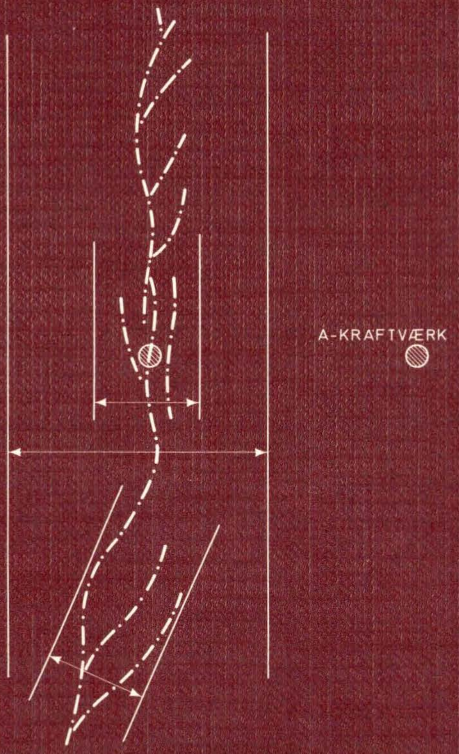
Danmarks Geologiske Undersøgelse

Geological Survey of Denmark. Yearbook 1979

Årbog 1979



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Indhold

The relative pollen productivity of the common forest trees in the early Holocene in Denmark

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The relative pollen productivity of the common forest trees in Denmark has been studied earlier, and numerical correction factors for tree pollen diagrams were suggested. Comparison of calculated area frequencies with pollen concentration in an early Holocene deposit from Denmark indicate that the relative pollen productivity of the various trees present at that time was nearly the same as to-day. The application of correction models to Holocene deposits is discussed.

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The primary aim of pollen analysis is to illustrate vegetational composition at specific points in time and changes in vegetation throughout periods of time. The effect of changes in climate and the impact on vegetation of changes in soil conditions and man's activities can only be understood if vegetational composition is recorded truthfully in the pollen diagrams.

Von Post (1916) realized that various tree genera or species may differ in pollen productivity; unequal pollen productivity has been recognized in pollen analytical literature since that time. Differences in pollen productivity are thus likely to cause a distorted picture of tree abundance in tree pollen diagrams, and changes in percentage frequencies of trees may be artefacts which do not reflect changes in species area. Pollen influx curves may reflect changes in species abundance in a realistic way; influx values, however, also show a distorted picture of relative species abundance. »Isopoll« maps based on pollen percentages are also likely to be misleading if the tree assemblages differ within the area mapped.

It should be recognized that the representation of a tree species within a tree pollen spectrum depends on the composition of the tree assemblage. If species with high or low pollen productivity occur together with others of the same kind, they will be equally represented, and a species with low pollen productivity becomes overrepresented if it occurs together with another species with still lower pollen productivity. Statements that a species is characteristically overrepresented or underrepresented by its pollen percentages are still not infrequent. The ratio of the pollen percentage of a species to its area percentage (representation or R-value, Davis 1963) is equally uncharacteristic, as the R-value for a species depends on the species combination and the abundance of the species (Davis 1963, Andersen 1970). Thus the R-value for a species varies considerably with its frequency, even in a simple case where only two species occur together (Table 1). One may still find statements that species have characteristic R-values, even in text-books on pollen analysis, and one may see R-values used for a correction of pollen spectra. R-values cannot be used in models for transferring pollen data to vegetational composition.

As pointed out by Andersen (1970, 1975, 1978, cp. Webb et al. 1978) tree pollen spectra from moss polsters, soils or small hollows within forest record the composition of single stands, whereas pollen spectra from moderately sized bogs or lakes record tree composition within a wide area. In the former case vegetation can be resolved into tree associations on various soil types, whereas pollen spectra from outside the forest record mixed vegetation on a regional basis.

Pollen transfer within forest is simple, as pollen is transported directly from the vegetation to the sampling site (Andersen 1970, Raynor et al. 1975). Tree composition within small plots can be calculated accurately and it is possible to compare many plots of varying tree composition. Andersen (1970) thus calculated correction factors for North European tree species based on a direct comparison of tree areas with pollen deposition within forest. Pollen deposition figures calculated by observations from pollen traps were similar to those obtained by means of the surface samples (Andersen 1974b), and corrected pollen percentages from the surface

Table 1. Area percentages, pollen percentages and R-values for two species, A and B, occurring together. The pollen productivity of species A is four times that of B.

Species A			Species B			R_A/R_B
area (%)	pollen (%)	R_A	area (%)	pollen (%)	R_B	
5	17	3.5	95	83	0.9	4.0
10	31	3.1	90	69	0.8	4.0
50	80	1.6	50	20	0.4	4.0
90	97	1.1	10	3	0.3	4.0
95	99	1.0	5	1	0.3	4.0

samples compared favourably with the area percentages of the trees present around the sampling sites.

Because of the simple pollen transfer model, Andersen (1970) assumed that the variations in pollen representation found were due to differences in pollen productivity. Immaturity or artificial drainage had influenced the pollen productivity of two species *(Fagus silvatica* and *Alnus glutinosa)* in some cases. Hence, the correction factors found refer only to mature trees growing under natural conditions.

Throughout ten years the trees examined flowered profusely every second year except for some cases where the biennial pattern was interrupted due to unusual weather conditions (Andersen 1974b, 1980). The intensity of flowering in the flowering years was governed by short-term climatic variations (Andersen 1980). Such variations in flowering intensity are likely to become smoothed out at long observation periods. The correction factors in Andersen (1970) were thus calculated by means of samples from moss humus which include the pollen rain from more than 15 years.

Andersen (1978) showed corrected tree pollen diagrams from Holocene sediments deposited in small wet hollows within forest. It was assumed by Andersen (1978) that the pollen productivity of the tree species was the same in the past as it is to-day. The corrected tree pollen analyses were therefore supposed to reflect the abundance of the trees better than the uncorrected spectra. It was assumed, moreover, that the pollen productivity of *Corylus avellana* was similar to that of trees with a high pollen productivity such as *Betula, Alnus* and *Quercus*. These assumptions were unproven. It is attempted in the present work to examine the validity of the correction factors when used for tree pollen spectra from a Holocene deposit.

Site

The site examined is a very small wet kettle-hole (18×12 m) in Næsbyholm Storskov, a forest in central Sjælland, Denmark (Fig. 1). The kettle-hole contains organic deposits 123 cm deep, 4 cm clay-gyttja, and Late Weichselian clay in the deepest part. The organic deposit consists mainly of decayed wood and leaves. The sediment appeared homogeneous; however, wood particles may occur in varying amounts due to incomplete breakdown and mixing of wood fragments with the sediment.

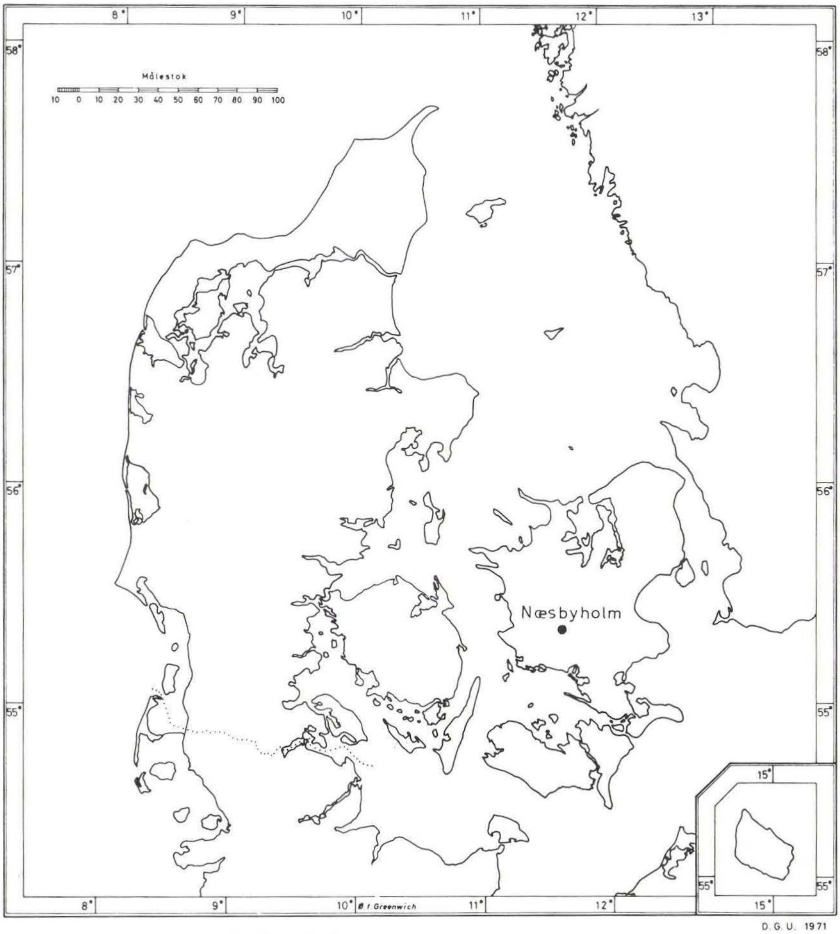

Fig. 1. Location of site (Næsbyholm).

Methods

Cores were extracted with a modified Russian peat corer (Tolonen 1967). The cores were cut into 1 cm-segments and freezedried. Subsamples for pollen analysis were weighed and mixed with *Lycopodium*-tablets (Stockmarr 1973). They were treated with hydrochloric acid, potassium hydroxide, hydrofluoric acid, and acetolysis mixture, and were mounted in silicone oil according to Andersen (1960). 400-1000 tree pollen grains and 200-1500 *Lycopodium* spores were counted per sample.

Tree species identified were *Betula pubescens* or *verrucosa, Pinus silvestris, Ulmus glabra, Tilia cordata, Alnus glutinosa* and *Quercus robur. Corylus avellana* was considered a tree.

Tree pollen frequencies were determined in percentages of the tree pollen sum (AP) and the sum of the corrected tree pollen numbers (APc). The following numerical corrections were used before calculation of the corrected pollen frequencies: *Pinus, Betula, Alnus, Quercus, Corylus* × ¼, *Ulmus* × ½, *Tilia* × 2 (Andersen 1970, 1978). Concentrations of tree pollen were calculated as numbers of pollen grains per milligram dry sample ($P \times mg^{-1}$) according to the formula,

$$\frac{\text{number of tree pollen (AP)} \times \textit{Lycopodium} \text{ spores added}}{\textit{Lycopodium} \text{ spores counted} \times \text{weight of sample (mg)}}$$

The determinations of pollen concentration are influenced by variations in the specific gravity of the sediment. The determinations of pollen concentration in the samples with high content of mineral matter (below 123 cm) were accordingly disregarded. Incomplete homogenization of wood fragments may influence the pollen concentration in the organic sediment samples.

Forest succession

Diagrams of uncorrected and corrected tree pollen frequencies are shown in fig. 2. The diagrams comprise the Preboreal, the Boreal and the Atlantic Chronozones (according to Mangerud et. al. 1974). The vegetational sequence above the section in fig. 2 was strongly influenced by human activities (Neolithic, Bronze Age and Early Iron Age) and was not considered in the present work.

The kettle-hole is so small that an unbroken tree canopy extends over it. The sampling site can thus be compared directly with sampling sites on forest ground. In such cases the pollen deposited derives mainly from trees standing within 20-30m (Andersen 1970). Due to steepness of the kettle-hole only dry-land forest was present; *Ulmus* and *Alnus* therefore were scarce and less frequent than in contemporary regional pollen records from lakes (in Mikkelsen 1949, Andersen 1978).

The corrected pollen diagram in fig. 2 shows Preboreal *Betula*-forest replaced by *Pinus*-dominated forest. A *Pinus*-peak with lower maximum frequency can be recognized in regional pollen diagrams from southern Denmark at the transition from the Preboreal to the Boreal (Andersen 1978). The present record shows that *Pinus* was dominant at the dry-land sites at that time. *Corylus* prevailed in Boreal time, *Pinus* and *Betula* had be-

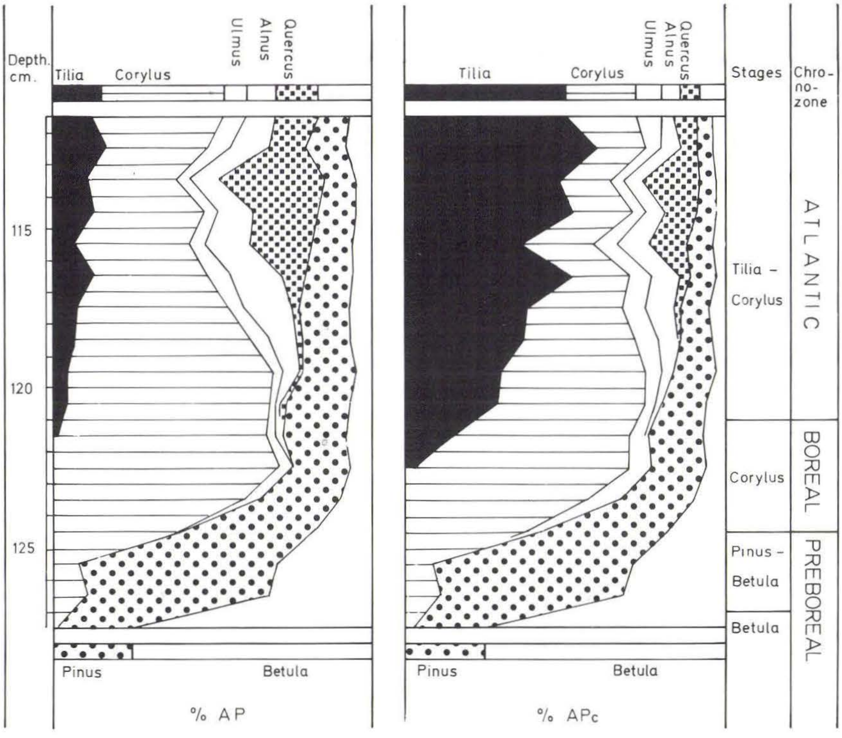

Fig. 2. Uncorrected (% AP) and corrected (% APc) tree pollen frequencies. Chronozones according to Mangerud et al. 1974.

come scarce, and *Ulmus* occurred with low abundance. *Tilia* suppressed *Corylus* in Atlantic time in agreement with records from similar Danish sites (Andersen 1978), *Ulmus* and *Alnus* were scarce, whereas *Quercus* became of secondary inportance some time after the *Tilia*-expansion. Increase in *Quercus*-frequencies was also recorded at other Danish sites in middle Atlantic time (Andersen 1978).

The pollen diagram in fig. 2 extends from about 9-10 000 to about 5000 radiocarbon years before the present.

The interpretation of the Early Holocene forest succession described above was based on an assumption that the pollen spectra were corrected accurately, and that the corrected pollen diagram thus illustrates the areal extension of the trees around the site.

Tree pollen concentations

It has been stated earlier that it can be assumed that nearly all tree pollen deposited at the site derived from trees within the near vicinity. The deposition of tree pollen must therefore have been higher at a time when the forest was composed of trees with high pollen production than when trees with low pollen production prevailed. Hence, changes in the deposition of tree pollen reflect changes in total tree pollen productivity due to changes in tree assemblage.

Pollen deposition rates could not be determined accurately in the present instance. The sequence in fig. 2. comprises a long time span (nearly 5000 years) within only 15 cm. A sample for conventional radiocarbon dating would require several cm of sediment; hence sufficiently accurate ages and sedimentation rates could not be calculated. The determinations of tree pollen concentation were considered instead.

The tree pollen concentration in the organic sediment decreases from about 7000 pollen grains per milligram at the lowermost level to about 3000 at the topmost level ($p \times mg^{-1}$, curve 1 in fig. 3). The decrease is correlated with depth ($n= 12$, $r=0.691$, $P=0.013$, P stated for a null hypothesis). The variation includes variation due to changes in total tree pollen productivity, variation due to differences in sediment composition, and errors inherent in the determination of pollen concentration.

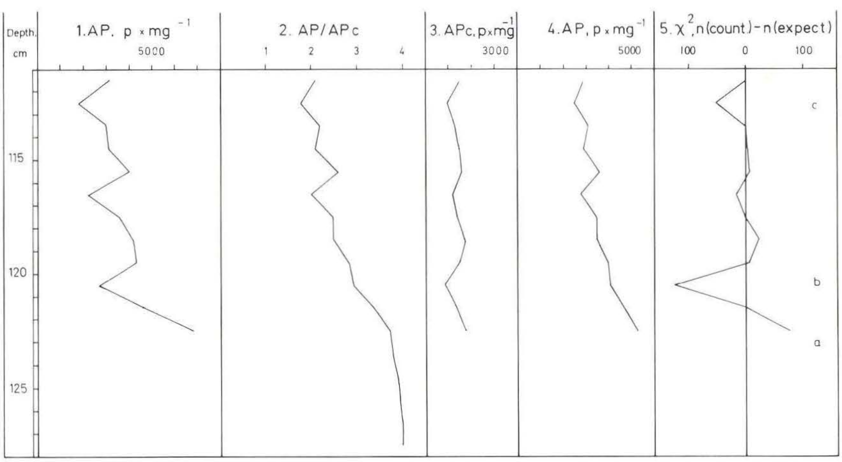

Fig. 3. 1, measured tree pollen concentration. 2, AP/APc ratio. 3, corrected tree pollen concentration. 4, calculated tree pollen concentration (average corrected tree pollen concentration, 1392 $pxmg^{-1} \times$ AP/APc ratio). 5, chi-squared for counted and expected numbers of tree pollen (χ^2–values for negative differences are shown at the left hand side and for positive differences at the right hand side of zero).

Changes in tree pollen productivity can be estimated by comparing the ratios of the tree pollen sum to the sum of the corrected tree pollen numbers at the various levels (AP/APc-ratios, curve 2 in fig. 3). The AP/APc ratio is 4 if only high pollen producers were present, and 0.5 if a low pollen producer *(Tilia)* occurred alone due to the correction factors selected. The figures are independent of variation in sediment composition and indicate true changes in total tree pollen productivity if the correction factors are accurate. The AP/APc-ratios in fig. 3 decrease from 4 at the lowermost levels to about 2 at the topmost levels indicating a change from tree assemblages consisting of high pollen producers (*Betula, Pinus, Corylus)* to an assemblage where a low pollen producer *(Tilia)* prevailed. The curve is correlated with the curve for tree pollen concentration (curve 1 in fig. 3; $n=12$, $r=0.865$, $P=0.0003$). The measured values for tree pollen concentration are thus closely related to the calculated figures for pollen productivity.

The variation of the tree pollen concentration due to changes in pollen productivity can be minimized if the number of tree pollen (AP) in the formula on p. 9 is replaced by the sum of the corrected tree pollen numbers (APc). The thus corrected tree pollen concentration should be the same at all levels if the corrections are right and if the sediment is homogeneous. The values for corrected tree pollen concentration (curve 3 in fig. 3) are uncorrelated with depth ($r=0.214$, $P=0.504$). Hence the decrease of the measured

Table 2. Corrected tree pollen sum (APc) calculated as pollen concentration, difference from the mean ($\bar{x}$ = 1393, s = ± 257 pxmg^{-1}), and *Tilia*-frequency in corrected tree pollen spectra at various depth levels.

Depth (cm)	APc (pxmg^{-1})	Diff. n−$\bar{x}$ (pxmg^{-1})	Diff. (P)	*Tilia* (% of APc)
111.5	1490	98	0.213	50
112.5	1003	−389***	<0.001	60
113.5	1347	− 45	0.556	48
114.5	1488	96	0.222	52
115.5	1552	160	0.054	36
116.5	1165	−227**	0.011	52
117.5	1410	18	0.813	38
118.5	1662	270**	0.004	37
119.5	1499	170	0.177	30
120.5	927	−465***	<0.001	29
121.5	1354	− 38	0.618	15
122.5	1809	417***	0.001	3

Significance levels: *<5 %, **<1 %, ***<0.1 %

pollen concentration with decreasing depth noticed above is due mainly to a change in pollen productivity. The corrected tree pollen concentration varies between 900 and 1800 $p \times mg^{-1}$ (table 2). The figures at five levels differ from the mean; positive and negative differences are random, however, and the average concentration is nearly the same at levels with low *Tilia*-frequency (at or below 30%; 1397 $p \times mg^{-1}$) and high *Tilia*-frequency (above 30%; 1390 $p \times mg^{-1}$). The corrected pollen concentration is thus the same for various tree assemblages, and the remaining variation reflects random scattering of pollen concentration.

The AP/APc-ratios were transformed to pollen concentration by multiplying the average corrected tree pollen concentration (1393 $p \times mg^{-1}$) with the AP/APc ratios (curve 4, fig. 3). This curve indicates tree pollen concentration in a homogeneous sediment and is less variable than the curve for the measured tree pollen concentration (curve 1, fig. 3). The difference between the two curves was estimated by calculation of chi-squared values for counted and expected numbers of tree pollen grains at each level (curve 5, fig. 3). Particularly large terms of chi-squared were found for three levels (a, b and c in fig. 3); the differences at these three levels exceed the general error level and so indicate particularly large variations in the measured pollen concentration. These variations were probably due to incomplete homogenization of the sediment at the three levels.

Tree pollen concentration compared with corrected tree pollen percentage

It has been shown that the variation in the measured tree pollen concentration was minimized by way of the correction procedure. However, the correction to the frequencies of the individual tree genera has not yet been tested.

The relation of the pollen concentration found for each tree genus to its percentage value at the same level was examined. In the present instance, the pollen concentration must be zero at zero pollen percentage and should increase proportionally with the pollen percentages if the pollen percentages reflect area percentages correctly. Linear correlations for pollen concentration with the original and the corrected pollen percentages are compared in table 3. The coefficients of correlation for the corrected pollen percentages are somewhat larger and the standard deviations ($s_{y.x}$) and intercept values somewhat lower than those found for the original pollen percentages. Hence, the corrected pollen percentages reflect the true area percentages better than the original pollen percentages.

Table 3. Linear correlation of the measured pollen concentration with the percentage of tree pollen (AP) and with the corrected percentage (APc, n = 12), r = coefficient of correlation, $s_{y.x}$ = standard deviation of pollen concentration, V.R. = variance ratio, icpt = intercept (pollen concentration at zero pollen percentage).

	r		$s_{y.x}$			icpt	
	AP	AP_c	AP ($pxmg^{-1}$)	AP_c ($pxmg^{-1}$)	V.R. (P)	AP ($pxmg^{-1}$)	AP_c ($pxmg^{-1}$)
Betula	0.262	0.824***	± 88	± 52	0.039*	101**	- 5
Pinus	0.751**	0.905***	±196	±126	0.072	- 376***	- 45
Corylus	0.872***	0.937***	±587	±418	0.128	-1513***	-259
Quercus	0.974***	0.992***	± 74	± 40	0.022*	5	- 6
Alnus	0.891***	0.971***	± 80	± 42	0.017*	27	- 4
Ulmus	0.516	0.863***	± 47	± 26	0.026*	79***	- 40***
Tilia	0.837***	0.910***	± 61	± 46	0.174	94***	25

Significance levels: *<5 %, **<1 %, ***<0.1 %

The coefficients of correlation are slightly larger when the three levels with non-homogeneous sediment (a, b and c in fig. 3) were omitted (table 4), the corresponding standard deviations and intercept values are generally somewhat smaller (table 4), and the observed points fall very near straight regression lines (fig. 4). The intercept values found for *Betula, Pinus, Corylus, Alnus* and *Quercus* are nearly zero (table 4, n=9). The pollen percentages for these species were accordingly corrected accurately. The intercept values for *Ulmus* and *Tilia,* however, differ from zero (negatively for *Ulmus,* positively for *Tilia).* Hence, it can be suggested that the corrected

Table 4. Linear correlation of the measured pollen concentration with the corrected tree pollen percentage for all samples (n = 12) and with three samples omitted (levels a, b and c in Fig. 3, n = 9). Otherwize as Table 3. The significance level for all coefficient of correlations (r) is less than 0.1 %.

	r		$s_{y.x}$			icpt.	
	n = 12	n = 9	n = 12 ($pxmg^{-1}$)	n = 9 ($pxmg^{-1}$)	V.R. (P)	n = 12 ($pxmg^{-1}$)	n = 9 ($pxmg^{-1}$)
Betula	0.824	0.951	± 52	± 21	0.005**	- 5	13
Pinus	0.905	0.973	±126	± 51	0.005**	- 45	18
Corylus	0.937	0.980	±418	±158	0.003**	-259	11
Quercus	0.992	0.995	± 40	± 35	0.343	- 6	6
Alnus	0.971	0.973	± 42	± 37	0.368	- 4	9
Ulmus	0.863	0.917	± 26	± 19	0.172	- 40***	-25**
Tilia	0.910	0.935	± 46	± 30	0.113	25	27*

Significance levels: *<5 %, **<1 %, ***<0.1 %

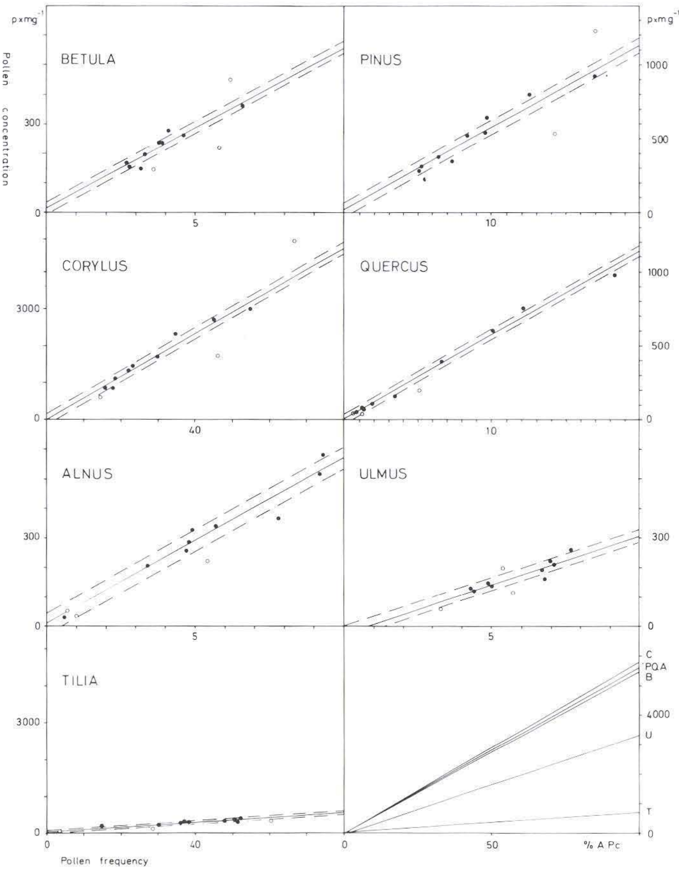

Fig. 4. Observed pollen concentration in relation to corrected pollen percentages (% APc) and calculated regression lines. o, samples omitted (the levels a, b and c in Fig. 3). The broken lines indicate ± $s_{y.x.}$ C = *Corylus*, P = *Pinus*, Q = *Quercus*, A = *Alnus*, B = *Betula*, U = *Ulmus*, T = *Tilia*.

pollen percentages for *Ulmus* and *Tilia* differ slightly from the true area percentages.

The regression of pollen concentration on pollen percentage is exponential if the pollen percentages of a species are too high compared with the area percentages, and logarithmic if the pollen percentages are too low (fig. 5). Intercept values differ from zero if such regressions are calculated as linear functions (negatively for the exponential and positively for the logarithmic functions, fig. 5). As the intercept values found for linear regression for *Ulmus* and *Tilia* differ from zero (negatively for *Ulmus*, positively for *Tilia*, table 4, n=9), it can be suggested that these functions are not strictly

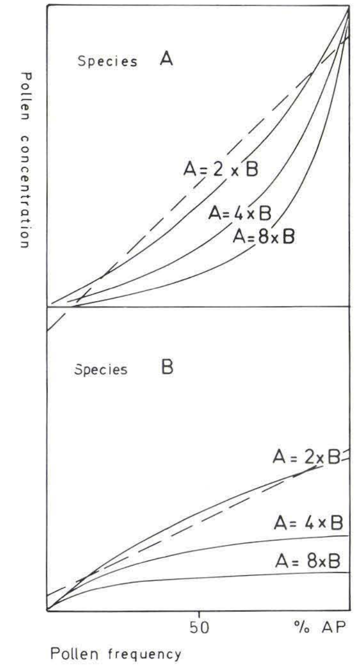

Fig. 5. Relationship of pollen concentration to pollen frequency for two species, A and B. The pollen productivity of species A is 2, 4 and 8 timers larger than that of species B. The regressions for species A are exponential and those for species B logarithmic. The broken lines indicate linear regression (for A= 2×B).

linear and that the corrected pollen percentages found for *Ulmus* are slightly too high (exponential function) and those calculated for *Tilia* slightly too low (logarithmic function).

The steepness of the regression lines in fig. 5 reflects pollen productivity of the various trees; relative pollen productivity can thus be calculated from the coefficient of regressions. The regression lines, intercept values and regression coefficients found for *Betula, Pinus, Corylus, Alnus* and *Quercus* are nearly the same (fig. 4, table 4, n=9, and table 5). The pollen productivity of these five genera was thus nearly the same, as assumed by Andersen (1970, 1978). Correlation was calculated for all observations of *Betula, Pinus, Corylus, Alnus* and *Quercus* (n=45, r=0.994, P=0.001, intercept=–1), and the relative pollen productivity (Prel) of the various trees was calculated in relation to the regression coefficient for the five genera (57.93=4.0, table 5). The figures thus found for *Ulmus* (2.3) and *Tilia* (0.45) differ slightly from the figures found by Andersen (1970, 2.0 and 0.5). Hence, the correction factors for *Ulmus* and *Tilia* may rather be × 1/2.5 and ×

Table 5. Regression coefficient (b) for linear correlations of *Betula, Pinus, Corylus, Quercus* and *Alnus* (BPCQA, n = 45) and single tree genera (n = 9), relative pollen productivity, calculated (P–rel) and as assumed by Andersen (1970, 1978, P–rel*), and correction factors used (c.f.).

	b	P–rel	P–rel*	c.f.
BPCQA	57.93	4.0	4.0	× 1/4
Betula	54.35	3.8	4.0	× 1/4
Pinus	55.76	3.8	4.0	× 1/4
Corylus	57.73	4.0	4.0	× 1/4
Quercus	56.38	3.9	4.0	× 1/4
Alnus	55.95	3.9	4.0	× 1/4
Ulmus	33.22	2.3	2.0	× 1/2
Tilia	6.50	0.45	0.50	× 2

2.5 (instead of × ½ and × 2.0). Pollen percentages calculated for *Ulmus* and *Tilia* with the correction factors found here differed only slightly from those calculated with the original correction factors (–2 % for *Ulmus*, 6 % for *Tilia*); the difference is thus unimportant.

Conclusion

The comparison of pollen concentrations with corrected pollen percentages has shown that *Betula, Pinus, Corylus, Alnus, Quercus, Ulmus* and *Tilia* had nearly the same relative pollen productivity in the early Holocene as to-day. Hence, the correction factors suggested by Andersen (1970, 1978) can be used for tree pollen spectra from Holocene deposits in small hollows, where pollen was derived from trees standing within the near vicinity.

Webb et al. (1978) stated that transfer functions for sites outside forest should be found by comparing modern pollen spectra from such sites with vegetational composition in a wide area. Such a procedure is impossible in Europe because sufficiently large natural forests composed of all tree species present in the Holocene do not exist, and because the present forests are subjected to artificial management with the result that the tree stands are of varying age and rarely reach flowering age before they are felled. Hence, Holocene tree pollen spectra from lakes or bogs can only be corrected if the correction factors found for forest sites can be applied. Pollen emitted from the flowers in the tree tops is partly lifted into the air and partly transported into the trunk space by turbulent winds (Raynor et al. 1975). One may assume, accordingly, that similar quantities of pollen are dispersed into the air above and below the tree canopy. Pollen emitted into the air above the tree tops must be transported a long distance before reaching a sampling site in a lake or bog. Tauber (1965) postulated large differences between the dispersal capacity of heavy *(Fagus)* and light *(Betula)* pollen grains transported horizontally to a sampling point within a lake. The figures in Tauber (1965) were calculated by means of a formula for losses from a pollen cloud by deposition on the ground stated by Chamberlain. Andersen (1974a) maintained that losses from a pollen cloud passing over forest vegetation are due to filtration when the lowermost part of the cloud passes the tree tops rather than to ground deposition. At normal wind velocities the differences between the filtration losses of large and of small pollen grains are much smaller than comparable differences when pollen is lost due to ground deposition (Andersen 1974a) and may be insignificant. Hence, the correction factors based on relative pollen productivity can be supposed to be applicable also to tree pollen spectra derived from lakes (cp. Andersen 1978). An examination of tree pollen deposition in a lake compared with original and corrected pollen percentages as done for the small hollow mentioned above might or might not justify this postulate.

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Dansk Sammendrag.

Holocæne pollendiagrammer kan korrigeres for skovtræernes forskellige pollenproduktion således at arealværdier kan beregnes, men man har ikke vidst om træernes pollenproduktion dengang var den samme som i dag. Pollenspektre og pollenkoncentrationer fra en tidlig Holocæn aflejring fra Næsbyholm Storskov er blevet bestemt og sammenlignet og det kan vises at de tilstedeværende træarters pollenproduktion dengang var den samme som i nutiden. Anvendelsen af korrektionsfaktorer på pollendiagrammer fra aflejringer i små moser i skov og fra søer og moser diskuteres.

Postscript

Birks and Birks (1980, p. 200) compared pollen productivity (Rrel values) calculated for Białowieża Forest in Poland with similar figures stated to be from Draved Forest, and found large differences. The figures from Białowieża were based on collections in pollen traps for only three years, which were not even in sequence (1960, 1962 and 1963). As annual flowering in trees varies greatly, figures calculated from only three accidental years will vary greatly too and are without value for a calculation of pollen productivity. The figures in Tabel 10.5 in Birks and Birks (1980) stated to be from Draved and extracted from Andersen (1970) are fictitious, as *Carpinus* and *Ulmus* are absent from that forest. A statement in Birks and Birks (1980, p. 201) that the tree canopy in Białowieża is more closed than in Draved Forest is also incorrect. The Białowieża Forest contains very scattered old trees whereas a lower canopy of young trees derived from about 1920 (Piggott 1975) was only 40 years old in 1960 and hence hardly of flowering age yet. Draved Forest, in contrast, has a relative closed canopy of 100-300 year old trees (cp. Andersen 1970).

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Distinguishing between tills of different geneses from Korsør Lystskov, Denmark

Poul Erik Nielsen

Nielsen, P. E.: Distinguishing between tills of different geneses from Korsør Lystskov, Denmark. *Danm. geol. Unders., Årbog 1979:* 21-30, København, 1. december 1980.

Lithology and dynamics are described in a till from Korsør Lystskov, Denmark. Based on granulometric analyses, stone counts and studies of glaciodynamic structures, including fabric, the till complex is interpreted as consisting of a lodgement till overlain by ablation till, affected by a later overriding glacier.

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In Denmark, contrasting views on the mode of formation of Weichselian tills have been proposed, and several properties have been used in attempt to characterize different types of tills.

Primarily based on morphological investigations and visual inspection in the field, Marcussen (1973) describes widespread deposits consisting of flow till. In order to distinguish between flow till and lodgement till, Marcussen (1975) used four indications: the setting of the sediments, the orientation of the elongated particles, the degree of preconsolidation, and the morphological appearance of the till. Interpretations of the fabric analyses have been discussed by Krüger & Marcussen (1976). In addition to the properties mentioned above, Krüger (1979) discusses five structural and textural features indicating a subglacial deposition, namely: lenses of sorted material, smudges, small-scale deformations of till matrix and smudges by clasts, clasts consistently striated, and clasts with stoss- and lee sides.

One of the most convincing evidences of a subglacial origin of a till is the existence of shear induced glaciodynamic structures (Lawruschin 1971). Berthelsen (1979) in a paper demonstrates the occurrence of recumbent folds and boundinage structures formed by subglacial shear.

In the following, a sequence of tills from the Korsør Peninsula, Denmark, will be discussed with special reference to lithology and dynamics.

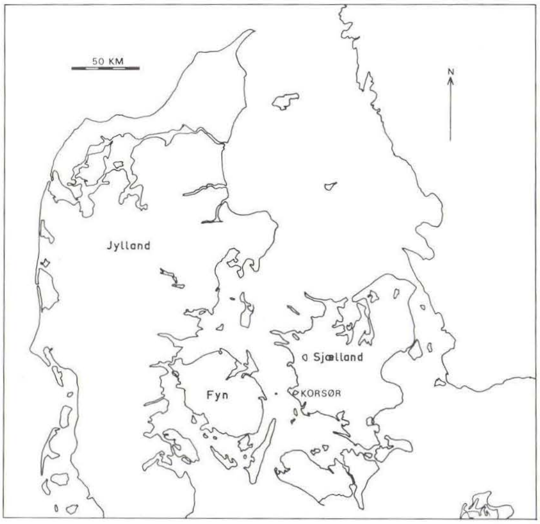

Fig. 1. Location map.

Observations

The section, located on the south coast of the Korsør Peninsula (fig. 1), has been described by Hansen & Nordmann (1950) as part of a terminal moraine landscape, and by Marcussen (1973) as a landscape consisting entirely of flow till formed by superimposed mudflows in a kame dominated region. Nielsen (1980) has described a lower till deposited by a glacier from a southern direction overlain by a till belonging to an advance from nearly the same direction.

The cliff consists mainly of till and till-like sediments (fig. 2), and can be divided into a lower till with a complex character, and an upper till not treated here.

Visually the lower till can be separated into three units. The lowermost part is a very stiff, homogeneous and compact silty till, usually with a uniform bluegray colour. Upwards through the unit the colour gets a little lighter, and smudges of chalk occur, in places with downpressed crystalline blocks. When slightly weathered, platy or jointed structures are developed. A close examination reveals that the individual plates have a thin coat of sand, often only one grain thick.

The transition to the middle unit of the lower till is gradual. The till becomes lighter and yellowish with a more sandy appearance. The till shows a faint layering due to differences in silt and clay content. There seems to be

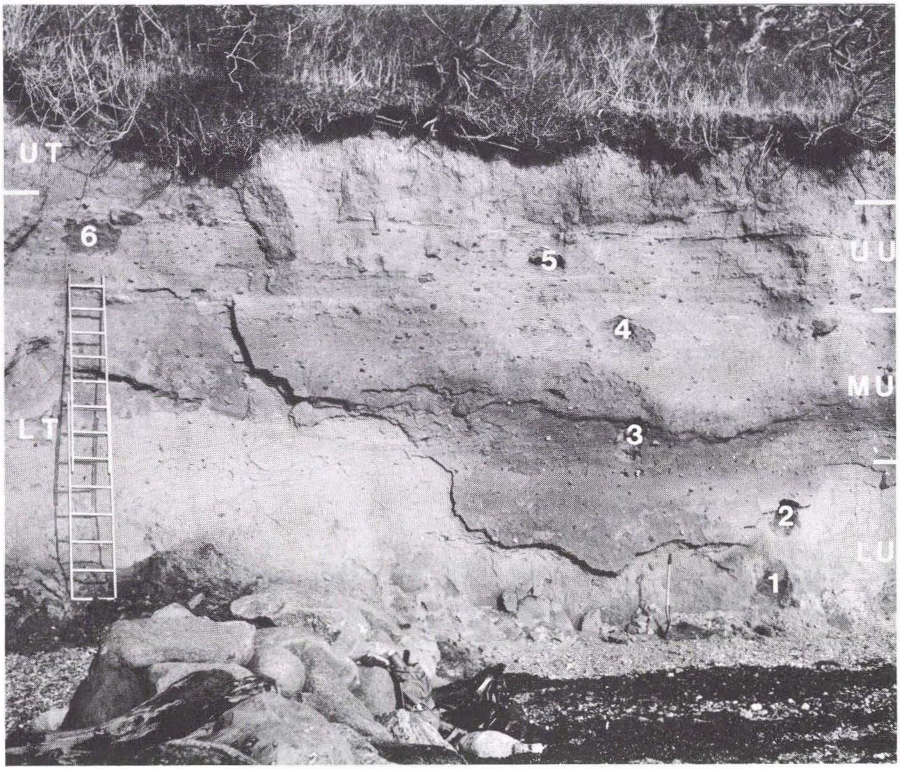

Fig. 2. The section at Korsør Lystskov showing a lower till (LT) divided into a lower unit (LU), a middle unit (MU) and an upper unit (UU), overlain by an upper till (UT). Numbers indicate sample sites referred to in the text.

little difference in the physical properties between this unit and the underlying one.

In places, the transition to the upper unit of the lower till is sharp. In windblown sections the sediments are seen to be clearly stratified and consist of sandy till with a differentiation between sandy and clayey layers. The sediments have a high content of sorted silt inclusions.

In order to investigate the causes of the visual differences in the lower till and make an attempt to explain the mode of formation, mechanical analyses, stone counts and fabric analyses were carried out at different sites in the till.

Mechanical analyses

Six samples from the lower till (fig. 2) were collected, and cumulative curves prepared in the laboratory (fig. 3). Using the grain size parameters of Folk

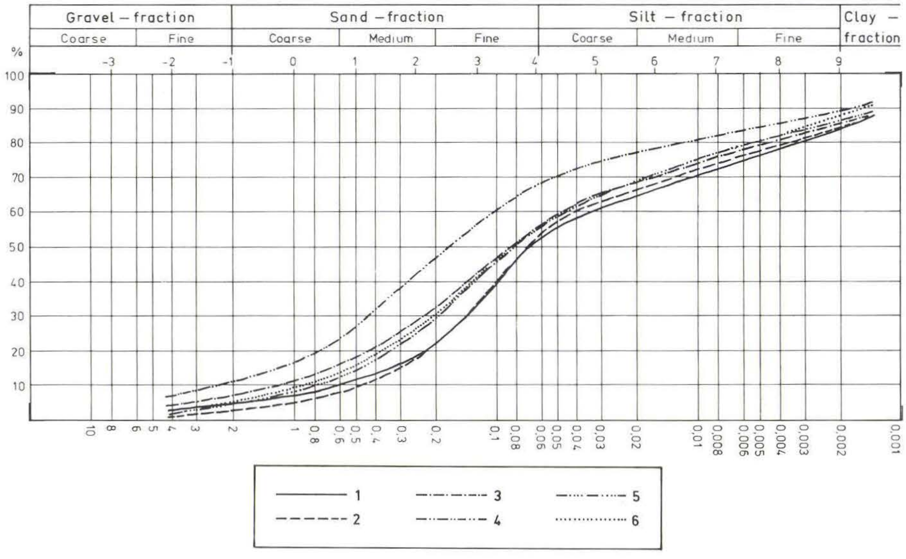

Fig. 3. Granulometric analyses: cumulative curves. For location of samples, see fig. 2.

