Stratigraphy and sea-level fluctuations in the Upper Miocene Gram Formation, south-western Denmark

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Hansen, J. & Hansen, T. 2003–12–15: Stratigraphy and sea-level fluctuations in the Upper Miocene Gram Formation, south-western Denmark. *Bulletin of the Geological Society of Denmark*, Vol. 50, pp. 157–169, Copenhagen. ISSN 0011–6297. https://doi.org/10.37570/bgsd–2003–50–13

Correlation between four published and one unpublished lithological logs from the Gram clay pit permits a comparison between previous studies of this critical exposure. The boundary between the Gram Clay and the Gram Silt in the Gram clay pit is redefined. A sea-level curve, based mainly on foraminiferal data from the Sæd, Gram and Lille Tønde borings in southern Jutland, is con-structed and compared with a published sea-level curve from the North Sea. It appears that sea level recorded from southern Jutland was controlled mainly by eustacy.

Key words: Denmark, Gram Formation, Miocene, lithostratigraphy, sea-level fluctuations.

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The marine Gram Formation (Rasmussen 1956) was deposited from late Serravalian to Messinian (Miocene) (Laursen & Kristoffersen 1999). At that time the North Sea covered the western part of Denmark, but the precise position of the eastern palaeocoastline is uncertain due to subsequent erosion. In Denmark the formation is restricted to central and southwestern Jutland (Fig. 1) and crops out over most of Schleswig-Holstein in northern Germany. The formation consists mainly of dark grey micaceous clay and silt containing an abundant and diverse macrofauna of molluscs, bryozoans, echinoids, crabs, fishes and sea-mammals (e.g. Rasmussen 1956, 1961, 1966). The Gram clay pit is located in South Jutland (Fig. 1., Loc. G) and is the type locality of the Gram Formation (as it is defined by Rasmussen 1956). The adjacent Gram-1 boring (DGU File No. 141.277) (Fig. 1, site 5) was drilled in 1963 and has since then been used as the reference section for the formation in many publications.

Rasmussen (1956, 1966) divided the Gram Formation into the Glauconite Clay, Gram Clay and Gram Silt. The boundary between the Gram Clay and Gram Silt has not been defined in the clay pit, but the exact depth for the boundary is given in the Gram-1 boring.

The Gram Clay has been intensively studied including foraminiferal (Laursen & Kristoffersen 1999) and molluscan biostratigraphy (Rasmussen 1966). Lithological and palaeomagnetic studies are presented by Beyer (1987, 1993), Rasmussen (1956, 1966) and Rasmussen & Larsen (1989).

The lithological and stratigraphical studies on the Gram Formation at the type locality have never been connected, making comparisons difficult if not impossible. The first aim of this paper is therefore to compile the lithological data assembled by earlier authors and to redefine the boundary between the Gram Clay and Gram Silt in the Gram clay pit.

Even though the studies of the formation and its depositional environment have been many and extensive the aspect concerning the changes in relative sea level seems to have been overlooked. As this is an area which is beginning to gain interest because of its possible usefulness as a correlational tool, the second aim is to construct a sea-level curve for the Gram Formation of southern Jutland and compare it with one for the North Sea.

Material, methods and data

For the purpose of this paper a new log (Fig. 2) was measured in the now disused Gram clay pit. The exposed strata in the pit are approximately six metres thick. The measured section (Fig. 1, site 2) was extended more than one metre below current ground level. The boundary between the Gram Clay and Gram Silt was used as a reference level (Fig. 2).

