											1	1	*	*	1	2		9	47	12	7	7	1	*	1	3	1	*	2												
	166.1	38			*	*							*	1	1	1	1	3	1	7	38	25	11	3	2	1	*	1	*	1	*	1	*	*	*	*	*	*	*	*	*		
	166.3	39			*								*	3	*	1	2	3	2	6	36	21	10	5	2	1	*	3	*														
	166.9	40			*								1	1	*	1	*	1	1	8	37	18	19	4	1	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
	167.2	41			1								2	1	1	1	1	1	*	5	29	22	17	3	*	1	*	9	1	*	1	*	1	*	*	*	*	*	*	*	*		
	167.5	42						*					1	3	1	*	1	2	1	6	41	23	9	2	*	3	*	1		*	1												
	167.9	43			*								2	4	1	2	2	2	2	8	44	13	4	2	*	4	1	1	*	1		*	1										
	168.2	44			*	*							1	2	1	*	1	2	2	*	8	41	16	14	2	*	2	*	1	2		1	1								*		
	168.5	45				1							*	3	*	*	1	2	1	*	4	29	44	3	4	*	1	*	1	1	*	*	*	*	*	*	*	*	*	*	*	*	
	168.9	46	*		*	*	*	*	*				*	1	2	1	2	1	1	*	3	26	29	5	12	4	2	*	*	*	*	3								*	*	*	
	169.2	47			*								1	2	*	1	1	3	1	2	27	21	15	8	5	*	1	*	2		2												
	169.5	48			*								*	3	1	*	1	2	2	*	26	16	18	12	3	1	1	7	*		1												
	170.1	50											1	1	1	*	*	*	*	31	38	15	4	2	1	1	2																
	170.5	51			*								1	1	1	*	1	3	*	*	36	16	26	7	1	1	1	*	*	*		1											
	171.0	52			*	*							*	1	*	*	1	1	*	*	24	9	36	4	*	1	*	*	4														
	175.0	53			*	*							*	2	*	*	1	1	*	2	25	17	18	12	*	*	*	3		*	*	*	*	*	*	*	*	*	*	*	*	*	
	181.0	54			*								3	1	*	*	3	1	*	2	38	15	5	19	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
185.0	55			*						*		2	1	*	*	2			7	31	12	16	12	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
189.5	56			*						*		10	*	*	1	*	*		9	29	25	4	11	*	*	*

Fig. 4. Legend for figs. 3a and 3b.

olids is extremely low. The lower water depth combined with reduced salinities presumably excluded those two groups from the faunas.

The faunas of zone AP2 are boreal to boreal-arctic in character, and this zone is therefore interpreted as a transition period between the preceding warm and a subsequent mainly arctic period.

The sequence between 113 m depth and the uppermost sample at 86.3 m is included in foraminiferal zone AP1. The sediment varies much more in this part of the marine sequence. The lower part of zone AP1 is mainly clay with a content of sand and a few pebbles. It is overlain by 9 m of clay between 100 and 91 m. The sediment finally coarsens, consisting of alternating layers of clayey sand, coarse sand and sandy clay with scattered pebbles and fragments of mollusc shells and plant material.

Zone AP1 has been subdivided into two sub-zones (AP1a and AP1b). In general, the faunas in zone AP1 are characteristically dominated by *Elphidium excavatum* and *Cassidulina reniforme*. At certain levels *Elphidium asklundi* is quite common, and other important accessory species in zone AP1 include *Nonion orbiculare*, *Islandiella helenae*, *I. norcrossi*, *Stainforthia loeblichii*, *Buccella frigida*, *Elphidium magellanicum* and *E. albiumbilicatum* (fig. 3a). The faunas are mainly arctic except at two intervals, where the boreal content increases to significant levels (fig. 3b), viz. at about 102–100 m (samples 16 and 15) and again from 91 m depth to the uppermost sample at 86.3 m (subzone AP1a). These alternating faunal elements suggest the presence of two stadials and two interstadials in zone AP1.

The uppermost part of the marine sequence was not cored at Apholm 7.131b. Some cutting samples were however, available from an adjacent borehole (Apholm 7.131a). This material was unfortunately difficult to interpret. A sample from 80 m depth for example, possessed an arctic foraminiferal fauna. A barren zone occurred around 65 m, but arctic faunas returned in the overlying sediments. The upper boundary of the marine sequence could not be defined on this material. To do so would require a more detailed biostratigraphical study of these sediments making use of undisturbed core material.