& Ward (1957), values of mean size, standard deviation, skewness and kurtosis were computed (fig. 4). As the 95th percentiles are never attained, the last point determined by the hydrometer is extrapolated to 100 % at 14 Ø using a straight-line plot, a convention adopted from Folk & Ward (1957). The variation between the cumulative curves is very small with the exception of sample 4, which is clearly different and shows greater mean size and high standard deviation and kurtosis. K_G-values greater than 1.1 indicate that the central part of the curve is better sorted than the tails.

In general, the differences between the curves in the fraction finer than 4 Ø are very small. All samples are positive- to very positive-skewed (Folk & Ward 1957): i.e. they have a tail of fines.

The mean weight percentages per 1.0 Ø interval are shown in fig. 5. Using this delineation the dominant fractions become more obvious.

Sample no.	1	2	3	4	5	6
Mean Size	4.86	4.90	4.66	3.40	4.43	4.30
Standard Deviation	3.81	3.62	3.87	4.07	3.78	3.77
Skewness	0.35	0.38	0.33	0.28	0.34	0.28
Kurtosis	1.09	1.05	1.13	1.33	1.14	1.10

Fig. 4. Textural parameters.

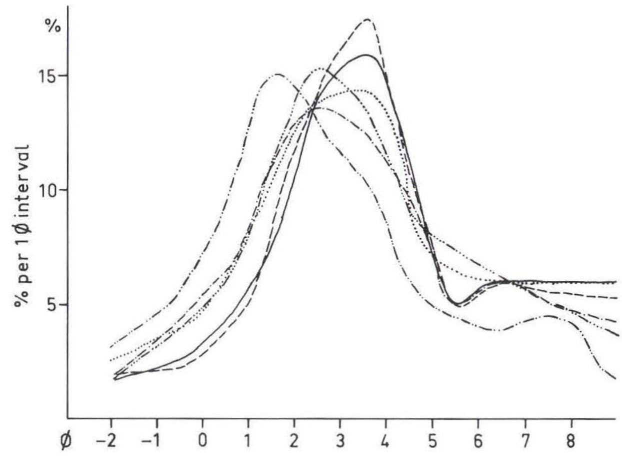

Fig. 5. Mean weight percentages per 1.0 Ø interval.

Stone counts

Petrographic variation of pebbles in the section could support an idea of a multiple till complex as indicated by the visual differences. However, the stone counts showed in fig. 6 and fig. 7 seem strongly to contradict such an idea. Fig. 6, which shows the composition of the exotic elements, reveals little differences between the individual samples. It is interesting to notice, however, that when using the relations between crystalline rocks, local sediments and exotic sediments (fig. 7) a vague trend seems to emerge. The con-

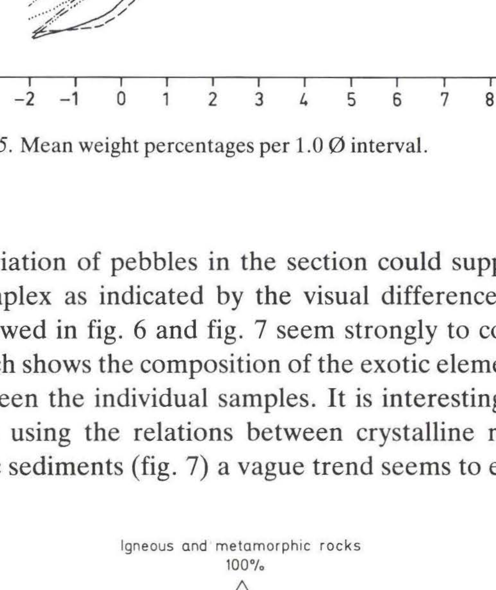

Fig. 6. Triangular diagram showing stone count data (>4 mm) from the lower till.

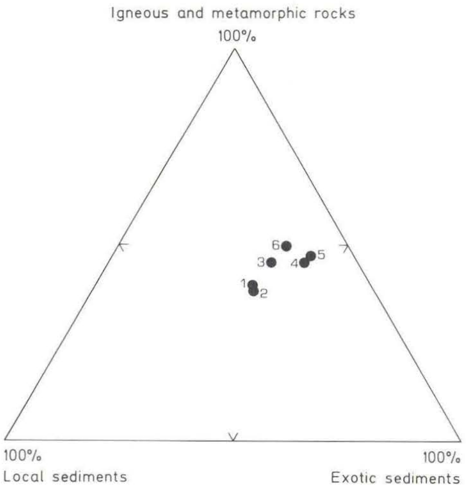

Fig. 7. Stone counts showing the proportion between local and exotic elements (>4 mm). Local sediments: Cretaceous limestone and flint. Exotic sediments: Paleozoic limestone + shale + sandstone.

tent of local sediments, being nearly constant in sample 1 and 2, starts to decrease during sample 3, 4 and 5, but ends up with a slight increase in sample 6.

Till fabric

Five till fabric analyses have been carried out in the lower till (fig. 8). The measurements, 50 points per diagram, are plotted on equal-area net and contoured after the method described by Kalsbeek (1963).

The diagrams from the lower unit (fig. 8, 1&2) show an a-lineation with plunge in the southern direction. There is some resemblance to the mixed types described by Lindsay (1970). The fabric from the middle unit is more inconsistent with two maxima, one in the northeastern and one in the southwestern direction. In the upper unit the majority of the pebbles are lying with their long-axes subhorizontal. However, diagram 5 has a maximum in the southeastern direction while No. 6 shows a faint symmetry with a weaker maximum.

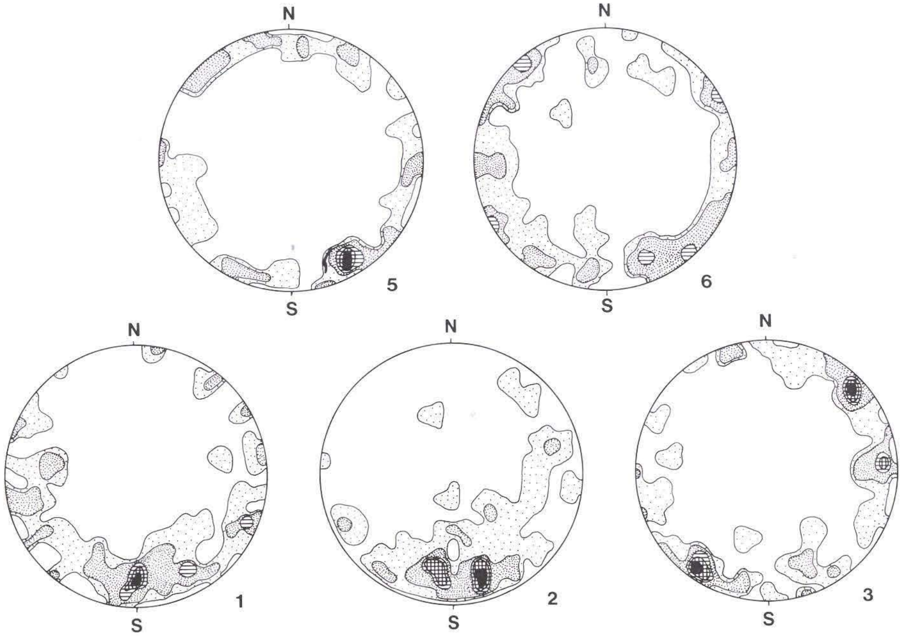

Fig. 8. Till fabric diagrams from the lower till. 50 measurements per sample are plotted on equal-area net (lower hemisphere) and contoured after a method described by Kalsbeek (1963). Contours: 3, 6, 8, 10 points per 1 % area. For location see fig. 2.

Discussion

Several hypotheses for the origin of the lower till can be considered:
(1) a multiple till complex as indicated by the visual differences,
(2) a true flow till complex as suggested by Marcussen (1973), or
(3) a lodgement till overlain by ablation till affected by a later overriding glacier.

The stone counts and grain size distribution are not in agreement with hypothesis 1. The petrology and grain size in Danish tills are very variable, and different tills often show approximately the same characteristics, but the variation in this till, however, is too small to justify an idea of different tills. According to Bahnson (1973) the lithology must display specific variations.

There appears to be no support for hypothesis 2. The lower part of the section bears all the characteristics of a lodgement till. The sediment is stiff and homogeneous with a well developed subhorizontal jointing representing earlier shear planes (Boulton 1970).

Some information can be drawn from the granulometric analyses (fig. 4). The sediment is fine-grained and poorly sorted with a standard deviation

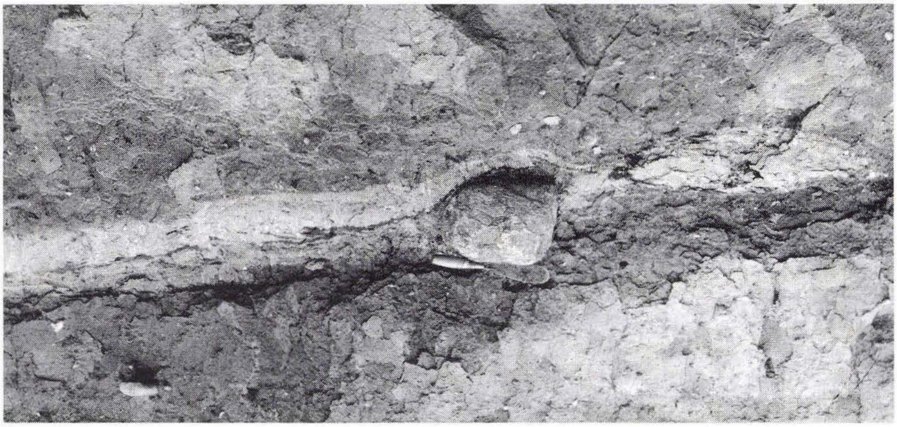

Fig. 9. Small-scale deformation of till and chalk-floe by clast. Note the stoss- and lee sides. Glacier movement from right to left.

around 3.70. The curves are very positive-skewed, indicating a tail of fines. They also show a distinct mode in the fine sand/silt range (fig. 5), a circumstance which seems to be typical for tractional debris in recent glaciers (Boulton 1978). Further support for a subglacial origin is the sporadic occurrence of small-scale deformations of till by clasts (fig. 9), indicating a lodgement of individual particles (Krüger 1979). In agreement with this, the till fabric shows a clear a-lineation with plunge in the upglacier direction (fig. 8, 1&2). Based on the data presented, it is proposed that the lower part of the section is a lodgement till, and not a flow till as suggested by Marcussen (1973).

The data from the middle unit of the lower till are more inconsistent. Concerning the exotic elements (fig. 6) little difference exists between this unit and the underlying one. There is, however, a clear decrease in the content of local sediments (fig. 7), in particular Cretaceous limestone. This decrease coinsides with a colour change from bluegray to yellowish and an increase in grain size (fig. 3). In proportion to the lower unit, the distinct mode has moved upwards in grain size (fig. 5), but the deficiency in the fraction 3–5 Ø is greater than in the clay-fraction. According to Drake (1971) this could reflect the possibility of the small grains being washed out in an ablation till. The idea of the middle unit being an ablation till or a basal melt out till in the sense of Dreimanis (1976) is partly supported by the till fabric (fig. 8,3). The diagram shows a marked decrease in plunge, and the clear a-lineation has been replaced by an incipient b-lineation indicating a compressive flow. The fabric is interpreted as a relic and an englacial fabric.

The upper unit of the lower till shows some resemblance to the lower unit. The distinct mode in the fine sand/silt range is reestablished (fig. 5), and values for standard deviation and kurtosis are about the same. In proportion to the middle unit, mean size has decreased. A closer inspection of the stratification earlier mentioned, reveals large amounts of secondary chalk precipitated along subhorizontal planes. The inclusions of sorted silt are often slightly torpedo-shaped (Berthelsen 1978) with their long-axes parallel to the planes. There are no signs of primary sedimentary structures.

Investigations outside the section (Nielsen 1980) show that the upper till has been deposited by a glacier advancing from a southern direction. The till fabric in the lower till seems to reflect this movement. One diagram (fig. 8, 6) shows considerable variations with a symmetry around a line from the north to the south, while another (fig. 8, 5) has a clear maximum indicating a movement from the south. Consequently the upper unit is interpreted as the reactivated part of the ablation till, intensively sheared during the overriding of a later glacier from a southern direction. The decreasing mean size could be a product of crushing during the renewed shearing.

Conclusion

The lower till from Korsør Lystskov is interpreted as a lodgement till overlain by an ablation till, the upper part affected by a later overriding glacier. Evidences that the lower unit is a lodgement till are: strong a-lineation with upglacier plunge, subhorizontal jointing, deformation of till by clasts often showing stoss- and lee sides (Krüger 1979), lack of washing, and a distinct mode in the fine sand/silt fraction. Evidences that the middle unit is an ablation till are: inconsistent fabric, mechanical analyses show signs of washing and weathering. The present author interprets the upper unit as the upper part of the ablation till intensively sheared during a later advance based on: subhorizontal extensive stratification, decreasing grain size and fabric.

It is stressed that the observations presented here provide no support for a flow till hypothesis. However, more work on different tills must be done to get better knowledge of their characteristics and modes of formation.

Acknowledgements. The study has been supported by grants from the Danish Natural Science Research Council and the Geological Survey of Denmark for which I am grateful.

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An apparatus for temporal sampling without air contact of pore water from swamp sediments

Søren Nielsen and Dieke Postma

Nielsen, S. and Postma, D.: An apparatus for temporal sampling without air contact of pore water from swamp sediments. *Danm. geol. Unders., Årbog 1979,*: 31-39, København, 1. december 1980.

An apparatus has been designed which allows temporal sampling without air contact of pore water from swamp sediments. The system consists of a PVC filterprobe containing a glassfiber filter, a Pyrex glass sampling system and an arrangement for pressure filtration through a membrane filter. Sample recovery occurs in a N_2-filled glove box in which analyses sensitive to oxidation are carried out. The field operation of the system is described, and practical problems that may occur are dealt with. The preliminary results could be reproduced and shows little data scatter.

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In most geochemical studies, the pore water is extracted from the sediment by squeezing or centrifugation. However, these methods only allow temporal sampling when the sediments are homogeneous such as those found mostly in marine and lake sediments (for example Thorstenson and Mackenzie 1974; Matisoff et al. 1975).

For studying seasonal variations of oxidation/reduction processes in the pyrite and siderite containing swamp sediments of the Skjernå delta (Jutland, Denmark), pore water extraction by squeezing or centrifugation is not suitable. This is due to the fact that the sediments here are far from homogeneous, and sampling at exactly the same spot is therefore desirable. This can be accomplished by permanent installation of filters in the sediments, from which samples are drawn by suction. Sampling by suction always involves a risk of degassing, particularly of CO_2, which may lead to erroneously high pH measurements. It is a further complication that many samples from deeper layers contain high Fe^{2+} concentrations at a near neutral pH. As the oxidation of Fe(II) is extremely fast at near neutral pH (Stumm and Lee 1961), great care must be taken to prevent the admittance of air ot the sample (Troup et al. 1974).

Precipitation of Fe(III) oxyhydroxides in the sample leads to erratic phosphate analyses (Bray et al. 1973) and may also affect alkalinity determinations. Hydrogen sulfide is present in some of the samples, and here there is a risk of degassing as well as of oxidation.

Oxidation during sampling and analysis should thus be rigorously prevented, while degassing should be limited to an absolute minimum. Finally, as the sampling rate proved to be low at several locations, sampling times of up to 12 hours should be permitted.

Through experimentation with different equipment, a system for temporal sampling of pore water by suction has been developed which satisfies the requirements for minimal disturbance of the sediment layering, no admittance of air and minimal degassing. The system consists of a filterprobe for permanent installation in the sediment, a portable sampling system, and an arrangement for subsequent membrane filtration and immediate analyses without air contact.

Apparatus

The filterprobes (fig. 1). The filterprobe is constructed in PVC and consists of a filterhead (A), lengths of one meter piping (B), pipe connections (C) and a terminal cap (D). The filterhead is pointed and perforated with approximately 50 holes, 3 mm Ø, drilled obliquely in order to prevent clogging when inserting the probes into the sediment. The head can be opened for attaching a glassfiber filtertube (E) (Whatman, size Al, 60 × 12 mm, poresize 2 μm).

The sample is drawn from the filterhead through flexible PVC tubing (F) (3 mm i.d.) which passes through the piping, pipe connections and terminal cap. The end of the tubing is equipped with a brass tubefitting (G) and a plug for sealing between sampling (Kuhnke screwed tube joint, sleeve and plug).

The sampling system (fig. 2). The sampling system is constructed in Pyrex glass with ground joints and stop cocks. It consists of a sample flask (A) (250 ml) equipped with a gas washing head with a stop cock (B) in the inlet and a vacuum reservoir flask (C) (1000 ml) that is closed with a 3-way stop cock (D). The sample flask and the vacuum reservoir are connected by flexible PVC tubing. Flexible PVC tubing is connected to the inlet of the sample flask with brass fittings.

In this investigation we use 5 filterprobes at each location, therefore 5 sampling systems are placed together in a plywood box.

The filtration system (fig. 3). The samples are filtrated by using a stainless steel pressure filtration cartridge (E) equipped with a 2-way switching valve

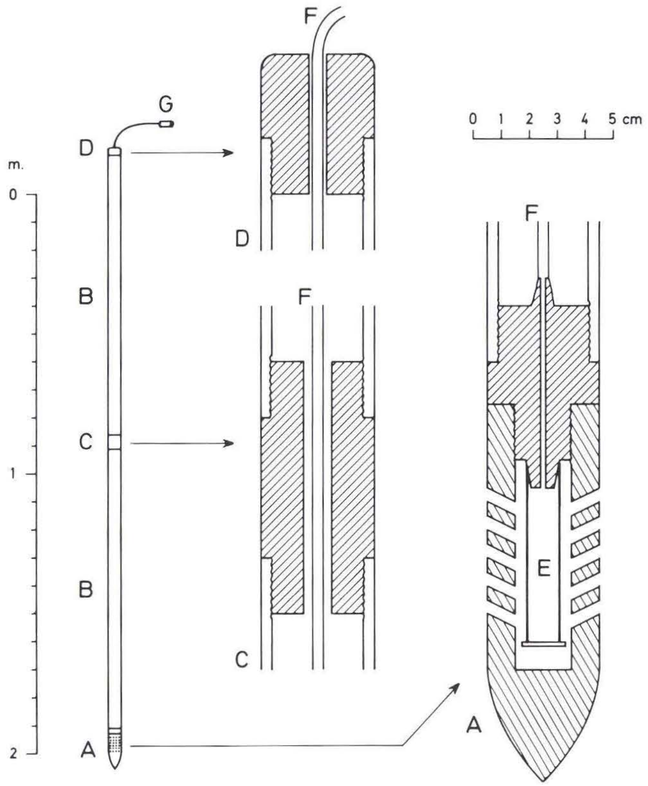

Fig. 1. The filterprobes. A: Filterhead. B: Piping. C: Pipe connection. D: Terminal cap. E: Filtertube. F: Flexible sample tubing. G: Tube fitting.

(F) at the inlet, and a toggle valve (G) for air venting and overflow. The outlet is led through a 2-way stop cock (H) into a N_2-filled glove box. Analyses which are sensitive to oxidation are carried out in the glove box.

Operation

The filterprobes are installed by pre-drilling with a Hiller sampler (West 1968) of slightly smaller diameter than the filterprobe until about one meter above the desired sampling depth. The filterprobe is subsequently placed in the hole and pushed down to filter depth.

Before sampling, the PVC tubing from the filterprobes is connected to an evacuated glass flask in order to remove the water accumulated in the filterhead and the tubing (approximately 40 ml).

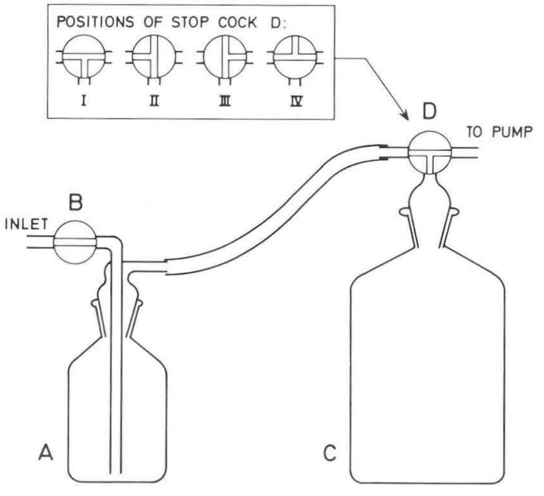

Fig. 2. The sampling system. A: Sample flask. B: Stop cock. C: Vacuum reservoir. D: 3-way stop cock.

A filterprobe is then connected to the sampling system, which is preflushed with N_2. The sampling system is evacuated to 200 mm Hg using a portable peristaltic pump (stop cock B closed, stop cock D in position I). The system is checked for leaks after a few minutes by using a manometer on the peristaltic pump.

After moving stop cock D to position II, the sampling is started by opening stop cock B, and the equipment is left overnight. Nighttime sampling is preferred since strong solar irradiation may cause photoreduction of Fe(III) compounds (Stumm and Morgan 1970). Even though the sample flasks are protected from light as they are mounted in plywood boxes, some light may penetrate the PVC tubing which connects the sample flasks with the filterprobes. Connection tubing should therefore be kept as short as possible.

When sampling is terminated the following morning, the sampling system is disconnected from the filterprobes (B closed, D in position III), and the samples are brought to a van equipped as field laboratory.

The sample flask is connected to the filtration system as shown in fig. 3. Membrane filters with a poresize of 0.1 μm are used since Kennedy et al. (1974) showed that these filters yield more correct results than 0.45 μm filters for dissolved Fe and Al, and show little tendency for clogging.

Before each sample is introduced into the filter cartridge, the cartridge is fitted with a new membrane filter and flushed with N_2 (G closed, F in position I, H in position I).

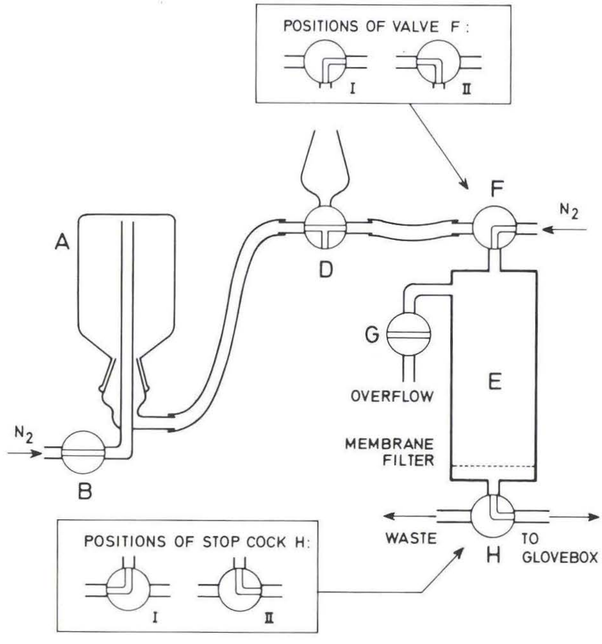

Fig. 3. The filtration system. A: Sample flask. B: Stop cock. D: 3–way stop cock. E: Filtration cartridge. F: 2-way valve. G: Toggle valve. H: 2-way stop cock.

The sample is then transferred to the filter cartridge by applying a gentle N_2-pressure through stop cock B into the inverted sample flask (G open, F in position II, D in position IV). N_2-pressure of about 2 atmospheres is applied to the filter cartridge, and the sample is recovered in a N_2-filled glove box after discarding the first 10 ml (G closed, F in position I, H in position II).

In the glove box, pH is measured, alkalinity determined and reagents added for spectrophotometric determination of H_2S, Fe^{2+} and PO_4–P. The analytical procedures have been described by Postma (1980).

Filterprobes have been installed at 3 locations in the Skjernå delta (Jutland, Denmark). The sediments vary from wood peat to reed peat with a significant content of silt and clay. At each locality filterprobes have been placed at depths of 0.5, 1.0, 1.5, 2.0 and 2.5 m below the surface.

The filterprobes at a depth of 0.5 m were above the groundwater level during the summer months and could not be sampled. At a greater depth, sample recovery in most cases exceeded the volume of the sample flask (250 ml) by 250–500 ml. As the inlet of the sample flask is placed at its bottom, the content of the sample flask will be flushed with at least its own volume. This minimizes the contact area between the sample and the overlying gas phase, and the risk of degassing the sample is hereby reduced.

Several problems had to be dealt with during field operation. Some probes, placed in clay-rich sediments, showed a sampling rate too slow for filling the sample flasks overnight. The sampling rate was improved by attaching quartz glass wool to the entrance holes of the filterhead. The glass wool served as a »wick« and increased the contact area with the sediment, ensuring a sufficiently high sampling rate.

In earlier tests, attempts were made to pump directly on the filterprobes through a hypodermic needle to a vial with silicone rubber septum. The N_2-filled vial was then evacuated through another hypodermic needle connected to the peristaltic pump. This method had to be abandoned due to an inacceptably low sampling rate.

Attempts were also made at placing membrane filters in the sampling system between the filterprobes and the sample flask. However, the membrane filters, when wet, proved to be impermeable to small gas bubbles. After accumulation of sufficient bubbles at the filter surface, the vacuum in the sampling system was not transmitted to the filterprobe.

Operation during the winter proved to be a problem due to the freezing of water in the sample tubing. The tubing and the sampling system above ground were kept slightly over the freezing point by insulating with glass wool bats and heating with a small catalytic oven. Within the upper end of the filterprobes, the water in the sample tubing was thawed by removing the terminal caps of the PVC outer tubes and lowering a U-formed piece of copper tubing. Hot water was circulated through the copper tubing by a peristaltic pump, and the frozen water was thawed within a few minutes. After discarding the first volume the filterprobes were connected to the sampling system, and no further problems were encountered.

A somewhat unexpected problem was an invasion of larvea of sawfly (Tenthredinidae, selandriini) in the PVC tubing of the filterprobes between sampling periods. Even though the tubing was sealed at the end, the larvea proved to be capable of rasping through the soft tubing. The problem was solved by protecting the tubing with hard plastic caps.

Discussion

The features of the equipment can be illustrated with some preliminary results, collected over a period of 8 months.

Measurements of pH at one locality are shown in fig. 4. At depths of 0.5 and 1.0 m the pH varies considerably as would be expected, since in this zone

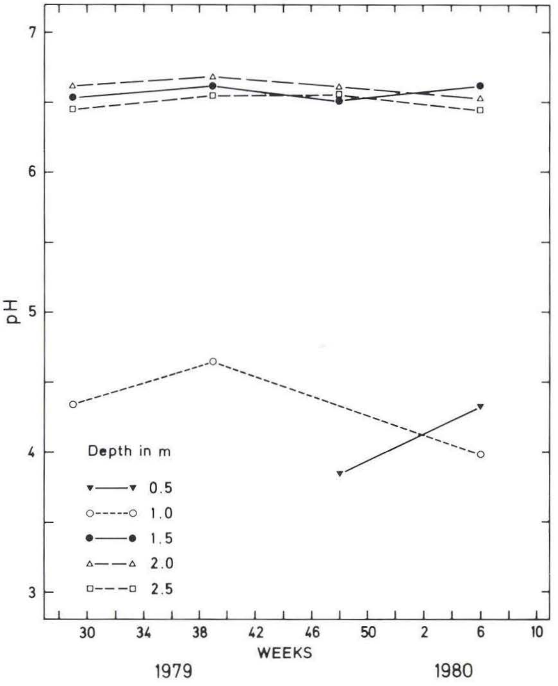

Fig. 4. The seasonal variation of pH at different depths. Data collected over a period of 8 months in Skjernå delta swamp sediments (locality C).

the redox conditions show seasonal variation However, at a depth of 1.5 m a very constant pH is found, which indicates that no sample contamination from higher levels occurs. At depths of 1.5, 2.0 and 2.5 m the pH variations at each level are well within a range of 0.2 pH units. This indicates that sampling procedures can be reproduced.

Some results for Fe^{2+} concentrations at another locality are displayed in fig. 5. The extremely high Fe^{2+} concentrations at depths of 1.0 and 1.5 m are related to pyrite oxidation. At 1.5 m the corresponding pH ranges from 5.38 to 5.75, while at 2.5 m a still high Fe^{2+} concentration (0.72–0.88 mM) is found at a pH range of 6.32 to 6.63. Considering that the oxidation rate of Fe^{2+} at this pH is very fast (Stumm and Lee 1961), the measured Fe^{2+} concentrations are unlikely to be reproducible if sample oxidation takes place.

Compared with other descriptions of apparatus for sampling by suction from soil sediments, the reported apparatus has several advantages. First, the filterprobes do not contain ceramic cups (Wagner 1962), since it has been shown that they may produce erratic results for phosphate and cations

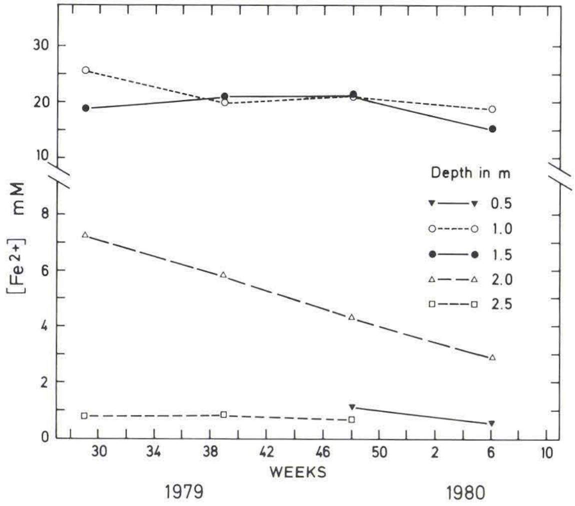

Fig. 5. The seasonal variation of Fe^{2+} concentration at different depths. Data collected over a period of 8 months in Skjernå delta swamp sediments (locality B).

(Stevenson 1978; Quin and Forsythe 1976). Secondly, there is no need for pre-drilling down to sample depth with subsequent backfilling as in other apparatus (Stevenson 1978; Quin and Forsythe 1976; van Breemen 1976), and this reduces the risk of sample contamination. The present instrumentation also compares favourably to the apparatus of Quin and Forsythe (1976) due to a significantly lower risk of degassing and a much lower sample volume in the filterprobe. Finally, the supplemental instrumentation described here enables sampling and analysis without air contact, which is of major importance when dealing with anoxic sediments.

Conclusion

The apparatus described in this report has in practice proved to be suitable for temporal sampling of pore water without air contact. Furthermore, it has several advantages compared to the apparatus described earlier for similar purposes.

Acknowledgements. For valuable assistance during the evaluation and testing of the apparatus in the field, we would like to thank laboratory technician Ellen Zimmer Hansen. Furthermore, we would like to thank tool maker Peder Skogstad for fruitful discussions during the manufacturing of the filterprobes, and the staff of the Geochemical Department for performing the laboratory analyses. A useful review of the manuscript by Jens Jacobsen is kindly acknowledged. The project has benefited from a grant of the Danish Natural Science Research Council.

Dansk sammendrag

Der er udviklet et apparatur, som gør det muligt at udtage porevandsprøver fra forskellige niveauer i inhomogene mosesedimenter. Apparaturets udformning tilstræber prøvetagning uden kontakt med luftens ilt og med en minimal afgasning af prøven.

Prøven udtages fra et PVC-rør, hvori der er monteret et glasfiberfilter (fig. 1). Da røret kan forblive i sedimentet er det muligt at følge sæsonvariationer af kemiske parametre. Prøven bliver opsamlet i Pyrex-glas flasker (fig. 2) og trykfiltreret ind i en N_2-fyldt handskekasse gennem et membranfilter (fig. 3). I handskekassen udføres analyser som kan påvirkes af oxidation.

Anvendelsen af apparaturet i felten er beskrevet, og problemer som kan opstå bliver behandlet. Nogle foreløbige resultater vist i fig. 4 og 5 tyder på god reproducerbarhed og lille spredning.

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A sedimentological mineralogical investigation of the Tertiary sediments from the borehole M–2X in Central Trough, North Sea

Ole Bjørslev Nielsen

Nielsen, O. B.: A sedimentological mineralogical investigation of the Tertiary sediments from the borehole M–2X in the Central Trough, North Sea. *Danm. geol. Unders. Årbog 1979:* 41–50, København, 1. december 1980.

Grain size and mineralogical analyses have been carried out on samples (cuttings) of Paleocene to Upper Miocene age from the M–2X borehole in the Central Trough of the North Sea.

The Paleocene sequence and the Lower Eocene ash series are dominated by smectite, while kaolinite has not been detected. However kaolinite occurs in large amounts in the younger Eocene sediments. At the transition from the Paleogene to the Neogene the grain size increases abruptly, the amount of smectite decreases and that of kaolinite and illite increases. Kaolinite indicates a subsequent supply of terrigenous weathering products presumably from the Baltic area and/or from the land areas of Scotland. The large amounts of smectite in the Paleocene and Lower Eocene is thought to be a result of a halmyrolytic transformation of the volcanic material. The distinct change in the type of sediments in the Upper Oligocene is thus believed to have been a response to the uplift of the surrounding landmasses and/or a lowering of the sea level.

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The purpose of this study is to elucidate the possibilities of a lithological correlation between the sediments from the M–2X borehole (fig. 1) and those of the surrounding boreholes as well as from the on-shore localities. Furthermore, the possible origins and the modes of dispersal of the sedimentary material will be discussed.

The investigation includes a lithologic description of the material derived from the cuttings, an analysis of the grain size distribution, and a qualitative and semi-quantitative analysis of the mineralogical composition which was performed partly on the crushed bulk samples and partly on the oriented samples of the clay fraction ($< 2\ \mu m$).

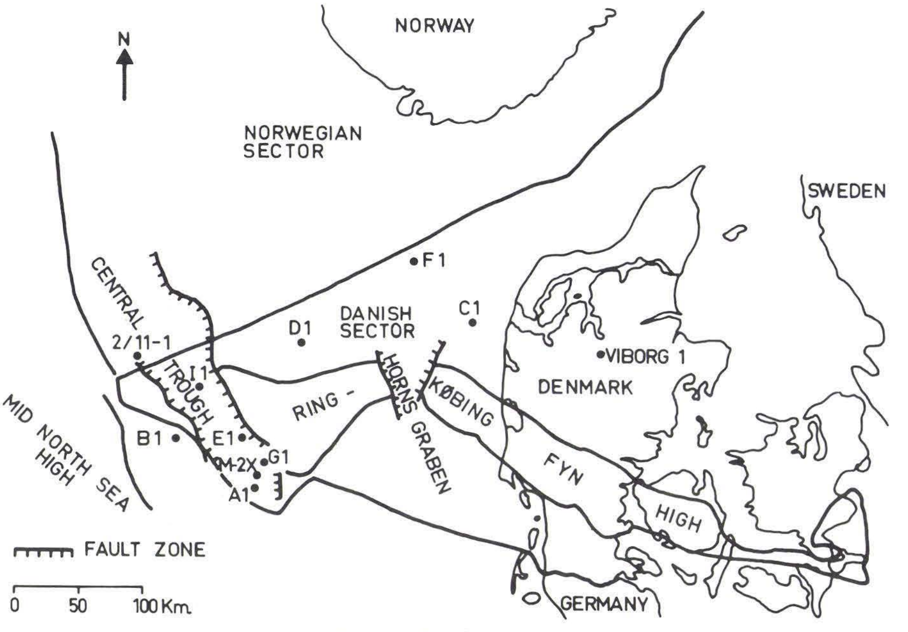

Fig. 1. Location map (Based on O. Michelsen 1978).

Methods

The analysis of the grain size was carried out using the Andreasen-pipette method while the mineralogical composition was determined by means of the X-ray diffractometry.

In order to calculate the content of the minerals in the bulk samples peak heights were used according to the method described by Schultz (1964). Clay mineral peak heights at the maximum intensity plus the intensity at ½° 2θ at each side of the position for the maximum intensity were used as peak intensities according to the method described by Tank (1963). Peaks from glycollated samples at 17 Å were ascribed to smectite, at 10 Å to illite and at 7 Å to kaolinite. No chlorite was identified. The peak intensity at 10 Å was multiplied by a factor 4 and the 7 A peak intensity was multiplied by a factor 2 before comparing with the uncorrected 17 Å peak intensity. (Biscaye 1965).

Results (Conf. fig. 2 and fig. 3)

The samples from the interval between ca. 5100' and ca. 6100' consist of silty clays with the fraction $< 2\ \mu m$ constituing more than 60 %. Besides the clay minerals the samples contain quartz and pyrite. In many samples calcite, gypsum and feldspar were also identified.

The average grainsize (the median) is smaller than 1 μm. Unoriented powder diffractograms show reflections from kaolinite and illite, but in contrast to the superposing interval also very distinct smectite reflections (001) occur.

The clay fraction is characterized by high amounts of smectite, especially in the lowermost part of the interval, where kaolinite was absent. The basal spacing of smectite within this interval is located in 12,75–13,25 Å range. Upwards the kaolinite content increases and reaches a peak at about 5700'. The illite content within this interval is very uniform, but shows a faint tendency to increase upwards. Besides the clay minerals, the clay fractions in this interval contain minor quantities of quartz and jarosite.

The samples from the interval between ca. 3700' and ca. 5100' differ in many aspects from the samples of the underlying interval. The material is coarse grained clayey silt with a median ranging from 4 to 8 μm and increasing upwards. The amounts of quartz and feldspar increase while those of pyrite and clay minerals decrease. The clay content varies from 30–40 %. Calcite occurs in minor amounts in the lower part of the interval while gypsum is absent.

In contrast to the interval below the clay fraction is characterized by the absence of quartz and jarosite and by a very distinct decrease upwards of smectite. At the same time the illite and kaolinite content increases. The basal spacing of smectite within this interval is located in 13.75–14.25 Å range.

Discussion

No biostratigraphical analyses of the material from the borehole M-2X have been published so far, but a comparison of the different logs of this boring with those of the surrounding boreholes especially A-1, A-2, G-1 (Rasmussen 1974 and 1978) indicate that the boundary between the Danian limestone and the Paleocene clay is situated at about 6106' (fig. 4), the upper boundary of the ash-series at about 5990', the Eocene/Oligocene boundary at about 55-5600', the Middle/Upper Oligocene boundary at about 5200' and the Middle/Upper Miocene boundary at about 4100'.

The upper boundary of the ash-series and the boundary between the Middle and the Upper Miocene is marked by very characteristic gammaray log peaks and is therefore believed to be relatively closely determined.

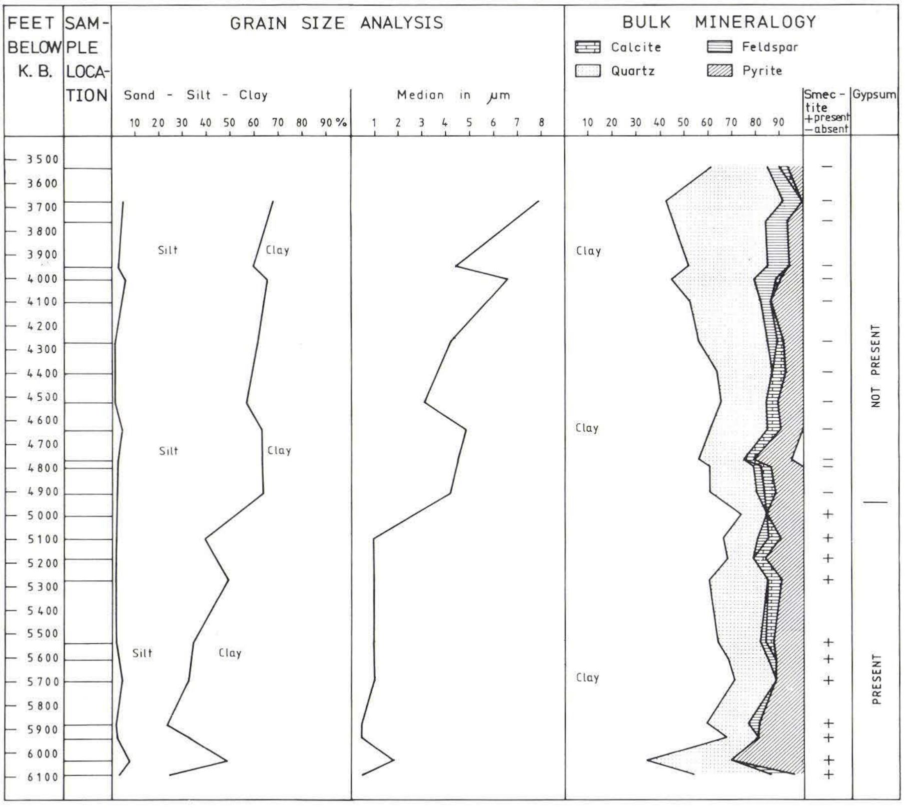

Fig. 2. Grain size and bulk mineralogy.

The grain size.