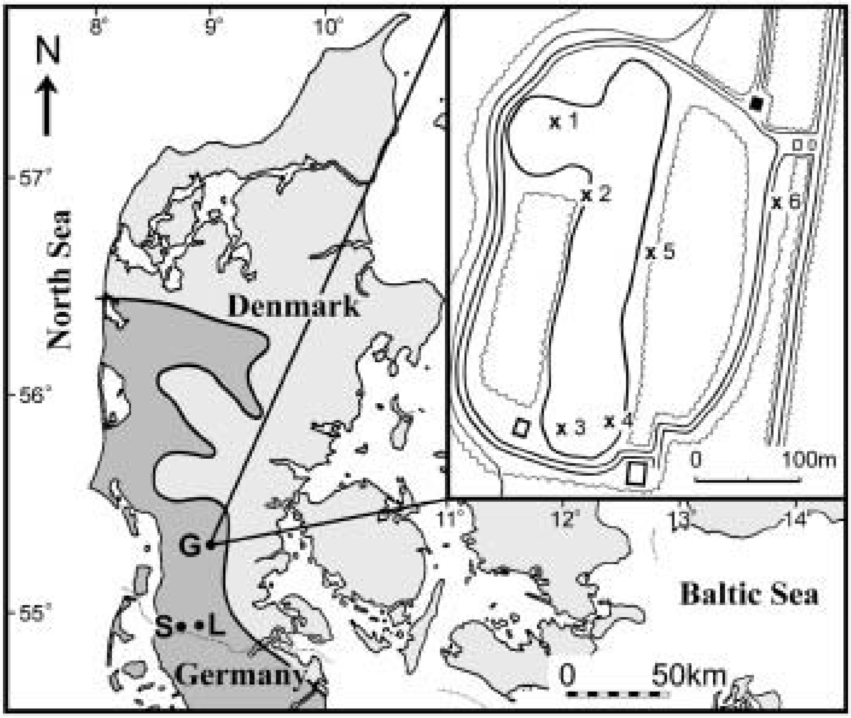


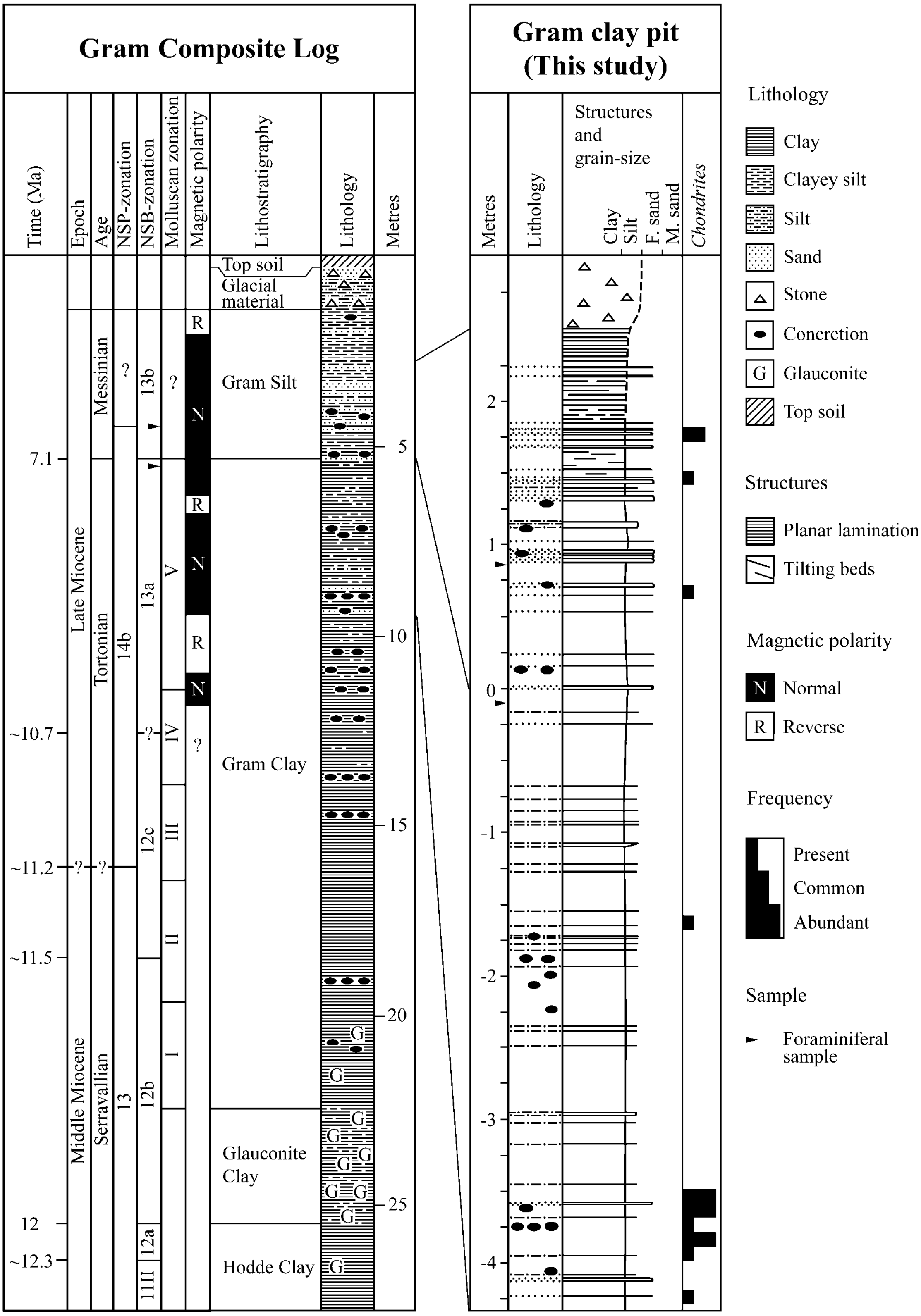
Fig. 1. Map showing the distribution of the Gram Formation in Denmark (from Rasmussen 1966) and the location of the localities: Gram (G), Sæd (S) and Lille Tønde (L). The smaller map shows the outline of Gram clay pit (Redrawn from Roth 1994). The crosses mark the investigated sites. Site 1: Beyer 1987, 1993; site 2: this study; site 3: Laugesen & Gilbe 1986; site 4: Rasmussen & Larsen 1989; site 5: Gram-1 (DGU File No 141.277) Rasmussen 1966; site 6: Rasmussen 1956.

The composite log was constructed by correlating the lithological logs from the clay pit to the Gram-1 bore log. In the few cases, where the depths of marker beds did not match exactly, the depths of the borehole were used. The least squares method was used to interpolate beds between the marker beds.

A sea-level curve was constructed for the Gram Formation, using the foraminifera (Laursen & Kristoffersen 1999) and the kaolinite/smectite analyses (Rasmussen & Larsen 1989) together with the lithological log. The distribution of the eight deep-water and benthic foraminifera species, *Cassidulina laevigata* d'Orbigny, *Globocassidulina subglobosa* (Brady), *Hoeglundina elegans* (d'Orbigny), *Melonis affine* (Reuss), *Pullenia bulloides* (d'Orbigny), *Sphaeroidina bulloides* d'Orbigny, *Uvigerina pygmaea langeri* von Daniels & Spiegler and *Uvigerina venusta deurnensis* de Meuter & Laga are used. The data are given in percentage intervals by Laursen & Kristoffersen (1999). Data in this study were assessed by taking the lower value for each percentage interval. The accumulated percentages of the eight deep-water species from the Gram-1 borehole and the upper and stratigraphically younger sample of this study were plotted (Fig. 4). This curve was compared and adjusted to the kaolinite/smectite ratios, which may be used as an indirect depth indicator, because of the differentiation during transport distances for the clay minerals (Rasmussen & Larsen 1989, pp. 49–50). Maximum peaks in the clay ratio are thus generally indicative of lowstands (nearshore), while low ratios mainly indicate highstands (more offshore) (Fig. 4). The distribution of silt and sand beds in the lithological log was used as a check on the variations seen in the two main indicators. The foraminiferal data from the Lille Tønde and Sæd boreholes (Laursen & Kristoffersen 1999) were analysed in the same manner and compared with those from the Gram-1 borehole.

A composite sea-level curve for South Jutland was constructed by combining the three curves on the basis of the foraminiferal zone boundaries. The foraminiferal NSB and NSP zones (Laursen & Kristof-

Fig. 2. The lithology, palaeomagnetic polarity and distribution of *Chondrites* at Gram clay pit. The lithological log has been constructed from a profile on the western slope of the pit (Fig. 1, site 2). The data on grain size are modified from Rasmussen & Larsen (1989). Chronostratigraphy and foraminiferal zonations are from Laursen & Kristoffersen (1999). The molluscan zonation follows Rasmussen (1966) and the palaeomagnetic data are from Beyer (1993). The left log is a composite log based on the Gram-1 boring (Rasmussen 1966; Beyer 1993; Laugesen & Gilbe 1986; Rasmussen 1956; Rasmussen & Larsen 1989; this study).


Gram Composite Log
Time (Ma)
Epoch
Age
NSP-zonation
NSB-zonation
Molluscan zonation
Magnetic polarity
Lithostratigraphy
Lithology
Metres
Top soil
Glacial material
Gram Silt
Gram Clay
Glauconite Clay
Hodde Clay
Late Miocene
Middle Miocene
Messinian
Tortonian
Serravallian
7.1
~10.7
~11.2
~11.5
12
~12.3
14b
13
13b
13a
12c
12b
12a
11II
V
IV
III
II
I
R
N
5
10
15
20
25
Gram clay pit (This study)
Metres
Lithology
Structures and grain-size
Clay
Silt
F. sand
M. sand
Chondrites
Lithology
Clay
Clayey silt
Silt
Sand
Stone
Concretion
Glauconite
Top soil
Structures
Planar lamination
Tilting beds
Magnetic polarity
Normal
Reverse
Frequency
Present
Common
Abundant
Sample
Foraminiferal sample

fersen 1999) were used to convert the sea-level curve to a chronostratigraphic scale (see Berggren, Kent, Swisher & Aubry 1995).