Correlations and age

The foraminiferal zones in Apholm 7.131b can be correlated with corresponding zones described from Skærumhede I (Knudsen and Lykke-Andersen, 1982) and from Skærumhede II (Konradi and Knudsen, 1974; Knudsen, 1976). An attempt has also been made on fig. 3b to correlate these zones with oxygen isotope stages established by Shackleton and Opdyke (1973).

The arctic zone AP4 in Apholm corresponds to zone N4 in the Skærumhede I boring (Knudsen and Lykke-Andersen, 1982). The faunas in these two zones are very similar. Accessory species such as *Islandiella helenae* and *Stainforthia loeblichii* are common in both. These arctic zones are considered to represent the Late Saalian corresponding to oxygen isotope stage 6 (Shackleton and Opdyke, 1973). An age of about 127,000 BP has been mentioned by e.g. Kellogg et al. (1978), Ruddiman et al. (1980), Belanger (1982) and Streeter et al. (1982) for the boundary between oxygen isotope stages 6 and 5.

Zone AP3 with its boreal to boreal-lusitanian deep water faunas is correlated with zone N3 of the Skærumhede I boring. The faunal composition is similar, and even details in the faunal succession through the zone can be compared. *Nonion barleeianum* occurs with higher frequencies in the lower part of each zone, miliolid species are important in the upper part, and a slight increase in shallow water species, such as *Elphidium excavatum* and *E. gerthi* occurs in the uppermost samples of both zones AP3 and N3. Only few faunas from zone N3 of the Skærumhede I boring have however, been analysed clo-

sely (Knudsen and Lykke-Andersen, 1982), and some details are therefore missing from that boring. Planktonic specimens found in zone AP3 at Apholm, have for instance not been found in Skærumhede I.

Zones AP3 and N3, which reflect true interglacial conditions, are here referred to the Eemian Interglacial, and a correlation with oxygen isotope stage 5e (Shackleton and Opdyke, 1973) is suggested. The upper boundary of stage 5e is placed at about 115,000 BP by Kellogg et al. (1978), Ruddiman et al. (1980) and Streeter et al. (1982). If this correlation is correct, the 50 m thick zone AP3 was deposited within a time period of about 12,000 years. A corresponding foraminiferal zone is found in many other borings from the Frederikshavn area. The thickness varies from 25 to 60 m over the whole area (Knudsen, 1984). Eemian faunas from a section at Fjøsanger in western Norway have been described by Mangerud et al. (1981). Beds N to J from that section were correlated with oxygen isotope stage 5e (see also Mangerud et al., 1979). Feyling-Hanssen (1981) described Eemian Interglacial faunas from a boring in the northern North Sea. His Eemian zone W was later (Feyling-Hanssen, 1982) placed in oxygen isotope stage 5e. In that area the Eemian deposits were only a few metres in thickness.

Recently published Ionium-dates (Vogel, 1982) support an age of about 120,000 years for the peak sea-level during the Eemian (Zagwijn, 1983).

Zone AP2 at Apholm, containing faunas reflecting the transition between the boreal-lusitanian environments of zone AP3 and the mainly arctic zone AP1, corresponds to zone N2 of the Skærumhede I boring (Knudsen and Lykke-Andersen, 1982). The sample number is low in zone AP2, but despite this, it is apparent that the upper part of that zone, which is rich in *Cassidulina reniforme*, corresponds to zone VIII at Skærumhede II (Konradi and Knudsen, 1974), whereas the lower part with very few *C. reniforme* can be correlated with zone IX.

The palaeoenvironmental conditions, which existed during the deposition of zone AP2, are compatible with the Early Weichselian intermediate climatic regime described by e.g. Kellogg (1980) and Belanger (1982) from the Norwegian Sea. This period is correlated with oxygen iso-

tope stages 5a-d established by Shackleton and Opdyke (1973). They can also be compared with the climatic response patterns (CRP) described by Belanger (1982). The present faunas do not follow the same pattern as the benthonic deep water faunas of the Norwegian Sea (CRP2), which suggest that a rather uniform temperature existed from stage 5e through to stage 5d. It is not the same as the planktonic evidence (CRP1) either, which betokens an abrupt temperature change between stage 5e and 5d. The foraminiferal faunas in zone AP2 at Apholm on the other hand indicate a gradual change to cooler conditions through the zone. As mentioned by Streeter et al. (1982) and by Belanger (1982), low surface salinities have probably affected the planktonic faunas of the Norwegian Sea during the intermediate climatic regime (5a-d). The sea was presumably covered by ice during the winter (Streeter et al., 1982), and summer melting would give a low-salinity near-surface layer. Such reduced salinities in the surface layer would also influence the shallower water masses as represented by the zone AP2 in Apholm. Evidence for a gradual deterioration in climate may presumably be more clearly reflected in these shallower faunas than in any of the Norwegian Sea faunas mentioned by Belanger (1982).