Compared with the borehole 2/11–1, located about 130 km to the northwest of M-2X (Karlsson et al. 1979), it is obvious that, generally, the material from M-2X is somewhat more fine-grained in the Eocene and Oligocene sections, but somewhat more coarse-grained in the Miocene section. In the Paleocene and the lowermost Eocene the sediments in both boreholes are more coarse-grained than higher up in the sections. This is presumably caused partly by the presence of the volcanic ash particles of sand and silt grain sizes. This same phenomenon was described previosuly from the boreholes in the North Sea Basin as well as from the on-shore localities. A distinct change in grain size between the Middle and the Upper Oligocene is not obvious in the 2/11-1 borehole. Karlsson et al. (1979) suggested, in agreement with Parker (1975), that 2/11-1 during the Paleocene was located in a distal part of a submarine fan with a source to the northwest. The boundary of the substratum, i.e. the Maastrichtian or Danian limestone, is

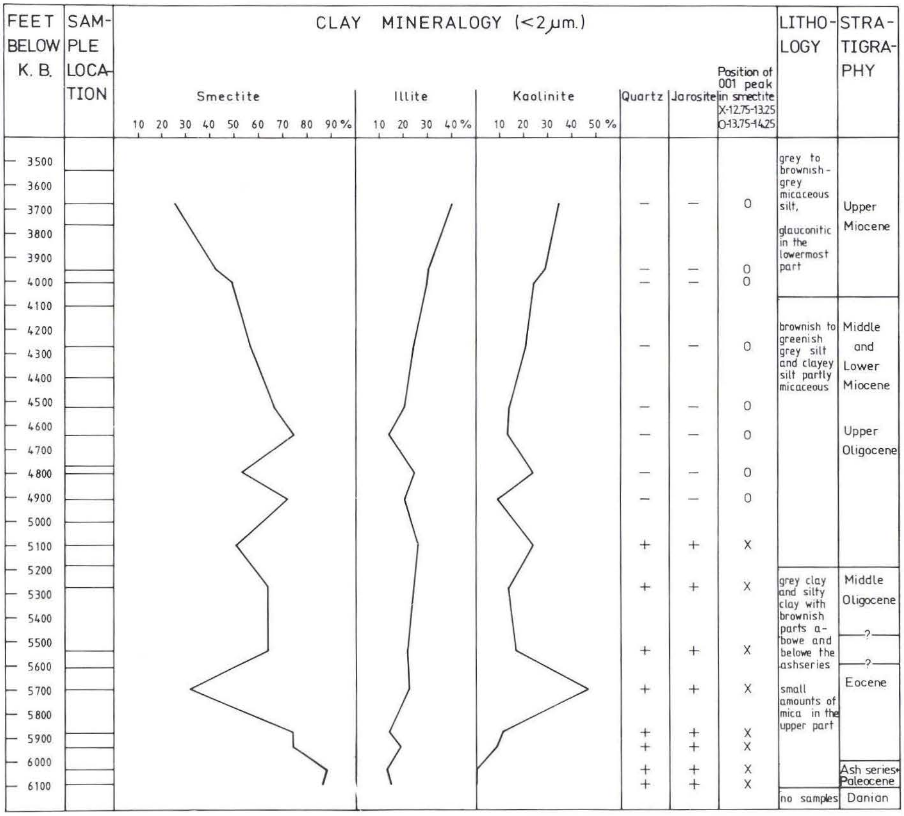

Fig. 3. Mineralogy of clay fraction.

situated about 2400' lower in 2/11–1 than in M-2X and the thickness of the sediments up to about the Upper Miocene boundary is more than two times greater in 2/11-1 than in M-2X. This indicates that the sources of the materials to the northwest were of a decisive importance during this period.

The thicknesses of the Eocene and Oligocene sequences are of the same magnitude as those of the on-shore localities while the Paleocene clay deposits are remarkably thinner (Dinesen et al. 1977).

The abrupt change in the grain size in the Upper Oligocene could mean that there was another source delivering more coarsely grained material to the southeastern part of the Central Trough. On-shore localities in Denmark are also often characterized by an abrupt change to more coarsely grained clay, silt and sand in the Upper Oligocene (Christensen and Ulleberg 1973). This change in the grain size is often related to an erosional unconformity. Vail et al. (1977: 85) have described a large scale global fall in the sea level in the early Upper Oligocene. This event might be responsible

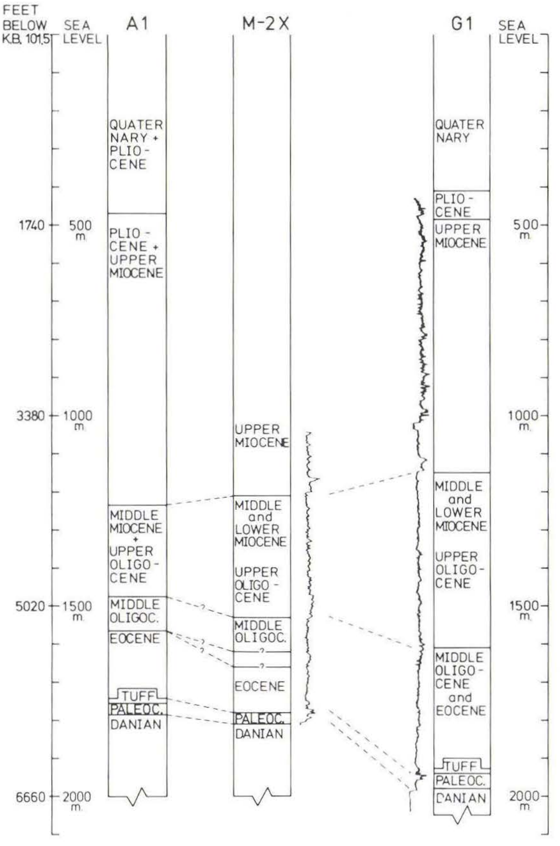

Fig. 4. Correlation between M-2X and A-1, G-1.
The logs are gamma-ray logs.
(A-1 and G-1 from Rasmussen, 1974 and 1978 respectively).

for this unconformity on localities closer to the shore. The increase in the grain size in the M-2X could also be explained in this way.

The mineralogy.

The gypsum in the bulk-samples and the jarosite content in the clay fraction of the Paleogene sediments is believed to originate from a post-drilling weathering of the pyrite. The widespread marl formations from the Paleogene of Denmark, i.e. Kerteminde Marl of Paleocene age and Røsnæs Clay and Søvind Marl of Lower and Upper Eocene age, respectively, are not found in the M-2X borehole. According to the descriptions of the other

North Sea boreholes (Rasmussen 1974 and 1978), these sediments are not characteristic of the Danish part of the North Sea either, although there is no general hiatus in the intervals mentioned. This absence, or scarcity, of carbonates apparently indicates different depositional environment.

An abundance of quartz in the clay fractions in the Paleogene is also reported by Karlsson et al. (1979). It was proposed that this quartz originated as a result of a halmyrolytic transformation of glass into smectite, silica and zeolites (Müller 1967).

Quartz, feldspar, calcite and pyrite in the bulk samples are known to be of silt and sand grain sizes. None of these minerals – except for some quartz – occurs in the clay fraction. The increase in the amount of quartz and feldspar in the Neogene sediments corresponds to an increase of the grain sizes, especially of the silt fraction.

The clay minerals.

The clay mineral composition and its variation is generally in agreement with the observations made on the samples from the borehole 2/11-1 and on those from the on-shore localities. Smectite is dominant in the Paleocene sediments and in the ash-series. This possibly indicates that a halmyrolytic transformation of the volcanic material has taken place (as proposed by Nielsen (1974) and Karlsson et al. (1979)). The supply of the terrigenous material was very limited. Tank (1963) suggests that smectite in the Paleocene may originate from the reworking of the Cretaceous and Danian bentonite intervals, as described by Christensen et al. 1973, Unmack 1949 and Valeton 1959, 1960. According to Hansen and Andersen (1969) an earlier Paleocene volcanism might have been responsible for the presence of clinoptilolite replaced foraminifera. Heulandite has also been identified in the Paleocene of the Viborg 1 borehole in Central Jutland (fig. 1) and in the local tuffs of Paleocene age in the North Sea (Harrison et al. 1979 and Knox 1979).

It is here believed that the names heulandite and clinoptilolite are apparently used interchangeably for the same mineral, as the distinction, based on the X-ray diffractograms, is not sharp (Brown et al. 1969).

The characteristic occurrence of kaolinite above the ash-series is in good agreement with the observations made on the samples from the borehole 2/11-1 and also from the Danish on-shore localities. Is is remarkable that the amount of kaolinite is so high, as it seems that it decreases westwards in Danish localities. This as previously mentioned, might be the result of a supply from another and closer source area to the northwest.

The upwards decrease in smectite and increase in illite and kaolinite probably reflect a diminishing role of volcanism as a source of the sedimentary material while, at the same time, the supply of terrigenous material was becoming more important. In contrast to 2/11-1 chlorite has not been identified in the Upper Miocene. This might be because either the material of the entire Miocene section was not investigated as yet or the source of chloritic material was from the northwest and thus did not reach as far southeast in the Central Trough as M-2X. Further analysis of the Upper Miocene and younger sediments in M-2X, as well as other boreholes, will presumably show whether the occurrence of chlorite in the Neogene sediments is a general feature for the North Sea Basin.

The observed change of basal peak position for the smectite at the transition from the Paleogene to the Neogene could be explained by the differences in exchangeable cations, or due to variation in amount and composition of interstratified components.

Conclusions

This investigation has shown that the mineralogy and the texture of the Tertiary deposits from the borehole M-2X are subject to very characteristic changes, which are generally in agreement with the results obtained from other North Sea boreholes and outcrops in Denmark. In a few cases the differences may indicate a variable influence of supply of the terrigenous material from different sources, presumably the Baltic area and Scotland.

Compared with the on-shore localities, there are no proper marl horizons, the carbonate never exceeding about 10 %.

In the Paleogene sediments smectite is the main mineral, quartz is present in the clay fraction and kaolinite is absent in the lowermost part of the section, which is probably due to a halmyrolytic transformation of the volcanic material and to a very minor supply of the terrigenous material. Higher up the amount of smectite decreases and kaolinite appears. This is believed to be caused by a supply of the weathering products from the surrounding land masses. Pyrite and quartz make up most of the silt- and sandfraction.

At the transition to the Neogene the grain size increases abruptly and continues to increase upwards. Similar conditions are described for the on-shore localities. This is believed to be a result of the uplift of the surrounding land masses and/or of a decrease in sea level.

Upwards in the Neogene smectite decreases and kaolinite and illite increase concurrently with the increase in grain size. These conditions may arise from a decrease in the supply of smectite, as the volcanic activity ceased, or because the sedimentation was taking place under more energy-rich conditions, possibly closer to the coast and generally under a regressive phase. Such events might have resulted in a decrease of smectite which normally is believed to be the most fine-grained of the identified minerals, and therefore would be kept in suspension and deposited under more quiet conditions.

Acknowledgements. The samples studied were kindly placed at my disposal by Dansk Boreselskab A/S. Financial support was provided by the Danish Natural Science Research Council.

Dansk Sammendrag

Prøver fra boringen M-2X i Central Trough, Nordsøen dækkende intervallet fra overfladen af Danienkalken til op i Øvre Miocæn er blevet underkastet texturelle og mineralogiske undersøgelser.

Det fremgår heraf, at overgangen fra Paleogen til Neogen markeres af et tydeligt skift i kornstørrelsesfordelingen fra finkornede siltede leraflejringer i Paleogen til lerede siltaflejringer i Neogen. Aflejringerne bliver tydeligvis grovere opadtil. De mineralogiske analyser har afsløret, at smectit dominerer i Paleogen især i Paleocæn og under aflejring af askeserien, og at kaolinit ikke er tilstede heri, men først dukker op senere i Eocæn. Samtidig med den stigende kornstørrelse i Neogen sker der et fald i indholdet af smectit og en forøgelse i illit- og kaolinit indholdet. Chlorit er ikke registreret.

Den kraftige dominans af smectit i Paleocæn og Nedre Eocæn er sandsynligvis forårsaget af en halmyrolytisk omdannelse af vulkansk materiale. Kaolinit kan tolkes som et indicium for en senere tilførsel af terrigent forvitringsmateriale sandsynligvis fra det baltiske område eller fra landområder omkring Scotland. Det er meget tydelige skrift i sedimentets textur i Oligocæn er eventuelt forårsaget af tektonisk hævning af omkringliggende landområder eller af en sænkning af havspejlet.

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Sedimentological and palaeobotanical investigations of a Miocene sequence at Lavsbjerg, Central Jutland, Denmark

Henrik Friis, Ole Bjørslev Nielsen, Else Marie Friis, and Basil Eric Balme

Friis, H., Nielsen, O. B., Friis, E. M., and Balme, B. E.: Sedimentolgical and palaeobotanical investigations of a Miocene sequence at Lavsbjerg, Central Jutland, Denmark. *Danm. geol. Unders., Årbog 1979:* 51–67, København, 1. december 1980.

Miocene deposits from a 120 m deep boring in Central Jutland have been analysed for sedimentological and palaeobotanical characteristics. Primary minerals are largely unaltered in the major part of the sequence and clay mineral transformation as well as dissolution of unstable heavy-minerals have only been recognized between and immediately below the brown-coal sequence. The depositional environment is interpreted as being a shallow sea into which a large delta was constructed. The delta plain was subsequently covered by swamp vegetation from where acid waters penetrated the deltaic sequence and caused mineralogical changes.

Part of the Miocene sequence yielded abundant Carboniferous and a few Mesozoic megaspores. The latter may be derived from the Fennoscandian Borderzone whereas the Carboniferous material most likely was derived from more distant sources. Petrographical characters of these spores point to a British origin, which may strongly indicate that the megaspores were transported by currents in the Sea.

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During the Miocene a sequence of interfingering marine and non-marine sediments was deposited in the central and western part of Jutland (see fx. Rasmussen 1961). The depositional environment for these sediments has been previously discussed mainly on basis of their fossils, although a few studies have included results from analyses of petrography and sedimentary structures (fx. Larsen and Friis 1973; Asgaard and Bromley 1974; Friis and Johannesen 1974; Radwanski et al. 1975; Dinesen 1976; Friis 1976). To evaluate the potential of combined petrographic and palaeontological investigations in the interpretation of depositional environments in the Danish Miocene, samples from a boring 120 m deep made by the Geological Survey of Denmark at Lavsbjerg in the Fasterholt area, Central Jutland (fig. 1)

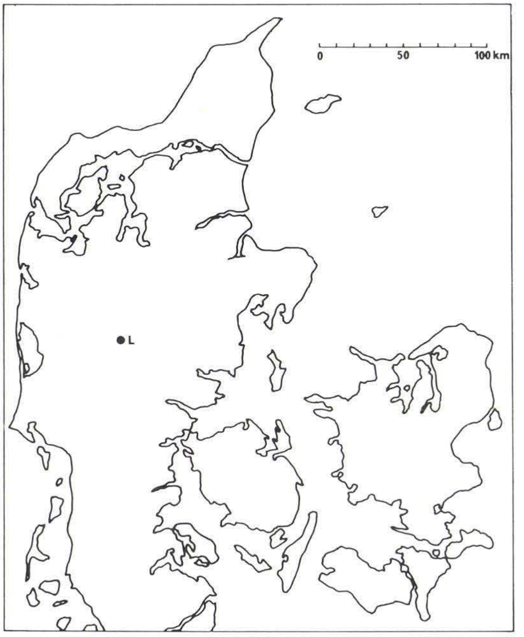

Fig. 1. Location of the Lavsbjerg Boring (L).

were analysed. The lithology of the boring is shown in fig. 4. It includes in its topmost part the basal bed of the Gram Formation, which is of Late Miocene age. Underlying the Gram Formation are black Middle Miocene clays of the Hodde Formation. The sandy and clayey sequence below the Hodde Formation is probably Middle Miocene and the upper part, which contains brown-coal layers, can with certainty be referred to the Middle Miocene Odderup Formation (for a discussion of the general lithostratigraphy of the Danish Miocene see Rasmussen 1961).

The general geology of the Miocene deposits within the Fasterholt area has been described by Koch and Friedrich (1970) and Koch et al. (1973).

Methods

X-ray mineralogy

The quantification of the bulk mineralogy was performed using the method described by Schultz (1964) and mostly based on corrected peak height values. Clay mineralogy was quantified according to principles described by Biscaye (1965) based on corrected peak areas. A detailed description of sample processing is given by Nielsen (1980).

The samples used for X-ray mineralogy were also analysed for grain-size distribution (sand fractions were sieved and silt and clay fractions were settled in water using the Andreassen pipette method) and the content of total carbon was estimated using a LECO induction furnace.

Heavy – mineral analyses

After treatment with H_2O_2 the samples were wet-sieved to separate the 74–250 μm grain-size fraction and heavy-minerals were extracted using bromoform (S. G. = 2.89). The grains were mounted in Clearax (R. I. = 1.66) and percentual distribution of the transparent heavy-minerals (except mica) was estimated from a count of 200 grains.

Palaeontological analyses

The plant material investigated in the present study was obtained by washing on a 120 μm sieve. After drying in air it was separated from mica by gravity differentiation in $ZnCl_2$ (S. G. = 1.90).

Results

Grain-size and organic carbon

Detailed grain-size analyses were made on samples selected from the silty and clayey beds for clay-mineral analyses (fig. 2), whereas grain-size data for the sands were obtained only from the preparation of heavy-mineral fractions (fig. 4).

Because the $CaCO_3$ content is low (generally 3 % or less from X-ray diffractograms) the analytical figure for total carbon is interpreted as representing solely organic carbon. It appears (fig. 2) that the content of organic carbon is generally high (about 5 %) and to some degree correlates with grain-size. In the topmost 2 m (Hodde and Gram Formations) and in the bottom part, the C % is significantly lower than in other fine-grained samples. In the brown-coal seams the C-content is generally higher, more than 10 % organic C.

The youngest Tertiary sediments (2–4 m below surface) are very fine-grained silty clays with a minor amount of organic carbon (1–3 %).

Mineralogy

There is a fairly close correlation between the amount of clay minerals identified on bulk X-ray diffractograms and the percentage of clay-sized particles determined from grain-size analyses, but the absolute values differ somewhat, especially in the interval from 11.5–26.0 m below surface. The estimated values of clay minerals from X-ray diffractograms are invariably

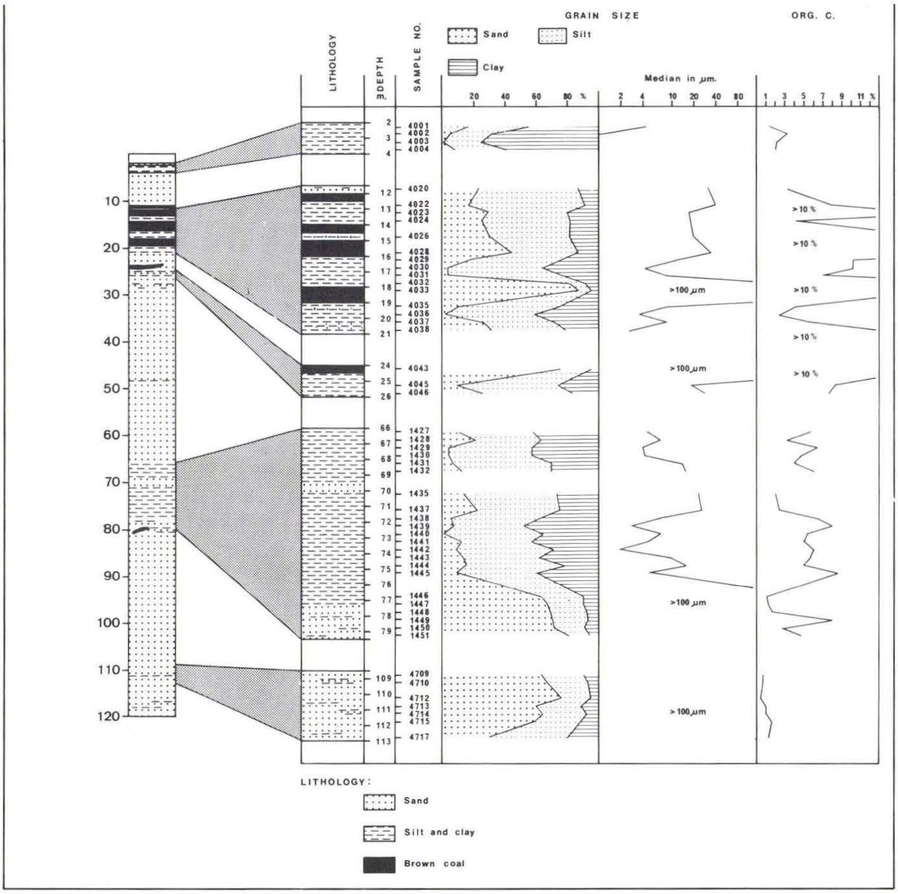

Fig. 2. Grain-size distribution and carbon-content of fine-grained intervals.

greater than the amount of clay-sized particles. Above and below this interval the differences are distinct but smaller (fig. 2).

The main minerals, apart from clay minerals are quartz and feldspar which vary with grain-size, pyrite and minor amounts of calcite. The position and sharpness of reflections on the diffractograms after different treatments of the clay presumably indicates the presence of several different irregularly interstratified minerals which vary in amount and composition throughout the section. Further analyses are necessary in order to define these interstratifications more precisely. In the most coarsely grained silt and clay beds, i. e. from 76.5–79.5 m and 108.5–113.0 m below surface, the mineralogical composition is strongly dominated by quartz, and for these no analyses of bulk mineralogy have been recorded. The clay mineralogy is

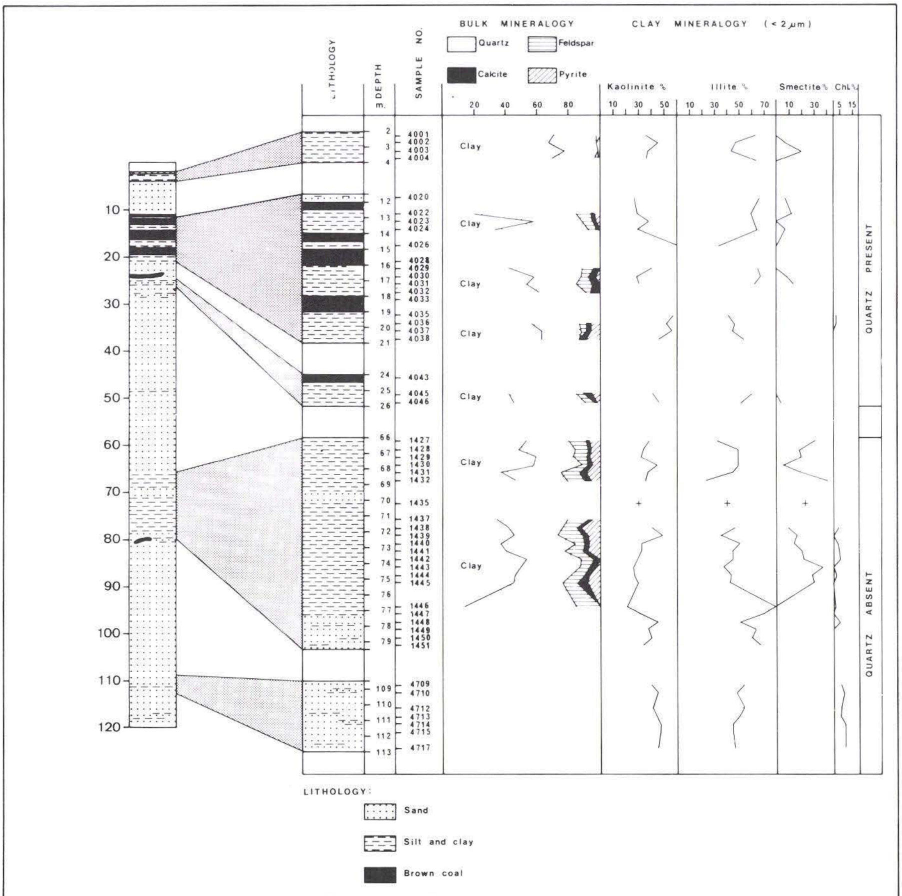

Fig. 3. X-ray mineralogy of fine-grained intervals.

characterized by the absence of smectite and almost equal amounts of kaolinite and illite with a slight tendency for illite to be more abundant. Chlorite occurs in proportions of about 10 %. Quartz is absent in the clay fraction (fig. 3).

The interval between 66.0 and 75.5 m below surface is subdivided by a coarse-grained sand bed. In the lower part, i. e. from 70.0–75.5 m, kaolinite, illite, smectite and chlorite are present. There is a tendency for kaolinite to be positively correlated to the median and for smectite to show negative correlation (figs. 2 and 3). Illite varies between 40–50 % and chlorite does not exceed 7 %. In the upper part, above 70.0 m chlorite is absent, kaolinite occurs in relatively constant proportions of about 35 % while illite and smectite percentages vary, apparently independently of grain-size.

Quartz is absent in the clay fraction over the entire interval.

The brown-coal-bearing interval from 11.5–26.0 m below the surface is generally characterized by a higher amount of kaolinite than above and below. Smectite and chlorite are absent except for small amounts near the top and the bottom of the interval. Illite makes up about 50 % of the clay fraction which also contains quartz. In the upper part there is a tendency for kaolinite to decrease and for smectite to increase (fig. 3).

In the uppermost interval from 2.0–4.0 m below surface illite and kaolinite dominate, smectite is present and chlorite does not occur. The sediment is notably more fine-grained in these marine clays. In the uppermost sample the grain-size increases presumably because of the presence of glauconite aggregates similar to those described from the basal part of the Gram Formation by Rasmussen (1966) and Dinesen (1976).

Tabel 1. Percentual distribution of heavy-minerals in the Lavsbjerg boring. (Op = opaque; Mi = mica; NO = non-opaque; Zi = zircon; Ru = rutile; Tu = tourmaline; Ky = kyanite; Si = Sillimanite; St = staurolite; An = andalusite; Ga = garnet; Ep = epidote; Am = Amphibole).

Depth (M)	Op	Mi	NO	Zi	Ru	Tu	Ky	Si	St	An	Ga	Ep	Am
10.5–10.9	60	7	33	11	8	6	16	4	5	–	6	38	2
21.5–22.0	57	17	26	7	6	13	32	8	15	4	5	7	1
26.0–26.5	70	17	13	36	17	5	17	10	10	1	2	2	1
27.0–27.5	72	10	18	25	10	7	20	4	12	2	12	4	1
28.0–28.5	77	1	22	15	9	4	35	5	11	–	16	3	–
29.0–29.5	79	1	20	14	9	3	24	2	8	2	34	1	–
34.0–34.5	83	–	17	14	2	7	21	5	5	2	42	1	1
38.0–38.5	69	1	30	8	5	5	22	2	8	1	35	11	–
39.0–39.5	65	–	35	4	8	4	14	1	6	–	30	31	–
40.0–40.5	67	1	32	6	3	4	14	4	6	–	37	22	–
41.0–41.5	60	1	39	12	6	2	12	3	2	–	30	28	1
42.0–42.5	59	3	38	6	4	6	12	5	8	1	30	22	1
43.0–43.5	63	3	34	6	4	2	12	2	2	–	25	43	1
44.0–44.5	49	–	51	2	–	3	8	1	6	1	19	53	2
45.0–45.5	43	2	55	5	2	1	11	2	2	–	21	53	–
46.0–46.5	45	5	50	3	3	1	9	2	3	–	17	58	–
47.0–47.5	28	22	50	4	1	2	7	2	1	1	11	67	2
48.0–48.5	31	38	31	2	2	1	6	–	1	–	7	76	1
49.0–49.5	11	55	34	2	–	1	4	–	2	–	7	74	7
50.0–50.5	26	37	37	3	3	1	4	1	–	–	11	71	3
51.0–51.5	34	24	42	2	2	2	2	–	1	–	12	74	2
52.0–52.5	37	11	52	3	4	2	2	1	–	–	10	71	3
53.0–53.5	26	33	41	4	4	2	7	1	–	–	11	63	4
54.0–54.5	20	29	41	4	3	3	1	1	–	–	11	69	5
55.0–55.5	21	15	64	2	2	2	2	–	–	–	4	76	4

Heavy-minerals

The heayy-mineral distribution is shown in table 1. It is noteworthy that in the upper part (10–45 m below surface) the unstable epidotes and amphiboles are almost completely absent, but increase in abundance gradually with depth in the interval 35 to about 50 m (fig. 4). In the underlying sequence, there is a high, but slightly fluctuating content of these minerals. It is also interesting that the downward increase in epidotes takes place when amphiboles are still absent, whereas the large fluctuation of the epidote percentages from 80–100 m below surface corresponds to a fluctuation in the amphibole percentages.

A high proportion of the epidote grains are corroded except in samples from the interval 48–66.5 m below surface, where less than one third of the grains are corroded.

Depth (M)	Op	Mi	NO	Zi	Ru	Tu	Ky	Si	St	An	Ga	Ep	Am
56.0-56.5	33	18	49	1	3	1	2	1	1	–	9	67	9
57.0-57.5	32	5	63	3	3	–	1	–	–	–	10	74	5
58.0-58.5	20	14	66	2	4	–	1	1	–	–	9	75	5
59.0-59.5	21	19	60	2	3	2	3	1	1	–	9	67	10
60.0-60.5	29	9	62	–	5	2	2	–	–	–	7	67	13
61.0-61.5	25	5	70	1	3	1	1	1	1	–	7	61	21
62.0-62.5	23	2	75	1	–	1	2	1	1	–	8	58	26
63.0-63.5	17	4	79	–	1	–	–	–	–	–	5	72	18
64.0-64.5	18	14	68	–	2	2	2	–	–	–	3	66	19
65.0-65.5	28	6	66	1	1	1	–	–	–	–	4	71	16
66.0-66.5	20	25	55	1	1	2	–	1	–	–	4	81	7
68.5-69.0	14	59	27	1	4	–	1	–	–	–	3	72	14
69.5-69.8	25	11	64	2	1	2	–	1	1	–	7	72	8
69.8-70.5	24	23	53	–	2	3	1	1	1	–	4	72	11
74.5-75.0	26	16	58	1	2	1	1	1	–	–	5	76	9
75.0-75.5	29	60	11	1	1	2	6	3	1	1	6	62	11
76.5-77.0	40	15	45	5	3	2	3	1	2	1	9	67	3
77.0-77.5	43	13	44	5	5	1	5	2	–	–	13	60	7
79.0-79.5	49	11	40	8	5	6	6	4	3	–	13	47	4
85.0-85.5	33	12	55	1	5	5	11	4	4	–	15	51	2
89.5-90.0	42	5	53	3	5	1	8	6	1	1	23	46	2
95.0-95.5	36	16	48	3	2	2	2	1	1	–	8	76	2
100.0-100.5	38	19	43	1	2	2	2	–	–	–	5	77	7
105.5-106.0	22	20	58	–	1	2	1	–	–	1	5	80	6
109.0-109.5	12	61	27	1	2	2	1	–	–	–	4	77	9

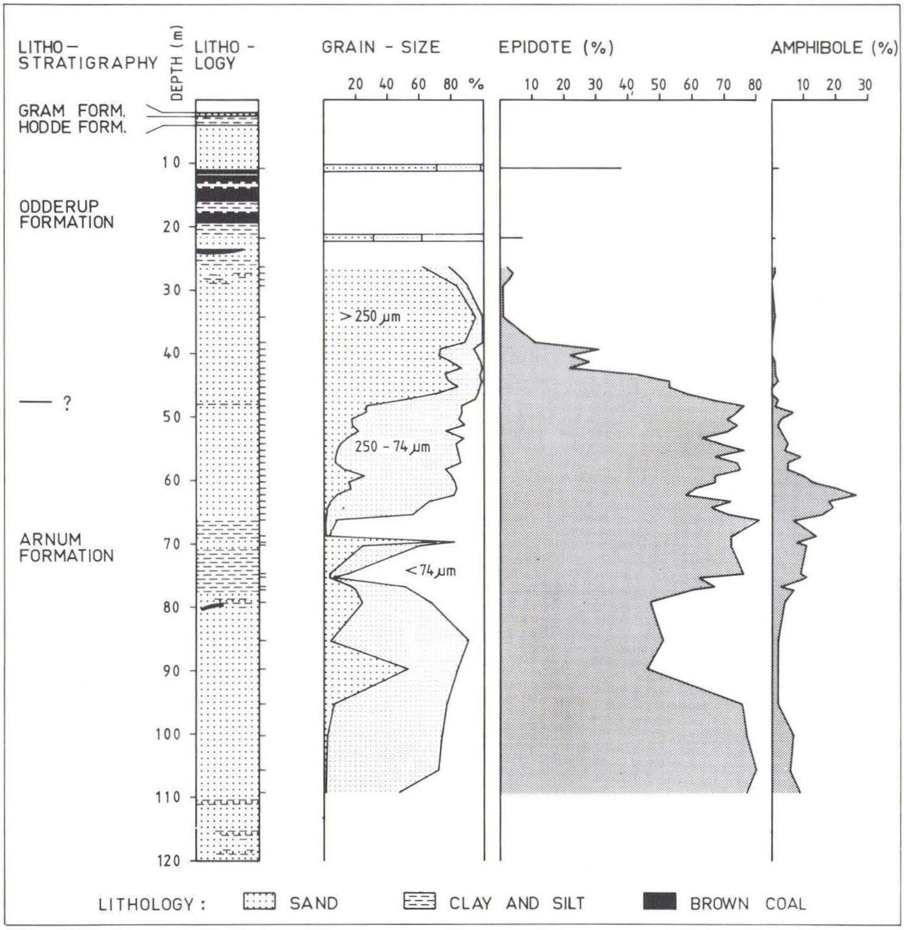

Fig. 4. Distribution of epidotes and amphiboles.

Megaspores (coal clasts)

Very few fossil plant remains have been recovered throughout the section, except the sandy interval from 47.0–64.5 m below surface. In this interval large numbers of megaspores were recovered. Some of these were identified as Tertiary species of *Azolla* and *Salvinia;* they are yellowish or light-brown and usually only slightly compressed. Another larger assemblage of megaspores could not be attributed to any known Tertiary species or genus. This group is devisible into two types, the more abundant being dark brown, thickwalled and much flattened, the other brownish and only slightly compressed. The dark brown megaspores are assignable to species predominantly described from Carboniferous sediments, the most abundant type being *Setosisporites hirsutus* (Loose) Ibrahim. Other species recognized were *Lagenicula horrida* Zerndt, *Laevigatisporites glabratus* (Zerndt) Potonié & Kremp, *Triangulatisporites rugosus* (Loose) Potonié & Kremp, *Cystosporites giganteus* (Zerndt) Schopf, *Setosisporites praetextus* (Zerndt) Potonié & Kremp and *Tuberculatisporites* spp.

It is not possible to give an exact stratigraphic age based on megaspores of the sediment from which they were derived, but small pieces of organic material attached to the megaspores were collected for palynological preparations. Small numbers of spores and pollen grains were recorded from this material. Most specimens were well preserved, but the majority of forms were represented by one or two examples and it was not possible to assign these with confidence to previously described species. The following forms were recorded: *Calamospora* sp., *Lycospora pusilla* (Ibrahim), *Granulatisporites* cf. *adnatoides* Potonié & Kremp, *Raistrickia saetosa* (Loose), *Verrucosiporites verrucosus* Ibrahim, *Cyclogranisporites* cf. *multigranus* Smith & Butterworth, *Densosporites* spp., *Densosporites sphaerotriangularis* Kosanke, *Punctatosporites granifer* Potonié & Kremp, *Punctatosporites minutus* Ibrahim, *Florinites* spp., *Florinites junior* Potonié & Kremp.

Most of the forms listed are long-ranging species in the Namurian-Westphalian of Western Europe. However, *Florinites,* several specimens of which were recognized, is not common prior to the Westphalian A in either continental Europe or Britain (Smith & Butterworth 1967, Clayton et al. 1977) and together with a high relative frequency of specimens of *Densosporites* and *Punctatosporites* it suggests that the assemblage is not older than Westphalian B. Although a younger age cannot be ruled out, the assemblages appear close to those characterizing Zone NJ of Clayton et al. which comprises the Westphalian B and lowermost Westphalian C.

The microfossils are pale to golden yellow and not greatly devolatilised. This indicates that the coals from which they were derived were not high rank and probably lay in the high volatile bituminous range.

The other type of non-Tertiary megaspores are very similar to megaspores recovered from Jurassic deposits of Denmark. Unfortunately no palynological preparations could be made of this material as no organic material was attached to the megaspores, and they are only generally referred to the Mesozoic; the age of the sediments from which they were derived has not been determined with certainty, although a Jurassic age seems most likely.

Discussion

The analytical results may be discussed in relation to provenance of the detrital material, depositional environment and to diagenetic transformations, which may in turn be partly controlled by depositional environment.

Some variations in mineralogical composition are clearly related to grain--size variations, fx. the quartz-feldspar content of silty samples, and in some samples the mutual distribution of kaolinite and smectite. But there are some prominent features that cannot be explained in this way. They will be discussed for separate sections of the entire profile.

The interval 11.5–47.0 m below surface.
In this interval the kaolinite content is significantly higher between and just below the brown-coal seams than in deeper sections. There is no correlation between grain-size and the content of kaolinite. In samples with high percentages of kaolinite, smectite percentages are low or nil. Quartz is always present in the clay fraction (fig. 3). Unstable heavy-minerals are missing and only introduced gradually with depth (fig. 4).

The variations in the mineralogical composition of the clay fraction may partly be due to differences in provenance but there is evidence suggesting that diagenetic transformation is a more likely agent. As may be seen from fig. 3 the topmost part of this interval does contain smectite in small amounts. Probably smectite was present among the material over the entire interval at the time of deposition and has later been destroyed and partly replaced by kaolinite. The excess silica may have formed clay-sized quartz crystals which are present only in this interval. Such a transformation could result from percolation of acid, humic waters from the swamps in which peats were accumulating.

Such conditions are also supported by the variations in heavy-minerals (fig. 4). Epidotes and amphiboles are missing in the upper part where they may have also been removed by acid percolating water. The lower stability of amphiboles as compared to epidotes strongly indicates that the dissolving water was acidic (cf. Nickel 1973).

The intensity of dissolution clearly decreases downwards, connecting the phenomenon to the brown coal seams at the top of the interval. The boundary between coarse-grained and fine-grained sand at about 47 m below surface may have controlled the movement of the water and thus restricted the zone of mineral destruction.

Similar profiles with a gradual downwards increase in epidote percentages have been described from other Miocene sections by Friis (1974, 1978) and ascribed to weathering on a flood plain (Friis and Johannesen 1974).

Very few detrital quartz grains carry small overgrowths, some of them rounded and clearly prior to deposition, but others may be post depositional. However, the quartz in the clay fraction may indicate that conditions prohibited formation of quartz-overgrowth, as would be expected if the detrital grains were coated. Füchtbauer (1974) mentions the formation of microcrystalline quartz-aggregates instead of quartz overgrowths on detrital grains, in clayey sandstones of the German Triassic.

The present data are inconclusive as to depositional environment, as only diagenetic changes brought about by swamp-formation at the top are recognized. It is likely however, that the coarse-grained sequence and brown-coal sequence were deposited in a deltaic or coastal plain environment.

The interval 47–66 m below surface

The most important observation is the intriguing occurence of reworked Mesozoic and Carboniferous megaspores, which outnumber Tertiary megaspores (exclusively from aquatic plants).

There seems to be two possible origins of the Carboniferous and Mesozoic megaspores in the Tertiary sediment, viz.

1. The megaspores were reworked in the Tertiary from both Mesozoic and Palaeozoic outcrops exposed during the Tertiary.
2. The megaspores were derived from Mesozoic sediments which contained Mesozoic megaspores as well as rebedded Carboniferous material.

The latter explanation could be supported by the work of Windle (1979) who stated that reworking of Carboniferous mega- and miospores was particularly common in the Lower Jurassic of northern Europe, and in his destribution map, showing localities with reworked Carboniferous spores in Jurassic sediments, three localities in Scania were recorded. However, the number of Carboniferous megaspores is much higher than that of the Mesozoic megaspores and therefore the first explanation seems to be more likely. It is further supported by the fact that a few megaspores of the Mesozoic type were recovered from a nearby boring at Fasterholt Plantage were they were not associated with Carboniferous megaspores.

Carboniferous coal fragments were recorded from Oligocene deposits of Belgium by Vandenberghe (1976) who compared the reflective measurements of reworked fragments with those of different coal fields of Europe. The redeposited fragments were shown to derive from low rank coal, and Vandenberghe excluded the high rank Ruhr, Aachen and Belgian coals as possible parent rocks. He concluded that low rank coals in northern England were the most likely source of coal fragments in the Belgian Oligocene.

The high volatile bituminous range of the Danish plytoclasts corresponds to vitrinitic reflections not higher than 1.2 (Teichmüller & Teichmüller, 1979). This according to Vandenberghe (1976 and personal communication 1979) also strongly points to a British origin. Rebedded megaspores of Carboniferous age very similar to those recovered in Denmark were also reported from Tertiary and Quaternary deposits of southeast England (Dijkstra 1950).

The Fennoscandian shield was very productive during the Miocene and contributed clastic material to the eastern and southeastern margin of the North Sea (Edelman 1938; Weyl 1952; Larsen and Dinesen 1959). It has not been possible to demonstrate the presence of sand-sized clastic material from other source areas, so it is considered most unlikely, although not impossible that the coal clasts were brought to the Danish area by the same rivers that transported the clastic material from Fennoscandia. Carboniferous sediments are unknown in Fennoscandica, and the coal fragments were almost certainly brought to the North Sea by other river systems and later redistributed by marine currents.

A further indication of marine conditions during deposition is the abundance of unstable heavy-minerals. Unlike the Miocene fluvial deposits of central Jutland (Friis 1974), this part of the Lavsbjerg section does not show strong weathering as one would expect to find in sediments deposited in a continental environment.

The interval 66–76 m below surface.

This fine-grained interval is characterized by high amounts of unstable heavy minerals and by fairly large amounts of smectite. In contrast to the section above 26 m there is no quartz in the clay fraction. Chlorite is a significant component in the lower part. These features strongly indicate that the sediment was not subject to post depositional weathering and again this suggests a marine or deltaic depositional environment. There are no clear indications of source area for the clay fraction, but the tendency for grain-size and mineralogy to be correlated may indicate that the clays were introduced into the marine environment from near-by rivers and sorted according to grain-size, as demonstrated by fx. Porrenga (1966). This would imply that the smectite and chlorite were also derived from the east. The occurence of chlorite is remarkable. The mineral is generally unknown from older Tertiary sediments in the eastern part of the North Sea Basin, and has been previously recorded from Upper Miocene deposits of the Central Graben (Karlsson et al. 1979). The earlier occurence of chlorite in Central Jutland than in the Central Graben also points to an eastern source area, which is probably the Fennoscandian Shield. Further investigations of this problem are in progress (Nielsen 1980).

A few shark teeth were found in this interval, and these further support the inference of a marine depositional environment.