The sea-level curve from South Jutland was compared with the North Sea sea-level curve (Sørensen & Michelsen 1995). To assist correlation of the Southern Jutland sea-level curve with the other, palaeomagnetic data from the Gram clay pit (Beyer 1987) were compared with the palaeomagnetic log published by Cande & Kent (1992).

Lithological data from Gram clay pit

Only a few of the more important lithological features are presented below, but a more detailed description of the exposed upper Gram Clay and lower Gram Silt is found in Appendix A.

The lower 4.3 m of the profile (0 – 4.3 m below zero, Fig. 2) are dominated by homogeneous micaceous silty clay.

The sand bed taken as the zero datum is very rich in clay. Its thickness varies between zero and a few centimetres, but is generally about 1.5 centimetres thick.

The upper part of the profile (0 – 3.0 m above zero, Fig. 2) is characterised by an upward increase in grain size and quartz content and by distinctly thicker fine-sand beds. The bed of fine-grained sand situated 0.9 m above zero is one of the thickest and easiest to locate. It is at least 10 centimetres thick and is composed of four amalgamated beds.

Above the western part of the clay pit a few metres of a very sand-dominated unit within the Gram Silt can be studied. The transition from silty clay to well-laminated sand is not exposed and it is uncertain how thick the strata are between the studied section and the overlying younger sand. A log of the upper sand unit has been provided by Beyer (1993; Fig. 2).

The benthic fauna seems to have been mainly epibenthic or lived in the uppermost few centimetres of the sediment, otherwise the silt beds would have been destroyed. Among the different types of burrows observed in the section, only the distribution of the root-like *Chondrites* has been studied. It occurs at six levels, especially in the lowermost part of the profile (Fig. 2).

Foraminiferal data from Gram clay pit

Two samples from the studied section in the clay pit have been examined for their content of foraminifera. The lower sample is from 0.1 m below datum (Fig. 2) and constituted 200 g dry sediment. The fraction above 0.1 mm yielded about 3700 foraminifera. The following percentages of benthic taxa have been obtained:

<1% *Glandulina morsumensis* van Voorthuysen
12% *Hoeglundina elegans* d'Orbigny
7% *Melonis affine* (Reuss)
10% *Nonion bournaeum* d'Orbigny
10% *Sphaeroidina bulloides* d'Orbigny
4% *Textularia gramen* d'Orbigny
10% *Trifarina tenuistriata* (Reuss)
1% *Uvigerina pygmaea langenfeldensis* von Daniels & Spiegler
3% *Uvigerina pygmaea langeri* von Daniels & Spiegler

The sample is assigned to the foraminiferal NSB 13a Subzone on basis of the high percentages of *Sphaeroidina bulloides* and *Hoeglundina elegans* and low percentage of *Glandulina morsumensis*. The index species *Uvigerina pygmaea langeri* for NSB 13a Subzone has a rather low percentage occurrence, which might indicate the sample level is close to the upper boundary of the subzone.

The second sample of 45 g dry sediment was taken from 0.85 m above the zero datum (Fig. 2). The fraction above 0.1 mm was studied and yielded about 250 foraminifera. The following percentages of benthic taxa are calculated:

1% *Cassidulina laevigata* d'Orbigny
2% *Glandulina morsumensis* van Voorthuysen
4% *Hoeglundina elegans* (d'Orbigny)
5% *Melonis affine* (Reuss)
28% *Nonion boueanum* (d'Orbigny)
2% *Sphaeroidina bulloides* d'Orbigny
3% *Textularia gramen* d'Orbigny
2% *Trifarina tenuistriata* (Reuss)
0% *Uvigerina pygmaea langenfeldensis* von Daniels & Spiegler
2% *Uvigerina pygmaea langeri* von Daniels & Spiegler

The sample is assigned to the foraminiferal NSB 13b Subzone on basis of the relative high percentage of *Glandulina morsumensis* and low percentages of *Trifarina tenuistriata* and *Uvigerina pygmaea langeri* (cf. Laursen & Kristoffersen 1999).

The pelagic foraminifera *Bolboforma metzmacheri* is present in both samples, indicating a correlation with