A eustatic fall in sea-level of 32 m at the Eemian-Weichselian boundary, which commenced in the Late Eemian, was mentioned by Zagwijn (1977 and 1983) for the southern North Sea area. A drop of about the same order of magnitude was suggested by Jelgersma (1979), who found evidence of a sea-level more than 40 m lower than the present in the Early Weichselian of the German Bight of the North Sea. Kellogg et al. (1978) mentioned a major drop in sea-level of about 50 m at 115,000 BP followed by a slight recovery at about 105,000 BP. This fits fairly well with the evidence found in the Apholm boring. A slight shallowing in water depth towards the end of zone AP3 is followed by a sudden change to much shallower conditions during deposition of the lower part of zone AP2. In the upper part of this zone the faunas reflect a return to somewhat deeper waters. The abrupt change apparent at the zone AP3-AP2 boundary would nevertheless appear to suggest a decrease in water depth of more than 50 m. Local tectonic movements could also however, have played a role here.

The boundary between isotope stages 5a and 4 is placed at 72,000 BP by Streeter et al. (1982). Kellogg et al. (1978) and Ruddiman et al. (1980) mention an age of about 75,000 years.

The mainly arctic foraminiferal zone *API* in Apholm is correlated with the lower part of zone N1 in the Skærumhede I boring (Knudsen and Lykke-Andersen, 1982). A correlation with zones VII, VI, V and IV in the Skærumhede II boring is also suggested (fig. 3b), based on the evidence of a changing boreal content in the faunas. The boreal-arctic faunas between 102 and 100 m depth in Apholm seem to correspond to zone VI in Skærumhede II, which is characterized by a slight increase in the relative proportion of boreal specimens. The faunas in the upper part of subzone AP1b, between 100 and 91 m depth, compare well with the high-arctic zone V faunas in Skærumhede II. There is a very high dominance of *Elphidium excavatum* and decreasing percentages of *Cassidulina reniforme* through that zone. The increased boreal content present in subzone AP1a, together with a coarsening sediment containing gravel and plant remains, is also seen in zone IV of Skærumhede II (Bahnsen, et al., 1974) and in zone E/F of the coastal cliff at Hirtshals (Lykke-Andersen, 1971). Radiocarbon dates from zone E in Hirtshals suggest an age corresponding to the Middle Weichselian Moershoofd Interstadial (Lykke-Andersen, 1981 and 1982). Zone AP1 in Apholm thus represents a continuation of the marine succession from the Early Weichselian starting in zone AP2 into the Middle Weichselian. Zone AP1 seems to include oxygen isotope stage 4 and a part of stage 3 (Shackleton and Opdyke, 1973), and it apparently belongs within the glacial climatic regime before Termination I (cf. Ruddiman et al., 1980; Belanger, 1982).

Foraminiferal list

The following two lists include the foraminiferal species, which accounted for more than 1.0% of the fauna in at least one of the samples from Apholm 7.131b. In addition to the listed species, the faunas often contained many species with frequencies of less than 1.0%, especially in zones AP2 and AP3. The planktonic species in zone AP3 are not mentioned here.

A. Species used in calculating the boreal content on the diagram, fig. 3b:

Ammonia batavus (Hofker, 1951)
Angulogerina angulosa (Williamson, 1858)
Astrononion tumidum Cushman and Edwards, 1937
Bolivina albatrossi Cushman, 1922
Bolivina spathulata (Williamson, 1858)
Buccella frigida (Cushman), var. *calida* (Cushman and Cole, 1930)
Bulimina marginata d'Orbigny, 1826
Buliminella elegantissima (d'Orbigny, 1839)
Cassidulina laevigata d'Orbigny, 1826
Cassidulina obtusa Williamson, 1848
Cassidulina subglobosa Brady, 1881
Elphidium albiumbilicatum (Weiss, 1954)
Elphidium gerthi van Voorthuysen, 1957
Elphidium incertum (Williamson, 1858)
Elphidium magellanicum Heron-Allen and Earland, 1932
Elphidium margaritaceum Cushman, 1930
Elphidium translucens Natland, 1938
Epistominella exigua Brady, 1884
Epistominella rugosa (Phleger and Parker, 1951)
Gavelinopsis praeegeri (Heron-Allen and Earland, 1913)
Globobulimina turgida (Bailey, 1851)
Gyroidina umbonatus (Reuss, 1851)
Hyalinea balthica (Schroeter, 1783)
Nonion barleeianum (Williamson, 1858)
Nonion depressulum (Walker and Jacob, 1798)
Nonion niveum Lafrenz, 1963
Nonionella iridea Heron-Allen and Earland, 1932
Planorbulina distoma Terquem, 1876
Planulina ariminensis d'Orbigny, 1826
Pullenia osloensis Feyling-Hanssen, 1954
Pullenia subcarinata (d'Orbigny, 1839)
Quinqueloculina padana Perconig, 1954
Sigmoilopsis schlumbergeri (Silvestri, 1904)
Sigmoilopsis tenuis (Czjzek, 1848)
Stainforthia fusiformis (Williamson, 1858)
Uvigerina peregrina Cushman, 1923