The interval 77–120 m below surface.

The interval is characterized by high proportions of unstable heavy-minerals. It is noteworthy that the lowest epidote percentages occur in the same sediments that show minimum amphibole percentages, whereas in weathered sections amphiboles are destroyed before significant reduction in epidote percentages takes place (Friis 1974). So, although between one third and one half of the epidote grains are corroded, corrosion and destruction did not occur after deposition. It probably indicates reworking of weathered sediments. This effect is descussed by Friis (1978).

In the clay fraction smectite is missing and illite more common that kaolinite. The highest quantities of chlorite are found in this interval. The absence of smectite cannot be explained in the same way as for the interval 11.5–26.0 m. The samples are rather coarse-grained and only contain small amounts of clay. Smectite may have occured in small proportions.

Depositional environment

Except for the brown-coal sequence, which has been excavated in the area, there is little information on the depositional environment of the investigated sequence. The exposed upper sequence containing the brown-coal seams has been described in detail by Koch et al. (1973) who concluded that the brown-coals were deposited in swamps on a large delta which was subsequently invaded by the sea, where sediments referred to the marine Hodde and Gram Formations were deposited. Larsen (in Larsen and Friis 1973) suggested a marine origin for at least two intervals occurring below the brown-coals in a boring at Fasterholt. These intervals were characterized by a small but significant amount of amphibole in the heavy-mineral fraction as well as minor quantities of glauconite. There is a close agreement between the boring at Fasterholt and the studied section at Lavsbjerg, except that at Fasterholt the supposed marine interval is directly overlain by brown-coal, apparently without dissolution of amphiboles and epidotes below the brown-coal. Clay mineral analyses of this interval are similar to those from below the brown-coal seams at Lavsbjerg with quartz in the clay fraction and smectite almost completely missing. Chlorite is a characteristic component of this interval. This indicates that the transformation of smectite to kaolinite may occur before destruction of sand-sized amphibole and epidote grains takes place.

The occurrence of glauconite in small proportions is a characteristic feature of the supposed marine intervals in both the Fasterholt and the

Lavsbjerg sections. This appears to support the conclusion that the sediments are of marine origin, but as Koch et al. (1973) have mentioned, the possibility of reworking must also be considered. In the Lavsbjerg section a small number of reworked foraminifera was found in the interval 47–66 m. They originate from Eocene sediments (F. N. Kristoffersen, personal communication 1979) indicating that reworked earlier Tertiary sediments some of which probably contained glauconite have contributed to the Miocene sediments.

On the other hand the coincidence of several independent features, discussed above, point to deposition in a marine environment. As seen from fig. 4 the section contains a clearly defined unit that coarsens upward (77–29 m below surface). This unit is superposed by swamp deposits and later by marine deposits. It represents a typical sequence of prograding shorelines, fx. at river deltas, which may also typically be covered by thick swamp deposits with peat accumulation. The high amount of organic matter throughout the section (fig. 2) may also be explained by close proximity to a river mouth.

There are few fossils found in the sequence, apart from a few shark teeth in the clayey sediment at 67–77 m below surface. In the superposing fine sand, the presence of reworked Eocene foraminifera indicates that calcareous fossils were not generally destroyed and that their rarity in the sediment is an original feature, probably resulting from a high rate of sedimentation which would be expected at the front of a delta.

So, in our opinion the most plausible reconstruction of the depositional environment is a shallow sea (with depths not exceeding about 50–60 m) close to a river mouth where a large delta was constructed. Compaction and further subsidence may have brought the delta below sea-level and a new transgression invaded the area.

On this basis the lower part of the sequence is tentatively referred to the marine Arnum Formation of Middle Miocene age (fig. 4).

Concluding remarks

In the Lavsbjerg sequence two major units may be destinguished on the basis of their petrographic characters; an upper unit where dissolution of epidotes and amphiboles took place and where kaolinite and clay-sized quarz were formed, probably on the expense of smectite. These phenomena appear to be related to the brown-coal layers. In the lower unit there are no indications of such alterations. This indicates that the sediments between, and especially below, the brown-coal layers were altered, probably by percolating acidic waters from the swamps in which the brown-coal peats were formed, whereas deeper parts of the sequence were not affected.

The occurrence of reworked Carboniferous material in the lower part points to contribution of at least suspended matter from a source area other than the Fennoscandian Shield, and this material was probably transported to the Danish area by the sea. A marine origin of this part of the sequence is therefore likely.

It is suggested that the upwards coarsening sequence from ca. 77 m below surface resulted from the construction of a delta prograding into a rather shallow sea. The fine-grained deposits with brown-coal layers represent the top-set deposits of the delta.

Using this model the resulting sequence will consist of marine sediments without primary alteration of constituent materials, overlain by delta-plain deposits. Swamp formation on the delta resulted in mineral dissolution and transformation in the underlying sediments.

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Dansk sammendrag

Undersøgelsen omfatter en sedimentologisk og palæobotanisk bearbejdelse af miocæne aflejringer fra den 120 m dybe boring Lavsbjerg Øst i Fasterholtområdet (fig. 1). Lagseriens lithologi og lithologiske inddeling fremgår af fig. 4. I hovedparten af lagserien er der tilsyneladende ikke sket ændringer af de primære mineralsselskaber, men i en zone imellem og under brunkulslagene er der påvist væsentlige forandringer, fremkaldt af gennemstrømmende surt grundvand. Disse ændringer omfatter omdannelse af smectit til kaolinit under afgivelse af SiO_2, der findes som kvarts i lerfraktionen (fig. 3), samt nedbrydning af ustabile tungmineraler i sandstørrelse, først og fremmest amfiboler, men også epidoter (fig. 4). Virkningen af det gennemstrømmende, sure vand aftager gradvist nedad og kan ikke spores under 50 m's dybde. Denne begrænsning af grundvandets påvirkning tyder på, at hovedparten af lagserien er aflejret under marine eller deltaiske forhold.

En del af lagserien (47.0–64.5 m) indeholder omlejrede karbone megasporer. Omdannelsesgraden af dette materiale er forholdsvis lav og viser overensstemmelse med værdier for nordengelske kulaflejringer, hvorimod de tysk-belgiske kulaflejringer udelukkes som moderbjergarter på grund af en noget højere omdannelsesgrad. Der har næppe i Miocæn været blotninger af karbone sedimenter inden for det fennoskandiske denudationsområde, som har leveret hovedparten af det klastiske materiale i de danske miocæne aflejringer. Det er derfor mest nærliggende at antage, at det karbone materiale er transporteret til Fasterholtområdet med havstrømme. Dette betragtes som et yderligere argument for marine aflejringsforhold.

Det er vanskeligt at angive selve aflejringsmiljøet nøjere ud fra det her undersøgte materiale. Som det fremgår af fig. 4 indeholder lagserien en delsekvens (77–29 m), der er karakteriseret ved tiltagende kornstørrelse opad. Sådanne sekvenser dannes typisk ved kyster under fremrykning, for eksempel i forbindelse med deltaudbygninger i havet. Det høje indhold af organisk materiale (fig. 2) sammen med et meget beskedent indhold af invertebratfossiler peger også på, at aflejringen er sket i nærheden af en flodmunding. De groveste sedimenter i denne delsekvens kan være aflejret i en mundingsbarre. De overlejres af en serie finkornede sedimenter med brunkulsindslag, som man netop ville vente det på en sumpdækket deltaflade. Fra sådanne sumpe kunne surt grundvand trænge ned igennem de underliggende aflejringer og påvirke deres bestanddele som ovenfor omtalt.

Ved fortsat indsynkning og kompaktion af deltaets sedimenter er havet pånv trængt ind over området og har aflejret Hodde Formationens marine sedimenter.

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Depositional environments, diagenetic history and source areas of some Bunter Sandstones in northern Jutland

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Cores from the wells Mors 1 and Gassum 1 representing the Lower Triassic Bunter Sandstone Formation in the Danish Subbasin have been reexamined with regard to their primary sedimentary structures and their petrology. Four sedimentary facies are recognized within the series of fine- and mediumgrained, reddish sandstones in which fossils and trace fossils have not been found. The facies and the facies sequences suggest deposition of the sandstones by braided rivers.

The petrographical study of thin sections demonstrates two separate phases of diagenetic alterations. The first: infiltration of clay and precipitation of iron oxides comprises features wellknown from recent desert sediments. This phase may or may not be accompanied by growth of authigenic quartz and feldspar. The second phase: growth of authigenic clay and dolomite or ankerite represent deeper burial diagenesis.

The mineralogy of the sandstones indicate a metamorphic-plutonic terrain as the main source area, presumably the Fennoscandian Shield. However, zeolitic aggregates of volcanic origin in the Mors 1 samples and absence of these aggregates in the Gassum 1 samples coupled with the occurrence of sillimanite-bearing grains suggest different sub-source area for the two localities.

It is concluded that the regional pattern of sediment transport into the Danish Subbasin has involved transportation from various parts of the Fennoscandian Shield via a fringe of alluvial fans along the Fennoscandian Border Zone. The present study thus adds new evidence in support of the existing interpretations of early Triassic paleogeography and palaeoclimatology.

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The Lower Triassic Bunter Sandstone Formation (~ Lower and Middle Buntsandstein) comprises mainly red-coloured sandstones. In the Danish-North German Basin finegrained sand- and siltstones are found, which have recently been studied at Helgoland (Clemmensen 1979). These sediments grade northwards into more coarsegrained sandstones in the Danish Subbasin and further northwards into the coarsegrained sediments of the Skagerrak Formation (Bertelsen 1980). The geological setting and the spatial relationship of the Bunter Sandstone Formation are discussed extensively by Bertelsen (1980) in his paper on lithostratigraphy and depositional history of the Danish Triassic.

In the Danish Subbasin the Bunter Sandstone Formation has been cored in the wells Mors 1 and Gassum 1 (fig. 1) where it is represented by a 700–900 m thick series of sandstones contemporaneous to both the Bunter Shale Formation and the Bunter Sandstone Formation distinguished in the Danish-North German Basin (Bertelsen 1980). These cores were redescribed in 1979 at the Geological Survey of Denmark in connection with a geothermical project, and the results are presented in this paper.

It has been the aim of the present study of the sedimentary structures and the petrography of the cores to characterize the depositional environment and describe the diagenetic history of these red, unfossiliferous sandstones, in which trace fossils have not been observed, and hereby to contribute to the knowledge of the Early Triassic palaeogeography.

Sedimentary facies

General

In Mors 1 the thickness of the Bunter Sandstone exceeds 900 m (fig. 1), and the upper boundary is identified below 4.3 km depth (Bertelsen 1977). Two relatively closely spaced intervals at depths between 5.0 and 5.1 km were cored (fig. 1,2) and two 12–13 m long cores are available which allow recognition of facies sequences. The cores consist of medium and finegrained, grayish red (5R 4/2), well-sorted, largescale crossbedded sandstones with a varying content of intraformational clasts of dark reddish clay (10R 3/4, 5YR 3/4). All colours are named according to the rock-color chart by Goddard et al. (1975). Wire line log data indicate that sandstones are the dominant lithology in Mors 1, and the two cores may be representative for the formation as a whole.

In Gassum 1 the Bunter Sandstone Formation occupies depths between 2.7 and 3.4 km (Bertelsen 1977) and nine intervals from depths between 2.8 and 3.1 km were cored (figs. 1,3). These 3–5 m long cores and the scarce wire line log data indicate that the formation is lithologically uniform throughout. In Gassum 1 the sandstones are medium- to finegrained, well-sorted, pale reddish brown (10R 5/4) and dominantly largescale crossbedded, and they contain varying amounts of thin intraformational clasts, at times resembling drapes, of moderately brown clay (5YR 3/4).

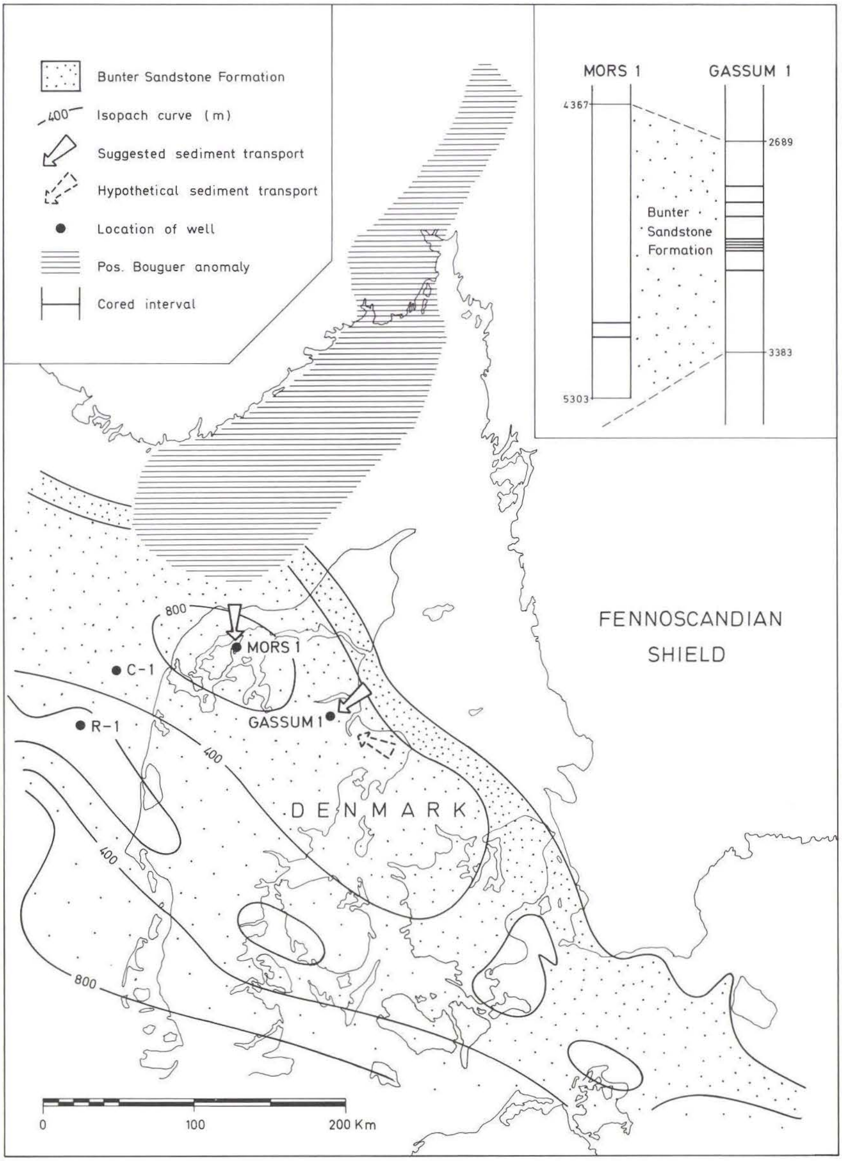


Fig. 1. Location map. The isopach map of Lower and Middle Buntsandstein is drawn from Michelsen & Bertelsen (1979). The spacing between the dots indicate the proportion of sand to finer grain-sizes, with sand/siltstones dominating to the south. The positive Bouguer anomaly, outlining the Oslo palaeorift igneous province, is drawn from Husebye & Ramberg (1978). On the inset figure, showing the relative position of the Mors 1 and Gassum 1 cores within the Lower and Middle Buntsandstein Series, the depths are given in meters below mean sea level. Drawn from Bertelsen (1977). Please note, that the cores are correlated along the upper boundary of the Bunter Sandstone Formation and that this is situated at different depths in the two wells.

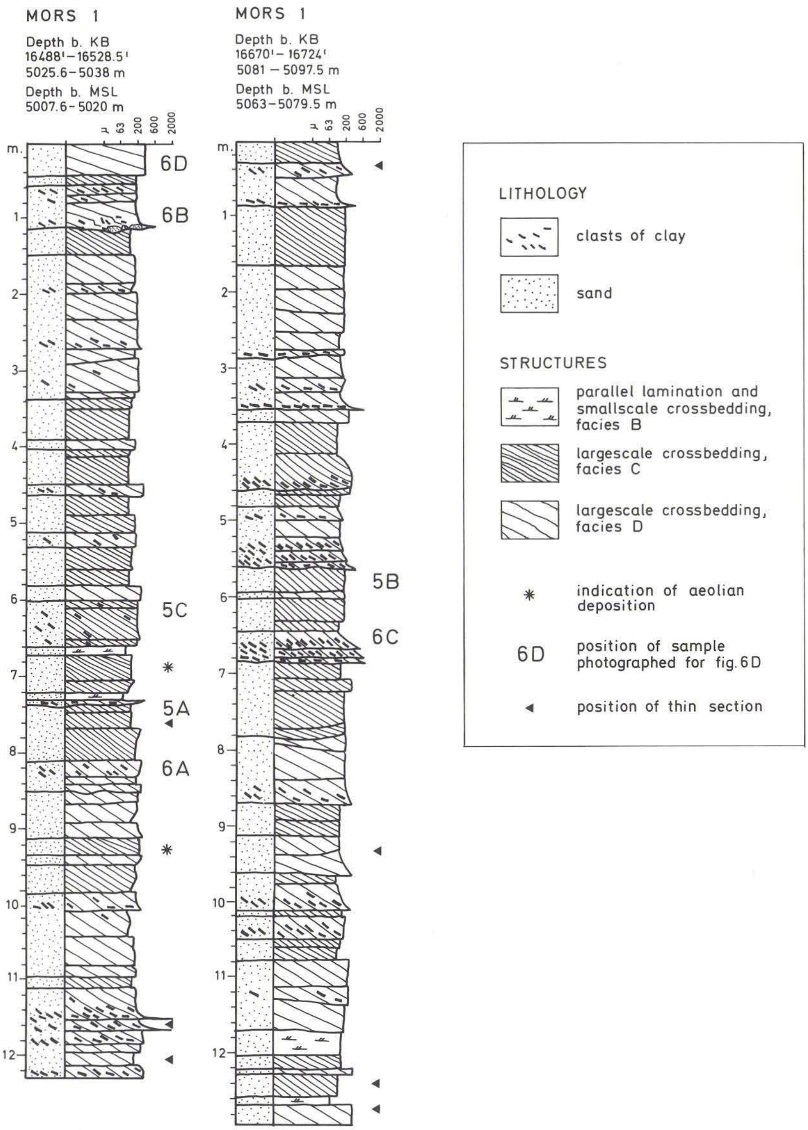


Fig. 2. Sedimentological logs of the Mors 1 cores. The dominance of the facies C and D is seen. The depth in feet below Kelly Bushing to the interval that was cored is the figure used in the captions to figs. 4–7. When the length of the cored interval is compared to the length of the cores it is seen that recovery was high.

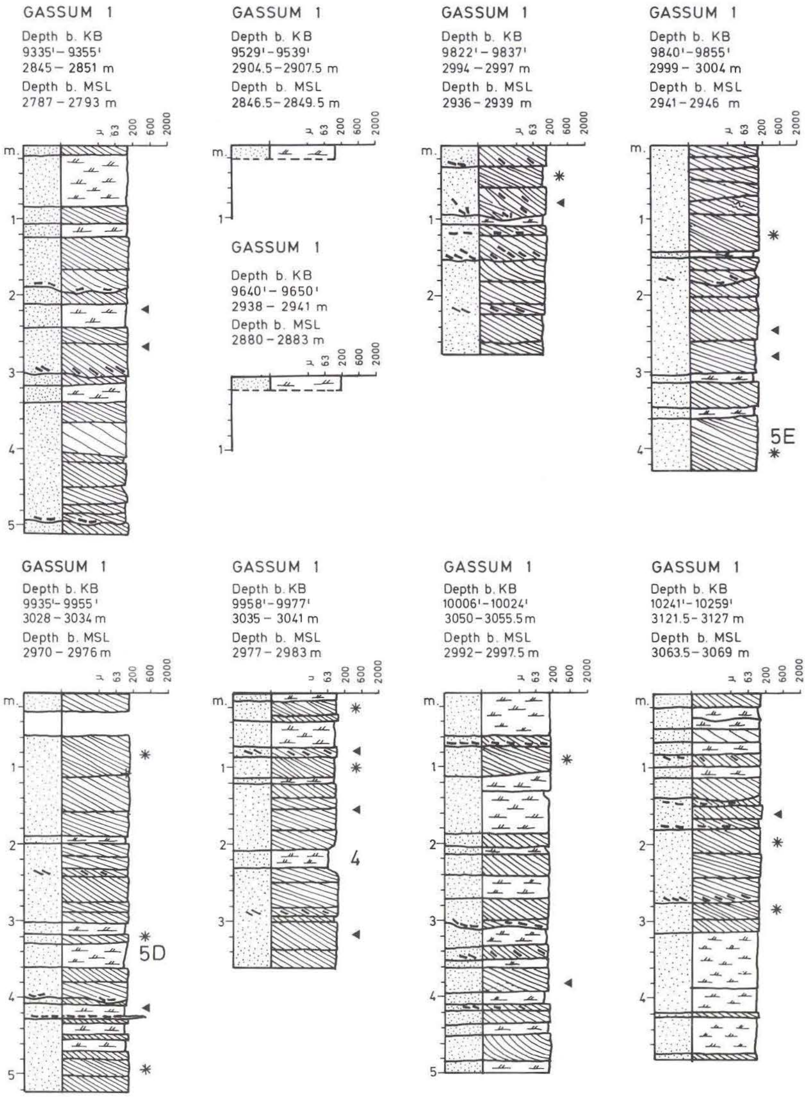


Fig. 3. Sedimentological logs of the Gassum 1 cores. The dominance of the facies B and C is seen. For further explanation see fig. 2.

Recognition of largescale sedimentary structures in cores represent some difficulties which are very well illustrated by Glennie (1970, figs. 120–122.). Still it is thought possible to recognize four sedimentary facies in the Mors 1 and Gassum 1 material, and they will be described in the following.

The cores were not oriented during drilling and therefore the direction of the currents depositing the crossbedded sands cannot be determined.

Facies A: Intraformational clay clasts

Description

Silty, non-calcareous, brown (10R 3/4, 5YR 3/4) clay constitutes intraformational clasts. These are often angular and 3–5 mm thick, but rounded clay pebbles are also seen. The clasts are lying 1) parallel to foreset laminae in largescale crossbedded sand (figs. 6A, C) or 2) they may be concentrated as a lag conglomerate at the bottom of a crosslaminated bed (fig. 6B, see also figs. 2,3).

Interpretation

Smith's (1972) studies of mud clasts indicate that angular clasts generally have undergone very little transport and therefore largely represent erosion and redeposition of layers of clay. Contrary the rounded clay pebbles represent separated phases of erosion and deposition but probably only transport over short distances.

If the thickness of the original clay layers correspond to the thickness of the clasts, the clay layers may have represented single episodes of deposition of suspended matter in quiet waters. Sedimentation of facies A may have taken place in abandoned courses of rivers or in small (temporary) lakes.

The strength of wet clay clasts is considerably larger than flakes of dry clay (Smith 1972) so presumably at least the angular clasts were transported wet and deposited by the same current that eroded them. Therefore the presence of intraformational clasts in the Bunter Sandstone Formantion is interpreted to indicate alternating periods of deposition, subaerial exposure and fluvial redeposition (see also Blatt, Middleton & Murray 1972, p. 286).

Distribution

The total amount of clay clasts is less than 5 %, but the repeated occurrence of intraformational clasts indicate that deposition of clay layers continually took place during sedimentation of the Bunter Sandstone Formation.

Facies B: Finegrained sand with parallel lamination or smallscale crossbedding

Description

This facies is characterized by very finegrained, silty, relatively well-sorted sand with parallel laminae c. 5 mm thick or smallscale, often planar, crossbedding (fig. 4). The foresets are unidirectional. Intraformational clasts are absent.

The sediment may have the red colours characteristic for the cores as a whole, but often light brownish gray (5YR 6/1) or greenish gray (5G 6/1) colours are seen. Facies B appear to be stronger cemented than the more coarsegrained sediments.

Interpretation

As the content of clay and fine silt is negligible, and because small current ripples were formed, it is inferred that the finegrained sediment was deposited in slowly flowing water during lower flow regime conditions. There is an absence of fossils or trace fossils in all facies and facies B may accordingly represent either fluvial or lacustrine deposits.

Distribution

Facies B occurs almost exclusively in the Gassum 1 cores where it constitutes up to c. 40 % of the cores (fig. 3).

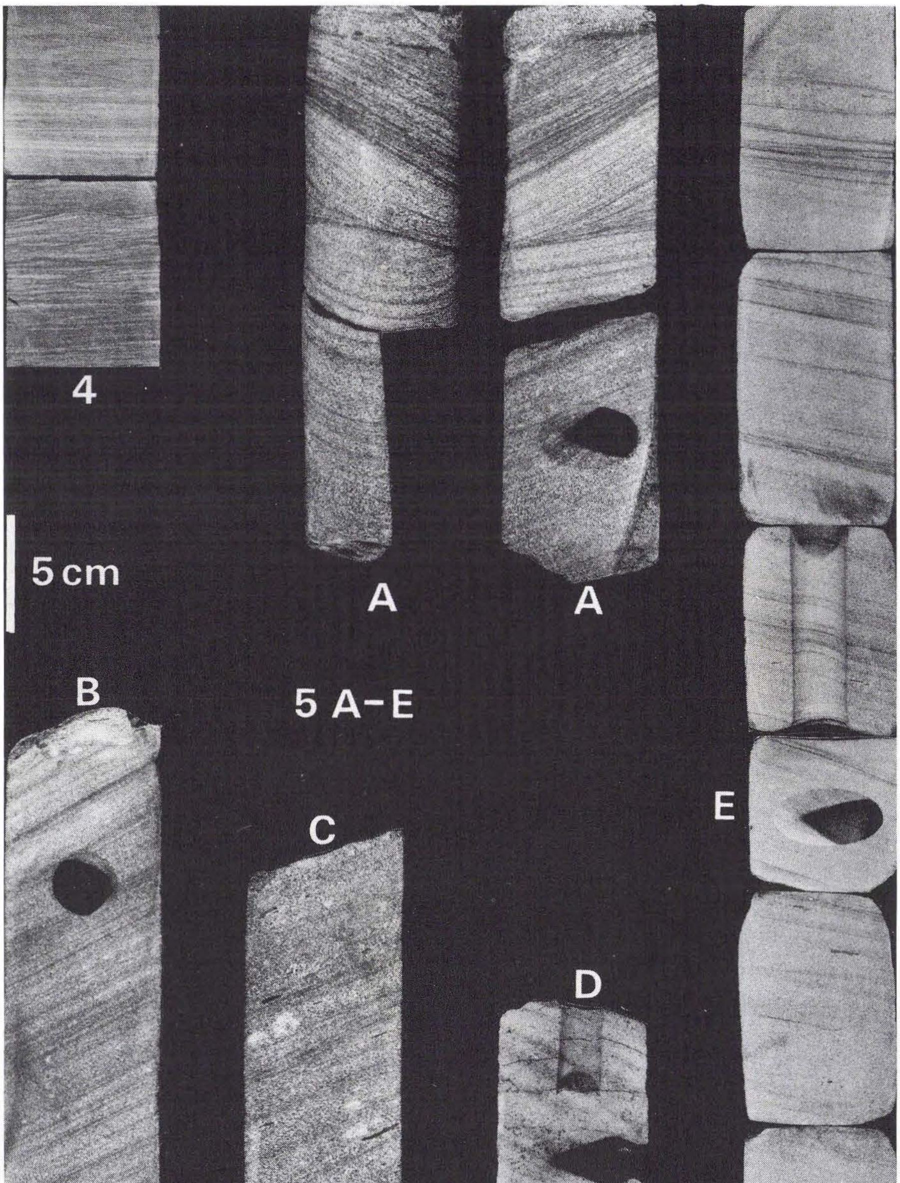
Facies C: Fine- to mediumgrained, largescale crossbedded sand

General

The sand is greyish red (5R 4/2) in the Mors 1 cores and pale reddish brown (10R 5/4) in the Gassum 1 cores. The facies comprises largescale crossbedded, generally well-sorted, sand with clearly defined foreset laminae at times distinguished by clear variations in grain-size.

The facies is divided into two subfacies through the presence or absence of intraformational clay clasts.

Facies C is the dominant facies in the Bunter Sandstone Formation in the Mors 1 and Gassum 1 wells (figs. 2,3) where it constitutes 40–55 % of the cores.


4
5 cm
A
A
B
5 A-E
C
E
D

Subfacies C1: Fine- to mediumgrained, largescale crossbedded sand without clay clasts

To the above general description may be added: The subfacies is developed as up to 60 cm thick, planar crosslaminated sets of well-sorted sand without intraformational clasts. The individual foreset laminae may be wedgeshaped (fig. 5E), or subfacies C1 may display unusual »high angle contacts« to underlying sedimentary units (fig. 5D).

Aeolian sediments are described from the Bunter Sandstone Formation at Helgoland (Clemmensen 1979) and might be expected to occur in the Mors 1 and Gassum 1 cores, too. The clast-free, largescale crossbedded sand with wedgeshaped foreset laminae of subfacies C1 resemble the descriptions of aeolian sediments given by McKee (1966), Glennie (1970, 1972), Clemmensen (1978, 1979). Also the deposition of the angular foresets without bottomsets »uphill« against an inclining surface (fig. 5D) reflects a depositional mechanism presumably only possible in aeolian sediments: Deposition must have taken place from a migrating bedform in which the particles rolled down the foreset without forming bottomsets, and where the surface in front of the migrating bedform was not eroded by the depositing current.

Thus subfacies C1 is interpreted as aeolian deposits. Its distribution is seen in figs. 2 and 3, where it is marked as facies C with an asterix to the right.

Fig. 4. Facies B. Finegrained silty sand with parallel lamination or smallscale crossbedding. A well preserved current ripple is seen approximately in the middle of the picture. Gassum 1, 9,958'–9,977'.

Figs. 5 A-E. Facies C. A-C illustrates subfacies C2, and D-E illustrates subfacies C1. (A) Two crosslaminated sets deposited by currents from two directions c. 90° apart. The core is seen from the outside (left) and cut, parallel to current, (right). Foresets are tangential. Subfacies C2 is erosively overlain by facies D. Mors 1, 16,488'–16,528.5'.

(B) Largescale crossbedded sand with clearly defined foreset laminae, subhorisontal in the bottom. Intraformational clasts are not seen. Mors 1, 16,670'–16,724'.

(C) Subfacies C2 with few intraformational clasts and some examples of wedge-shaped foreset laminae. The pale spots are strongly cemented by dolomite. Mors 1, 16.488'–16,528.5'.

(D) Subfacies C1. »High angle contact« between upper and lower crossbedded units. Gassum 1, 9,935'–9,955'.

(E) Subfacies C1. No intraformational clasts, some wedge-shaped foreset laminae. Well-sorted sand with heavy minerals concentrated as dark streaks along some foresets. Gassum 1, 9,840'–9,855'.

Subfacies C2: Fine- to mediumgrained, largescale crossbedded sand generally with clay clasts

To the general description of facies C may be added: Intraformational clasts occur widely but never abundantly (fig. 5C) or may be absent, and the crossbedding is tabular with angular or tangential foresets. The dip of these may vary from more than 20° to less than 10° (fig. 5B). Some slightly dipping sets show gradual transitions into horisontally bedded sand, assumedly representing the subhorisontal part of tangential foresets. Often several sets (height c. 10 – c. 30 cm) can be seen to have been deposited by unidirectional currents, but changes in current directions are also observed (fig. 5A). The subfacies may be erosive or overlie an eroded surface.

The subfacies is interpreted as fluvial, deposited by migrating megaripples under upper lower flow regime conditions. The well-sorted sediment with distinct crosslamination and at times contrasts in grain-sizes between foreset laminae indicate slipface sedimentation and low rates of suspension transport.

Subfacies C2 includes all beds of facies C that does not posses the characteristica of subfacies C1. The distribution of subfacies C2 is shown in figs. 2 and 3 as facies C.

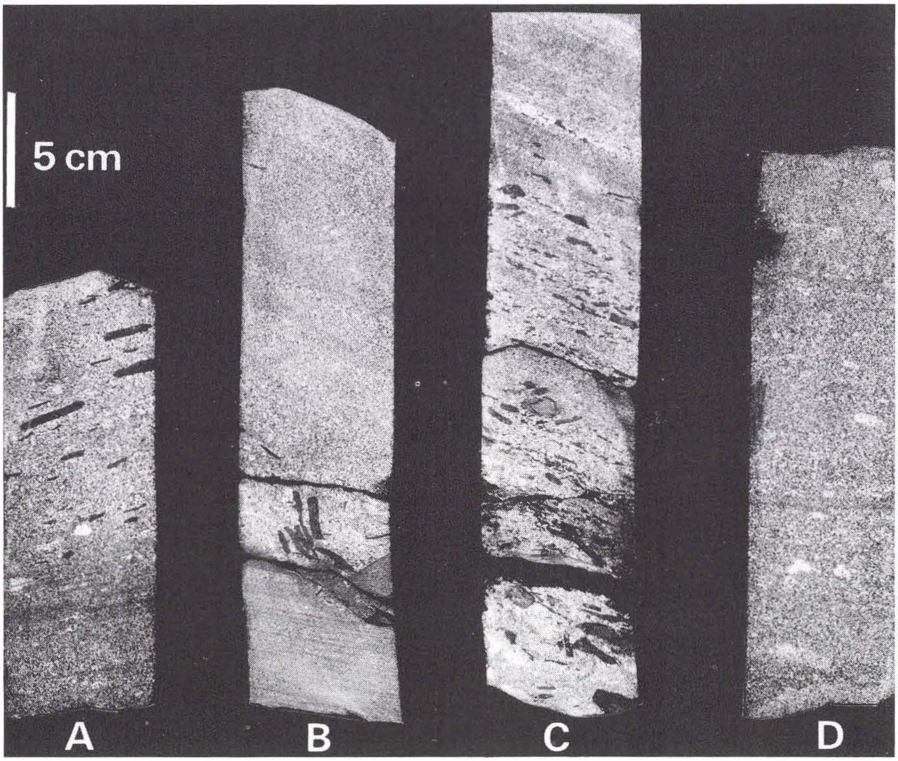
Facies D: Mediumgrained, largescale crossbedded sand

Description

Medium grained, grayish red (5R 4/2), relatively poorly sorted sand locally with a high content of intraformational clasts (fig. 6). Facies D is largescale crossbedded, the height of the sets varies from 2 to 50 cm, the foresets dip between 10° and 30°, and the individual foreset laminae are thick (0.5–3 cm) and are often difficult to distinguish (fig. 6D). Clay clasts in varying numbers are lying parallel to the foreset laminae (fig. 6 A,C). Lag-conglomerates containing imbricated and almost overturned clasts are also observed (fig. 6 B). The facies is seen with concordant as well as clearly erosive boundaries towards other facies.

Interpretation

The facies is, in the present depositional context, interpreted as fluvial due to the large content of intraformational clasts, the erosive boundaries, the largescale crossbedding and the grain-size of the sand. The imbricated clasts (fig. 6 B) and the indistinguishable foreset laminae indicate that deposition occurred rapidly from a current with high velocity and with a large sediment load.



Figs. 6 A-D. Facies D. The content of intraformational clasts is varying and the clasts often occur parallel to foresets, either spread through the bed (A) or concentrated in certain levels (C). In (B) facies D erosively overlies facies C and the lag-conglomerate contains both sandstone clasts and clay clasts. The latter are imbricated and almost overturned. In (D) the sediment is almost structureless and clasts are absent. The pale spots are strongly cemented by dolomite. (A), (B), (D): Mors 1, 16,488'–16,528.5'. (C): Mors 1, 16,670'–16,724'.

Distribution

Facies D is predominantly seen in the Mors 1 cores where it alternates with facies C. Facies D here constitutes c. 60 % of the cores (fig. 2).

Discussion of facies sequences and depositional conditions

The immediate impression from the sedimentological logs (figs. 2,3) is that cyclic facies sequences are not developed. This is confirmed when the facies transitions are tested by Selley's (1970) method, which further illustrates that:

1. The number of transitions from facies X up into facies Y corresponds exactly to the number of transitions from facies Y up into facies X.
2. Transitions between facies B and D are very rare.
3. Facies C alternates with either facies B or facies D.

The last two points agree well with the interpretation that facies D represents the highest fluvial energy conditions, while facies C, though generally fluvial, was deposited at lower energy conditions, and facies B and especially facies A represent low energy environments of quiet waters.

From the lack of pattern in the facies sequences it is inferred that the river changed its course often and randomly so that systematic facies sequences did not develop. It is concluded that the Mors 1 and Gassum 1 cores represent distal and finegrained braided river deposits.

Lower Triassic palaeoclimatic conditions have been interpreted by Clemmensen (1979). Denmark was situated at a palaeolatitude of c. 20° N within a central trade wind region and characterized by desert environments with short rainy seasons.

In such climates braided river deposits characteristically are formed (Glennie 1970, p. 29) and because channels become filled with their own, or aeolian, deposits, the next flood finds its old route partially or completely blocked. It must then seek alternative routes and, in so doing, builds up a braided alluvial plain. A model for the depositional environment of the Bunter Sandstone formation is illustrated in fig. 7.

The primary sedimentary structures and the facies sequences seen in the Bunter Sandstone Formation in Mors 1 and Gassum 1, thus corresponds closely to those described by Glennie (1970) from recent desert environments. Also the early diagenetic textures: clay infiltration and iron oxide precipitation, described in the following and indicating an oxidizing environment, are in agreement with the otherwise interpreted palaeoclimatical conditions for the Bunter Sandstone Formation.

Microscopic petrography

Methods and samples

The petrographical study is based on 18 thin sections whose position are indicated on figs. 2, 3. The number of thin sections is limited, because examination of the cores at low magnification indicated close similarity in compositions of the various facies within the same well but larger differences between the sediments cored at the two localities. For identification of certain minerals X-ray diffraction and universal stage methods has been used.

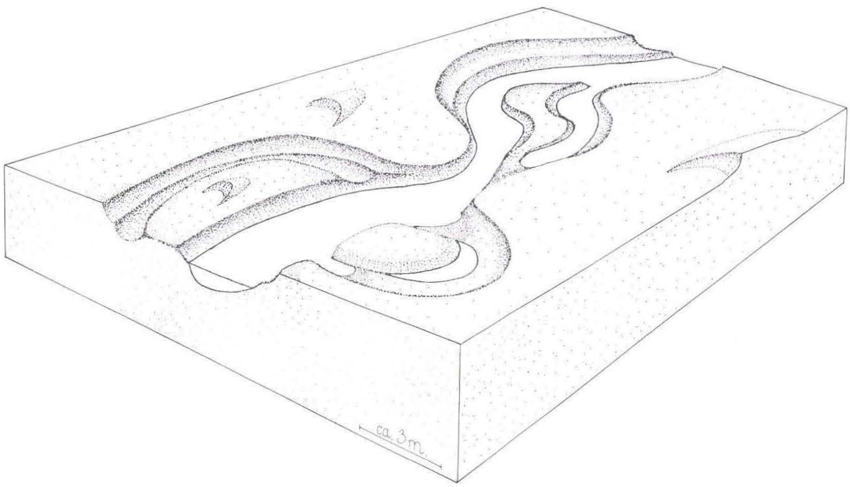


Fig. 7. A model for the depositional environment of the Bunter Sandstone Formation. In the main course of the river facies D was deposited under relatively high energy conditions. The repeated shifting of the course and the accompanying erosion of previously deposited clay layers, facies A, produced the clay clasts so abundantly found in facies D. In little more sheltered parts of the braided river the fluvial sediments of subfacies C2 were deposited, while sedimentation of the fine-grained facies A and B took place in more or less abandoned courses of the river. Aeolian redistribution of the fluvial deposits producing subfacies C1 is illustrated by the scattered barchanes, though other morphological forms are just as likely to have existed.

Detrital constituents

General

Quartz and feldspars, with the predominance of kalifeldspars, constitute the main detrital components. Rockfragments are of less importance apart from a special type, zeolite-haematite aggregates. These comprise 11–26 % of the detrital constituents in Mors 1, but has not been observed in Gassum 1 (fig. 8). Of minor and accessory occurrence are micas (biotite, muscovite, chlorite), opaque minerals (magnetite, haematite, ilmenite), zircon, rutile, tourmaline and apatite.

Omitting the zeolite-haematite aggregates, the detrital mineralogy is dominated by metamorphic-plutonic constituents, monomineralic as well as rockfragments, listed in fig. 8. These assemblages are found to be very similar for the two localities (fig. 8, B1–B2). Of special interest are the sillimanite containing fragments, which occur as fibrolite-quartz and fibrolite-microcline fragments, and which are found in Gassum 1 only. They occur in subordinate amounts and are incorporated with fragments of type 1 and 2 in fig. 8.

	Type of aggregate	A1 Gassum 1	A2 Mors 1	B1 Gassum 1	B2 Mors 1
		%	%	%	%
Metamorphic	1. Quartz aggr.	14	11	67	68
	2. Quartz-feldspar aggr.	2	2	8	10
	3. Quartz-mica aggr., metamorphic	2	1	7	6
Plutonic	4. Mica aggr., metamorphic	< 1	< 1	1	1
	5. Mica aggr., sed. or met.	< 1	< 1	2	1
	6. Chert	2	1	10	8
Sedimentary	7. Sand-/silt-/claystone fragments		1		4
	8. Clay clasts, intraformational	1	< 1	5	2
	9. Zeolite-haematite aggr.		18		
	Sum	21	35		
	Sum – zeolite-haematite aggr.	21	17	100	100

Fig. 8. Content of rockfragments in Bunter Sandstone samples from Gassum 1 and Mors 1. A1–A2: The content of various rocktypes as percent of detrital components (average of 11 and 5 samples respectively). B1–B2: To fasciliate comparison of the non-zeolitic rock fragments (types 1–8) between the two wells the values from A1–A2 is recalculated to a sum of 100 %. (It should be remembered, that the quartz aggregates (type 1) and quartz-feldspar aggregates (type 2) are allotted to the Q- and F-pole respectively, when using the classification method of Folk (1968)).

The sandstones from Gassum 1 cluster inside the subarkose field, while Mors 1 samples with their high content of rockfragments fall within the field of feldspatic litharenite, (fig. 9). The fabric in the sandstones is illustrated in figs. 10 A-B.