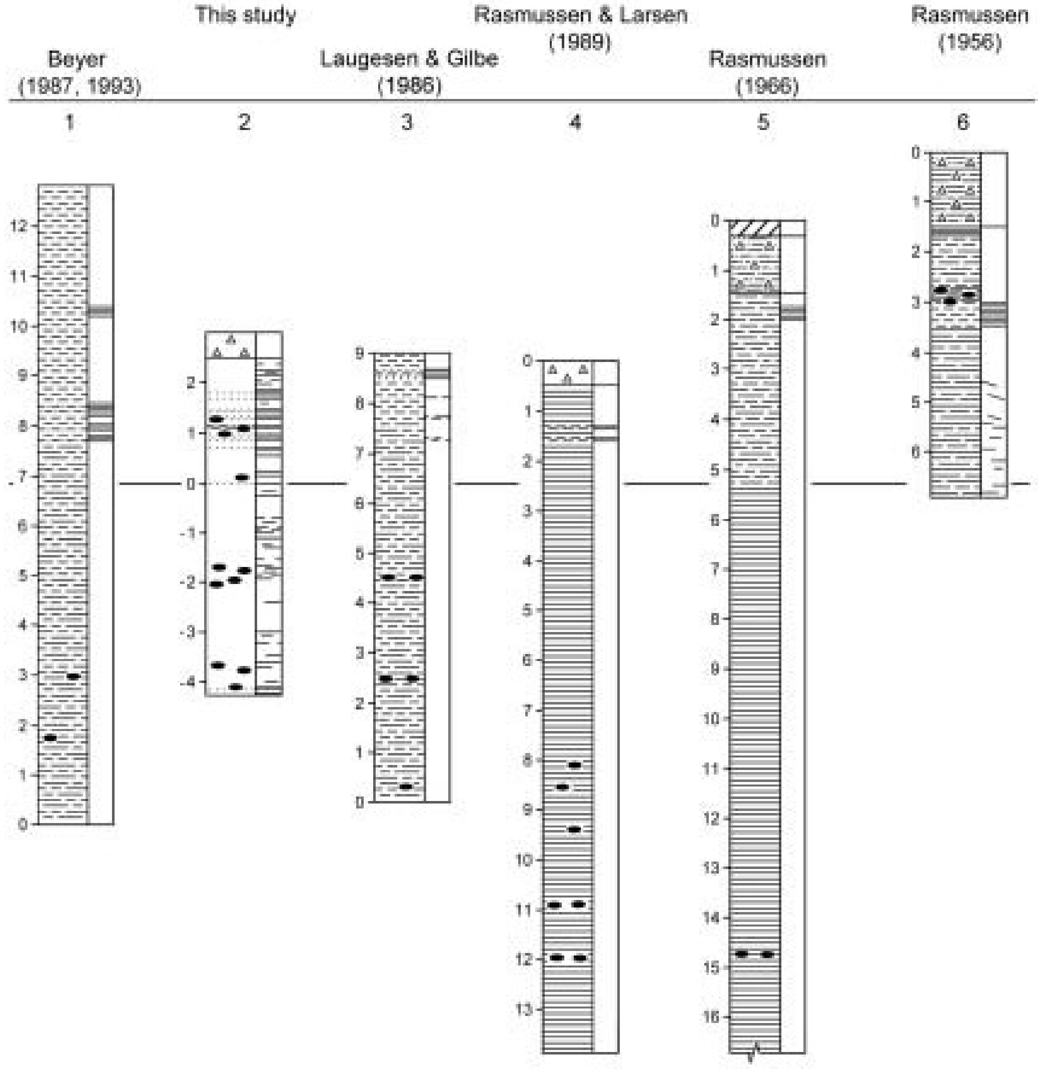


Fig. 3. Lithological logs of the upper part of the Gram Formation at the locality of Gram clay pit. The logs are situated with the Gram Clay/Silt boundary as datum. The lower nine metres of the log from Rasmussen (1966) have been omitted. For clarity, only the more distinct beds are shown in the lithological column on the log. Legend for symbols is shown in Figure 2.

the NSP 14b Subzone. This corresponds to observations on the Lille Tønde borehole (cf. Laursen & Kristoffersen 1999).

Lithostratigraphy in the Gram clay pit

Based on lithology, a correlation was made between the logs of Beyer (1987, 1993); Laugesen & Gilbe (1986) and Rasmussen & Larsen (1989) (Figs 1, 3, sites 1, 3 & 4) and the one presented in this study (Figs 1, 3, site 2). The single and most conspicuous sand bed observed in this study lies at about 0.9 m above datum. It provided the best tie point between the four logs, as it was present at all sites.

The boundary between the Gram Clay and Gram Silt is gradual (Rasmussen 1956) and therefore a precise definition was not given for the succession exposed in the clay pit. According to Rasmussen (1956) the boundary was located around halfway up in the south-western end of a long profile, but below ground level at the north-eastern end (Fig. 1, site 6). An exact

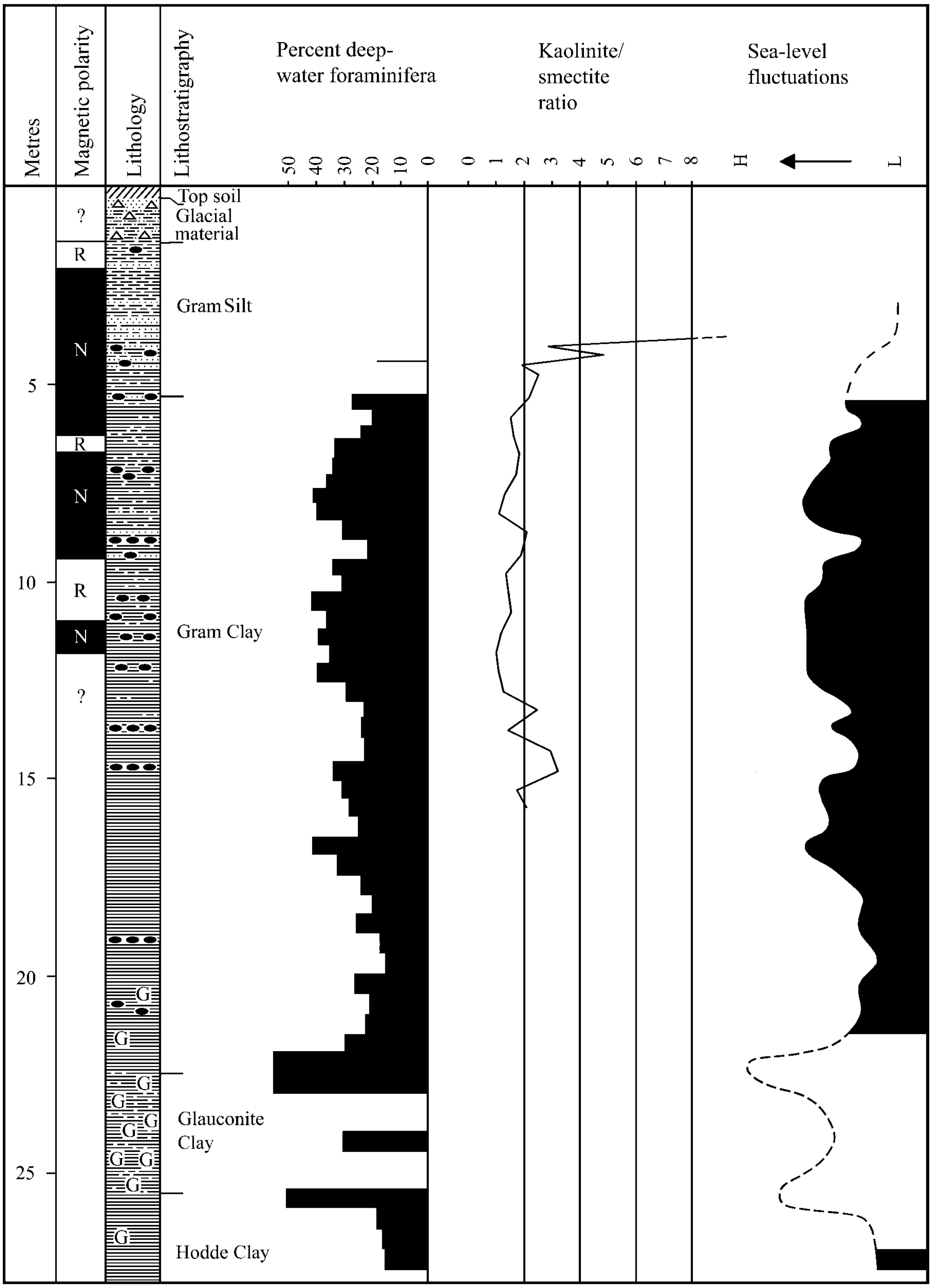


Fig. 4. Sea-level fluctuations based on lithology, percentage of deep-water foraminifera and the kaolinite/smectite ratios for the composite Gram log. Dotted lines indicate intervals with lack of or sparse data. H indicates highstand while L indicates lowstand. The palaeomagnetic log is from Beyer (1993).

depth at 5.3 m below ground level was later used as the boundary in the Gram-1 borehole (DGU File No. 141.277) (Rasmussen 1966, pp. 146–150) (Fig. 1, site 5).

