DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/96

Dinocyst zonation and lithostratigraphy of the Miocene Succession in the Westerlangstedt-BR1 borehole

Karen Dybkjær & Erik S. Rasmussen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/96

Dinocyst zonation and lithostratigraphy of the Miocene Succession in the Westerlangstedt-BR1 borehole

Karen Dybkjær & Erik S. Rasmussen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

Contents

Summary

This report presents the results of a detailed biostratigraphic analysis of the Miocene succession in the borehole Westerlangstedt-BR1, based on fossil dinoflagellate cysts (dinocysts). The borehole is located south of the village Eggebek, south of Flensburg in Germany, (Fig. 1) and was drilled in 2005 using the “straight flush”-drilling method.

The purpose of the study is to test whether the recently published Danish Miocene dinocyst zonation of Dybkjær & Piasecki (2010) can be applied to the Miocene succession in the Schleswig-Holstein area and to provide a detailed and well-documented correlation between the Miocene succession in the Westerlangstedt borehole and the succession in the southern part of Jylland, Denmark.

Caving of Upper Miocene and Pliocene/Pleistocene material was found throughout the studied succession and also reworking of especially Jurassic and Palaeogene palynomorphs was observed. In spite of these problems it was possible with confidence to subdivide the studied succession using the dinocyst zonation defined by Dybkjær & Piasecki (2010) and based on that, to correlate the succession with the Danish Miocene succession, as outlined in the following;

The following dinocyst zones were found:
372 m – 339 m: The *Sumatradinium hamulatum* Zone (Lower Miocene)
339 m – 285 m: The *Cordosphaeridium cantharellus* Zone (Lower Miocene)
285 m – 246 m: The *Exochosphaeridium insigne* Zone (Lower Miocene)
246 m – 231 m: The *Cousteaudinium aubryae* Zone (Lower Miocene)
231 m – 186 m: The *Labyrinthodinium truncatum* Zone (Middle Miocene)
186 m – 132 m: The *Unipontodinium aquaductum* Zone (Middle Miocene)
132 m – 117 m: The *Achomosphaera andalousiense* Zone (Middle Miocene)
117 m – 87 m: The *Gramocysta verricula* Zone/*Amiculosphaera umbraculum* Zone (Middle to Upper Miocene)

Based on a combination of the dinocyst stratigraphy, the lithology of the samples and the geophysical log-pattern, the studied succession can be subdivided into the following lithostratigraphic units, following the lithostratigraphy defined in the Danish area (Rasmussen *et al.*, in press);
1) 372,4 m (TD)–348 m: The Klintinghoved Formation
2) 348 m–292 m: The Bastrup Formation
3) 292 m–252 m: The Arnum Formation
4) 252 m–164m: The Odderup Formation
5) 164 m–132 m: The Hodde Formation
6) 132 m–117 m: The Ørnhøj Formation
7) 117 m–80 m: The Gram Formation

The Miocene succession is unconformably overlain by Quaternary deposits.

Introduction

The present report is based on cuttings samples from the borehole Westerlangstedt BR-1, located south of the village Eggebek in Schleswig-Holstein, Germany. The location of the well is shown in Figure 1.

The purpose of the study was to test if it is possible to apply the dinocyst zonation defined in the Danish area (Dybkjær & Piasecki, 2010) to the Schleswig-Holstein area and to present a detailed correlation between the Miocene succession found in the Westerlangstedt well and the Danish Miocene succession.

The results of the study are presented within the frame of the lithostratigraphy of Rasmussen *et al.* (in press) (Fig. 2) and the dinocyst zonation of Dybkjær & Piasecki (2010) (Fig. 3).

Figure 1: Location of the Westerlangstedt-BR-1 borehole and of the Danish boreholes included in the log-correlation panel in Figure 6.