Zeolite-haematite aggregates

The zeolite-haematite aggregates occurring in Mors 1 consist of eu-subhedral, acicular or stubby zeolite prisms with 5–10 % of interstitial haematite. Euhedral apatite prisms as well as very rare, ellipsoidal quartz grains may occur in the aggregates, figs. 10 B-C.

An attempt to determine the zeolites by X-ray diffraction on whole-rock samples was impeded by interference from other minerals, wherefore universal stage microscopy was applied. This, however, was limited by the small size of individual grains, which may occasionally reach 250 μm but commonly are less than 50 μm, and by the common occurrence of thin twin lammellae. However, the existence of two different minerals was established: a) one mineral occurring as stubby prisms, sometimes twinned, was undeterminable by the optic method; b) a mineral with often subparallel acicular prisms with the following optical data: colourless, monoclinic, length-fast, optically

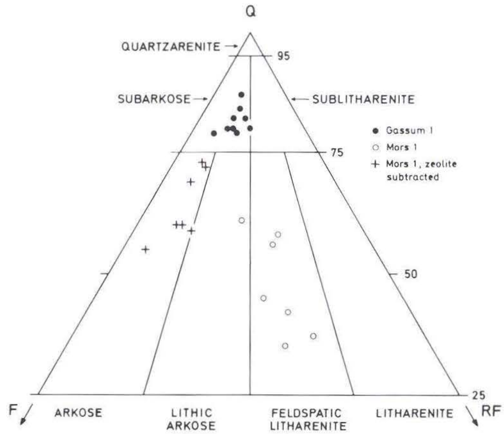


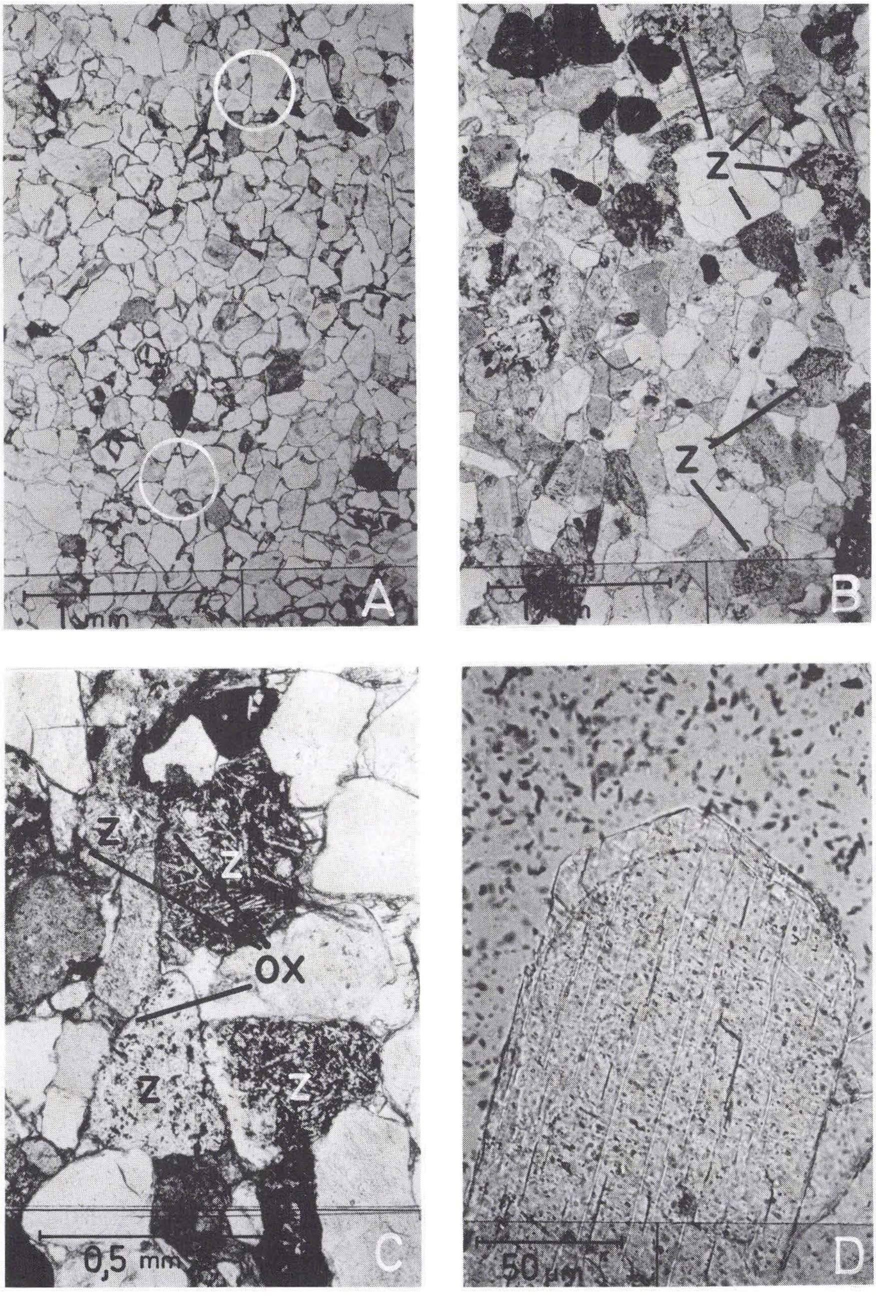
Fig. 9. Triangular classification plot of sandstones from the Bunter Sandstone Formation from the wells Gassum 1 and Mors 1. After Folk (1968). To fasciliate comparison of compositional maturity between the wells Mors sandstones is plottet in two versions: with original composition (o) and secondly with a composition resulting after subtraction of zeolite-haematite aggregates (+). The latter displays that the Mors 1 sandstones are the least mature in terms of feldspar content.

negative, $2V_X$: 50–68° X∧c: 28–35°. These data are reasonably consistent with data for scolecite given by Tröger (1959), though a discrepancy is found for the angle X∧c, which by Tröger is given as 15–18°. However, the data are scarce and separation of the zeolites followed by X-ray analysis will be needed for acurate determination.

Discussion

Zeolites and haematite are known to occur within a wide range of geological environments. Formation of zeolites is though nearly always linked to ignous activity. The occurrence of zeolites in cavities and crevices in lavas is well known. Hay (1966) summarized the occurrence in sedimentary rocks. His work demonstrates that authigenic and metamorphic formation of zeolites are largely dependent upon the presence of volcanic material. Zeolite-forming saline, alkaline lagunal or lake environments may or may not attribute their extreme chemical conditions to nearby igneous activity.

Zeolites easily react with aqueous solutions and are also mecanically very unstable; their occurrence as detrital constituents therefore require a nearby situated source. For the zeolites occurring in the Bunter sandstones in Mors 1 possible sedimentary sources are penecontemporaneous deposits from saline, alkaline lakes or Zechstein lagunal deposits. However, calcium-rich zeolites as scolecite are not likely to occur in deposits of alkaline lakes, and metamorphic scolecite has only been reported in sedi-


A
Z
Z
B
Z
Z
OX
Z
Z
0,5 mm
C
50 μm
D

mentary rocks upon burial to about 12000 feet (Hay 1966, table 5). Such conditions are unlikely to have been found in Zechstein deposits in early Triassic times. Scolecite however, occurs at surface conditions in weathered volcanic rocks (Deer, Howie & Zussman 1963). Volcanic activity was intense in the Oslo palaeorift during the Permian. Gravity measurements (Huseby & Ramberg 1978) indicate that the palaeorift, corresponding to a positive Bouguer anomaly, continued at the least as far southwards as the northernmost Skagerrak (fig. 1). Lower Permian volcanics encountered in the wells C-1, D-1, R-1, and L-1 in the Danish North Sea sector (Rasmussen 1974, Michelsen 1976) suggest that the volcanic region have extended even further as indicated by Ziegler (1978).

We suggest that the zeolitebearing sediments in the Mors 1 cores originated from this area. The occurrence of apatite in the aggregates is consistent with such an origin. The ellipsoidal quartz grains may represent relict quartz-phenocrysts from weathered quartz-porphyric rocks, such as are known to occur in the Oslo rift.

In Gassum 1 the lack of zeolite-haematite rockfragments combined with the presence of sillimanitic fragments suggest that the sandstones reflect a source area within purely metamorphic-plutonic basement terrains. Such may be found anywhere within the Fennoscandian Shield outside the Oslo Palaeorift Region.

Diagenesis

Early diagenesis

The sandstones are ferruginous, owing their reddish colour to limonite and haematite coatings. Biotites in these red-coloured zones are found to be strongly oxidized. In the greenish-grey parts, which occur only to a minor

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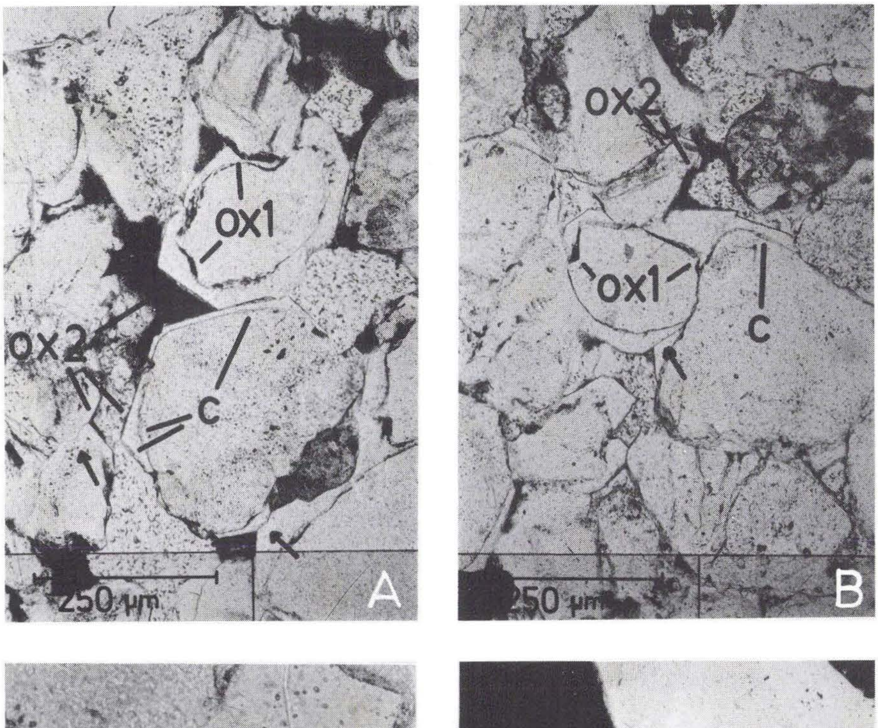
Figs. 10 A-B. Characteristic fabric of Gassum 1 and Mors 1 Bunter Sandstones. Scales are identical; plane light.

A. Gassum 1. Note frequent iron oxide rims (black rims). Light grey rims are mechanically infiltrated clay coatings. Both are absent at grain contacts (for example upper right part, lower part; encircled).

B. Mors 1. Of the »dusty« grains most are feldspars. Note high frequency of zeolite-haematite aggregates (z).

Fig. 10 C. Mors 1. Zeolite-haematite aggregates (z). Upper part shows aggregate with typical acicular zeolites. Note that the aggregates are rounded and overgrown by incomplete iron oxide rims (ox), thus proving the detrital origin; plane light.

Fig. 10 D. Gassum 1. Rounded, detrital microcline with authigenic, euhedral feldspar outgrowth. In this case only a dust line marks the detrital surface; plane light.


ox1
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c
250 µm
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m
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250
D

extent and only in Gassum 1, iron oxide overgrowths are insignificant and biotites are less altered.

Clay occur commonly as coatings on detrital grains. The coatings are reddish brown and may reach a thickness of 5μm, but are commonly thinner, and are built up by clay platelets aligned subparallel to the grain surfaces. This is seen from the entire width of the clay rim being extinct, when the edge of the coated grain is orientated parallel to the polarizors. The same type of clay occasionally fill porespaces partly or wholly (figs. 10A and 11 A,B).

A common feature in the Gassum 1 cores is two events of clay infiltration and iron oxide precipitation separated by a period of quartz growth. On detrital quartz grains the oldest clay and oxide rims are overgrown by syntaxial and euhedral secondary quartz. These overgrowths may again be covered by clay coatings, which in turn are impregnated by iron oxides (fig. 11 A-B). Euhedral outgrowths of feldspar on detrital feldspars have occurred more or less simultaneously with authigenic quartz growth (fig. 10 D).

Alignment of clays parallel to grain surface are by Crone (1975), Walker (1976) and Walker, Waugh & Crone (1978) found to be typical of mechanically infiltrated clays deposited by water with clay particles in suspension sinking into dry and very permeable sediments.

The formation of iron oxide rims necessitates water as a medium to dissolve intrastratal iron-bearing minerals and to transport the iron to the sites of precipitation.

Thus clay infiltration is a process occurring above the watertable, while iron oxide precipitation primarily occurs below. Clay coatings are thus expected to be impregnated and overgrown by oxides with time and burial, and this is observed to have occurred in both the Mors 1 and the Gassum 1

Figs. 11 A-B. Gassum 1. Euhedral, authigenic quartz overgrow clay coatings impregnated with iron oxide (Ox1). The authigenic quartz is in turn covered by second generation of impregnated clay (Ox2). Unimpregnated clay is light grey (c). Note that authigenic quartz joining across porespace do not contain clay coatings on crystal faces (arrows) and thus predates second event of clay infiltration; plane light.

Fig. 11 C. Mors 1. Incomplete iron oxide rims (ox) overgrown by colourless clays, which are aligned radially to detrital grain surfaces (rc). Medial sutures have been formed by the juncture of clays growing inwards from opposite sides of the pores. Upper right and lower middle show the colourless clays grown as interlocking crystals to produce a meshwork texture (m). Note that iron oxide rims are missing at grain contacts; upper part: plane light; lower part: crossed polarizors.

Fig. 11 D. Mors 1. Quartz (q) and dolomite (d) filling voids left after growth of porelining, colourless clay (arrows). Quartz and dolomite occupy separate voids; crossed polarizors.

samples. The repeated events of infiltration and iron oxide precipitation found in Gassum 1 are most readily explained as caused by an oscillating watertable, returning drowned zones to dry conditions and thus allowing a rejuvenation of the process.

Late diagenesis

In Mors 1 the clay-oxide rims are overgrown by colourless clay. It forms radiating porelinings up to 12 μm wide, or fill pores producing a meshwork texture, fig. 11C. Replacement of detrital feldspars by colourless clay may be contemporaneous with this episode. A determination of the clays has not been attempted, though the radial growth suggests chlorite or smectite (Wilson & Pittman 1977). This phase of authigenic growth of clay has not been observed in Gassum 1.

The last diagenetic events in Mors 1 is growth of quartz and dolomite. These minerals fill porespace left after growth of colourless clay. Commonly the two minerals occupy separate voids, fig. 11 D; when they occur together dolomite is found to display euhedrality against quartz. This phenomenon, however, does not determine the sequence of growth, as carbonates are known to replace quartz during formation of euhedral crystals.

In Gassum 1 growth of ankerite and white mica follows the early diagenesis. Ankerite acts as porefilling material and occupies domains varying in size from single porespaces to 1 mm large aggregates. Intraformational clay clasts and infiltrated clay can be replaced to varying degrees. Ankerite overgrows all early diagenetic phases and corrosion of both detrital and authigenic quartz and feldspars occur. The dolomite in Mors 1 also display corrosion textures. In Gassum 1 crystallization of white mica from detrital clay has been observed in the samples from the greenish-grey zones. The microscopic texture does not allow determination of growth sequence of ankerite and white mica. X-ray diffraction studies on intraformational clay clasts from Mors 1 shows the presence of 10 Å clays, thus suggesting that growth of white mica took place at Mors as well. X-ray diffraction was also used in the determination of the carbonate cements.

Source areas and transport directions of the sediments

Several authors have, on various grounds, suggested that the clastic material constituting the Bunter Sandstone Formation was derived from the Fennoscandian Shield:

1. Michelsen & Bertelsen (1979) estimated the variations in the ratio of sand versus silt+clay through the Danish and North German Basins and

suggest the Fennoscandian Shield as the source area for the Bunter Sandstone Formation.

2. Larsen & Friis (1975) on basis of heavy minerals in samples of probably Late Triassic age (Bertelsen 1980) from the Skagerrak Formation (Bertelsen 1980) in northern Jutland demonstrated that these sediments were provided from the Fennoscandian Shield. This is supported by Bertelsen (1980) who delineates the Skagerrak Formation as a marginal facies along the Fennoscandian Shield, and notes that the general lithology and the wire line log motifs indicate deposition by braided streams on a continental plain (Bertelsen 1980).
3. Larsen & Friis (1975 p. 40) suggest, that the garnet content of the Bunter Sandstone Formation in the North German Basin indicate sediment transport from the Fennoscandian Shield. However, in Gassum 1 and Mors 1 samples garnets have not been observed. Unless this is due to strong diagenetic alterations, as proposed by Larsen (1970) to occur in the Danish Subbasin below a 2 km level, it suggests that the direction of transport of garnet bearing sediments to the North German Basin was not across the Danish-Norwegian Basin. This is supported by the palaeogeographical evidence presented by Michelsen & Bertelsen (1979) (see also fig. 1), namely that parts of the Ringkøbing-Fyn High formed a land barrier between the Danish and the North German Basins.

The above mentioned papers suggest that the source areas of the detrital, clastic material of the Bunter Sandstone Formation in the Danish Subbasin lay north and northeast of the basin. Transport directions from east have presumably been of lesser importance as the Danish Subbasin probably was separated from the Polish Trough by the Stevns Block in eastern Denmark and the Skurup Platform in southern Sweden (Bertelsen 1980).

The present study of the detrital grains in the Bunter Sandstone Formation adds the following details to this picture:

For the sediments in the Mors area a source area within the Permian Oslo volcanic region is suggested on basis of the content of zeolite-haematite rockfragments. The high content of metamorphic-plutonic rockfragments also found (fig. 8), may also easily reflect a northern sediment transport direction. We therefore suggest that the source area for the Mors 1 samples lay to the north and that sediment transport was towards south (fig. 1).

For the sediments in the Gassum area a source area within the Fennoscandian Shield but east of the Permian Oslo volcanic region is suggested on basis of the presence of silliminite-bearing rockfragments and the absence of zeolite-haematite grains. This implies sediment transport from the source area towards south or southwest to the Gassum area (fig. 1).

If only sediment composition (fig. 9) and grain size distributions were considered the Gassum area sediments might represent more mature equivalents to the Mors area sediments, and the zeolites, being unstable, might have disappeared during transport. This possibility is rejected because it would involve sediment transport towards southeast, parallel to the basin axis but towards the basin margin (fig. 1).

The almost identical assemblages (fig. 8) of rockfragments in the two wells, apart from the zeolitic aggregates, are believed to reflect the presence of vast heterogeneous drainage areas of predominantly metamorthic-plutonic composition and provides no clues to the exact position of the source areas.

The isopach map (fig. 1, after Michelsen & Bertelsen 1979) show that the Mors 1 well was drilled in the depocentre of the Bunter Sandstone Formation in the Danish Subbasin. The thickness of the formation increases more than 250 m over the relatively short distance between the Gassum 1 and the Mors 1 wells, which might suggest that the sediments were to some extent reworked and transported along the basin axis towards the depocentre. Such a northwesterly directed sediment redistribution cannot, however, be traced petrographically.

Conclusions

The well-sorted, mainly large-scale crossbedded sandstones with their varying content of intraformational clasts of clay are interpreted as dominantly fluvial deposits, probably to some extent reworked and redeposited as aeolian sediments. Four water-laid sedimentary facies are recognized representing deposition at increasing energy levels from quiet waters to upper part of lower flow regime.

The random interbedding of the facies indicate rapidly changing depositional conditions, and in connection with the lack of fossils or trace fossils, sedimentation is interpreted to have taken place in an environment dominated by braided rivers.

Two diagenetic stages are recognized, the earliest being formation of rims of infiltrated clay followed by iron oxide impregnation, accompanied in Gassum 1 by a penecontemporaneous growth of authigenic quartz and feldspar. The later stage includes in Mors 1 growth of authigenic clay later followed by growth of quartz and dolomite. In Gassum 1 crystallization of white mica and precipitation of ankerite occurred.

The presence of a mixed assemblage of zeolitic aggregates and metamorphic-plutonic grains in the Mors 1 samples indicate a source area of the sediments within the region influenced by the volcanic activity of the Oslo palaeorift. Drainage patterns apparently roughly followed a north-southerly direction.

The lack of zeolite-aggregate grains and the presence of sillimanite bearing fragments in the Gassum 1 samples indicate sediment transport from metamorphic terrains, presumably the more easterly parts of the Fennoscandian Shield.

Sediment transport was probably perpendicular to the Fennoscandian Border Zone directed into the basin from northeast via a fringe of alluvial fans, but some sediment transport parallel to the axis of the Danish Subbasin and thus from more easterly directions may have taken place.

The red colour of the sandstones indicating highly oxidizing conditions, the early stages in diagenesis, and the deposition of the sediments by braided rivers with occasional aeolian reworking corresponds very well to the desert environments characterizing northern Europe as a whole during early Triassic times. The present paper thus supports the existing picture of the early Triassic palaeogeography with the Fennoscandian Shield as a source area for detrital material and the Bunter Sandstone Formation in northern Jutland as dominantly fluvial, continental plain deposits along the northern margin of the Danish Subbasin.

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S. Schack Pedersen assisted in identification of the opaque minerals and Holger Lindgren provided the X-ray diffraction analyses. The photographic work was done by Irma & Carlos Torres and Kirsten Andersen completed the drawings.

We direct our best thanks to all the above mentioned persons.

Dansk sammendrag

Den foreliggende undersøgelse rummer en nybeskrivelse af de primære, sedimentære strukturer og petrologien i borekerner, som repræsenterer den nedre triassiske Bunter Sandstone Formation, fra dybdeboringerne Mors 1 og Gassum 1 i Det danske Subbassin. Formationen består af en serie rødlige, fin- og mellemkornede sandsten, i hvilke fossiler eller sporfossiler ikke forekommer. Der opstilles fire sedimentære facies, som, sammen med faciessekvenserne, sandsynliggør, at sandstenene er aflejret i et system af braiderende floder.

En petrologisk undersøgelse af tyndslib viser, at to adskilte faser kan skelnes i diagenesforløbet. Den første: nedskylning af lerpartikler og udfældning af jernoxider, omfatter fænomener, som er velkendte fra moderne ørkenaflejringer. Denne fase kan være ledsaget af afsætning af authigent udskilt kvarts og feldspat. Den anden fase: afsætning af authigent ler og dolomit eller ankerit, er processer, som er knyttet til indsynkningen af sedimenterne til større dybder.

Sandstenene indeholder vekslende mængder af bjergartsfragmenter som fjerntransporterede sandskorn. Hovedparten af disse, samt de iøvrigt dominerende sandskorn kun bestående af et enkelt mineral, er ikke karakteristiske for et bestemt, afgrænset kildeområde, men kan kun henføres til et metamorft-plutonisk grundfjeldsområde, formodentlig Det fennoskandiske Skjold. Imidlertid optræder der i prøverne fra Mors 1 zeolitholdige aggregater som detritale korn. Disse er af vulkansk oprindelse og stammer sandsynligvis fra de områder, som prægedes af den permiske vulkanisme i Oslograven. Dette indicerer, at sedimenterne omkring Mors er tilført fra nord. I prøverne fra Gassum 1 mangler zeolitaggregaterne, mens sillimanitholdige korn til gengæld optræder. Heraf sluttes, at sedimenterne i Gassumområdet stammer fra østligere dele af Det fennoskandiske Skjold, og at deres transportretning har været fra nordøst eller nord.

Den foreliggende undersøgelse af de røde, fossilfrie sandsten sandsynliggør, at disse er aflejret af braiderende floder. Dette, såvel som deres tidligt diagenetiske udvikling, indicerer, at Bunter Sandstone Formationen repræsenterer ørkenaflejringer. Sedimenterne stammer fra forskellige dele af Det fennoskandiske Skjold, og de antages at være blevet transporteret til Det danske Subbassin gennem en række alluvialkegler langs Den fennoskandiske Randzone. Undersøgelsen har tilvejebragt nye data, som understøtter de eksisterende tolkninger af de palæogeografiske og palæoklimatiske forhold i tidlig trias tid.

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Middle Volgian ammonites and trace fossils from the Frederikshavn Member of the Bream Formation, northern Jutland

Tove Birkelund and Gunver Krarup Pedersen.

Birkelund, T. and Pedersen, G. K.: Middle Volgian ammonites and trace fossils from the Frederikshavn Member of the Bream Formation, northern Jutland. *Danm. geol. Unders., Årbog 1979:* 95–104. København, 1. december 1980.

The lower part of the Frederikshavn Member of the Bream Formation in the central part of the Danish Subbasin (the Aars la well) can be referred to the Albani Zone of the Middle Volgian on the basis of ammonites belonging to the genus *Pavlovia*. The cored sediment and the trace fossil assemblage show deposition below wave-base in well-oxygenated water.

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A core from the Upper Jurassic to Lower Cretaceous Frederikshavn Member of the Bream Formation (Michelsen, 1978) has been made available for a study of its ammonites and its trace fossil assemblage.

The Aars 1a well was drilled in the centre of the Danish Subbasin (fig. 1) where the Jurassic formations attain maximal thickness, and rather close to the depocenter for the Frederikshavn Member.

The 7 m long core (core number 2) represents parts of the lowest cycle of the Frederikshavn Member (Michelsen, pers. comm. 1980).

Lithology

The core consists of clayey, slightly calcareous silstone. The colour changes gradually upwards from olive black to greyish green, as a result of a slight decrease in clay content (fig. 2).

The sediment is intensely bioturbated and primary sedimentary structures are almost obliterated (figs 3,4). The sediment seems to comprise two grain populations, and ghosts of sedimentary structures characteristic of heteroliths are preserved. One narrow level in the upper part of the core contains a few, up to 1 cm thick, layers of silt. These are structureless, without graded bedding and not bioturbated.

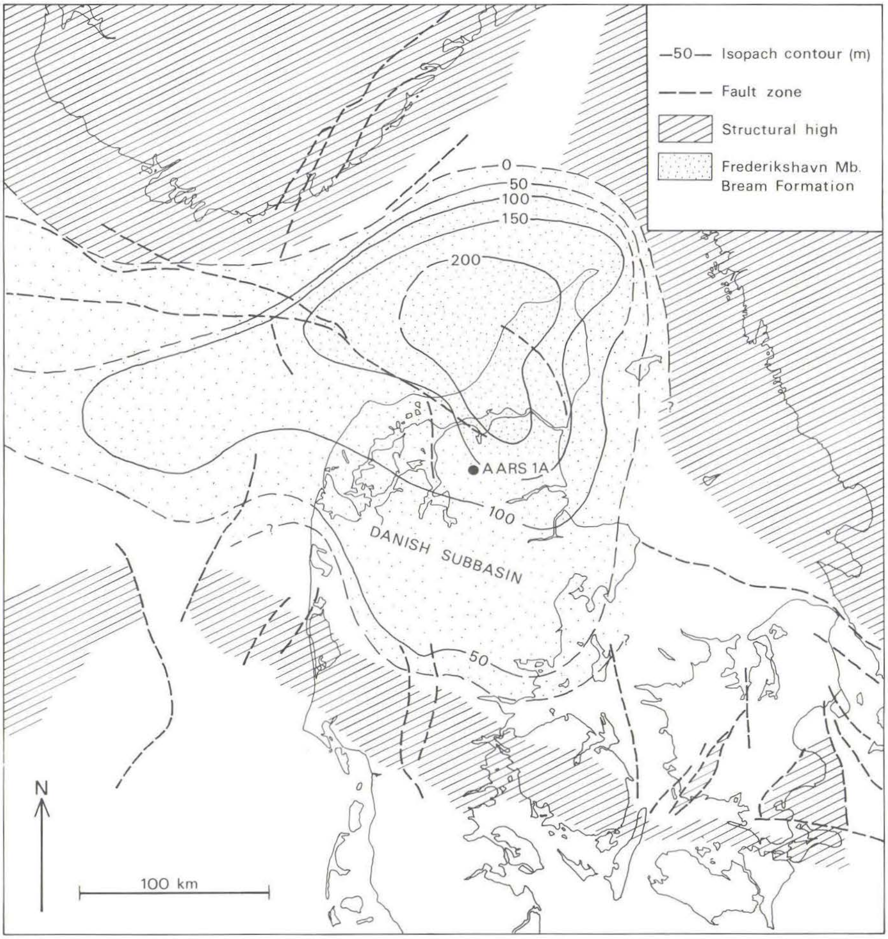

Fig. 1. Location map, also illustrating the geological setting and the extent and thickness of the Frederikshavn Member. Drawn from Michelsen (1978, Fig. 16).

Apart from the ammonites described in the following, the core contains bivalves, including oysters and pectinids, which are either randomly distributed in the sediment or concentrated at certain levels, and apparently do not occur in their growth positions.

Comminuted plant debris is common and one twig was also found.

Trace fossils

The trace fossil assemblage is characterized by *Chondrites* (figs. 3,4) and *Teichichnus rectus* (fig. 4). *Chondrites* occurs throughout while *Teichichnus*

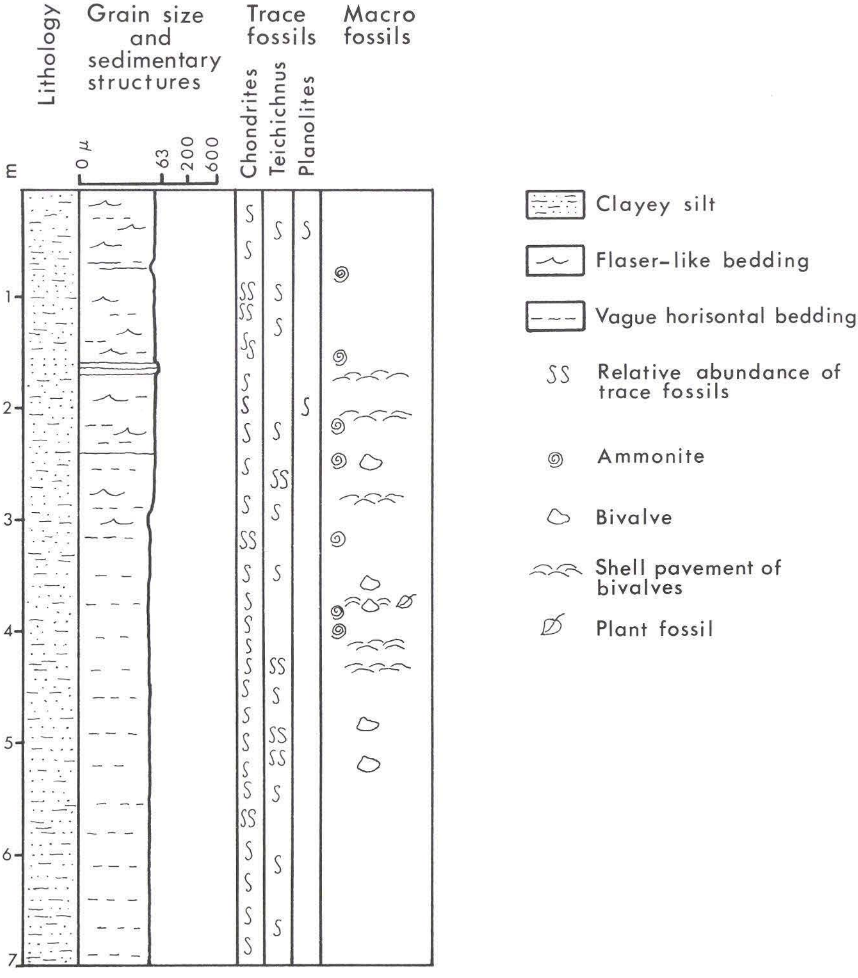

Fig. 2. Core of the Frederikshavn Member in the well Aars. The core is relatively uniform throughout with a slight decrease in clay content upwards accompanied by a gradual change toward paler colours. The whole core is intensely bioturbated and primary sedimentary structures are partly or wholly obliterated.

occurs widespread but not continuously. *Planolites* has been observed in the upper part of the core (figs. 2,3).

Chondrites Sternberg, 1833 is typically seen as pale greyish spots or lines about 1 mm wide and 1.5–15 mm long (figs. 3,4). The diagnostic branching pattern (Simpson, 1957) is seen on occasional bedding planes.

Teichichnus rectus Seilacher, 1955 occurs as pale cylindrical, sub-horizontal burrows with a diameter of about 0.5 cm and lengths of up to several centimetres, and with retrusive, subvertical spreiten (fig. 4a, b).

Planolites Nicholson, 1873 has only been observed in cross sections where it is seen as pale, cylindrical, slightly flattened burrows about 0.5 cm in diameter and apparently subparallel to the bedding (fig. 3).

All these trace fossils are fodinichnia produced by infaunal deposit feeders (Häntzschel, 1975) which seem to be typical for silty clayey marine sediments (Fürsich, 1975, Baldwin, 1977, Pickerill, 1977).

Depositional conditions

The general fine grain-size of the sediment, the existence of deposit-feeding infaunal benthos and the relatively numerous bivalves and ammonites suggest deposition below wave-base in well-oxygenated low-energy environments. Some degree of reworking is indicated by the shell pavements of bivalves and possibly by the thin, non-bioturbated, well-sorted silt layers.

The outlined depositional conditions are in accordance with the basinal development described by Michelsen (1978).

Ammonites

Two fairly well preserved specimens have been recovered from the uppermost meter of the core, one 90–100 cm below top and one 60–70 cm below top. Both of them belong to the genus *Pavlovia* and are related to two species occurring together in the Volgian succession of Milne Land, East Greenland, recently, summarized in Birkelund *et al.* (1978a).

Pavlovia (Epipallasiceras) cf./aff. *costata* Spath (fig. 5). (Spath, 1936, p. 58, pl. 10, fig. 7; pl. 18, fig. 3).

Level: 300–310 cm below top of the core.

The specimen is rather well preserved. The diameter is 68 mm and the umbilical ratio c. 26 % at a diameter of 52 mm. Sutures are not visible. The whorls are laterally flattened. The ribbing is fine on the inner whorls while the outer whorl shows coarse biplicate ribbing with the two secondaries close together or, in a few cases, triplicate ribbing. The primaries are straight and sharp and they bifurcate high on the whorl side.

The specimen seems to be closely related to *Pavlovia (Epipallasiceras)* aff. *costata* as described by Spath from Milne Land from the upper part of the »Glauconitic Series«. The species is also known from Raukelv Formation in Jameson Land (Surlyk *et al.* 1973, pl. 2, fig. 2).

Fig. 3. Part of the core, c. 190–205 cm below top, seen in section. The sediment is fossiliferous (S: bivalve shells) and intensely bioturbated. *Chondrites* (C) is seen in numerous sections and *Planolites* (P) occurs.

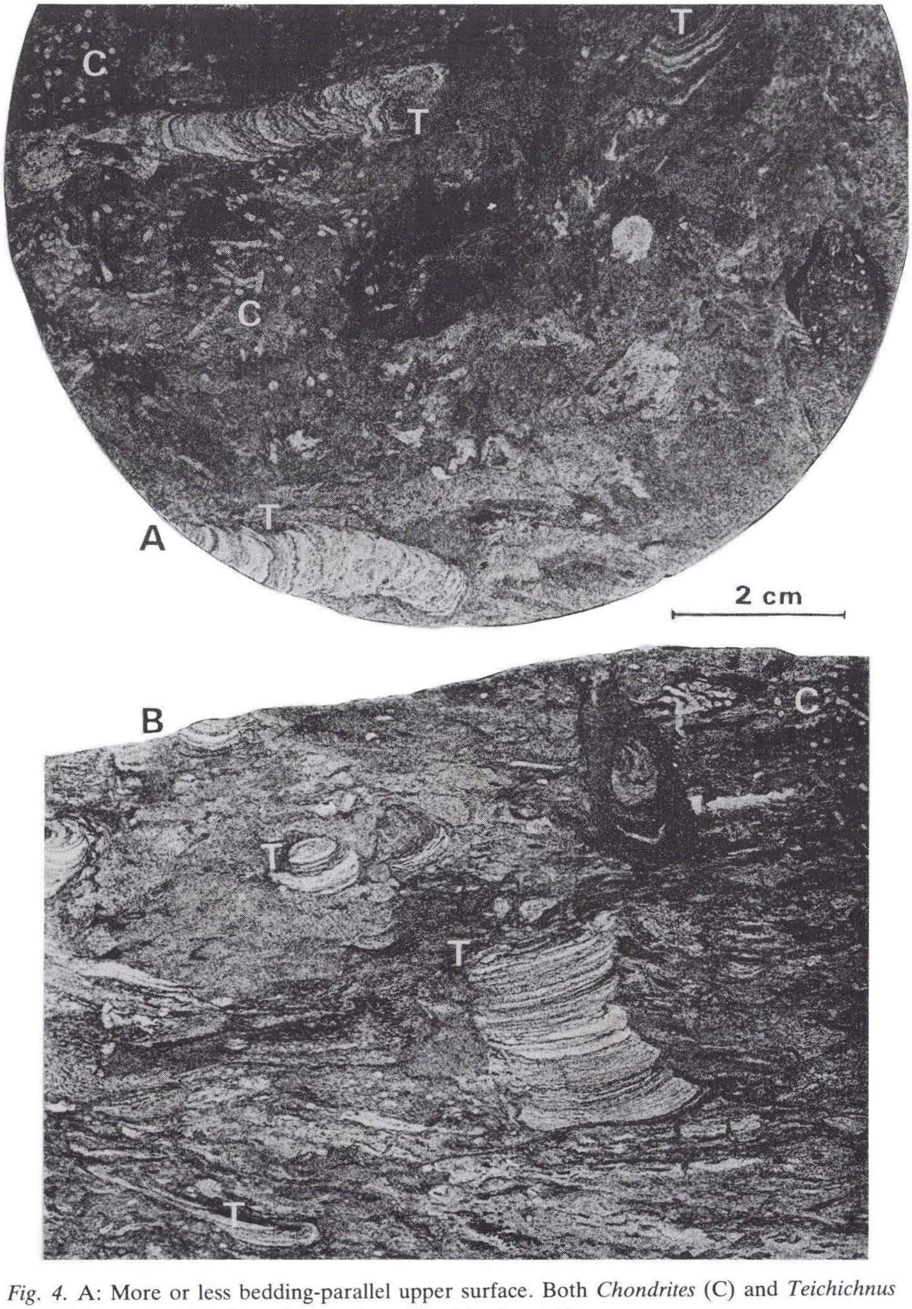

Fig. 4. A: More or less bedding-parallel upper surface. Both *Chondrites* (C) and *Teichichnus rectus* (T) are seen. The latter is retrusive with subhorizontal burrows.
B: *Teichichnus rectus* (T) cut at various angles.
Sample 500–510 cm below top of the core.

Fig. 5. Pavlovia (Epipallasiceras) cf./aff. *costata* Spath, 1936. 300–310 cm below top of the core. × 1.

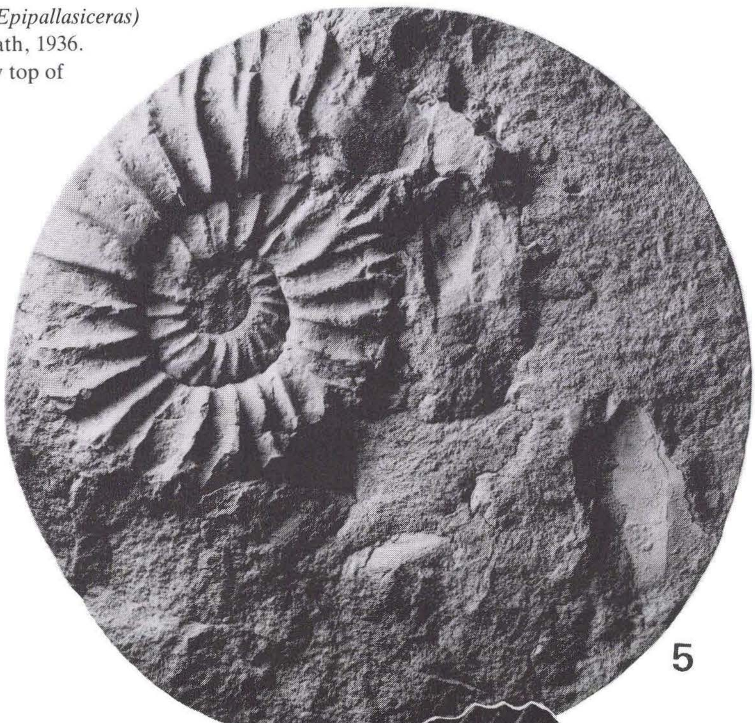

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Fig. 6. Pavlovia (Epipallasiceras) aff. costata Spath, 1936. J. H. C. No. 471, 1–3 km N. of Kap Leslie. Milne Land. × 1. Kept in Geological Museum of the University of Copenhagen.

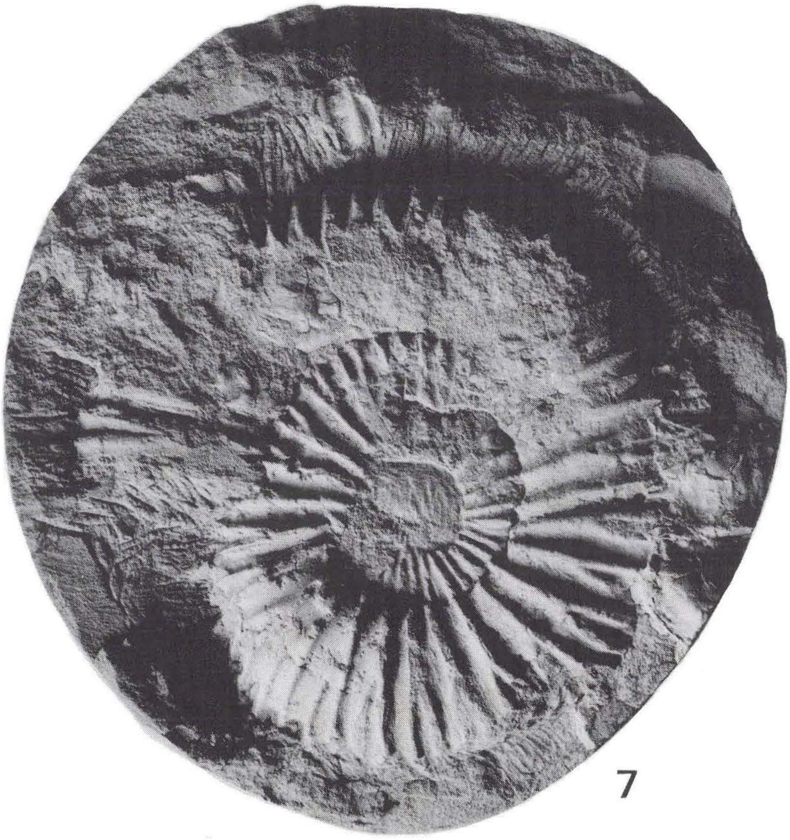

Fig. 7. Pavlovia cf./aff. *rotundiformis* Spath, 1936.
400–410 cm below top of the core. × 1.