The two foraminiferal samples examined herein indicate the datum level of this study lies at the NSB 13a/13b subzonal boundary. Laursen & Kristoffersen (1999) did not find NSB 13b subzone in the Gram Clay. The datum of this study must therefore lie at or above the Gram Clay/Silt boundary of Rasmussen (1966). This lead to the correlation shown on Figure 3, which is further corroborated by the observation of a general increase in the amount of small greenish grey pellets from 5.3 m (Gram Clay/Silt boundary) to between 6.4 and 6.9 m below surface in the Gram-1 borehole (see Rasmussen 1966, pp. 147, 149). The same increase was reported by Rasmussen & Larsen (1989, p. 18), who observed a general downward increase in the amount of pellets to about four metres below ground level or about 1.6 m below datum of this study. Consequently the Gram Clay/Silt Boundary of Rasmussen (1966) corresponds to the one to two centimetre thick fine-grained sand bed defined as the datum level in this study (Figs 2, 3).

Rasmussen (1956, p. 13) described a profile in the north-eastern end of his section (Fig. 1, site 6), where only the Gram Silt was exposed. The best fit between this profile and the other logs dealt with in this paper is shown in Figure 3. In this study inclined beds have been observed about 1.3 m above zero and upwards corresponding to those described by Rasmussen (1956). The inclination of the beds is probably due to glacial deformation.

Sea-level correlation

The Glauconite Clay was deposited in middle (30–100 m) to outer (100-200 m) neritic shelf environment, while the Gram Clay was deposited during rising sea level in an outer neritic environment (Laursen & Kristoffersen 1999). The succeeding Gram Silt was deposited in a middle neritic environment resulting from a general shallowing of the sea. The data on which the interpretations were based however, allow for a higher resolution, which is attempted here.

The first step is to compare the foraminiferal data with the kaolinite/smectite ratio and the composite lithological log of this study. At nearly 15 m below ground level the kaolinite/smectite ratio reaches a maximum while the foraminifera indicate a high sea level (Fig. 4). A high kaolinite/smectite ratio indicates near coast environments (Rasmussen & Larsen 1989). This discrepancy may relate to small correlational problems or to differences in sampling procedure. The foraminiferal percentages thus represent sample intervals, while the clay samples represent specific levels.

From the Gram Clay/Silt boundary at 5.3 m and upwards, no foraminiferal samples have been obtained from the clay pit except for the one at approximately 4.5 m investigated in this study. For this reason only a tentative sea-level curve could be constructed on the basis of the kaolinite/smectite ratio (Rasmussen & Larsen 1989) and the lithological log for the Gram Silt at Gram. From the boundary and upwards a shallowing trend is obvious (Fig. 4). The foraminiferal checkpoint is in agreement with the kaolinite/smectite curve. Above the last level measured by Rasmussen & Larsen (1989) (~3.55 m) the sea level apparently continues to fall, since the sediment between the storm beds are more sandy. The exposed and very sandy section above the western part of the pit (Beyer 1987) indicates that sea level during the deposition of the youngest strata was lower than during deposition of any earlier part of the Gram Formation.

It is of interest that in the upper part of the formation logged by the present authors, *Chondrites* is present only at levels deposited during periods of low sea level. This ichnofossil thus seems to be useful, here, as a palaeobathymetric indicator.

The constructed sea-level curve is compared with data for variations in the percentages of deep-water foraminifera at Sæd and Lille Tønde (Laursen & Kristoffersen 1999). There is a fair agreement between the three sea-level curves (Fig. 5). The differences between Gram and Lille Tønde may largely be ascribed to the sparseness and scatter of data within the Lille Tønde boring. A distinct difference between the three curves occurs at the boundary between the subzones NSB 13a and NSB 13b. The curve from Sæd drops markedly and then stabilizes whereas the curves from Gram and Lille Tønde show a maximum followed by a more even decrease. At Sæd, the sharp boundary between the subzones NSB 13a and 13b indicates a hiatus (Laursen & Kristoffersen 1999). This is supported by the disappearance of deep-water foraminifera, indicating an abrupt change from relative deep to very shallow water. If the foraminiferal data for Sæd and Lille Tønde are compared, the most probable correlation of the low sea level at Sæd is with the first lowstand after the NSB 13a/13b subzonal boundary at Lille Tønde. The hiatus at Sæd then corresponds to about 4 m of the NSB 13a Subzone and over 2 m of the lowermost part of NSB13b Subzone at Lille Tønde. There might be a small hiatus within the thick sand beds above the datum in Gram clay pit.

The three sea-level curves from South Jutland were combined in a composite log (see Material, methods