B. Species, which are considered either arctic or eurythermal:

Angulogerina fluens Todd, 1947
Astrononion gallowayi Loeblich and Tappan, 1953
Buccella frigida (Cushman, 1922)
Cassidulina reniforme Nørvang, 1945
Cibicides lobatulus (Walker and Jacob, 1798)

Cibicides pseudoungerianus (Cushman, 1922)
Elphidium asklundi Brotzen, 1943
Elphidium bartletti Cushman, 1933
Elphidium excavatum (Terquem, 1875)
Elphidium groenlandicum Cushman, 1933
Elphidium hallandense Brotzen, 1943
Fissurina danica (Madsen, 1895)
Fissurina laevigata Reuss, 1850
Islandiella helenae Feyling-Hanssen and Buzas, 1976
Islandiella norcrossi (Cushman, 1933)
Lagena striata (d'Orbigny, 1839), forma *typica*
Miliolinella subrotunda (Montagu, 1803)
Nonion labradoricum (Dawson, 1960)
Nonion orbiculare (Brady, 1881)
Parafissurina lateralis (Cushman), forma *carinata* (Buchner, 1940)
Pyrgo williamsoni (Silvestri, 1923)
Quinqueloculina seminulum (Linné, 1758)
Stainforthia loeblichii (Feyling-Hanssen, 1954)

Summary and conclusions

Foraminiferal faunas from a continuous marine sequence, reaching from Late Saalian through Eemian and Early Weichselian into the Middle Weichselian, have been described from the Apholm boring at Frederikshavn. The marine sequence, which rests on a non-marine Quaternary deposit, is subdivided into four foraminiferal zones, zone AP4 to zone AP1 (figs. 3a and 3b).

The lowermost zone AP4, from about 190 m depth in the borehole, contains mainly arctic foraminifera. The zone is correlated with zone N4 of the Skærumhede I boring and with oxygen isotope stage 6, and the faunal composition indicates that marine conditions first reached this area in Late Saalian times.

The faunas in AP3 indicate boreal to boreal-lusitanian conditions and water depths of at least 60–100 m. This zone is correlatable with zone N3 of the Skærumhede I boring and with oxygen isotope stage 5e, and it is referred to the Eemian Interglacial. Corresponding deep water facies of the Eemian have also been found in a series of other borings in North Jutland. They are known from Anholt (Lykke-Andersen, in prep.), western Norway and from the northern North Sea. Shallower and coastal facies of the Eemian are known from many localities farther to the south

in Jutland and from the Baltic and southern North Sea areas.

The boreal to boreal-arctic zone AP2 is correlated with zone N2 from the Skærumhede I boring and with zones IX and VIII of Skærumhede II. The faunas in zone AP2 reflect gradually colder conditions. The zone is placed in the Early Weichselian and correlated with oxygen isotope stages 5a-d. The foraminiferal faunas show that a considerable drop in sea-level took place at the transition from the Eemian (zone AP3) to the Weichselian (zone AP2). The faunal indications suggest, that this change in water depth may have been even larger than the 50 m suggested by Kellogg et al. (1978). Local tectonic effects cannot however, be overlooked in this area.

The zone AP3-AP2 boundary in Apholm is here correlated with the Eemian-Weichselian boundary. This boundary has earlier been placed higher in the sequence by e.g. Bahnson et al. (1974) and Knudsen (1976), who correlated the zone VIII-VII boundary and the base of the *Portlandia arctica* zone at Skærumhede with the Eemian-Weichselian boundary. Later Knudsen and Lykke-Andersen (1982) found evidence for a deeper position, and they tentatively proposed a correlation of the zone N3-N2 boundary with the transition from the Eemian to the Weichselian. This suggestion is supported by the present study.