Bed by bed collecting by J. H. Callomon in 1957 shows that *P. (E)* aff. *costata* occur in a number of faunas in the »Glauconitic Series« on the east coast of Milne Land. The specimen here described shows closest similarity to the earliest forms (fauna 40 in Callomon, Birkelund & Fürsich, in prep.) with the *Epipallasiceras* ribbing pattern very markedly developed: secondaries close together and long primaries. A specimen from fauna 40 from Milne Land is shown in fig. 6 for comparison. The holotype and only figured specimen of *P. (E.) costata* Spath itself came from the same bed as, and falls within the range of variability of *P. (E.) pseudaperta* Spath, which is slightly younger (fauna 42).

Pavlovia cf./aff. *rotundiformis* Spath. (fig. 7).
(Spath, 1936, p. 55, pl. 19, fig. 3 (holotype)).
Level: 400–410 cm below top of the core.

The specimen is partly crushed. The diameter is 80 mm and the umbilical ratio c. 26 % at a diameter of 72 mm. No sutures are visible. The ribbing is fine to a diameter of c. 35 mm, where it changes to a coarser somewhat *Epipallasiceras* like ribbing with paired bifurcating ribs. On the outer whorl the ribbing is typical pavlovid with coarse evenly spaced, biplicate ribs bifurcating on the middle of the flanks.

Spath (1936) described the species *P. rotundiformis* from the upper part of the »Glauconitic Series« of Milne Land and figured one specimen, the holotype. Additional collecting by J. H. Callomon in 1957 has revealed the range of variation of the species and the exact stratigraphic range. The ribbing of the specimen from Aars is weaker than that of the holotype but seems to fall within the range of variation of additional material. The species occurs together with *P. (E).* aff. *costata* at the east coast of Milne Land (faunas 40–41 in Callomon, Birkelund & Fürsich, in prep.).

Stratigraphic correlation

A detailed stratigraphic work on the zonation of the Volgian of Milne Land is in preparation by J. H. Callomon, T. Birkelund and F. Fürsich. It is now known that the faunas containing *P. (E).* aff. *costata* and *P. rotundiformis* overlie faunas which can be readily equated with the *P. pallasioides* and *P. rotunda* Zones of Dorset, although the two areas in question belong to different faunal subprovinces having only few species in common.

Cope (1978) divided the Dorset succession above the *P. rotunda* Zone into the *Virgatopavlovia fittoni* and the *Progalbanites albani* Zones and showed that the upper part of the *P. albani* Zone correlates with the *Epivirgatites nikitini* Zone of the Volga Basin. The *V. fittoni* Zone (Hounstout Clay and Marl) is characterized by the new genus *Virgatopavlovia* Cope, 1978. The inner whorls of this genus show closely paired bifurcating ribs with high furcation point as in *Epipallasiceras,* but the outer whorls have an irregular, frequently virgatotome ribbing, which is very different. Fragments belonging to *Virgatopavlovia* were earlier referred to *Epipallasiceras* by Cope (1971, p. 41). *Virgatopavlovia* is not represented in the Milne Land sequence.

The ammonites from the *P. albani* Zone (Parts of Portland Sand with Massive Bed at base in Cope, 1978; Emmit Hill Beds in Townson, 1975) are poorly known. A fragment from the Massive Bed referred to *Virgatites pallasianus* d'Orb by Buckman, 1926, pl. 693 has been referred to *Epipallasiceras* by Callomon (1961). This specimen may belong to a true *Epipallasiceras* and is, as far as it goes, much more similar to the *Epipallasiceras* specimen here described than early whorls of *Virgatopavlovia* spp. from the *V. fittoni* Zone. Except from this occurrence and rare occurrences in Andøya, northern Norway and possibly the Boulonnais (Pellat collection), *Epipallasiceras* is only known from East Greenland.

In conclusion, the ammonite level in the Aars well can be correlated with the upper part of the »Glauconitic Series« of Milne Land (Member 2g in Birkelund *et al.*, 1978a) and the lower part of the Portland Sand (Emmit Hill Beds, Townson, 1975) in the Dorset area. It is referred to the *P. albani* Zone of the standard ammonite zonation of NW Europe. The presence of the *P. albani* Zone has also been verified in the Ratjønna Member of the Dragneset Formation of Andøya (Birkelund *et al.*, 1978b).

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Cytheropteron? jutlandicum n.n. pro Cytheropteron? foveolatum Michelsen, 1975

Olaf Michelsen

Michelsen, O.: *Cytheropteron? jutlandicum* n.n. pro *Cytheropteron? foveolatum* Michelsen, 1975. *Danm. geol. Unders., Årbog 1979:* 105. København, 1. december 1980.

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Cytheropteron? foveolatum decribed as a new species in Michelsen (1975, p. 145) is a homonym of *Cytheropteron foveolata* (Brady, 1880), which was described as *Cythere foveolata* in Brady (1880, p. 75).

According to the International Code of Zoological Nomenclature (art. 59) the species *C. ? foveolatum* Michelsen, 1975 is re-named as *C. ? jutlandicum* n.n.

Acknowledgements: Mr. H. E. E. Petersen (Univ. Hamburg) is thanked for drawing my attention to the problem.

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Geologiske kriterier for placering af A-kraftværker: Et resumé af USAs lovgivning og dens anvendelsesmuligheder på danske forhold

Jens Morten Hansen og Claus Heinberg

Hansen, J. M. og Heinberg, C.: Geologiske kriterier for placering af A-kraftværker: Et resumé af USAs lovgivning og dens anvendelsesmuligheder på danske forhold. *Danm. geol. Unders., Årbog 1979:* 107–123, København, 1. december 1980.

The present paper gives a Danish summary of USAs legislation concerning seismic and geologic siting criteria for nuclear power plants (Code of federal regulations, 10, Energy: Chapter 1 – Nuclear Regulatory Commission (NRC), 514 pp.) and evaluates the possibility of application of American procedures in Denmark.

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Forud for ethvert større anlægsarbejde går normalt en række undersøgelser af geoteknisk art. Disse undersøgelser sigter primært på at fastslå jordlagenes mekaniske egenskaber især med hensyn til deres stabilitet, bæreevne og eventuelle ændring ved de påvirkninger, som byggeriet i sig selv påfører det øvre geologiske miljø. Sådanne undersøgelser kan derfor i alt væsentligt begrænses til belysning af en række veldefinerede parametre af ingeniørgeologisk art.

Mere overordnede geologiske vurderinger som de regionalgeologiske forhold, herunder det tektoniske mønster, har ikke hidtil været inddraget i væsentligt omfang. Undtagelser herfra er bl.a. større bro- og tunnelprojekter (Larsen & al. 1968, Stenestad 1976). Ved en eventuel projektering af A-kraftværker slår de hidtidige procedurer imidlertid ikke til, hvis man vil leve op til den praksis, som gælder i USA. At man i USA har valgt en særlig procedure ved anlæg og projektering af A-kraftværker skyldes ikke, at sådanne anlæg betragtes som værende specielt følsomme, men må ses som udslag af de ekstraordinære sikkerhedskrav, man må stille i forbindelse med driften af nukleare anlæg. En egentlig geologisk standardprocedure for placering af A-kraftværker findes naturligt nok endnu ikke her i landet. Man må derfor støtte sig på udenlandske erfaringer og regulativer ved en eventuel kommende udarbejdning af en procedure for geologisk og seismisk vurdering af de udvalgte lokaliteter. Her synes det mest nærliggende at henvise til det detaillerede kompleks af regler og anvisninger, som gælder på føderalt plan i USA, og som er sammenfattet i

»Code of federal regulations, 10, Energy: Chapter 1 – Nuclear Regulatory Commission (NRC), 514 pp.«

Denne lov indeholder en lang række påbud af forskrifter vedrørende projektering, anlæg og drift af A-kraftværker. En del af disse er af geologisk art, og da der herhjemme er tradition for, at man i A-kraft sammenhæng støtter sig på amerikanske kriterier, må det formodes, at eventuelle danske retningslinier vil støtte sig på dette dokument. Denne lov giver således et grundlag for at få overblik over:

1. geologisk set gunstige og ugunstige placeringer af A-kraftværker
2. arten og mængden af geologiske metoder og data, som skal beherskes samt hvilke undersøgelser, som skal sættes i værk
3. forskningsmæssige områder af relevans i denne sammenhæng

De følgende kommentarer vedrører udelukkende den geologiske del af § 100: Reactor Site Criteria, herunder især § 100.10 c: Physical characteristics of the site, including seismology, meteorology, geology and hydrology«. Speciel vægt er lagt på det omfattende appendix A: Seismic and Geologic Siting Criteria for Nuclear Power Plants.

Nævnte afsnit beskriver karakteren af de undersøgelser, der skal udføres for at fremskaffe de geologiske og seismiske data, som er nødvendige for at vurdere en lokalitets egnethed i forbindelse med drift af et A-kraftværk. Afsnittet beskriver ligeledes karakteren af de undersøgelser, som skal udføres for at tilvejebringe rimelig sikkerhed for at et A-kraftværk kan konstrueres og fungere på den foreslåede lokalitet uden unødig risiko for befolkningens sikkerhed og sundhed. Endelig beskrives procedurer for bestemmelse af de jordskælvsbetingede overfladeaccelerationer, som værket skal konstrueres til at kunne modstå samt den information, som er nødvendig for at bestemme mulige overfladeaccelerationer.

Appendix A (Seismiske og geologiske kriterier for placering af A-kraftvæker)

Indhold

Resumé af indholdet af Appendix A:

I. Formål

Hovedformålet er at sikre, at A-kraftværker placeres og konstrueres på en sådan måde, at deres sikkerhedsfunktioner ikke lider overlast ved jordskælv og forkastningsaktivitet. (Lignende kriterier er opstillet for en række andre naturkatastrofer).

II. Omfang

Loven gælder for alle, der søger om tilladelse til opførelse af A-kraftværker, idet ansøgerne pålægges at undersøge alle geologiske og seismiske forhold, som kan tænkes at få indflydelse på værkets drift og sikkerhed uanset om disse forhold er udtrykkeligt nævnt i de følgende kapitler. Der henvises til, at særligt omfattende undersøgelser kan kræves i områder med kompliceret geologi eller høj seismicitet.

III. Definitioner

Dette afsnit indeholder en række definitioner af geologisk karakter, som er vigtige for forståelse af de følgende afsnit.

(a) »Størrelsen« af et jordskælv er et mål for den energimængde, som frigøres i form af seismiske bølger. »Størrelsen« af et jordskælv måles på Richter-skalaen.

(b) »Intensiteten« af et jordskælv er et mål for effekten på mennesker, menneskabte konstruktioner og jordoverfladen på et bestemt sted. »Intensiteten« måles på den modificerede Mercalli-skala.

(c) »Nedlukningsjordskælvet« er det største, potentielle jordskælv, når man tager den regionale og lokale geologi, seismologi og specifikke egenskaber ved undergrundens materialer i betragtning. Det er det jordskælv, som producerer den maximale jordrystelse, hvorunder specifikke strukturer, systemer og komponenter er konstrueret til at forblive funktionsdygtige. Med strukturer, systemer og komponenter forstås indretninger, som er nødvendige for at sikre 1) kølevandstrykket i reaktoren og 2) muligheden for nedlukning af reaktoren.

(d) »Funktionsjordskælvet« er det jordskælv, som på grundlag af den regionale og lokale geologi, seismologi og specifikke egenskaber ved undergrundens materialer med rimelighed kan forventes at ville påvirke lokaliteten i løbet af værkets operative levetid. Det er det jordskælv, hvortil de dele af kraftværket, som er nødvendige for en fortsat drift uden unødig risiko for befolkningens sikkerhed og sundhed, er konstruerede.

(e) En »forkastning« er en »tektonisk struktur« langs hvilken differentiel bevægelse af jordskorpemateriale er foregået parallelt med brudplanet. En forkastning er forskellig fra andre typer af forstyrrelser som f.eks. jordskred, sprækker og kratre.

(f) »Overfladeforkastninger« er forskydninger på eller nær jordoverfladen forårsaget direkte af forkastningsbevægelser.

(g) En »potentielt aktiv forkastning« er en forkastning, som har udvist ét eller flere af følgende karakteristika:

1) Bevægelse på eller nær jordoverfladen mindst én gang inden for de sidste 35.000 år eller bevægelse af tilbagevendende natur indenfor de sidste 500.000 år.
2) Makro-seismicitet bestemt med tilstrækkelig nøjagtighed for at kunne påvise direkte forbindelse til forkastningen.
3) Strukturelle relationer omkring en »potentielt aktiv forkastning« af en sådan art, at aktivitet indenfor den ene karakteristik (som angivet i pkt. 1 og 2) med rimelighed kan tænkes at have medført aktivitet indenfor den anden. I nogle situationer kan disse geologiske indikationer være skjult af tykke lag. I sådanne tilfælde kan man eventuelt finde

indikationer andre steder langs forkastningen, som med rimelig sikkerhed kan sige noget om forkastningens egenskaber i nærheden af den valgte lokalitet. Sådanne indikationer skal anvendes ved bestemmelse af, om en forkastning er en »potentielt aktiv forkastning« eller ej. I mangel af modsatte evidenser (jvf. pkt. 1, 2 og 3) skal det påvises, at prækvartære geologiske strukturer med forbindelse til forkastninger ikke er »potentielt aktive forkastninger«.

(h) En »tektonisk provins« er en region karakteriseret af en forholdsvis høj grad af ensartethed m.h.t. de geologiske træk.

(i) En »tektonisk struktur« er en stor dislokation eller forstyrrelse i Jordens skorpe hvis geografiske udbredelse måles i miles.

(j) En »zone som kræver detaillerede forkastningsundersøgelser« er en zone, indenfor hvilken et A-kraftværk ikke bør placeres med mindre det gennem detaillerede undersøgelser af de regionale geologiske og seismiske karakteristika er påvist, i hvilket omfang man ved værkets konstruktion skal tage hensyn til eventuel forkastningsaktivitet.

(k) »Kontrolbredden« af en forkastning er maximumbredden af en zone, som indeholder kortlagte forkastningsspor. Hertil kommer alle mindre forkastninger, som med rimelighed kan antages at have været i bevægelse i Kvartærtiden, og som hænger sammen med eller kan formodes at hænge sammen med forkastningszonen inden for 10 miles, målt i begge retninger langs forkastningen fra det punkt på forkastningen, som ligger nærmest den valgte lokalitet (fig. 1).

IV. Påkrævede undersøgelser

Den valgte lokalitets geologiske, seismiske og ingeniørmæssige karakteristika skal undersøges i et omfang og en detailleringsgrad, der sikrer, at disse forhold er tilstrækkelig godt forstået, således at en rimelig og relevant vurdering af lokaliteten er mulig. Størrelsen af det område, som skal undersøges, og arten af data, der er relevante for undersøgelsen, afgøres ud fra karakteren af regionen omkring den valgte lokalitet. Undersøgelsen skal udføres som en gennemgang af relevant litteratur og feltundersøgelser og skal indeholde de trin, som er beskrevet nedenfor. Trinene fra (a)5 til (a)8 i dette afsnit kan undlades, hvis »nedlukningsjordskælvet« klart kan dokumenteres gennem en mindre indsats.

(a) Indsamling af den information, som er nødvendig for at beskrive »nedlukningsjordskælvet«. Disse data udgør samtidig et adækvat grundlag for valget af »funktionsjordskælvet«. Undersøgelserne omfatter:

1) Bestemmelse af de lithologiske, stratigrafiske, hydrologiske og strukturgeologiske forhold på og omkring lokaliteten. Herunder skal områdets geologiske historie belyses.

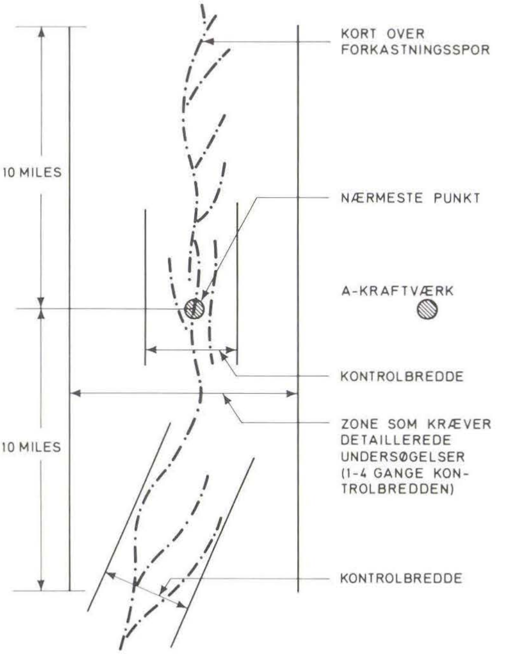

Fig. 1. Skitse visende procedure for afgrænsning af zonen, som kræver detaillerede geologiske undersøgelser forud for opførelse af A-kraftværker.

2) Identifikation og vurdering af »tektoniske strukturer« under og omkring lokaliteten, hvadenten disse er blottede eller skjulte. Vurderingen omfatter også de mulige følger af menneskelig aktivitet som f.eks. oppumpning af væsker fra undergrunden.
3) Vurdering af de geologiske evidenser for hvorledes materialer og lag under lokaliteten har opført sig under tidligere jordskælv. Vurderingen omfatter de lithologiske, stratigrafiske og strukturgeologiske data, som indgår i pkt. 1.
4) Bestemmelse af de statiske og dynamiske ingeniørmæssige egenskaber ved materialerne under lokaliteten. Heri indgår de egenskaber, som er nødvendige for at vurdere materialernes opførsel under jordskælv, f.eks. evnen til at transmittere seismiske bølger, vandindhold, porøsitet og styrke.
5) Opregning af alle historiske, registrerede jordskælv, som har påvirket eller med rimelighed kan tænkes at have påvirket lokaliteten. Jordskælv, som kan formodes at have forårsaget en overfladeacceleration på mere end 0.1 g skal inddrages i vurderingen.
6. Hvor det er muligt skal epicentre eller punkter med maximal intensitet for historisk rapporterede jordskælv korreleres med tektoniske

strukturer, hvoraf blot en del ligger indenfor en afstand på 200 miles. Hvor korrelationen ikke kan foretages til »tektoniske strukturer«, skal den foretages til »tektoniske provinser«, hvoraf blot en del ligger indenfor en afstand på 200 miles fra lokaliteten.

7. Forkastninger, hvoraf blot en del ligger indenfor en afstand på 200 miles fra lokaliteten, og som kan have betydning for etablering af »nedlukningsjordskælvet«, skal vurderes m.h.t. om der kan være tale om en »potentielt aktiv forkastning«. I mangel af absolut datering må man anvende relative dateringsteknikker på brud, kipninger eller lignende forstyrrelser af materialer eller geomorfologiske strukturer. Det påhviler ansøgeren at vurdere, om der kan være tale om en »potentielt aktiv forkastning« gennem en passende undersøgelse af de i afsnit III (g) nævnte forhold. Ved bestemmelse af »nedlukningsjordskælvet« skal der tages hensyn til alle »potentielt aktive forkastninger« over en vis længde. Denne længde varierer med afstanden til lokaliteten på følgende måde:

Afstand fra Lokalitet (miles)	Mindste længde af 'potentielt aktiv forkastning' (miles)
0– 20	1
20– 50	5
50–100	10
100–150	20
150–200	40

8. For »potentielt aktive forkastninger«, som ligger indenfor en afstand på 200 miles fra lokaliteten, og som kan være af betydning for »nedlukningsjordskælvet«, skal der foretages bestemmelser af:
   i) Forskastningens længde.
   ii) Forkastningens forbindelse til de regionale »tektoniske strukturer«.
   iii) Arten, størrelsen og den geologiske bevægelseshistorie, specielt det anslåede omfang af den største kvartære dislokation i forbindelse med hvilket som helst jordskælv langs forkastningen.

(b) Undersøgelser af forkastninger: Formålet med de påbudte undersøgelser er at fremskaffe information til bestemmelse af, i hvilket omfang et A-kraftværk skal konstrueres til at modstå forkastningsaktivitet. (Punkterne 1 og 2 er udeladt, idet de nøje svarer til punkter under afsnit (a)).

3. Bestemmelse af geologiske evidenser for overfladenære forkastninger ved eller nær lokaliteten.

4. Alle forkastninger længere end 1000 fod, hvoraf blot en del ligger mindre end 5 miles fra lokaliteten skal bestemmes m.h.t., om der kan være tale om en »potentielt aktiv forkastning«.
5. Opregning af alle historiske jordskælv, som kan have forbindelse med en sådan forkastning.
6. Korrelation af epicentre eller punkter med maximal intensitet for historiske jordskælv med »potentielt aktive forkastninger«.
7. For enhver »potentielt aktiv forkastning«, som er mere end 1000 fod lang, og som ligger indenfor en afstand på 5 miles fra lokaliteten skal følgende bestemmes:
   i) Længden af forkastningen.
   ii) Forkastningens forbindelse til de regionale 'tektoniske strukturer',
   iii) Arten, størrelsen og den geologiske bevægelseshistorie herunder den maximale kvartære bevægelse.
   iv) Forkastningens beliggenhed skal fastslås gennem en kortlægning af kvartære forkastningsspor indenfor en afstand på 10 miles, målt i begge retninger fra det punkt på forkastningen, som ligger nærmest lokaliteten.

(c) Undersøgelser med henblik på seismisk forårsagede flodbølger. (Dette afsnit stiller ikke særlige krav til geologien).

V. Seismiske og geologiske konstruktionskriterier

(a) Ved bestemmelse af konstruktionskriterier m.h.t. jordrystelser i forbindelse med projektering af A-kraftværker, skal der tages hensyn til de potentielle virkninger af jordrystelser forårsaget af jordskælv. Dette skal ske ved en vurdering af områdets seismologi, geologi og ved en vurdering af områdets seismiske og geologiske historie. Det kraftigste jordskælv i områdets »tektoniske strukturer« skal identificeres på basis af historiske jordskælv. Hvis der er »potentielt aktive forkastninger« i området, skal de kraftigste jordskælv med forbindelse til disse forkastninger bestemmes. Dernæst skal det antages, at de derved bestemte jordskælvs epicentre eller punkter for maximal intensitet er beliggende på det nærmeste punkt på den nærmeste »tektoniske struktur« eller »tektoniske provins«. Det jordskælv, som herved kunne tænkes at forårsage de kraftigste jordrystelser betegnes »nedlukningsjordskælvet«. I det følgende gives proceduren for bestemmelse af områdets jordrystelser:

1. Bestemmelse af »nedlukningsjordskælvet« foregår ved en seismisk og geologisk vurdering på basis af nedenstående undersøgelser.
   i) Det 'største' eller mest 'intense' historiske jordskælv, som er korreleret med 'tektoniske strukturer' i overensstemmelse med be-

stemmelserne i afsnit IV (a,6) skal bestemmes. Herudover skal man for 'potentielt aktive forkastninger' tage den information i betragtning, som kræves i afsnit IV (a,8) ved bestemmelsen af de største jordskælv. 'Størrelsen' eller 'intensiteten' af jordskælv bestemt på basis af geologiske evidenser kan være større end de største historiske jordskælv. Overfladeaccelerationerne på lokaliteten skal bestemmes således, at epicentrene eller punkterne for maximal intensitet med tilknytning til 'tektoniske strukturer' antages at være beliggende på den nærmeste 'tektoniske strukturs' nærmeste punkt.

ii) Hvor epicentre eller punkter for maximal intensitet for historiske jordskælv ikke kan relateres til 'tektoniske strukturer', skal man antage, at jordskælvene fandt sted på selve lokaliteten.

iii) Hvor epicentre eller punkter med maximal intensitet for historiske jordskælv ikke kan relateres til 'tektoniske strukturer', men kun til en 'tektonisk provins', skal man antage, at jordskælvene fandt sted i det nærmeste punkt til lokaliteten på grænsen til den 'tektoniske provins'.

iv) Det jordskælv, som frembringer den maximale overfladeacceleration på lokaliteten, således som det fremgår af ovenstående, kaldes 'nedlukningsjordskælvet'. Dette jordskælvs karakteristika skal bestemmes ud fra mere end ét jordskælv, hvor det er nødvendigt for at sikre, at den maximale overfladeacceleration inden for det relevante frekvensområde er omfattet af undersøgelserne. I tilfælde, hvor forkastninger, som kunne forårsage sådanne rystelser, ligger nær lokaliteten, skal der tages hensyn til 'nedlukningsjordskælvets' spektralfordeling. For at kompensere for de begrænsede data, der fremkommer som følge af ovenstående procedurer, skal disse data anvendes på en konservativ måde. Den maximale overfladeacceleration skal for hver enkelt fundamentplacering bestemmes med henblik på de underliggende jordlags evne til at transmittere jordskælvsinducerede rystelser.

v) Hvor den maximale overfladeacceleration ved 'nedlukningsjordskælvet' er bestemt til mindre end 0.1 g (10 % af tyngdeaccelerationen) skal det antages, at 'nedlukningsjordskælvet' har en overfladeacceleration på mindst 0.1 g.

2. Bestemmelse af »funktionsjordskælvet« skal specificeres af ansøgeren på basis af områdets seismologi og geologi. Hvis der opstår overfladeaccelerationer, som overstiger »funktionsjordskælvets« specifikationer, skal værket lukkes ned. For at værket kan genåbnes, skal bevillingshaveren overfor myndighederne godtgøre, at der ingen skader

er sket på de indretninger, som er nødvendige for fortsat drift uden unødig risiko for befolkningens sikkerhed og sundhed. Den maximale overfladeacceleration ved »funktionsjordskælvet« skal sættes til mindst halvdelsen af »nedlukningsjordskælvet«.

(b) Ved bestemmelse af, i hvilken grad det er nødvendigt at konstruere med henblik på overfladenær forkastningsaktivitet, skal værkets placering i forhold til »potentielt aktive forkastninger« undersøges. Det område, indenfor hvilket sådanne forkastninger har forårsaget forskydninger, fastlægges gennem en kortlægning af forkastningsspor omkring lokaliteten. Forkastningssporene kortlægges indenfor en afstand på 10 miles fra det punkt på forkastningszonen, som ligger nærmest lokaliteten. Den maximale bredde af de kortlagte forkastninger – »kontrolbredden« – fastlægges ud fra dette kort. Derefter forøges »kontrolbredden« med en faktor, hvis størrelse er afhængig af, hvor kraftigt et jordskælv der skal regnes med. Indenfor den derved fremkomne »zone for detaillerede forkastningsundersøgelser«, skal mulighederne for forkastningsaktivitet bedømmes. I det følgende er opregnet procedurerne ved bestemmelse af »zonen for detaillerede undersøgelser«:

Bredden af »zonen for detaillerede forkastningsundersøgelser« er afhængig af størrelsen på det maximale jordskælv, der skal regnes med. Sammenhængen fremgår af nedenstående skema:

Jordskælvets størrelse (Richter-skala)	Undersøgelseszonens bredde (multiplum af kontrolbredden)
op til 5.5	1 x
5.5–6.4	2 x
6.5–7.5	3 x
over 7.5	4 x

I tilfælde af, at forkastningerne indenfor den nævnte 2×10 miles zone er dækket af unge aflejringer, kan det være nødvendigt at søge oplysninger om kontrolzonens bredde i en større afstand.

Undersøgelseszonen kan ikke være mindre end en halv miles bred. Til gengæld kan zonen være bredere end ovenfor angivet, hvis geologien tilsiger det. F.eks. vil meget fladt liggende forkastninger kunne begrunde en udvidelse af undersøgelseszonen. Omvendt kan en med meget grundige undersøgelser dokumenteret tredimenssional model af området begrunde en indskrænkning af undersøgelseszonen. Sådanne undersøgelser kan være tæt placerede boringer eller tæt placerede geofysiske undersøgelser med høj opløsning. På det sted, hvor forkastningszonen ligger nærmest den valgte lokalitet, skal undersøgelseszonens midtpunkt falde sammen med forkastningscentret (fig. 1).

(c) (Omhandler vurdering af effekter af seismisk inducerede flodbølger).

(d) Bestemmelse af andre konstruktionskriterier:

1) Jordbundens stabilitet. (Dette punkt omfatter en række geotekniske forhold, som svarer nogenlunde til de forholdsregler man vil tage ved ethvert andet større byggeri).
2) Skræntstabilitet.
3) Kølevandsforsyning. Der skal tages hensyn til de geologiske/geotekniske virkninger af en langvarig nød-nedlukning og en sådan nedluknings krav om særlig meget kølevand. Det skal samtidig sikres, at indvindingen af vand til kølesystemerne ikke forstyrres af de samme naturkatastrofer, som værket eventuelt beskadiges af ved »nedlukningsjordskælvet«.
4) Fjerntliggende anlæg af betydning for værkets sikkerhed skal være konstrueret til at modstå »nedlukningsjordskælvet« efter de samme kriterier som selve værket.

VI. Ingeniørmæssig anvendelse af geologiske og seismiske konstruktionskriterier

Afsnittet indeholder en række bygningstekniske anvisninger og krav med henblik på a) jordskælv, b) forkastninger og c) seismisk fremkaldte flodbølger. Det fremgår bl.a., at A-kraftværket skal være sådan konstrueret, at installationer af betydning for sikkerheden ved nedlukning forbliver intakte ved et »nedlukningsjordskælv«. Endvidere skal værket kunne fungere uden unødig risiko for befolkningens sikkerhed og sundhed i tilfælde af et »funktionsjordskælv«.

RESUMÉ

Loven giver en detailleret procedure for de undersøgelser, der skal foretages af 1) jordskælv, 2) forkastninger og 3) seismisk inducerede flodbølger i forbindelse med projektering og bygning af A-kraftværker i USA. I artiklen fokuseres især på lovens afsnit om jordskælv og forkastninger. M.h.t. jordskælv skal virkningerne af alle rystelser, som i historisk tid kan formodes at have givet overfladeaccelerationer på mere end 10 % af tyngdeaccelerationen bedømmes i forhold til det foreslåede A-kraftværk. Endvidere skal epicentre for historiske jordskælv relateres til relevante tektoniske strukturer eller provinser indenfor en afstand på 200 miles. Såfremt jordskælvene kan relateres til en bestemt tektonisk struktur (forkastning), skal man antage, at jordskælvene fandt sted på den pågældende tektoniske strukturs nærmeste punkt til lokaliteten. Såfremt jordskælvene kun kan relateres til en bestemt tektonisk provins, skal man antage, at jordskælvene fandt sted i det punkt i den pågældende tektoniske provins, som ligger nærmest lokaliteten. Denne procedure skal danne grundlag for beregning af de overfladeaccelerationer, som A-kraftværket kan blive udsat for.

M.h.t. forkastninger og forkastningszoner herunder især forkastninger, som har været aktive indenfor de sidste 35.000 år, eller som har udvist tendens til bevægelser af tilbagevendende natur indenfor de sidste 500.000 år, skal man i en nærmere beskrevet detailleringsgrad kortlægge alle sådanne forkastninger, såfremt blot en del af en sådan forkastning ligger indenfor en afstand på 5 miles fra det projekterede A-kraftværk. Såfremt den planlagte lokalitet eller dens omegn er dækket af aflejringer, der gør det særlig vanskeligt at undersøge forkastningernes alder og strukturelle relationer, kan man søge problemet belyst i andre dele af den pågældende tektoniske provins. Herefter skal det vurderes, hvor kraftige jordskælv disse forkastninger har givet anledning til på lokaliteten.

Dernæst giver loven retningslinier for hvilke seismiske og geologiske konstruktionskriterier, der skal anvendes. Herunder skal især fremhæves proceduren for bestemmelse af det såkaldte »nedlukningsjordskælv«, d.v.s. det jordskælv, som kræver at værket lukkes, men som ikke må kunne forstyrre nødkølesystemet og andre installationer af betydning for langvarig nedlukning af værket. Ligeledes angives en procedure for bestemmelse af »funktionsjordskælvet«, d.v.s. det jordskælv, som hverken må kunne forstyrre selve værket eller installationer af betydning for befolkningens sikkerhed og sundhed.

Endelig giver loven retningslinier for, hvordan man ved værkets ingeniørmæssige projektering skal tage hensyn til vikningerne af »funktionsjordskælv« og »nedlukningsjordskælv«.

Kommentarer vedrørende danske forhold

Med hensyn til seismisk registrerede jordskælv kan lovens bestemmelser direkte overføres på danske forhold. Afsnittene om overfladenære forkastninger fokuserer især på begrebet neotektoniske forstyrrelser. Selv om en række neotektoniske forstyrrelser er beskrevet fra Danmark, er kendskabet til landets neotektonik stadig ganske overfladisk. De neotektoniske forstyrrelser, kendt fra Danmark, kan på det foreliggende litteraturgrundlag gøres op i mindst 5 hovedgrupper:

1) Jordskælv med relation til velkendte tektoniske provinser eller strukturer.

2) Jordskælv med ukendt relation til geologiske strukturer.
3) Salttektoniske forstyrrelser forårsaget af Perm- og Trias-saltets flydning.
4) Differentialbevægelser relateret til gamle tektoniske strukturer, herunder især forstyrrelser af kvartære lag i Den Fennoskandiske Randzone.
5) De regionale niveauforandringer forårsaget af isens bortsmeltning ved slutningen af sidste istid.

Hertil kommer andre neotektoniske forstyrrelser af mere uvis oprindelse som f.eks. de midtjyske spaltedale og søer (Milthers 1916, Kronborg, Bender & Larsen 1978).

Med hensyn til jordskælv registreret i historisk tid er det ikke altid muligt klart at relatere dem til tektoniske strukturer eller provinser. Således synes det særligt kraftige 1904-jordskælv, som havde epicentrum i Oslofjordens munding, at have givet anledning til særligt kraftige rystelser i Den Fennoskandiske Randzone (Harboe 1910) mens epicentret synes relateret til en anden tektonisk provins, nemlig Oslograven (Slunga 1979). Derimod synes en række andre kraftige jordskælv klart relateret til Den Fennoskandiske Randzone (Rosenkrantz 1934, Båth 1956, Gregersen 1979). En række andre og mindre kraftige jordskælv er vanskelige at relatere til nogen bestemt struktur eller provins (Lehmann 1956, Gregersen 1979, Tamrazyan 1969).

M.h.t. neotektoniske forstyrrelser forårsaget af saltstrukturens vertikale bevægelser, således som de finder sted på en række jyske lokaliteter (Madirazza 1968a, b, 1970, 1979, Håkansson & Hansen, 1980), eksisterer der stadig en række uafklarede problemer, som ikke er uden betydning for de anskuelsesmåder, man må anlægge i forbindelse med eventuel projektering af A-kraftværker i nærheden af eller på jyske saltstrukturer.

Neotektoniske bevægelser i gamle tektoniske strukturer eller provinser er kun ganske overfladisk undersøgt i Danmark. I den forbindelse knytter interessen sig især til Ringkøbing-Fyn Ryggen og Den Fennoskandiske Randzone. I disse mere eller mindre forkastningsbestemte strukturer er der for Den Fennoskandiske Randzones vedkommende sandsynliggjort neotektoniske bevægelser (Madsen 1912, Lykke Andersen 1979, Hansen 1980), mens der fra Ringkøbing-Fyn Ryggen endnu ikke foreligger publicerede neotektoniske undersøgelser. De få undersøgelser fra Den Fennoskandiske Randzone viser, at de kvartære bevægelser her er af en sådan størrelsesorden, at de må have givet anledning til jordskælv af en betydelig større intensitet end de registrerede jordskælv fra historisk tid lader antyde.

De regionale niveauforandringer (Mertz 1924), som især har bevirket en relativ hævning af Nordjylland, udgør et fundamentalt grundlag for en vurdering af de fleste neotektoniske forstyrrelser i Danmark. Imidlertid tyder meget på, at isobasernes forløb er betydeligt mere kompliceret, end vor nuværende viden tillader at trække dem. Således skal især fremhæves, at det isostatiske hævningsforløb synes at være væsentlig forskelligt på hver sin side af Den Fennoskandiske Randzone (Mörner 1969). Al den stund de regionale isobaser udgør et fundamentalt grundlag for en beregning af mere lokale – og i denne sammenhæng betydeligt vigtigere – uregelmæssigheder (Hansen & Håkansson 1980) er det derfor et vigtigt skridt mod en bedre forståelse af neotektoniske forkastningsbevægelser forårsaget af aktivering af gamle tektoniske strukturer og niveauforandringer forårsaget af saltbevægelser at få et mere detailleret indblik i den sen- og postglaciale isostasi.

P.gr.a. de kvartære lags relative store tykkelse i Danmark mangler man en oversigtlig fremstilling af eventuelle neotektoniske strukturer. En sådan oversigt kunne indledningsvis fremstilles ved en målrettet geomorfologisk kortlægning af landet f.eks. ved indtegning af samtlige terrænlineamenter over en vis størrelse og ved geomorfologisk analyse af saltstrukturområdet.

En sådan kortlægning ville kunne medføre en omtrentlig lokalisering af mulige neotektoniske strukturer, som sammen med de fra litteraturen kendte strukturer skulle undersøges nærmere i tilfælde af projektering af et A-kraftværk i området.

Næste skridt må være en undersøgelse af de åbne profilers tektoniske forhold med henblik på at finde forstyrrelser forårsaget af aktivitet i undergrunden. Her vil problemet oftest være at adskille glacialtektoniske fænomener fra ægte neotektonik. Som regel vil nøjere undersøgelser dog med god sikkerhed kunne fastslå oprindelsen. I denne forbindelse spiller de post- og senglaciale aflejringer en vigtig rolle. Disse aflejringer er ikke forstyrret af isen, og de er derfor specielt egnede til studier af eventuel neotektonisk aktivitet. Interessen retter sig især mod Nordjylland, som ligger i Den Fennoskandiske Randzone, og som har de mest udbredte marine flader. Ved en sådan indsamling af tektoniske data fra kvartære lag, vil den råstofgeologiske kortlægnings anden fase være af stor værdi. I denne fase indgår bl.a. geologisk opmåling af alle tilgængelige profiler, f.eks. i råstofgrave, kystklinter og større udgravningsarbejder. En tektonisk opmåling indgår som standard i disse profilbeskrivelser (Bondesen 1980). Dette kortlægningsarbejde påhviler amtskommunerne, men resultaterne tilgår DGU (jvf. råstofloven af 1977), og det vil således inden for en ret kort årrække være muligt at få et overblik over de kvartære lags tektoniske forhold i Danmark.

I den sammenhæng bør det nævnes, at en systematisk opfølgning og beskrivelse af de midlertidigt åbne profiler, der skabes i forbindelse med anlæg af et transmissionsnet for Nordsø-gassen med stor sandsynlighed vil træffe en betydelig del af de neotektoniske strukturer, som kan tænkes at eksistere i de neotektonisk set dårligst kendte dele af landet. Alene af den grund vil en beskrivelse af disse profiler være meget værdifuld.

Hertil kommer, at der i de seneste år er udarbejdet en række landsdækkende geologiske temakort, som i en overskuelig form fremstiller en meget stor geologisk datamængde. Blandt disse kort med tilhørende beskrivelser, som er fremstillet af amtskommunerne og DGU i forening, skal især fremhæves de geologiske basisdatakort (jvf. Binzer & al. 1979), kort over prækvartæroverfladens højdeforhold (jvf. Binzer & Andersen 1979), grundvandskemiske temakort (jvf. Knudsen & al. 1979) og morfogenetiske kort (jvf. Hansen, Larsen, Lund & Waagstein 1979). En analyse og sammenstilling af disse korttyper vil kunne føre til en udpegning af en række mulige neotektoniske elementer i den danske undergrund.

Med udgangspunkt i den eksisterende publicerede viden om de strukturelle forhold i de kvartære aflejringer og med henblik på den viden, som i de nærmeste år vil blive fremstillet i en overskuelig form, kan man således umiddelbart pege på 4 arbejdsområder af interesse for en kortlægning af neotektoniske strukturer forud for en eventuel målrettet, detailleret undersøgelse ved projektering af A-kraftværker:

1) Gennemgang og tolkning af eksisterende litteratur og geologiske kort.
2) Registrering af afvigelser fra det regionale isobasemønster.
3) Analyse af landskabselementer og geomorfologi.
4) Åbne profilers tektoniske vidnesbyrd.

Denne type arbejde kan som nævnt ikke stå alene ved eventuel projektering af A-kraftværker, men må følges op med detaillerede undersøgelser bl.a. omfattende boringer og geofysiske undersøgelser. Sådanne undersøgelser må afpasses efter de lokale forhold i forbindelse med en udvalgt lokalitet eller bestemt neotektonisk struktur, som er registreret ved en af de ovennævnte metoder. Her kan især seismiske undersøgelser med stor opløsning tjene til en registrering af strukturernes omfang både lateralt og i dybden. Dette kræver adgang til det nødvendige geofysiske udstyr, ligesom tolkningen af de geofysiske målinger kræver høj datamatkapacitet.

Det bør nævnes, at der allerede foreligger et betydeligt antal geofysiske (især seismiske) undersøgelser, hvoraf en del er frigivet og publiceret i overskuelig form (Baartman i Rasmussen 1978). Disse data er hovedsagelig indsamlet i forbindelse med olie- og gasprospektering og dækker store dele af det danske område.

Afslutningsvis kan det således konkluderes, at den geologiske baggrundsviden, som forudsættes at være tilstede forud for de detaillerede undersøgelser, i løbet af en kortere årrække vil kunne bringes i en sådan forfatning, at de amerikanske procedurer uden væsentlige ændringer vil kunne bringes i anvendelse herhjemme. Dette forudsætter dog, at de landsdækkende kortlægningsprojekter, som amtskommunerne og DGU er involveret i levnes mulighed for en planmæssig gennemførelse, samt at enkelte mere begrænsede kortlægnings projekter iværksættes.