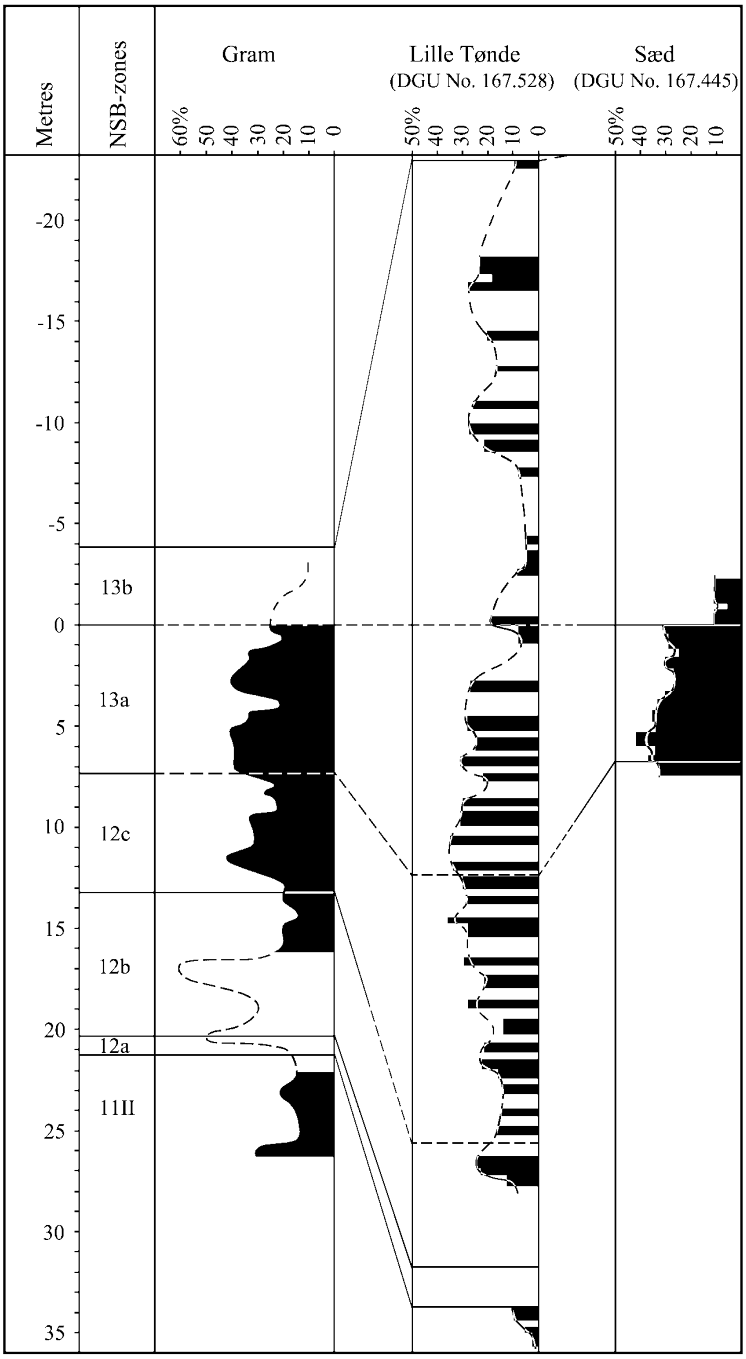
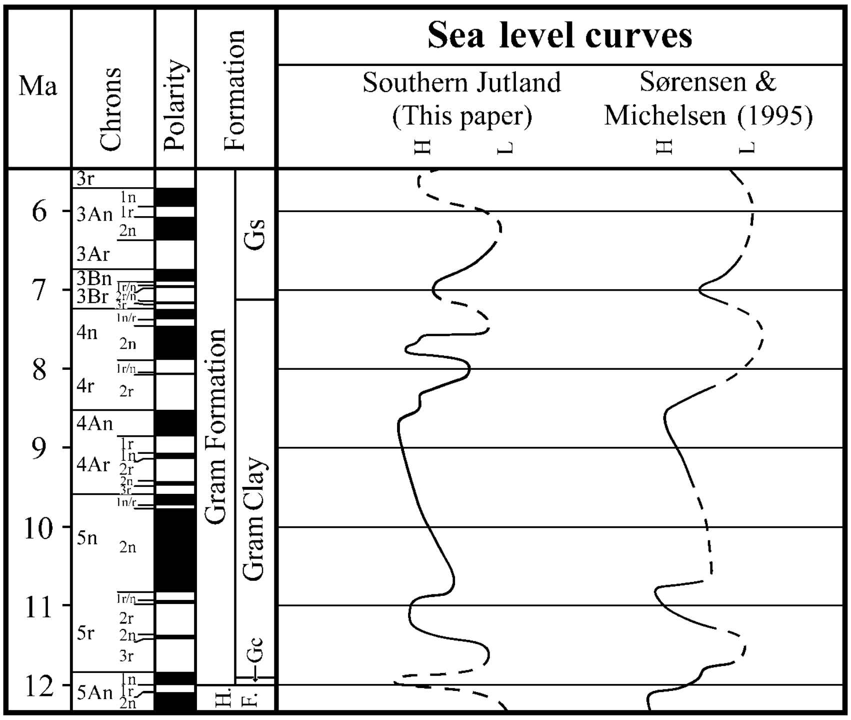


Fig. 5. Sea-level fluctuations based on deep-water foraminifera data presented by Laursen & Kristoffersen (1999). The datum lies at 5.3 m in the Gram-1 borehole, 33.25 m in the Lille Tønde borehole and at 92.7 m in the Sæd borehole. Sample intervals are in black.

Fig. 6. Correlations between southern Jutland and the North Sea sea-level curve. The curve from Sørensen & Michelsen (1995) has been converted to the time scale of Berggren *et al.* 1995. The geomagnetic polarity time scale is based on the one published by Cande & Kent (1992). Gc = Glauconite Clay, Gs = Gram Silt, H.F. = Hodde Formation.



and data). In order to facilitate a comparison of the constructed sea-level curve with that presented by Sørensen & Michelsen (1995), the latter was reassessed according to the revised time scale proposed by Berggren *et al.* (1995) and Laursen & Kristoffersen (1999). The composite curve of the present study was converted by correlating all the boundaries of the foraminiferal biozones and subzones into the time scale used by Laursen & Kristoffersen (1999) and afterwards assuming homogenous sedimentation between those boundaries.

The palaeomagnetic data reported by Beyer (1987, 1993) were furthermore reassessed on the basis of foraminiferal zone and subzone boundaries and the palaeomagnetic logs of Berggren *et al.* (1995) and Cande & Kent (1992). The two lower intervals of reversed polarity, noted by Beyer (1993) are on basis of the foraminiferal zone-boundaries confined to a time interval between 7.1 and about 10.7 Ma (Fig. 2). The lower reversed polarity of Beyer (1993) coincides with a regression (Fig. 4). This makes it correlateable with chron C4r from about 8.1 to 8.7 Ma corresponding to a similar regressive phase on the sea-level curve of Sørensen & Michelsen (1995) (Fig. 6).

The following reversed polarity zone of Beyer (1993) correlates to chron C4n1r (7.6–7.7 Ma) or C3Br (7.1–7.4 Ma) (cf. Berggren *et al.* 1995). The former should, according to the revised sea-level curve of Sørensen & Michelsen (1995), correlate to a general regression and lowstand, while the latter corresponds to a general transgression (Fig. 6). The actual reverse coincides with a general regressive phase (Fig. 4) and is furthermore followed by a large normal polarity-zone conflicting with the approximately synchronous upper boundaries of the NSB 13a Subzone and chron C3Br. The reversed interval is thus most likely to correspond to chron C4n1r, while chron C3Br probably is missing (Fig. 6). The Gram Clay/Silt boundary should following Laursen & Kristoffersen (1999) be situated between chron C3Bn and C3Br. The reversed polarity zone from above 7.1 Ma (Fig. 2) observed by Beyer (1993) is correlated to Chron C3Ar (6.6–6.9 Ma) (Fig. 6).

The two sea-level curves correlated in Figure 6 are broadly similar. The South-Jutland Miocene sea-level changes were apparently controlled by regional oscillations and only to a lesser degree by local factors during deposition of the Gram Formation.