The foraminifera of zone AP1 in Apholm indicate fluctuating high-arctic and boreal-arctic conditions. This zone is correlated with the lower part of zone N1 and Skærumhede I and with zones VII to IV in Skærumhede II. Zone AP1 represents the continuation of marine conditions in the area into the Middle Weichselian and is tentatively correlated with oxygen isotope stage 4 and a part of stage 3. The uppermost boundary of the marine sequence at Apholm cannot however, be defined on the basis of the available information. It must be emphasized that the marine sequence contains no indication of any glaciations in the present area during the Early and Middle Weichselian times.

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Dansk sammendrag

En marin Kvartær lagserie på mere end 100 m tykkelse i boringen Apholm 7.131b nord for Frederikshavn er foraminifer-stratigrafisk undersøgt. Da materialet fra Apholm består af en serie uforstyrrede kerneprover, giver undersøgelsen et værdifuldt supplement til tidligere foraminifer-stratigrafiske undersøgelser fra området, nemlig Skærumhede I og II boringerne vest for Frederikshavn.

Den marine lagserie i Apholm, som hviler på en ikke-marin Kvartær aflejring, kan inddeles i 4 foraminifer-zoner. Zone AP4 (190,2 m dybde), der overvejende indeholder arktiske foraminiferer, kan korreleres med zone N4 i Skærumhede I og henføres til Sen Saale. Faunaerne i zone AP3 (190–140 m) tyder på temperaturer lidt højere end i området i dag og vanddybder på mindst 60–100 m. Et indhold af planktoniske foraminiferer i enkelte niveauer tyder på en ret åben forbindelse til Norskehavet. Zone AP3 svarer nøje til zone N3 i Skærumhede I. Den formodes at repræsentere oxygen isotop enheden 5e og henføres til Eem Interglacial tid.

I zone AP2 (140–113 m) viser faunaerne en gradvis forværring af klimaet, idet arktiske arter dukker op. Vanddybden falder drastisk ved overgangen til zone AP2, men forøges atter en smule henimod slutningen af zone AP2. Zone AP2 kan korreleres med zone N2 i Skærumhede I og med zonerne IX og VIII i Skærumhede II. Den menes at repræsentere oxygen isotop enhederne 5a-d og henføres til en klimatisk overgangsfase i Tidlig Weichsel. Den pludselige ændring til lavere vanddybde ved grænsen mellem zonerne AP3 og AP2 svarer nogenlunde til et generelt fald i havniveau på omkring 50 m, som er beskrevet fra grænsen Eem-Weichsel. Muligvis kan også lokale tektoniske bevægelser have haft indflydelse.

Grænsen mellem zonerne AP3 og AP2 i Apholm er således her korreleret med Eem-Weichsel grænsen. Denne grænse har tidligere været placeret højere i den marine lagserie, bl.a. af Bahnson et al. (1974) og Knudsen (1976), som foreslog grænsen mellem foraminifer-zonerne VIII og VII, samt basis af *Porilandica arctica* zonen i Skærumhede korreleret med Eem-Weichsel grænsen. Senere undersøgelser af materiale fra Skærumhede I boringen, samt nye dateringer fra Hirtshals Kystklint, førte til, at Knudsen og Lykke-Andersen (1982) foreslog en placering af Eem-Weichsel grænsen dybere i lagserien, muligvis ved grænsen mellem foraminifer-zonerne N3 og N2, d.v.s. midt i *Turritella terebra* zonen. Denne antagelse støttes af undersøgelserne fra Apholm.

Faunaerne i zone AP1 (113 m til øverste prøve fra 86 m) i Apholm er hovedsagelig arktiske, men et skiftende borealt indhold tyder på, at 2 stadiale og 2 interstadiale perioder er repræsenterede. Som helhed kan zonen korreleres med en del af zone N1 i Skærumhede I. En nøjere sammenligning med foraminifer-zonerne i Skærumhede II viser, at underzonen AP1b kan omfatte zonerne VII, VI og V, mens underzonen AP1a sandsynligvis svarer til zone IV i Skærumhede II. Zone AP1 henføres til Weichsel, og synes at repræsentere oxygen isotop enhed 4 og en del af enhed 3.

De foraminifer-stratigrafiske undersøgelser fra Apholm viser, at der har været en kontinuerlig marin sedimentation i området fra Sen Saale, gennem Eem og Tidlig Weichsel og et stykke ind i Mellem Weichsel. Den øvre grænse for den marine lagserie kan ikke fastlægges på det foreliggende materiale fra Apholm boringen, men det må imidlertid bemærkes, at den undersøgte lagserie fra Apholm ikke viser tegn på glaciationer i området, hverken i Tidlig eller i Mellem Weichsel.

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