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XRF2: A fortran programme for treatment of XRF-data obtained with an absolutely calibrated XRF-spectrometer

Tom Svane Petersen and Ib Sørensen

Petersen, T. S. and Sørensen, I.: XRF2: A FORTRAN programme for treatment of XRF-data obtained with an absolutely calibrated XRF-spectrometer. *Danm. geol. Unders., Årbog 1979:* 125-138, København, 1. december 1980.

The paper presents a Fortran programme which will perform the necessary calculations for the conversion of measurements from an absolutely calibrated X-ray spectrometer to main element analysis in terms of oxides. The results are delivered in a form directly available for further treatment by other programmes performing geochemical calculations and plots.

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X-ray fluorescence spectrometry (XRF) has been developed into one of the modern instrumental methods for major element analyses which can yield the highest degree of precision. Accuracy, however, depends on how perfectly the matrix problems can be handled. An easy way to overcome such problems is to measure the unknown samples against similar materials with a known content of the elements studied. Natural standard reference materials with certified analytical values are generally preferred as calibrating tools for XRF. The method can not be considered as absolute, since it also depends on the other analytical methods used to obtain the values for the standard reference materials. Another drawback is that the analyst must estimate the composition of the unknown samples in order to choose a convenient set of calibrating normals, if at all accessible. For a geological survey that nearly always handles virtually unknown samples, this is a great disadvantage.

The X-ray spectrometer at the Geolocical Survey of Greenland in Copenhagen is calibrated absolutely, using synthetic calibrating normals, and hence the results obtained are completely independent of other analytical methods and of geochemical standard reference materials (Sørensen, 1976).

This paper describes a FORTRAN programme which performs the necessary calculations for converting the measurements from the X-ray spectrometer into major element analysis.

The programme is coded in ASCII-FORTRAN, and is operational on the UNIVAC 1108. The programme will run on the newly installed UNIVAC 1100/82 without alteration. (RECKU, The Regional Computer Center, University of Copenhagen). XRF2 requires a core memory smaller than 12K words and is therefore operational on any computer with a FORTRAN-compiler.

The programme has been used daily for 3 years and is part of a geochemical programme complex designed to yield input for norm, modus (Kalsbeek and Petersen, 1974), plotting on a Calcomp plotter, database etc. (Petersen and Jensen, 1978).

Experimental

Two different instrument have been used, a SIEMENS sequential spectrometer SRS 1, and a SIEMENS multi-channel spectrometer MRS 300.

The samples – crushed to a fineness less than 50μ – are ignited to 980° C for 4 h to remove H_2O, CO_2 and other volatiles. They are then made into homogeneous glass discs by melting 0.4 g sample material with 2.8 g sodium tetraborate.

Two different types of calibrating normals are used.

SYMEC, *sy*nthetic *m*ono *e*lement *c*alibrating normals, containing one single element, are prepared for each of the major elements in the following concentrations: 10, 16, 25 and 40 % element oxide relative to a supposed sample. However, for silica, the values 25, 40, 50, 63 and 80 % are prepared instead. For the minor elements, the values 1, 2.5, 4, 6.3 and 10 % are used.

SYMIX, *sy*nthetic *mix*ed normals are used for the determination of the interelement coefficients. Binary mixtures 50/50 and ternary mixtures 71/20/9 are generally used. More complex compositions can easily be prepared, but apart from special cases they are avoided since the experimental uncertainty often can mask the small interelement effects. All calibrating normals are prepared from specially selected pure chemicals, which are melted – in carefully weighted amounts – with sodium tetraborate, and cast into glass discs similar to the unknown samples.

The calculation method

The calculations of the concentrations in unknown samples are carried out in three separate steps.

1) The calculation of a set of apparent concentrations C_{Ei} is performed from the measured X-ray intensities E_i using the equation:

$$C_{Ei} = a + b.E_i + c.E_i^2$$

For each element (i) the calibrating coefficients a, b and c are determined by measuring a set of SYMEC. A second degree equation is used, which gives the best possibility for coping with the varying effects of non-proportionality, i.e. influence of dead time not corrected for, different mass absorption for the normals of extreme element concentrations, or other effect due to increasing element concentrations.

2) For two of the elements, P and Mg respectively, corrections for line coincidence and background influence are necessary. Both effects are handled by calculation, using the equation

$$C'_{Ei} = C_{Ei} - \sum_j K'_{i,j} . E_j$$

E_j is the measured intensity for the interfering element (j). Again, the coefficients $K'_{i,j}$ are determined experimentally by measuring the SYMEC. The multi-channel spectrometer offers a unique opportunity for studying the effects of varying element concentrations for all the elements analysed. But a sequential spectrometer is very helpful in distinguishing between real background influence and peak coincidence. The two instruments yield slightly different coefficients.

3) The apparent concentration values can be markedly different from the true concentrations and must be processed in a matrix correction procedure (Thiele, 1971). The fundamental view of this is that for element (i) the true concentration C_i can be derived from the apparent concentration C_{Ei} by multiplying with a calculated correction factor close to 1 – taking up contributions from all the interfering elements (j), according to their concentrations, e.g.

$$C'_i = C_{Ei} \cdot (1 + \sum_j K_{i,j} . C_{Ej})$$

$$C''_i = C_{Ei} . (1 + \sum_j K_{i,j} . C'_j)$$ C'_j are calculated in the foregoing step

.

.

.

$$C_i = C_{Ei} \cdot (1 + \sum_j K_{i,j} . C_j)$$

The calculations are carried through seven iterations because the true C_j values are only approximately known. In fact only the first two iterations have a pronounced effect on C_i. Note that C_{Ei} is the same through all the iterations.

The influence coefficients $K_{i,j}$ are determined experimentally by measuring the SYMIX. The coefficients for binary normals are found directly from the matrix equation. For the more complex compositions, the coefficients can be calculated from simple linear equations.

Presentation of the results

Conventional chemical methods are used for the determination of FeO(%), Na_2(%) and LOI(%; loss on ignition). All XRF values are obtained from materials which have been previously ignited. Therefore the XRF results are multiplied by a coefficient f = 1 – LOI(%)/100, to give the concentrations in the material »as received«.

FeO(%) is multiplied by 1.1113 and subtracted from f.Fe_2O_3(%). The difference is reported as Fe_2O_3(%).

FeO(%) is multiplied by 0.1113 and added to LOI(%), the sum is reported as Volatile(%).

Description of the programme XRF2

Programme XRF2 is divided into a main programme, one block data routine FLSBL and the UNIVAC 1100 series standard routines FACSF and ADATE. The main programme controls the input of data, the calculations and output operations. The results are delivered to a printer, a card puncher (unit 1) and a storage file (unit 11) for further treatment. FLSBL holds the matrix correction coefficients for the multi-channel spectrometer. FACSF is used to obtain the calibration coefficients from the disc storage files and ADATE supplies the programme with date and time of the run. If another installation is used, changes will be required in the main programme.

The calibration coefficients are not included in the programme, but are stored on a disc file. This is because the coefficients are often changed and it would otherwise be necessary to recompile the whole programme every time the calibration coefficients were changed.

XRF2 can calculate any number of analyses in one run. It can be used interactively (conversing) or in batch modus. The programme should be able to run on any UNIVAC 1100 type machine without any major alteration. If another type of installation is used (e.g. IBM-hardware) changes will be required. These changes fall into the category of common definitions and input/output operations.

List-directed input statements are used in XRF2 to read free-field record (e.g. READ (5, *)). List-directed input consists of a sequence of values separated by commas, blanks, slaches or end of line. If such a statement is not available, another blank common facility should be used instead.

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Dansk sammendrag

Der præsenteres et FORTRAN program, som kan foretage de beregninger, der er nødvendige for at omsætte målinger fra et absolut kalibreret røntgen-fluorescens-spectrometer til grundstofanalyser udtrykt som oxider. Resultaterne præsenteres i en form, som er direkte anvendelig for videre behandling af andre programmer, der foretager geokemiske beregninger og plot.

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PROGRAMME DOCUMENTATION

```
c***********************************************************************
c***Purpose                                                          ***
c***Programme for treatment of xrf-data obtained with                ***
c***an absolutely calibrated xrf-spectrometer                        ***
c***                                                                 ***
c***The program is interactive                                       ***
c***                                                                 ***
c***Remarks                                                          ***
c***Some special univac 1100 ascii-fortran features                  ***
c***                                                                 ***
c***subroutine required                                              ***
c***FACSF,ADATE are special univac 1100 routine                      ***
c***                                                                 ***
c***Block data required                                              ***
c***Flsb                                                             ***
c***                                                                 ***
c***Data file                                                        ***
c***with calibration coefficients                                    ***
c***                                                                 ***
c***Input oxides etc.                                                ***
c ***MgO, Na2O, FeO, MnO, loss on ignition                           ***
c***                                                                 ***
c***Input counts                                                     ***
c***Si, K, Cl, S, Al, Ti, Fe, Ca, Mg, P, Na, Mn, Sr, Zr              ***
c***                                                                 ***
c***Output oxides etc.                                               ***
c***SiO2, TiO2, Al2O3, Fe2O3, FeO, MnO, MgO, CaO,                    ***
c***Na2O, K2O, H2O, P2O5, Total and Sr                               ***
c***                                                                 ***
c***********************************************************************
      integer ip(20),id(20),iij(2),jj(2),oxl(20)
      integer ii(20),ox3(20),ox4(20),ioo(7)
      real g(20),cg(20),cf(20),ti(20),b(20,3),c(20),amkor(12,12)
      common /flsbl/amkor
      data ip/6,2,7,1,12,9,8,4,13,3,14,5,10,11,15/
      data ox3/´si´,´ti´,´al´,´fe´,´fe´,´mn´,´mg´,´ca´,´na´,´k2´
     * ,´vo´,´p2´,´sr´,´zr´,´su´/
      data ox4/´o2´,´o2´,´2o3´,´2o3´,´o´,´o´,´o´,´o´,´2o´,´o´,
     * ´lat´,´o5´,´  ´,´  ´,´m´/
      data ii/6,3,12,13,7,2,1,4,8,5,9,10/
      data oxl/´fe3´,´ti´,´k´,´ca´,´p´,´si´,´al´,´mg´,´mn´,´sr´,´zr´
     * ,´fe2´,´na´,´vol´,´sum´/
      data ioo/´§add´,´ ggu´,´*geo´,´kemi´,´.dib´,´ . ´/
c***
c***  date and time(special univac feature)
c***
      call adate(iij,jj)
      print 201
201   format(2(/),2x,´PRINT:´
     * ,t10,´0: print out to lab. ´,/,t10,
     * ´1: print out to lab. with constant ´,/,t10,´2: print out to´
     * ´ geologist §add data, if end §eof´,/,
     * t10,´3: print out to geologist with punch card: §add data, ´,
     * ´ if end §eof´)
      amno=0.
      idf=1
```

Fig. 1

```
c***
c***      background constant
c***
          fac1=0.002
          fac2=0.0167
          fac3=0.0148
          read(5,*) ikon
          gl=0
          iol=0
          n=12
c***
c***      print constant
c***
          print 344
344       format(/,2x,´§add constants´)
          do 55 i=1,n
55        read(5,*)(b(i,j),j=1,3)
          if(ikon.ne.1) go to 35
          print 234
234       format(2(/),2x,´ a,b,c constant y= a+bx+cx**2´)
          do 2 i=1,n
2         write(6,*)(b(i,j),j=1,3)
          print 235
235       format(2(/),2x,´matrix constants´)
          do 25 i=1,n
          write(6,208)(amkor(i,j),j=1,n)
208       format(8f10.7)
25        continue
35        continue
22        continue
          iol=iol+1
          if(ikon.eq.0.or.ikon.eq.1)  print 223
223       format(2(/),5x,´PRINT: rock identification/ §add file´)
          read(5,106,end=300,err=300)n11,n22,n33,n44
106       format(4a4)
108       format(2(/),3x,4a4,/)
          if(ikon.eq.0.or.ikon.eq.1)  print 222
222       format(5x,´PRINT: mgo, na20, feo, mno, loss on ignition ´,
        * ´if end type §eof´)
          read(5,*,end=300) amgo,anao,feo,amno,gl
          if(ikon.eq.0.or.ikon.eq.1) print 446,amgo,anao,feo,amno,gl
 446      format(/,5x,´MgO´,2x,f5.2,´ Na2O ´,f5.2,´ FeO ´,f5.2,´ MnO ´,f5.2,
        * ,´ loss on ignition ´,f5.2)
          glt=gl
          nl=13
c***
c***      read count (in fls - format)
c***
101       format(1x,6f10.4)
          if(ikon.eq.0.or.ikon.eq.1) print 204
204       format(5X,´INPUT count´)
          read(5,444)
444       format(1x)
          read(5,100)(ti(i),i=1,13)
          if(ikon.eq.1)write(6,100)(ti(i),i=1,13)
          ti(11)=ti(12)
          ti(12)=ti(13)
          do 1 i=1,nl
          c(ii(i))=ti(i)
          cg(ii(i))=ti(i)
1         continue
```

Fig. 2

```
100   format(5(5x,f8.0))
      if(ikon.eq.0.or.ikon.eq.1)  write(6,108)n11,n22,n33,n44
      gl=1-(gl/100)
      if(ikon.ne.0.or.ikon.ne.1) go to 558
      print 236,gl
236   format(2(/),2x,'loss on ignition ',f8.4)
       write(6,245)
245   format(1x)
      print 501,(oxl(i),c(i),i=1,n)
501   format(5(2x,a4,f10.0))
c***
c***  calculate y=a+bx+cx**2
c***
558   continue
      do 3 i=1,n
      c(i)=b(i,1)+b(i,2)*c(i)+b(i,3)*(c(i)**2)
3     cf(i)=c(i)
      if(ikon.eq.1 ) print 666
666   format(2(/),5x,'before background correction')
      if(ikon.eq.1) write(6,101)(cf(i),i=1,n)
c***
c***  background correction
c***
      c(6)=c(6)-c(5)*fac1
      cf(6)=c(6)
c     c(9)=c(9)-c(3)*fac2-c(5)*fac3
      cf(2)=c(2)
679   continue
      if(ikon.eq.1) print 656
656   format(2(/),5x,'after background correction')
      if(ikon.eq.1) write(6,101)(cf(i),i=1,n)
c***
c***  matrix correction
c***
      do 20 ih=1,7
      do 124 i=1,n
      ti(i)=0
      do 123 k=1,n
123   ti(i)=ti(i)+amkor(i,k)*c(k)
677   format(/,5x,'after ',i3,' matrix correction')
124   continue
      do 24 i=1,n
      c(i)=(ti(i)+1)*cf(i)
24    continue
      if(ikon.eq.1.and.(ih.eq.1.or.ih.eq.2)) print 677,ih
      if(ikon.eq.1.and.(ih.eq.1.or.ih.eq.2)) print 101,(c(i)
     * ,i=1,n)
20    continue
      if(ikon.eq.1) print 677,ih-1
      if(ikon.eq.1)print 101,(c(i),i=1,n)
c***
c***  correction for loss on ignition
c***
```

Fig. 3

```
      if(gl.le.0) go to 7
      do 60 i=1,n
60    c(i)=c(i)*gl
7     continue
c***
c***  calculate feo and fe2o3
c***
      c(12)=feo
      c(1)=c(1)-(feo*1.1113)
      c(13)=anao
      c(14)=feo*.1113+glt
      sum=0
      do 4444 il=1,n+3
4444  sum=sum+c(il)
      if(ikon.gt.1) go to 453
      print 569
569   format(2(/),4x,'after correction for loss on ignition',/)
      write(6,101)(c(il),il=1,n+4)
      print 338
338   format(/,5x,'following ordering are used:')
      print 339,(oxl(ij),ij=1,n+4)
339   format(6(5x,a4))
453   continue
c***
c***  prepare integer output file
c***
      id(15)=0
      do 567 il=1,14
      id(il)=(c(il)+0.005)*100.
      id(15)=id(15)+id(il)
567   continue
      id(16)=id(10)/100
      id(17)=id(11)/100
      c(11)=0
      c(10)=0
      id(10)=id(15)-id(10)-id(11)
      if(ikon.eq.1.or.ikon.eq.0) go to 252
      c(15)=float(id(10))/100.
581   format(2(/),5x,'**** GGU MAJOR ELEMENT ANALYSES ****',/,5x,
     * 'i procent')
c***
c***  write calculated oxides
c***
      if(ikon.eq.3.or.ikon.eq.2) print 231,n11,n22
231   format(2(/),5x,'Identification No.: ',a4,a3,/)
      jk=n+3
      do 251 i=1,jk
      if(c(ip(i)).gt.-.005.and.c(ip(i)).lt.0.005) go to 251
      write(6,700)ox3(i),ox4(i),c(ip(i))
251   continue
      do 5556 iy=16,17
      if(id(iy).le. 0) go to 5556
      write(6,800)ox3(iy-3),ox4(iy-3),id(iy)
800   format(10x,a2,a3,1x,i6)
5556  continue
252   continue
c***
c***  write calculated oxides on file 11
c***
      write(11,238)(id(ip(i)),i=1,13),n11,n22
      if(ikon.ne.3) go to 566
c***
c***  punch calculated oxides
```

Fig. 4

```
c***
        write(1,238)(id(ip(i)),i=1,13),n11,n22
566     continue
238     format(12i4,4x,15x,i5,2a4)
700     format(10x,a2,a3,1x,f6.2)
        print 576
576     format(2(/))
        mod1=mod(iol,2)
        if(mod1.eq.0.) print 830,iij,jj
830     format('1',1x,2('*'),'  dated ',2a4,' time ',2a4,1x,2('*'),
     * ' ggu*geokemi.xrf version 5a 1-8-78 ',2('*'))
        go to 22
300     continue
        if(ikon.eq.3) print 532,iol
532     format(2(/),10('*'),' Note punch card number',i5,
     * 1x,10('*'))
        print 346
346     format(/,t5,'*** Note your analyses are stored on file 11 ***')
        stop
        end
```

```
        block data
c***
c***    matrix coefficient
c***
        real amkor(12,12)
        common /flsbl/amkor
        data ((amkor(i,j),j=1,11),i=1,11)
     * /.0,.00987,.0095,.0096,0.,.00226,.00167,.00141,0,0,0
     * ,.00137,0.,.008,.009,.0,.00172,.00086,.001,.0,0.,0.
     * ,.00073,.0007,.0,.00065,.0,.0019,.0013,.00100,0.,0.,0.
     * ,.0029,-.0005,.0065,.0,.0,.0020,.001,.0001,0.,0.,0.
     * ,.0001,0.,0.,.0001,0.,.0001,0.,0.,0.,0.,0.,
     * .00138,.0,-.0006,-.00031,0.,0.,.00129,.00112,0.,0.,0.,
     * .0014,0.,0.,-.0006,0.,-.0006,0.,.001,0.,0.,0.,
     * .001,.00088,-.00167,-.001,.0,-.00044,-.00045,0.,0.,0.,0.,
     *     0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
     *     0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
     * 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0./
        end
```

Fig. 5

Format used as input to the programme

card 1 col 1-7 Sample identification no. (format A3,A4)

card 2 Chemically determined MgO, Na_2O, FeO, MnO and "loss on ignition" (free-field records)

card 3 not used

card 4 XRF counts for Si, K, Cl, S, Al (format 5 (5x,F8.0))

card 5 XRF counts for Ti, Fe, Ca, Mg, P (format 5 (5x,F8.0))

card 6 XRF counts for Na, Mn , Sr, -, - (format 5 (5x,F8.0))

if more analyses repeat card 1-6 else type eof.

Example:

```
 1:079
 2:5.59,2.86,12.38,0,-.92
 3:  00 00000010
 4:  00 00610078  02 00517129  03 00007857  04 00006022  05 00196975
 5:  06 05702680  07 05403460  08 00789373  09 00010255  10 00004861
 6:  11 00068435  12 00275731  13 03257745
 7:080
 8:5.23,2.62,11.34,0,-.96
 9:  00 00000010
10:  01 00656384  02 00392042  03 00009169  04 00006505  05 00207626
11:  06 03803198  07 04870050  08 00772401  09 00010778  10 00003752
12:  11 00069077  12 00280406  13 03166265
13:083
14:6.71,2.60,9.87,0,-.56
15:  00 00000010
16:  01 00641631  02 00286001  03 00007120  04 00006340  05 00230084
17:  06 03141824  07 04338799  08 00852215  09 00012489  10 00003118
18:  11 00069499  12 00269748  13 03214088
```

Calibration coefficient example (a, b, c)

```
Fe) -.7391e-1,.2163e-5,.489e-13
Ti) -.2370e-1,.6290e-6,0
K ) -.1253,.13e-5,.7566e-14
Ca) -.3402e-1,.1116e-4,.4254e-12
P ) -.6435e-1,.1068e-3,-.1895e-9
Si) -.4631,.7425e-4,-.1810e-11
Al) -.1298,.6500e-4,.3102e-12
Mg) -.4441,.6115e-3,-.2569e-9
Mn) -.512,2.347e-6,0
Sr) -3.0861e+3,7.4626e-4,0
- ) 0,0,0
- ) 0,0,0
```

Fig. 6

Output format on punch-card and file 11

col 1-4	SiO_2 weight percent; Format F4.2. (without decimal point)
col 5-8	TiO_2 weight percent; Format F4.2 (without decimal point)
col 9-12	Al_2O_3 weight percent; Format F4.2 (without decimal point)
col 13-16	Fe_2O_3 weight percent; Format F4.2 (without decimal point)
col 17-20	FeO weight percent; Format F4.2 (without decimal point)
col 21-24	MnO weight percent; Format F4.2 (without decimal point)
col 25-28	MgO weight percent; Format F4.2 (without decimal point)
col 29-32	CaO weight percent; Format F4.2 (without decimal point)
col 33-36	Na_2O weight percent; Format F4.2 (without decimal point)
col 37-40	K_2O weight percent; Format F4.2 (without decimal point)
col 41-44	H_2O weight percent; Format F4.2 (without decimal point)
col 45-48	P_2O_5 weight percent; Format F4.2 (without decimal point)
col 49-67	Not used in this programme
col 68-72	Total for the oxide; Format F5.2 (without decimal point)
col 73-79	Sample identification; Format A3, A4

The arrangement of the oxides is called GGU-format

Example:

```
4644 4381274 3121238  14 5751054 286  63  46  46                      9990079
4990 2911338 2331134  15 6041033 262  44  30  34                     10008080
4861 2401477 218 987  12 7021132 260  28  54  27                      9998083
```

Fig. 7

Example of print out from an actual run

```
 PRINT: 0: print out to lab.
        1: print out to lab. with constant
        2: print out to geologist §add data, if end §eof
        3: print out to geologist with punch card: §add data,  if end §eof
>3

 §add constants
>§add a.xrf/konstanter
>§add a.xrf/data

     Identification No.: 079

          sio2   46.44
          tio2    4.38
          al2o3  12.74
          fe2o3   3.12
          feo    12.38
          mno      .14
          mgo     5.75
          cao    10.54
          na2o    2.86
          k2o      .63
          volat    .46
          p2o5     .46
          sum    99.90


     Identification No.: 080

          sio2   49.90
          tio2    2.91
          al2o3  13.38
          fe2o3   2.33
          feo    11.34
          mno      .15
          mgo     6.04
          cao    10.33
          na2o    2.62
          k2o      .44
          volat    .30
          p2o5     .34
          sum   100.08
```

Fig. 8

```
** dated 062080   time 163911   ** ggu*geokemi.xrf version 5a 1-8-78 **

   Identification No.: 083

        sio2   48.61
        tio2    2.40
        al2o3  14.77
        fe2o3   2.18
        feo     9.87
        mno      .12
        mgo     7.02
        cao    11.32
        na2o    2.60
        k2o      .28
        volat    .54
        p2o5     .27
        sum    99.98


********* Note punch card number    4 **********

*** Note your analyses are stored on file 11 ***
```

Fig. 9

Foraminifera from the type section of the *eugubina* Zone compared with those from Cretaceous/Tertiary boundary localities in Jylland, Denmark.

Inger Bang

Bang, I.: Foraminifera from the type section of the *eugubina* Zone compared with those from Cretaceous/Tertiary boundary localities in Jylland, Denmark. *Danm. geol. Unders., Årbog 1979:* 139-165, pls. 1-10. København, 1. december 1980.

The *eugubina* Zone, established by Luterbacher & Premoli Silva (1964) from the Scaglia Formation of the central Appennines, Italy, as the lowermost zone of the Tertiary, has been classed by later authors alternatively as uppermost Maastrichtian or lowermost Danian on the basis of different well-defined faunas.

An investigation of topotypes by SEM has resulted in the recognition of an equivalent Danish assemblage in a better state of preservation.

Inger Bang, Geological Survey of Denmark, Thoravej 31, DK-2400 Copenhagen NV, Denmark.

The *eugubina* Zone was established by Luterbacher & Premoli Silva (1964) from the Scaglia Formation of the central Appennines of Italy, and taken as the lowermost zone of the Tertiary. Since then, other authors have recognised the zone, but a problem seems to be that different faunas may have been designated as the *eugubina* Zone. Krasheninnikov & Hoskins (1973) for example, discussed the problems of identification, and figured five species (pl. 7, figs 6-8, pl. 8, figs 1-2, 9-11, pl. 11, figs 1-3, 7-9) from the *eugubina* Zone. All of them can be identified as forms known from the lower, but not the lowest Danian of Denmark. The same applies to specimens described by Premoli Silva and Bolli (1973) and referred to the *Globigerina eugubina* group (pl. 7, figs. 6-9).

Hofker (1978) recognised the zone in Hole 47. 2 of DSDP on the Shatsky Rise in the Pacific, describing the Upper Maastrichtian to Lower Tertiary section in detail. With *Globigerina eugubina* as type species, Hofker established the genus *Parvularugoglobigerina* which he considered to have affinities with both *Hedbergella* and *Rugoglobigerina.* On palaeontological and sedimentological grounds, he referred the *eugubina* Zone to the Uppermost Cretaceous.

It seems necessary to maintain that the zone should be defined by the original type section, and because of the basic phylogenetic differences between Cretaceous and Tertiary genera, it seems equally important to verify the affinities of Luterbacher & Premoli Silva's original types. For this reason, a sample from the type locality has been studied. The sample was kindly put at my disposal by Dr. Isabella Premoli Silva, and was labelled »Ceselli section, level 3«. SEM examination showed that the majority of the specimens belonged to a new genus, distinctly different from *Parvularugoglobigerina* and *Eoglobigerina,* but identical with sepcimens from an unpublished assemblage called the Lønnerup assemblage from the lower Danian of Denmark (pl. 1, figs 20-30 and plate 2). The new genus (provisionally called 'new genus L') has a smooth test surface and a slit-like aperture, more or less bordered by a narrow lip. As described by Luterbacher & Premoli Silva, the Ceselli specimens are in a poor state of preservation, ranging from casts to specimens with at least part of the test preserved, which makes it difficult to verify the details of the aperture, but generally, they seem to agree with the details determined for the better preserved Lønnerup assemblage.

The Ceselli sample

So far, 135 specimens from the Ceselli sample have been examined by SEM and some of them have been photographed (pls. 3 and 4). Comparison of the two faunas shows that the Ceselli material belonging to the new genus L seems to fall into three groups, of which *G. umbrica* (Luterbacher & Premoli Silva 1964 pl. 2, figs 2a-d) seems to be closely related to the most common Danish form (pl. 1, figs 21-24, 27-30). The majority of the Ceselli specimens belong to the species *G. eugubina* (Luterbacher & Premoli Silva 1964, pl. 2, figs. 8a-c) and *G. sabina* (Luterbacher & Premoli Silva 1964, pl. 2, figs. 6a-c, 7a-c). A few specimens of both have been identified in the Lønnerup assemblage (G. eugubina pl. 1, fig. 25 and pl. 2, fig. 6, G. sabina pl. 2, fig. 4). *Parvularugoglobigerina* sp. (pl. 3, figs. 5 and 21) seems to be synonymous with *G. cf. fringa* Subbotina (Luterbacher & Premoli Silva 1964, pl. 2, figs. 4a-c), but differs considerably from *G. fringa* Subbotina 1963, which is described as having a smooth test wall. *G. minutula* (Luterbacher & Premoli Silva 1964, pl. 2, fig. 5a) has not been certainly identified in the sample. As described, it seems identical with some *Parvularugoglobigerina* from the Lønnerup assemblage, as for instance pl. 1, fig. 12.

From the Ceselli sample, a *Globotruncanella* sp. has been identified, as well as a small group of foraminifera which differ from the majority in their lighter colour, better state of preservation, and their species composition:

Heterohelix striata, H. sp., *Guembelitria cretacea, G.* sp., »*Hedbergella*« sp., »*Globigerinella*« sp. and *Parvularugoglobigerina* sp. (pl. 4, figs. 1-3, 5-8).

A formal problem arises concerning the new genus L and *G. eugubina,* type species of *Parvularugoglobigerina* Hofker, which can only be resolved by the re-description of the original types.

The phylogenetic relationship of the new genus is uncertain. Premoli Silva & Bolli (1973) show *G. eugubina* in pl. 7, figs 2-5 along with *Eoglobigerina.* It is not possible to distinguish the apertures on the figures, but the tests otherwise show resemblances to the new genus L. In the same paper, pl. 7 fig. 1 and pl. 6, fig. 10, referred by the authors to *Woodringina hornerstownensis* Olsson group, seems also to be related to new genus L, as the aperture of the two is almost identical. The only difference from the established species lies in the number of chambers. Another possibly related form is a »Discorbis« sp. (pl. 5, figs. 7-8) which raises the question whether this group of forms is planktonic at all. It has not been possible to distinguish any pores on the smooth test surface (pl. 2), nor on the inside wall.

The Lønnerup assemblage

Like the Ceselli sample, the Lønnerup assemblage consists of small specimens mostly with a largest diameter of about 90μm. Besides the forms mentioned already, *Heterohelix* spp., »*Hedbergella*« sp., *Rugoglobigerina* sp., »*Globigerinella*« spp., *Guembelitria cretacea,* and *G.* sp. 2 occur (pl. 1). The assemblage was found in the Ny Kløv section (fig. 1-2 and Håkansson & Hansen 1979, pp. 180-181), 10-30 cm above the marl layer (i.e. in the lowermost Danian) in sample No 9 and 4/8. A few *Chiloguembelina* sp. (pl. 1, figs. 6-10) are considered the only positively autochthonous planktonic foraminifera in these samples.

In the Kjølby Gaard section (fig. 1), the Lønnerup assemblage has only been found at a stratigraphically higher level, together with the first *Eoglobigerina,* 70 cm above the clay layer forming the Cretaceous/Tertiary boundary (Håkansson & Hansen 1979, pp. 177-179).

As the two localities represent the most complete Maastrichtian-Danian sections found in the Danish embayment, the foraminiferal fauna will be described in more detail in a future publication in connection with the petrographical investigation of the limestones.

In this present account only some af the aspects concerning the planktonic

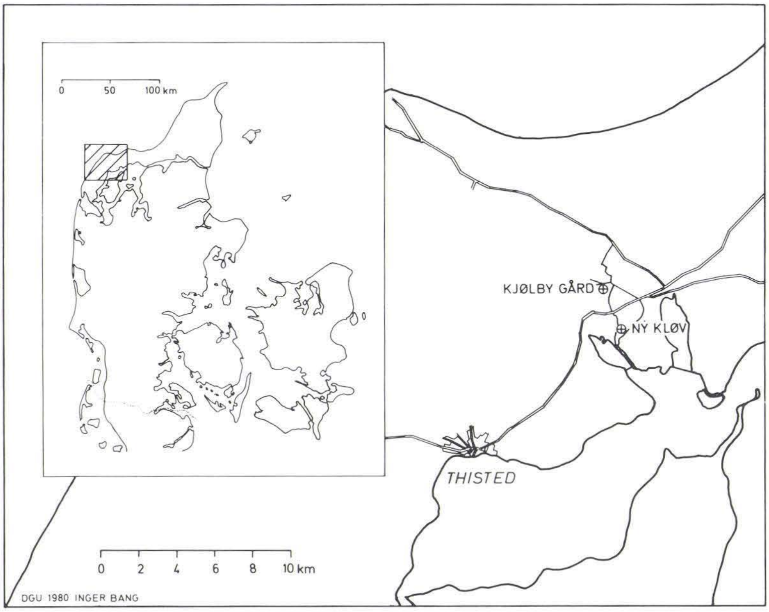

Fig. 1. Location map.

foraminifera will be shown by means of the range chart (fig. 2) and the SEM plates of the succession of planktonic foraminifera from the section at Ny Kløv.

The Ny Kløv section

The Lønnerup assemblage is figured on plate 1, and, as seen from the range chart, is dominated by *Heterohelix* spp. and *Guembelitria* spp. mostly sp. 2. Of *Parvularugoglobigerina* (pl. 1, figs. 11-17) a single specimen (cf) has been found in sample, 1 pl. 5, fig. 5. Higher in the profile at Ny Kløv (samples 6-7), *Parvularugoglobigerina* becomes relatively common, but not quite to the extent found in the lowermost Danian (samples 4/8 and 9). Furthermore, only some forms of the assemblage have been recovered from the Maastrichtian samples, which could suggest that gaps were present in the section. The possibility that the concentration in samples 4/8 and 9 could be due to sorting is countered by the fact that even amongst the smallest fraction (below 100μm) in the Upper Maastrichtian chalk, only a few specimens of *Parvularugoglobigerina* occur. Specimens of new genus L have not been found in Maastrichtian samples.

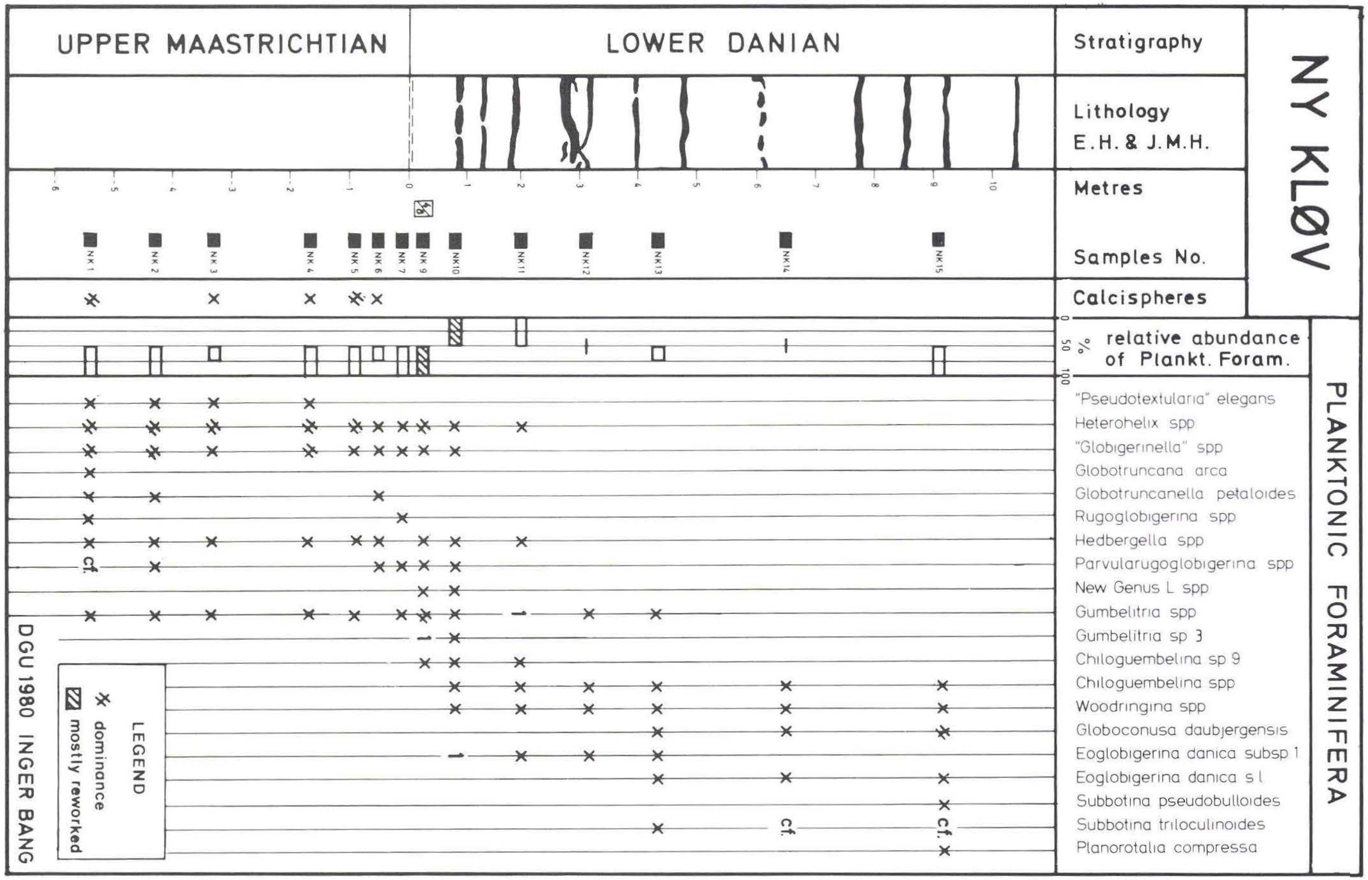

Fig. 2. Range chart plantonic foraminifera from the Ny Kløv section.

The *Chiloguembelina* found in the sample (sp. 9) differs considerably from established species and seems to confirm the view of Reiss (1963), who referred *Chiloguembelina* to a new family (within the Buliminidea) which he considered unrelated to the Heterohelicidae (Reiss 1963, pp. 55-56).

In samples as early as a height of 70-90 cm above the boundary, however, this species is almost replaced by forms referred to the *Chiloguembelina midwayensis* (Cushman) group, although they show considerable variation. *Chiloguembelina* sp. 9 continues with a number of subspecies as a sparse but characteristic element in the Lower Danian.

The characteristic fauna of the *Eoglobigerina danica* Zone is shown in plate 8, a zone which constitutes the lowermost Danian in most sections. The last *Eoglobigerina danica* subsp. 1 appears in sample 13 (pl. 9) together with the first genuinely trochospiral *Eoglobigerina* and *Globoconusa daubjergensis* (Brönnimann). Amongst the *Eoglobigerina* forms can be found a single morphospecies of *E. eobulloides* Morozova (pl. 9, fig. 14), and a cancellate specimen of *Subbotina* cf. *triloculinoides* (Plummer) (fig. 10) as well as a transitional form (fig. 16) to *S. pseudobulloides*.

The relationship between *Guembelitria* and *Globoconusa daubjergensis* will be demonstrated in a future paper based upon a better preserved fauna from a cored section from the island of Saltholm in Øresund. At the Danian type locality at Stevns (Bang 1971), the lower boundary of the *G. daubjergensis* Zone coincides with the hiatus between the Cerithium Limestone and the superposing bryozoan limestone. The *G. daubjergensis* from the Cerithium Limestone mentioned in that paper (p. 17) seems to be derived from the burrows within the limestone (p. 18).

Finally, at the top of the section, (sample 15), there appear the first representatives of what is considered to be the Danish equivalent of the *E. taurica* Zone of Morozova (1961), situated about 5 m above the lower boundary of the *G. daubjergensis* Zone. This fauna, which is dominated by *G. daubjergensis,* is shown on plate 10. A morphological resemblance to the fauna from the *eugubina* Zone is evident, but it seems important to maintain that no direct correspondence has been found between the earliest *Eoglobigerina* and the fauna of the *eugubina* Zone.

Acknowledgements. The SEM-print was made by *Irma Torres,* the figures by *Kirsten Andersen,* the manuscript was typed by *Vibeke Hermansen* and *Lene Kristensen, Yvonne Husfeld* assisted in recording and arranging the SEM-prints for the plates, for which help I wish to express my gratitude.

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Plate 1. Ny Kløv, sample No. 4/8.
Scale: 100 μm

1,2:	*Heterohelix* spp.
3,4:	*Guembelitria* sp. 2
5:	*Guembelitria cretacea* Cushman
6-10:	*Chiloguembelina* sp. 9
11-17:	*Parvularugoglobigerina* spp.
18, 19:	»*Globigerinella*« spp.
20-30:	New Genus L spp., see text.