The curves do not match at the interval around 12 Ma, i.e. the Glauconite Clay Maximum Flooding Surface (Fig. 6). It must be pointed out that the values extracted from the foraminifera in this interval are very tentative because the material is too sparse and therefore inconclusive. The pronounced, slightly ear-

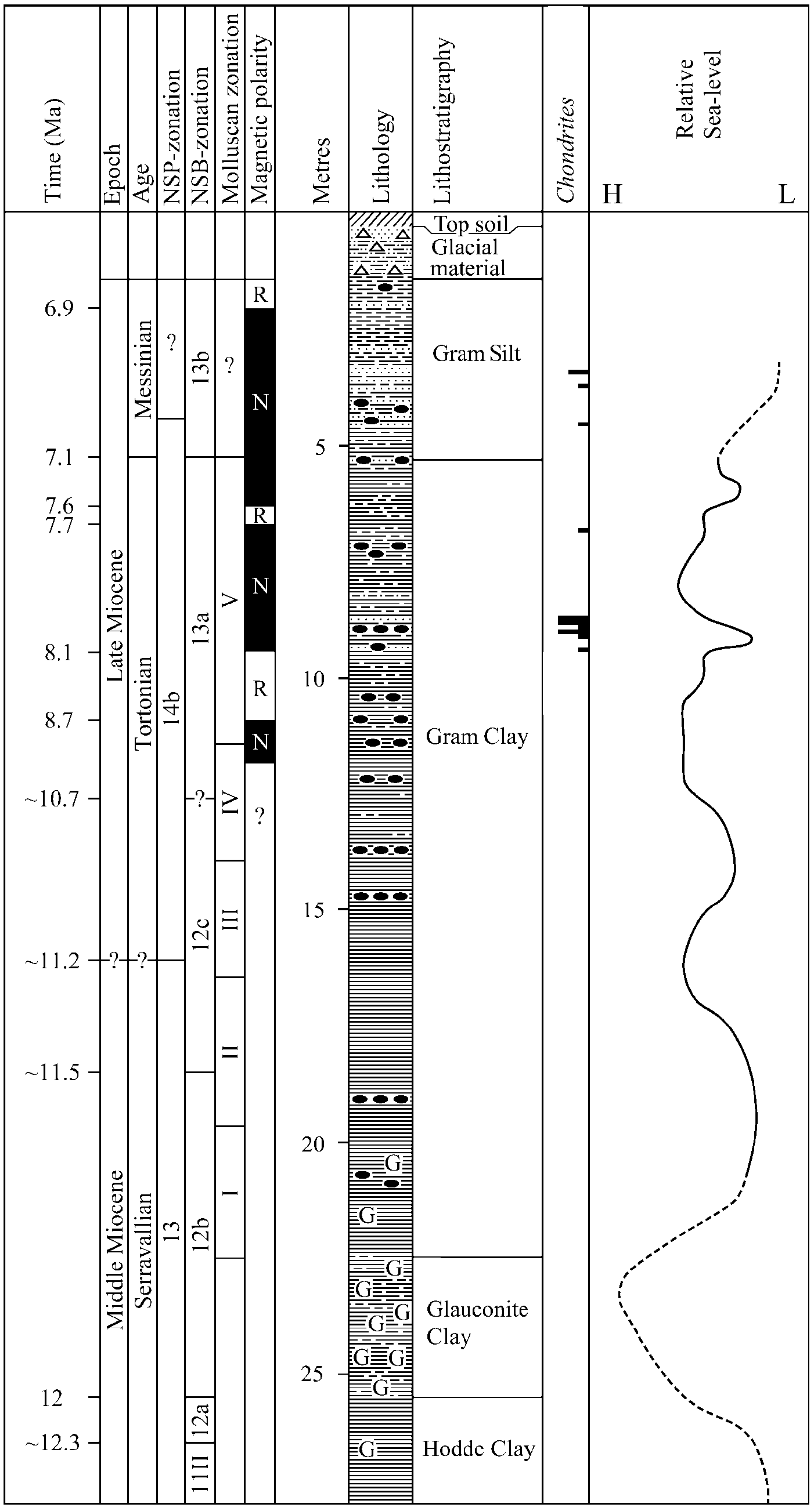


Fig. 7. Scheme showing the chronostratigraphic age of the sequence together with a relative sea-level curve and data for the distribution of *Chondrites* from the Gram clay pit. The ages are based on data from Beyer (1987, 1993), Laursen & Kristoffersen (1999), Sørensen & Michelsen (1995), Cande & Kent (1992) and Berggren *et al.* (1995).

lier highstand indicated by Sørensen & Michelsen (1996) could mark the same spike. If so, the interval is older than the 12.0 million years indicated by the foraminiferal zonation. This is supported by data from Alkærsig, Denmark, where the basal Gram Clay tentatively is assigned to the NSB 12a Subzone indicating an age between 12.3 and 12.0 Ma for the Glauconite Clay (cf. Laursen & Kristoffersen 1999). The highstand in the upper part of the NSB 13a Subzone in South Jutland confined to the time interval between 8 and 7.5 Ma on basis of palaeomagnetic data, does not match with any highstand on the North Sea sea-level curve (Fig. 6). It is probably too short to have been registered on the seismic data used by Sørensen & Michelsen (1995).

The small highstand at the foraminiferal boundary between the NSB 13a and 13b subzones followed by a marked lowstand is similar to the highstand seen at 7 Ma on the curve presented by Sørensen & Michelsen (1995). The reason for the relatively small amplitude of the high-stand is probably related to a hiatus or condensed layer at the NSB 13a/13b subzonal boundary as proposed by the palaeomagnetic data.

A further study on Miocene sea-level oscillations in southern Jutland has been presented by Rasmussen (1996). This study was based on seismic data and petrophysical borelogs and included the interval from Late Oligocene to the beginning of Late Miocene. His correlation with the sea-level curve proposed by Prentice & Matthews (1988) is realistic. But lithologically the correlation between a sandy interval at 10 Ma and the Glauconite Clay noted by Dinesen (1976) is incorrect. The reason for this correlation is obviously that the boundary between the Middle and Upper Miocene has been changed from that between the Hodde and Gram formations to one within the lower half of the Gram Formation.

It is emphasized that the ecostratigraphical correlation, based on the relative abundance of deep-water foraminifera, provides a high-resolution correlation between the borings, despite the fact that exact assignments to specific foraminiferal zones occasionally is problematic, possibly due to reworking. Furthermore some biozone boundaries or other time specifying markers are required as a frame for comparison; otherwise the equivalent sea-level oscillations may be incorrectly correlated. Such a problem occurs in the NSB 13b Subzone at Lille Tønde, Sæd and Gram. Here data suggest that the highest part of NSB 13b cannot be younger than 5.5 Ma (Laursen & Kristoffersen 1999). If this upper limit in time had not been inferred it would be very easy to make the error correlating the proposed highstand to the much younger one topping at the end of Early Pliocene (cf. Sørensen & Michelsen 1995, fig. 37). As a consequence this highstand indicated by the foraminiferal assemblage in the Lille Tønde borehole is missing on the North Sea sea-level curve.