Material and methods

The present report is based on cuttings samples from the borehole Westerlangstedt-BR1, in Germany (Fig. 1). The borehole was drilled in 2005 using the “straight-flush”-drilling method. The samples in the interval from 372,4 m (TD) and up to 80 m, each representing an interval of 3 m, were described lithologically and a total of 63 samples were selected for the palynological study. The samples were processed following standard palynological preparation methods, including treatment with HCl, HF, heavy liquid separation and brief oxygenation with $HNO_{3.}$ Following sieving on 20 µm filters the organic residue was mounted on glass slides using a glycerine jelly medium. The dinoflagellate cyst (dinocyst) content was analysed using a normal light microscope. A semiquantitative analysis consisting of counting at least 200 dinocysts from each sample, were performed where possible (in some samples there were to few dinocysts). All other marine algae, acritarchs and freshwater algae observed while counting the 200 dinocysts, were registered in order to assess the abundance of dinocysts relative to these other palynomorph groups. The qualitative analysis consisted of a thorough study of two palynological slides per sample in order to register all dinocyst species occurring in each sample. The taxonomy used herein follows “The Lentin & Williams Index” (Fensome & Williams, 2004).

In the text, dinocyst taxa which comprise more than 10% of the total number of dinocysts are ”dominant”, 5–10% are ”common”, 2–4% are frequent and an occurrence of less than 2% are ”sporadic” or ”consistent”, depending on whether the taxa in question occurs only in a few of the samples representing the described interval, or if it occurs in most of the samples.

The results of the palynological study are presented in Enclosure 1 and 2. The variations in the dinocyst assemblage and in the freshwater algae assemblage shown in Enclosure 1, reflect partly stratigraphic changes and partly changes in the depositional environment, e.g. in salinity, nutrient availability and sea water temperature. Dinocyst taxa, which are interpreted as a result of caving (downfall of material from younger strata during the drilling process) are marked with a ”C”. Occurrences marked with a ”?” indicate that the identification to species or genus level is questionable. Reworked dinocyst taxa are presented in a separate panel. Variations in the relative abundances within the dinocyst group are presented in Enclocure 2.

Based on first- and last occurrences of stratigraphically important species (”events”) the studied succession is subdivided into the dinocyst zonation defined by Dybkjær & Piasecki (2010) (Figs. 3, 4; Enclosures 1, 2). Furthermore, the succession is correlated with the Danish Miocene lithostratigraphic units (Rasmussen *et al.*, in press) (Figs. 2, 5). A log-correlation panel running north-south, from the Danish Rødding borehole to the Westerlangstedt borehole, is presented in Figure 6 in order to illustrate the straight forward correlation.