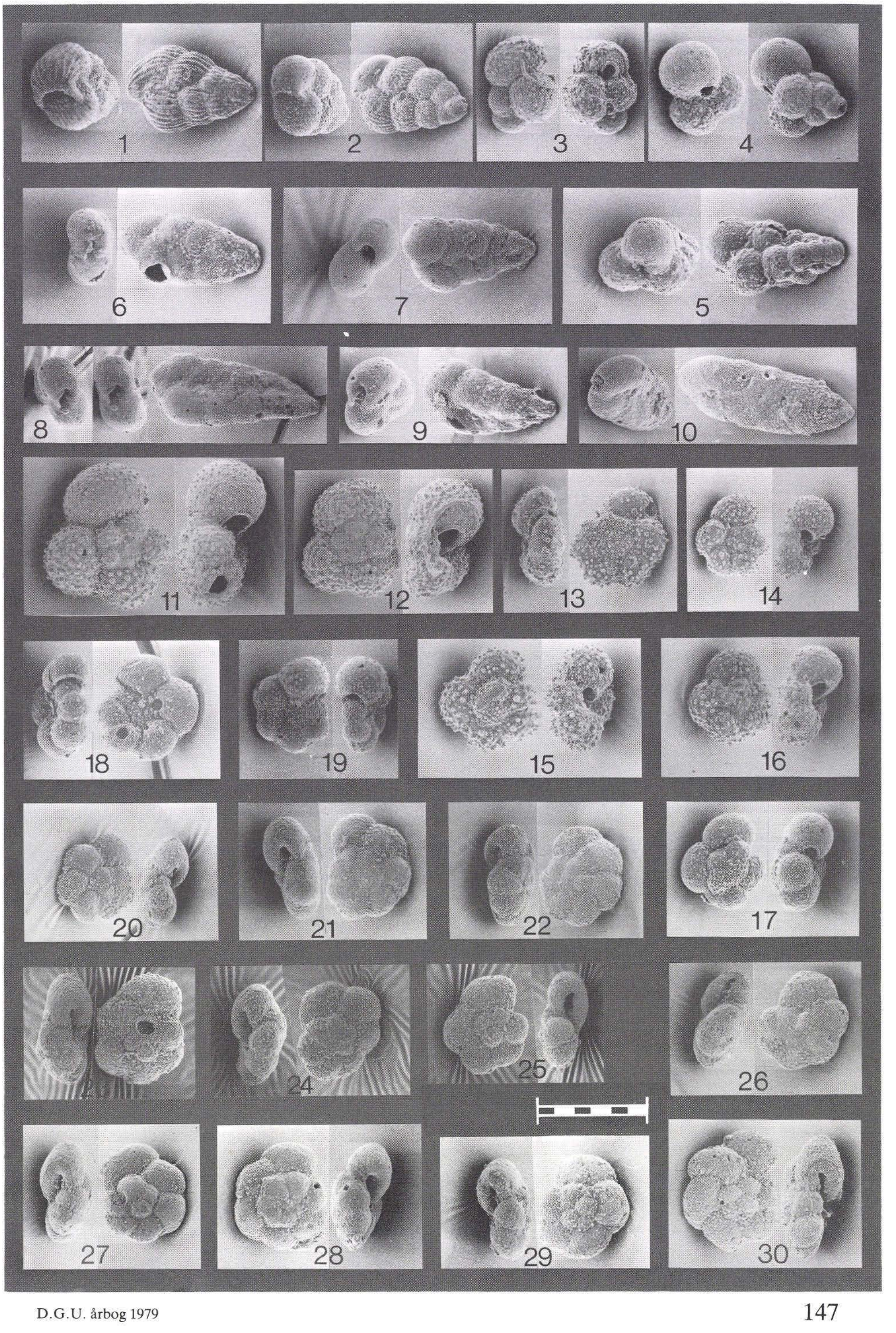
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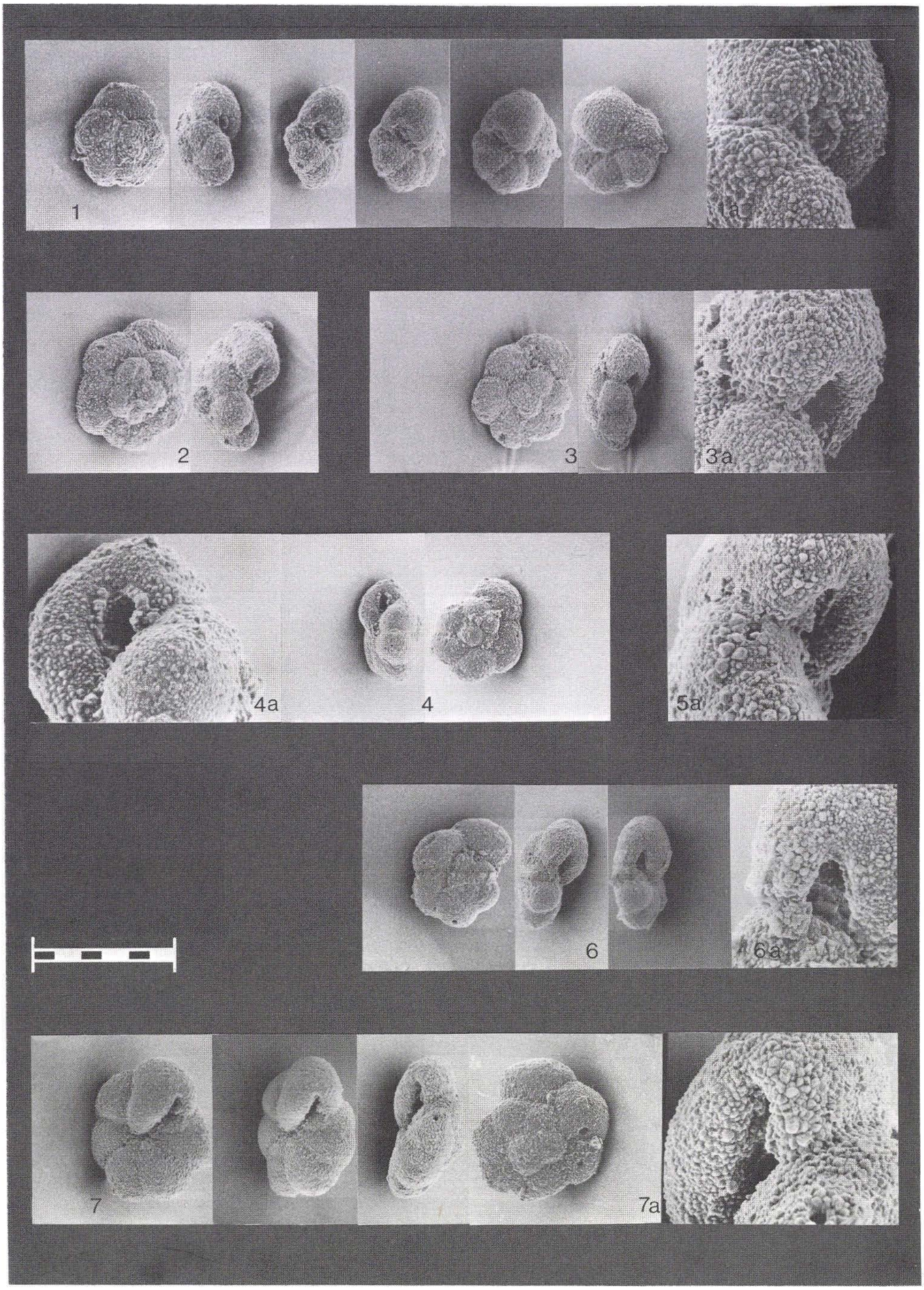
Plate 2. Ny Kløv, sample No. 4/8.
Scale: 100 μm

1-7: New Genus L spp.

1a, 3a, 4a, 5a, 6a, 7a: details of aperture, scale of plate $x\frac{1}{3,3}$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3a
4a
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5a
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6a
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7a

Plate 3. Ceselli section, level 3.
Scale: 100 μm

1:	*Globigerina umbrica* Luterbacher & Premoli Silva. la: detail of aperture, scale of plate $x\frac{1}{3,3}$
2, 3, 7:	*Globigerina sabina* Luterbacher & Premoli Silva
4, 5, 8:	*Globigerina eugubina* Luterbacher & Premoli Silva. 8a: detail of aperture, scale of plate $x\frac{1}{3,3}$

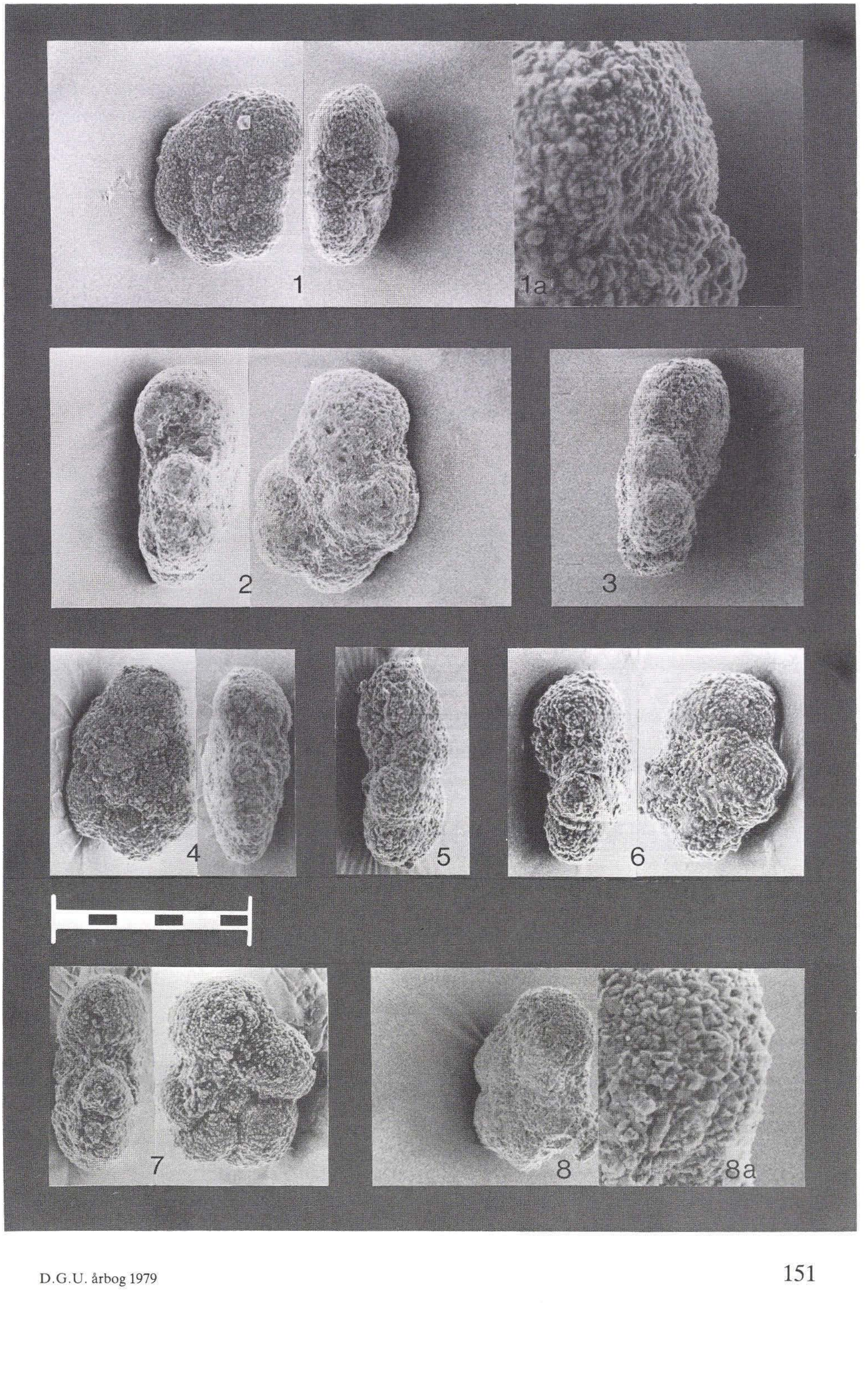
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Plate 4. Ceselli section, level 3.
Scale: 100 μm

1:	*Guembelitria cretacea* Cushman
2, 3:	*Heterohelix* spp.
4:	Calcisphaera
5, 21:	*Parvularugoglobigerina* sp.
6:	»*Globigerinella*« sp.
7:	*Guembelitria* sp.
8:	»*Hedbergella*« sp.
9, 10, 17:	*Globigerina sabina* Luterbacher & Premoli Silva
11-16, 18-20, 22:	*Globigerina* eugubina Luterbacher & Premoli Silva
23:	*Globigerina umbrica* Luterbacher & Premoli Silva

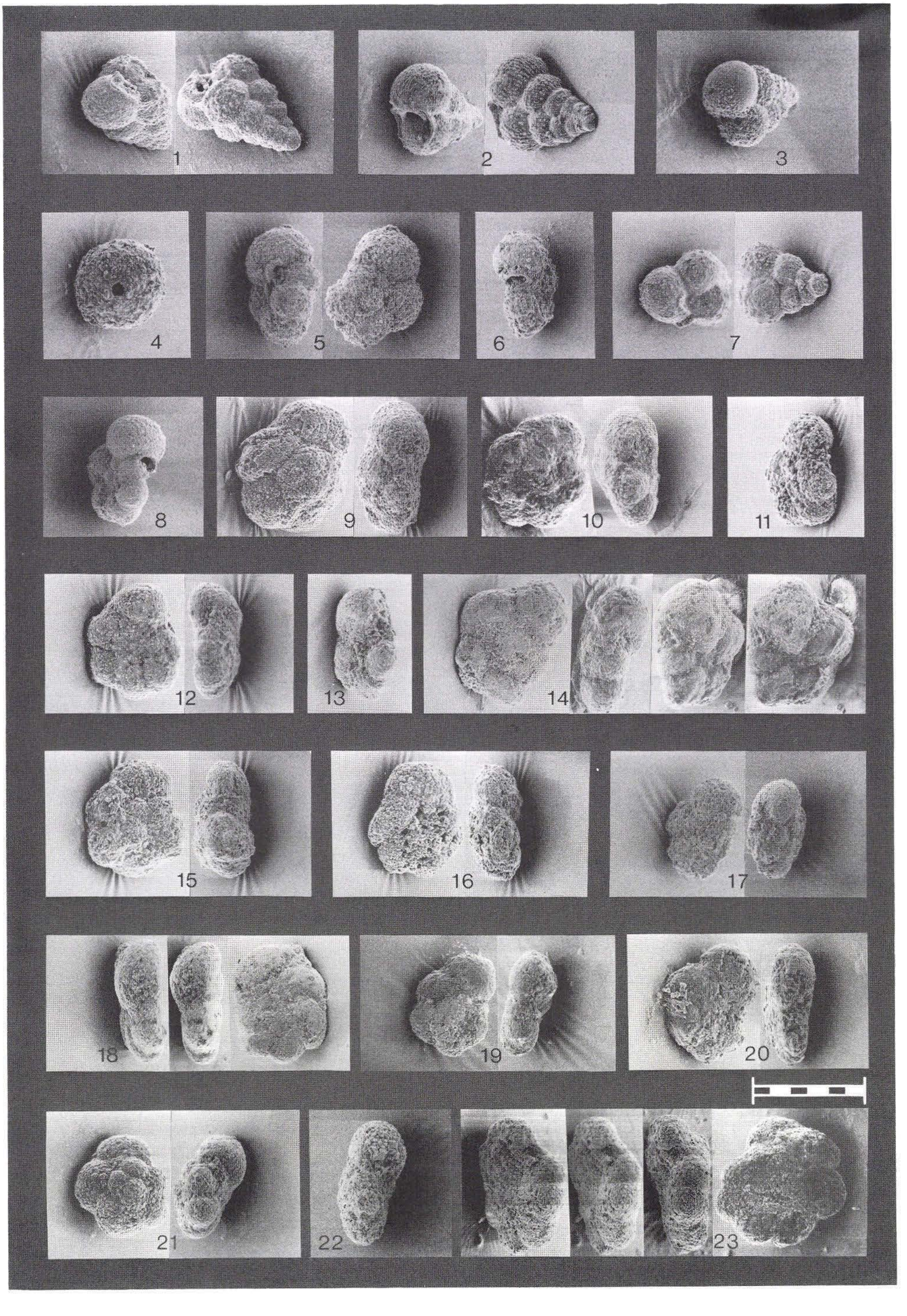
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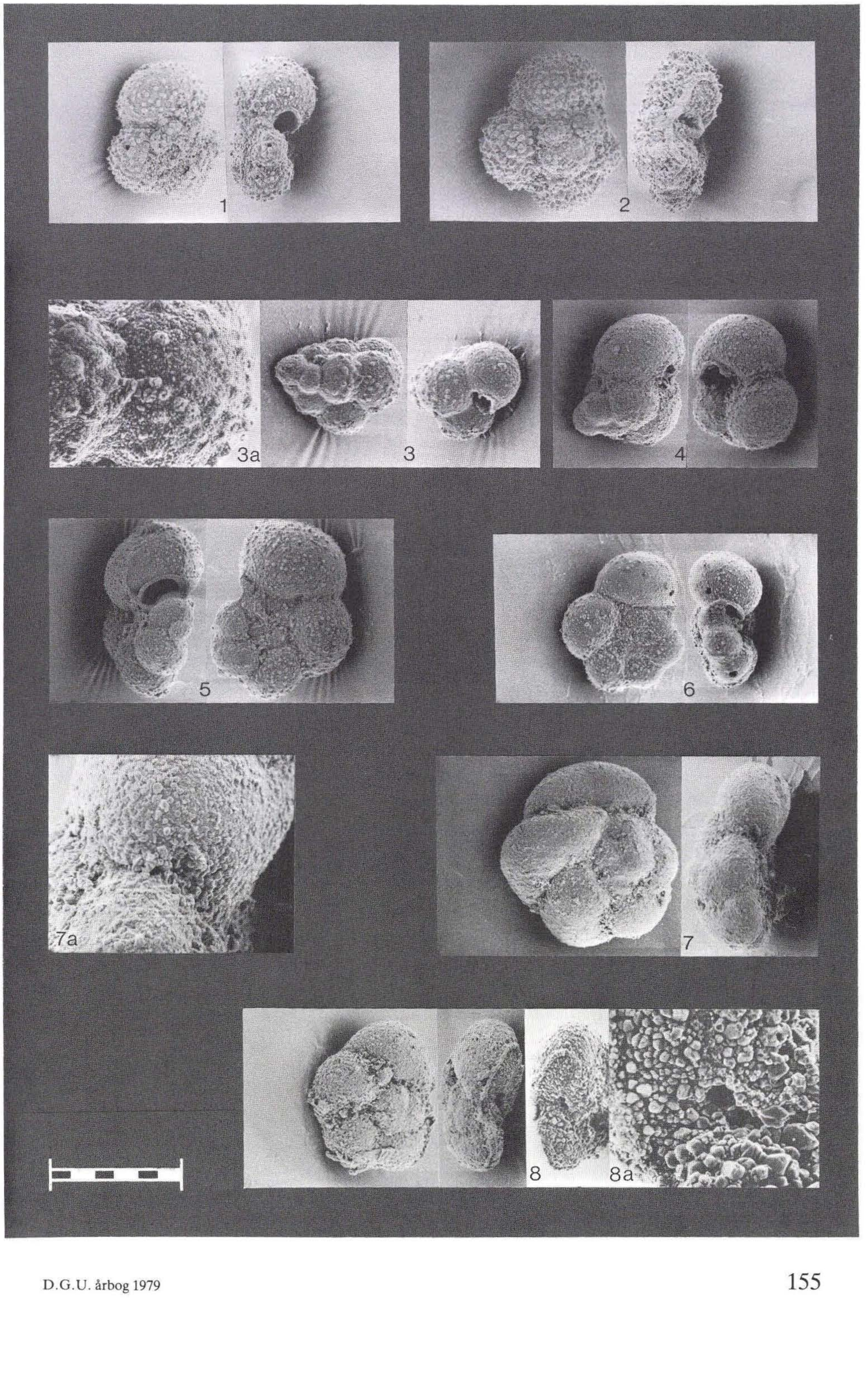
Plate 5. Ny Kløv, sample No. 7 (figs. 1, 2)
and sample No. 1 (figs. 3-8).
Scale: 100 μm

1, 2:	*Parvularugoglobigerina* spp.
3, 4:	*Guembelitria* sp.
	3a: detail of test surface, scale of plate x$\frac{1}{3,3}$
5:	*?Parvularugoglobigerina* sp.
6:	»*Hedbergella*« sp.
7, 8:	»*Discorbis*« sp. 8
	7a, 8a: detail of aperture, scale of plate x$\frac{1}{3,3}$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3a
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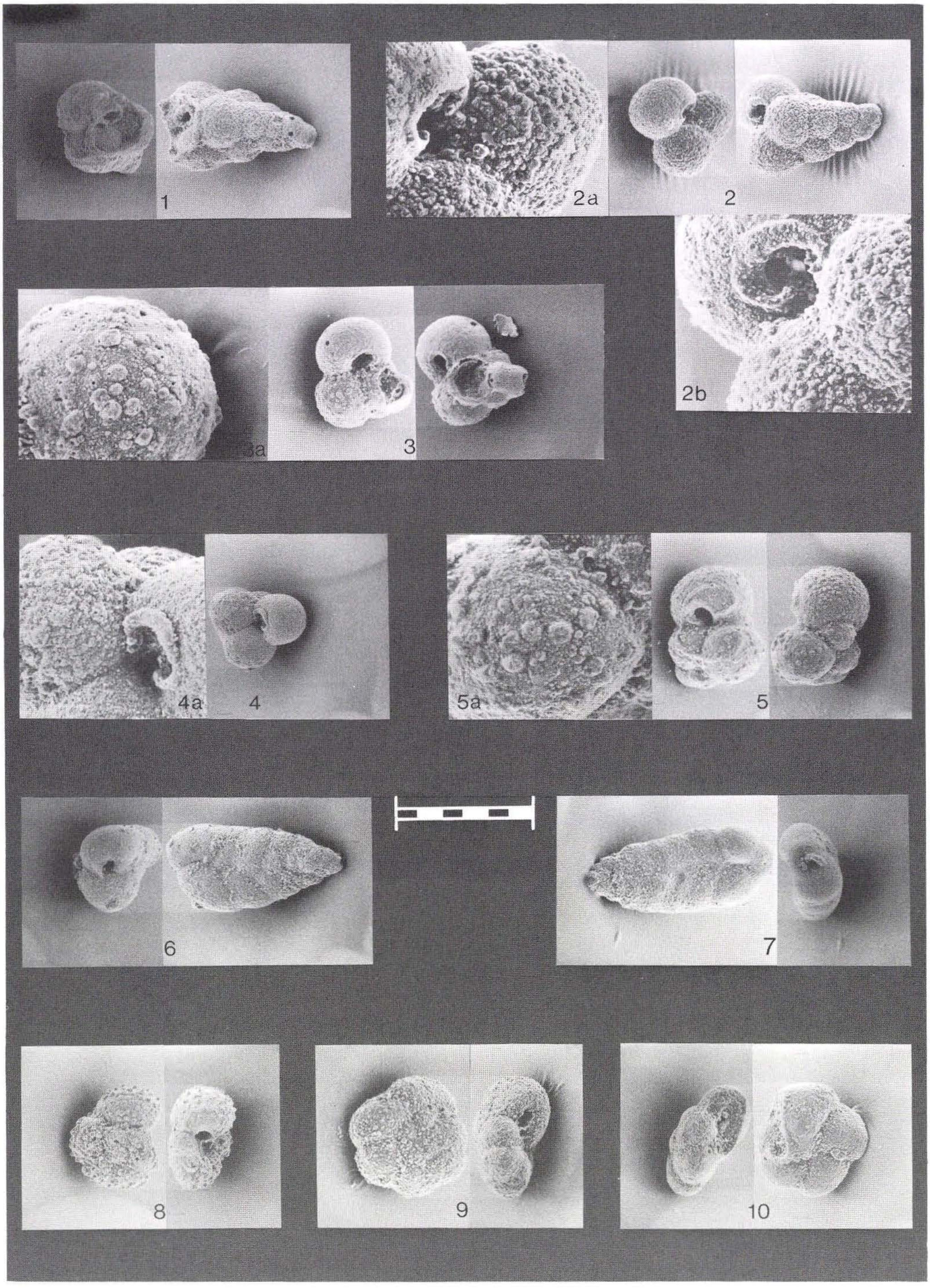
4
5
6
7a
7
8
8a

Plate 6. Ny Kløv, sample No. 9.
Scale: 100 μm

1:	*Guembelitria cretacea* Cushman
2, 4:	*Guembelitria* sp. 3
	2a, 2b, 4a: details of aperture, scale on plate $x\frac{1}{3,3}$
3, 5:	*Guembelitria* sp. 2
	3a, 5a: details of test surface, scale on plate $x\frac{1}{3,3}$
6, 7:	*Chiloguembelina* sp. 9
8:	*Parvularugoglobigerina* sp.
9, 10:	New Genus L sp.


1
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2b
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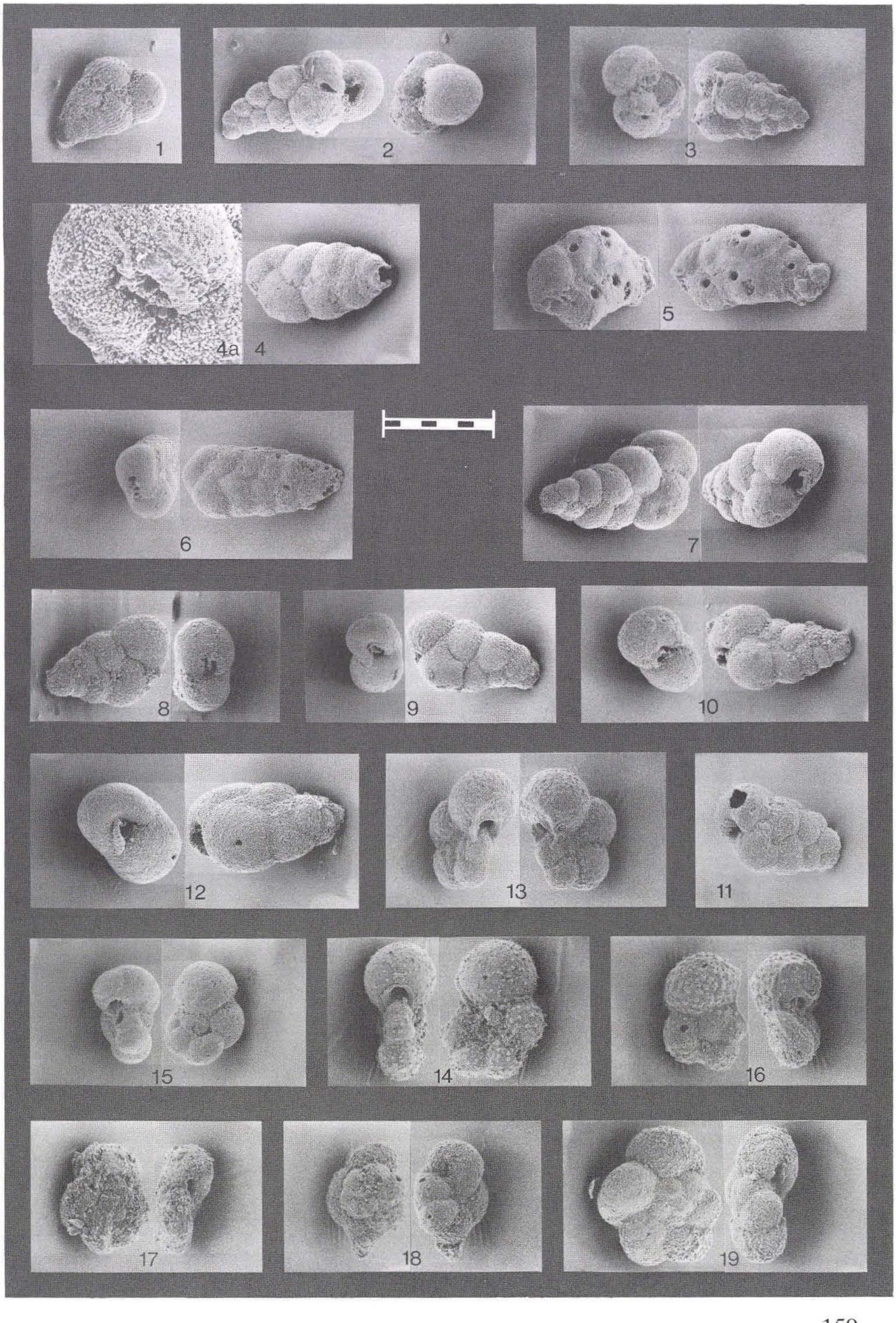
4a
4
5a
5
6
7
8
9
10

Plate 7. Ny Kløv, sample No. 10.
Scale: 100 μm

1:	*Heterohelix* sp.
2:	*Guembelitria* sp. 3
3:	*Guembelitria cretacea* Cushman
4, 5, 6:	*Chiloguembelina* sp. 9
	5: with microborings
	4a: detail of aperture, scale on plate $x\frac{1}{3,3}$
7, 8, 9, 10, 11:	*Chiloguembelina midwayensis* (Cushman)
12:	?*Woodringina* sp.
13, 14:	»*Globigerinella*« sp.
15:	*Eoglobigerina danica* subsp. 1
16:	*Parvularugoglobigerina* sp.
17, 18, 19:	New Genus L spp.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19

Plate 8. Ny Kløv, sample No. 11.
Scale: 100 μm

1, 2:	*Chiloguembelina* sp. 9
3:	*Guembelitria* sp. 2
4, 5, 6, 7, 8, 9:	*Chiloguembelina* spp.
10:	*Heterohelix* sp.
11:	*?Woodringina* sp.
12-20:	*Eoglobigerina danica* subsp. 1

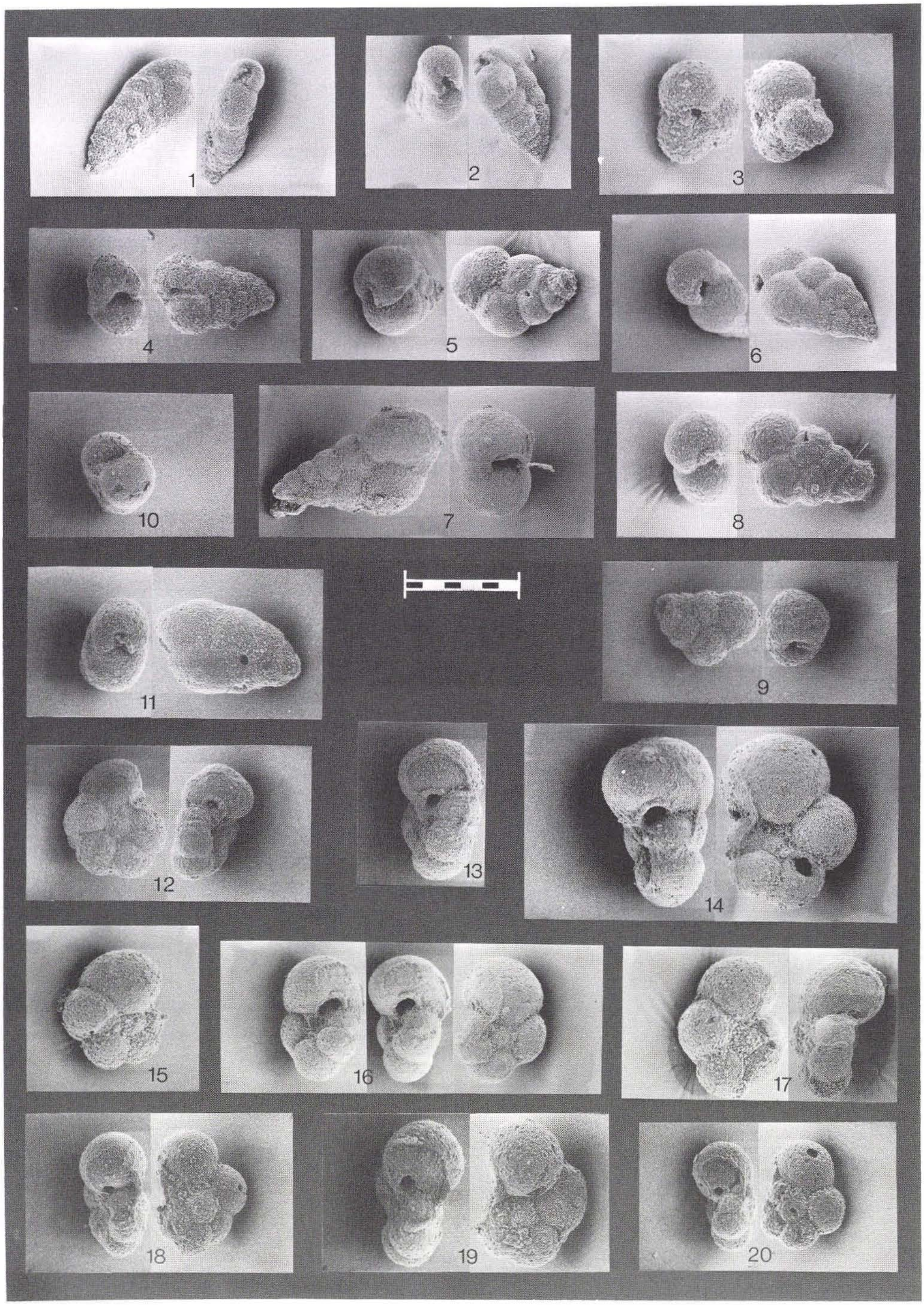
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Plate 9. Ny Kløv, sample No. 13.
Scale: 100 μm

1:	*Guembelitria cretacea* Cushman
2, 3, 4:	*Chiloguembelina* spp.
5:	*?Woodringina* sp.
6, 7, 8, 9:	*Globoconusa daubjergensis* (Brönnimann)
	8a: Detail of test surface, scale on plate x $\frac{1}{3,3}$
10:	*Subbotina cf. triloculinoides* (Plummer)
11, 12, 13, 15:	*Eoglobigerina danica* s. l.
14:	*Eoglobigerina cf. eobulloides* Morozova
16:	Transition form between *E. danica* and *Subbotina pseudobulloides* (Plummer)

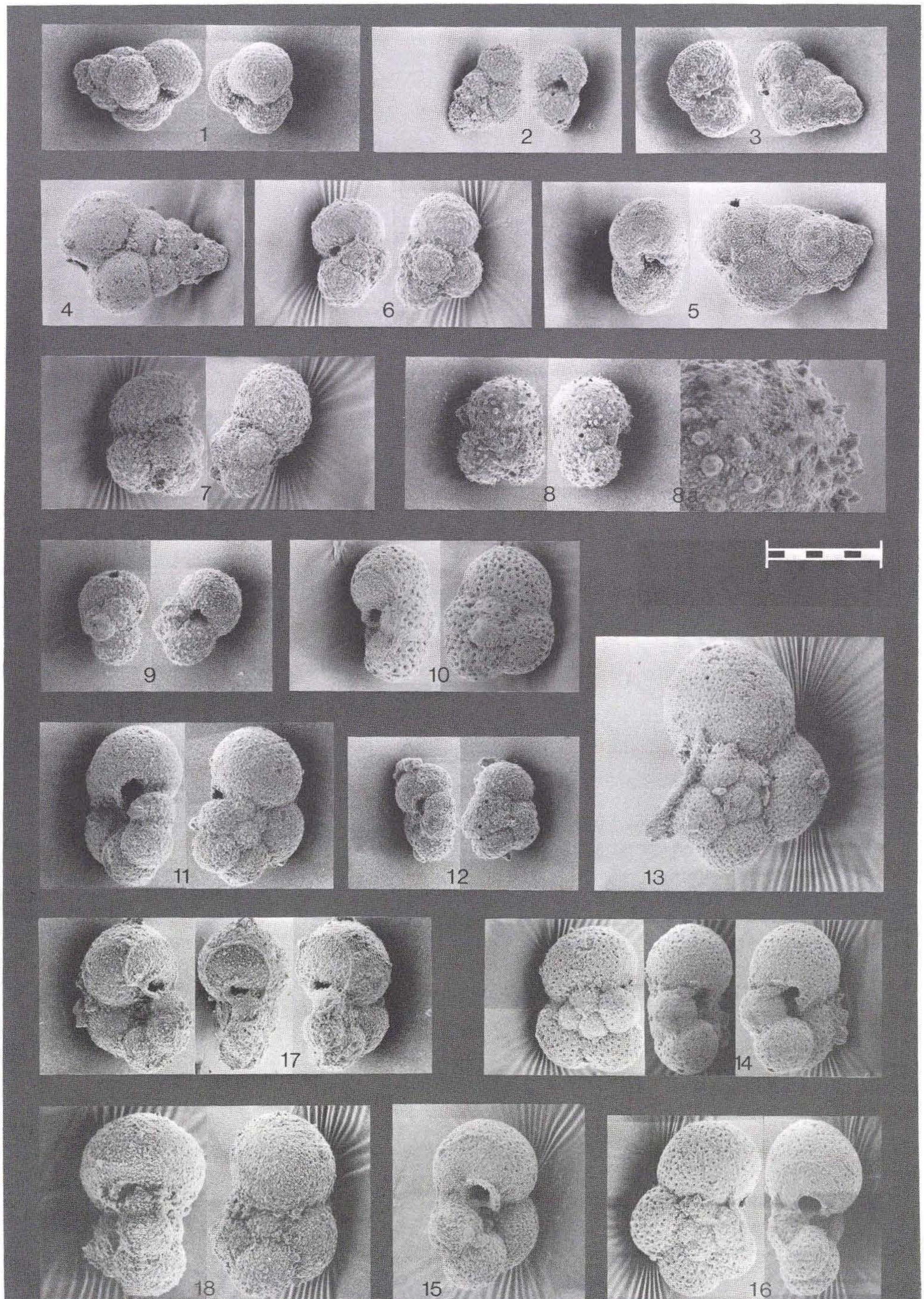
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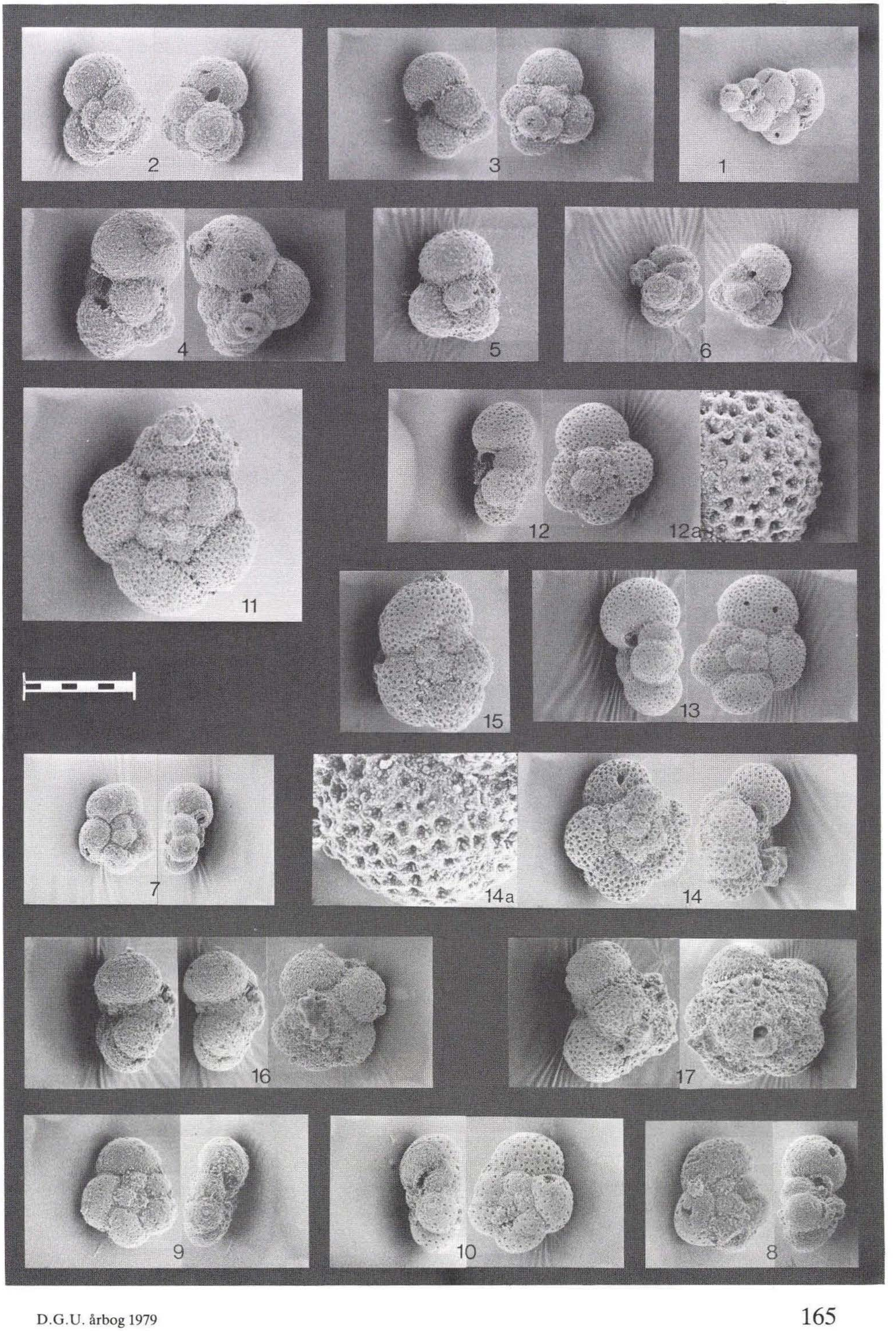
Plate 10. Ny Kløv, sample No. 15.
Scale: 100 μm

1:	*Chiloguembelina* sp.
2, 3, 4, 5, 6:	*Globoconusa daubjergensis* (Brönnimann)
7, 8:	*Eoglobigerina danica* s. l.
9, 10:	*Planorotalia compressa* (Plummer)
11:	Transition form between *E. danica* and *Subbotina pseudobulloides*
12, 13, 14:	*Subbotina pseudobulloides* (Plummer)
15:	*Subbotina cf. triloculinoides* (Plummer)
16:	*Eoglobigerina cf. pentagona* Morozova
17:	*?Eoglobigerina hemisphaerica* Morozova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14a
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Contents: *Bent Aaby* and *Jens Jacobsen:* Changes in biotic conditions and metal deposition in the last millennium as reflected in ombrotrophic peat in Draved Mose, Denmark, pp. 5-44, pls. 1-3. *Bent Aaby, Jens Jacobsen* and *Ole Stig Jacobsen:* Pb-210 dating and lead deposition in the ombrotrophic peat bog, Draved Mose, Denmark, pp. 45-68. *Svend Th. Andersen:* Identification of wild grass and cereal pollen, pp. 69-92. *Jóhannes Jóhansen:* Cereal cultivation in Mykines, Faroe Islands AD 600, pp. 93-104. *L. Aabo Rasmussen, H. Bahnson, N. Mikkelsen, A. V. Nielsen* og *K. Strand Petersen:* Om den geologiske kortlægning af Fjeldsområdet i 1978, pp. 105-118. *Knud Binzer* og *Claus Andersen:* Eksempel på kort over prækvartærets højdeforhold, pp. 119-130, 1 map. *Jens Morten Hansen:* A new dinoflagellate zone at the Maastrichtian/Danian boundary in Denmark, pp. 131-140. *Olaf Michelsen:* Report on the Jurassic of the Hobro No. 1 and Voldum No. 1 borings, Denmark, pp. 141-150, pls. 4-6. *Olaf Mikkelsen* og *Finn Bertelsen:* Geotermiske reservoirformationer i den danske lagserie, pp. 151-164. *Lars Jørgen Andersen:* A semi automatic level-accurate groundwater sampler, pp. 165-172. *Tom Svane Petersen* and *Gyrite Brandt:* The programming practices in geology, pp. 173-180. *Peter B. Konradi* og *Kaj Strand Petersen:* Oversigt over geologiske forskningsprojekter i Danmark og Færøerne, pp. 181-184. Publications issued 1978, pp. 185-186.

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