Conclusion

With the aid of a new, detailed lithological log of the succession exposed at Gram clay pit, a correlation with previously published logs has been made. These correlations make it possible to compare the various studies on palaeontology, geochemistry, sedimentology and palaeomagnetism carried out at the clay pit. The boundary between the Gram Clay and Gram Silt is defined in the Gram clay pit by correlation with the Gram-1 boring.

Based primarily on foraminiferal data from Laursen & Kristoffersen (1999), detailed sea-level curves are constructed for the Gram, Sæd and Lille Tønde borings of southern Jutland. These were compiled into a composite sea-level curve for the Middle and Upper Miocene of onshore Denmark (Fig. 7). Comparison with a previously published sea-level curve for the North Sea shows an overall good agreement, suggesting that the local sea-level changes mainly reflect eustatic fluctuations. The correlation of sea-level oscillations indicates that the Gram Formation was deposited from between 12.3 and 12.0 to about 5.5 million years ago.

Dansk sammendrag

Med udgangspunkt i en ny litologisk opmåling af den øvre del af Gram Formationen i Gram Lergrav er tidligere publicerede og upublicerede lagsøjler blevet korreleret. I den forbindelse foreslås grænsen mellem Gram Ler og Gram Silt placeret ved basis af et ca. 1,5 cm tykt finsandslag beliggende indenfor få centimeters nøjagtighed af den angivne grænse i den nærliggende Gram-1 boring (D.G.U. File Nr. 141.277). Der er blevet foretaget sammenligninger med mellem til sen miocæne havniveaukurver fra Sæd og Lille Tønde boringerne i Sønderjylland, og en generel havniveaukurve for Sønderjylland er konstrueret. Denne er sammenlignet med en tidligere publiceret kurve fra Nordsø-bassinet. Overordnet er disse kurver sammenlignelige, hvilket betyder, at havniveauet i Sønderjylland overvejende har været regionalt og ikke lokalt styret under aflejringen af Gram Formationen. Undersøgelsen viser yderligere, at det procentvise indhold af dybvandsforaminiferer kan bruges som et værktøj til at få en finere stratigrafisk inddeling og større tidsmæssig præcision, end der kan opnås alene ved brug af gængse biostratigrafiske metoder. De fundne aldre fremgår af Figur 7. I Gram Lergrav er den stratigrafiske forekomst af sporfossilet *Chondrites* relateret til lavt havniveau.

Acknowledgements

The authors thank Arne Thorshøj Nielsen for his help and guidance concerning the presentation of the sea-level variations seen at Gram and especially for his review and criticism of the paper. Thanks are also due to Hans Jørgen Hansen for his help with one of the foraminifera, to Peter Laugesen for permitting the use of data from the cand.scient. thesis of Laugesen & Gilbe (1986) and to Midtsønderjyllands Museum for their help in obtaining the palaeomagnetic report of Beyer (1987). David A.T. Harper, David L. Bruton and Bent E.K. Lindow are thanked for their constructive criticisms and improvement of the English text and E.S. Rasmussen and S. Piasecki for their review. Finally we wish to thank G.V. Laursen for her large and constructive review.

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Appendix A

The exposed strata in the Gram clay pit is approximately six metres thick. The measured section (Fig. 1, site 2) was extended more than one metre below current ground level. The boundary between the Gram Clay and Gram Silt was used as a reference level (Fig. 2).

The lower 4.3 m of the profile (0 - 4.3 m below zero, Fig. 2) is dominated by homogeneous micaceous silty clay. The fine-grained sediment is frequently interbedded with thin silty to sandy layers or lamina. In the lowermost 1.3 m., three sandy beds each with a thickness of about two centimetres occur. All other layers, except for one 0.25 m below zero, are less than one millimetre thick and therefore easily overlooked. The interval from 1.85 to 1.65 m below zero is characterised by sporadic layers of fine-sand formed by extensive bioturbation of the silt layers, which have been preserved only locally. The coarse material characterising the beds is generally dominated by authigenic and biogenic components such as pyrite and molluscs. Some of the molluscs are fragmented or show signs of attrition.

The upper part of the profile (0–3.0 m above zero, Fig. 2) is characterised by an upward increase in grain size, by distinctly thicker fine-sand beds and by a marked decrease in the fossil content from 0.5 m above zero and upward. The sand beds are characterised by a distinctly erosive base, fine planar lamination, and almost no bioturbation; in a few cases there is a fining upward trend. The quartz content generally increases upwards in the profile giving the layers a light grey appearance. Normally the fossils are dispersed throughout the beds. The sandy beds are a few centimetres thick in most places, but this varies laterally and some of the sandy beds disappear. The sand bed taken as the zero datum is very rich in clay. Its thickness varies between zero and a few centimetres, but is generally about 1.5 centimetres thick. The bed of fine-grained sand situated 0.9 m above zero is one of the thickest and easiest to locate. It is at least 10 centimetres thick and is composed of four amalgamated beds.

Erosion at the base of the sand bed at 1.45 m above the zero datum has been considerable (Fig. 2).

An interval with densely packed sand beds about 1.5 m above zero marks the base of a less homogeneous, more stratified dark sediment rich in light grey fine-grained quartz sand. This interval and the following deposits are nonfossiliferous; the few fossils present are represented by moulds.

The strata are generally horizontal, but units with dips of up to 20°(NE) have been observed adjacent to the fine grained sand bed 1.35 m above datum (Fig. 2) and above. Small fractures and faults are also common. These structures are possibly due to glacial deformation.

The upper half metre of the profile is of glacial or modern origin with a high content of stones and gravel. The colour of the sediment is reddish brown. The boundary between this unit and the underlying strata is often indistinct. Above the western part of the clay pit, a few metres of a sand-dominated unit within the Gram Silt can be studied. The transition from silty clay to well-laminated sand is not exposed and it is uncertain how thick the strata are between the studied section and the overlying younger sand.

Siderite concretions have been observed from four intervals; two in the lower half and two in the upper (Fig. 2). Of these, only the levels about 2 and nearly 4 m below zero are rich in concretions. The concretions do not occur in well-defined beds, but are located in relatively thick intervals, spanning more than 30 centimetres in the uppermost of those two horizons. The concretions are most abundant in the middle of the intervals, becoming sparser up and downwards. The concretions located in an interval from 0.75 to 1.3 m above zero are not preferentially concentrated. All concretions found in this study are around 10 centimetres in diameter.