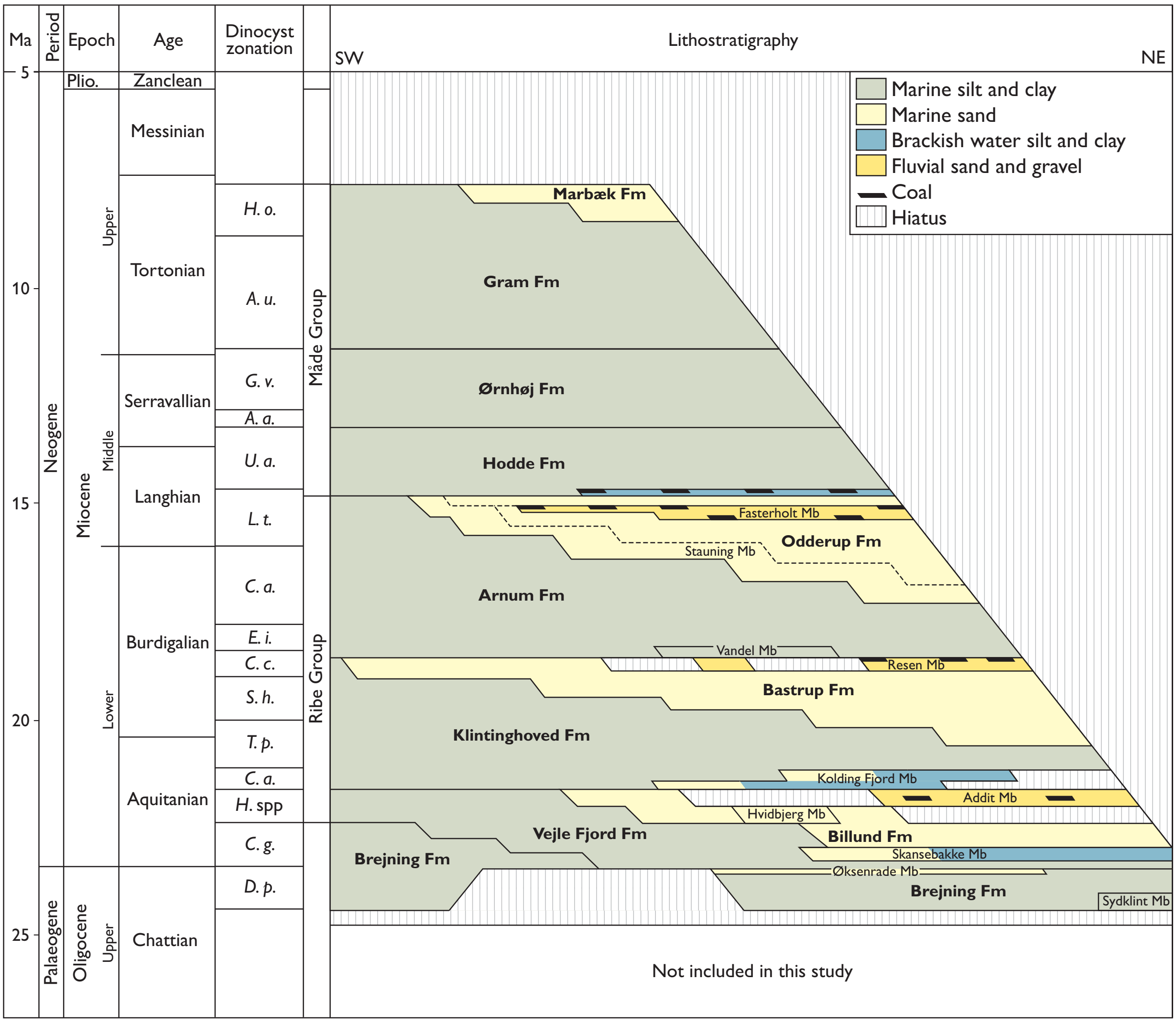

Fig. 2. Lithostratigraphy of the Danish Miocene (Rasmussen *et al.*, in press).

Palynology/biostratigraphy

The results of the palynological analysis are presented in Figure 4 and in Enclosures 1 and 2 and are discussed below. In Enclosure 1 all the recorded dinocyst species are presented, (whether interpreted as *in situ*, caved or reworked). The dinocysts species interpreted as reworked are shown separately. In addition, the recorded freshwater algae, acritarchs and ”other marine algae” (OM) are shown. The recordings are presented as percentages of the total number of dinocysts, acritarchs, freshwater algae and ”other marine algae”. In Enclosure 2 only the presumed ”*in situ*” and the caved dinocysts are shown in order to present the variations within the dinocyst group.

The *Sumatradinium hamulatum* Zone, 372 m – 339 m

Dinocyst zonation

This interval is referred to the *Sumatradinium hamulatum* Zone (Dybkjær & Piasecki, 2010) due to the presence of *Sumatradinium hamulatum* in the sample at 369–372 m and the first occurrence of *Exochosphaeridium insigne* in the sample at 336–339 m (Enclosure 1).

Dinocyst assemblage

The rather limited dinocyst assemblage is dominated by *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp., while *Apteodinium tectatum*, *Cordosphaeridium cantharellus*, *Dapsilidinium pseudocolligerum*, *Operculodinium* spp. and *Spiniferites pseudofurcatus* are common (Enclosure 2).

Severe caving during the drilling process is indicated by the presence of e.g. *Achomosphaera andalousiense*, *Cannosphaeropsis passio*, *Labyrinthodinium truncatum* and *Palaeocystodinium miocaenicum*/*minor*. In addition, reworking of Palaeogene deposits is indicated by the presence of e.g. *Eatonicysta ursulae*, *Diphyes* spp. and *Wetzeliella* spp. (see further Enclosure 1).

Age

Burdigalian (Early Miocene) (Fig. 3).

Depositional environment

The somewhat limited *in situ* dinocyst assemblage combined with abundant reworked dinocysts and a high, relative abundance of freshwater algae indicate a shallow marine depositional environment with some influence by freshwater run-off from land. This is supported by abundant terrestrial pland remains, i.e. wood-particles, cuticles and non-saccate and bisaccate pollen.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, the lower part of this interval (up to 348 m) is correlated with the Danish Klintinghoved Formation, while the upper part is correlated with the Bastrup Formation (Fig. 2).

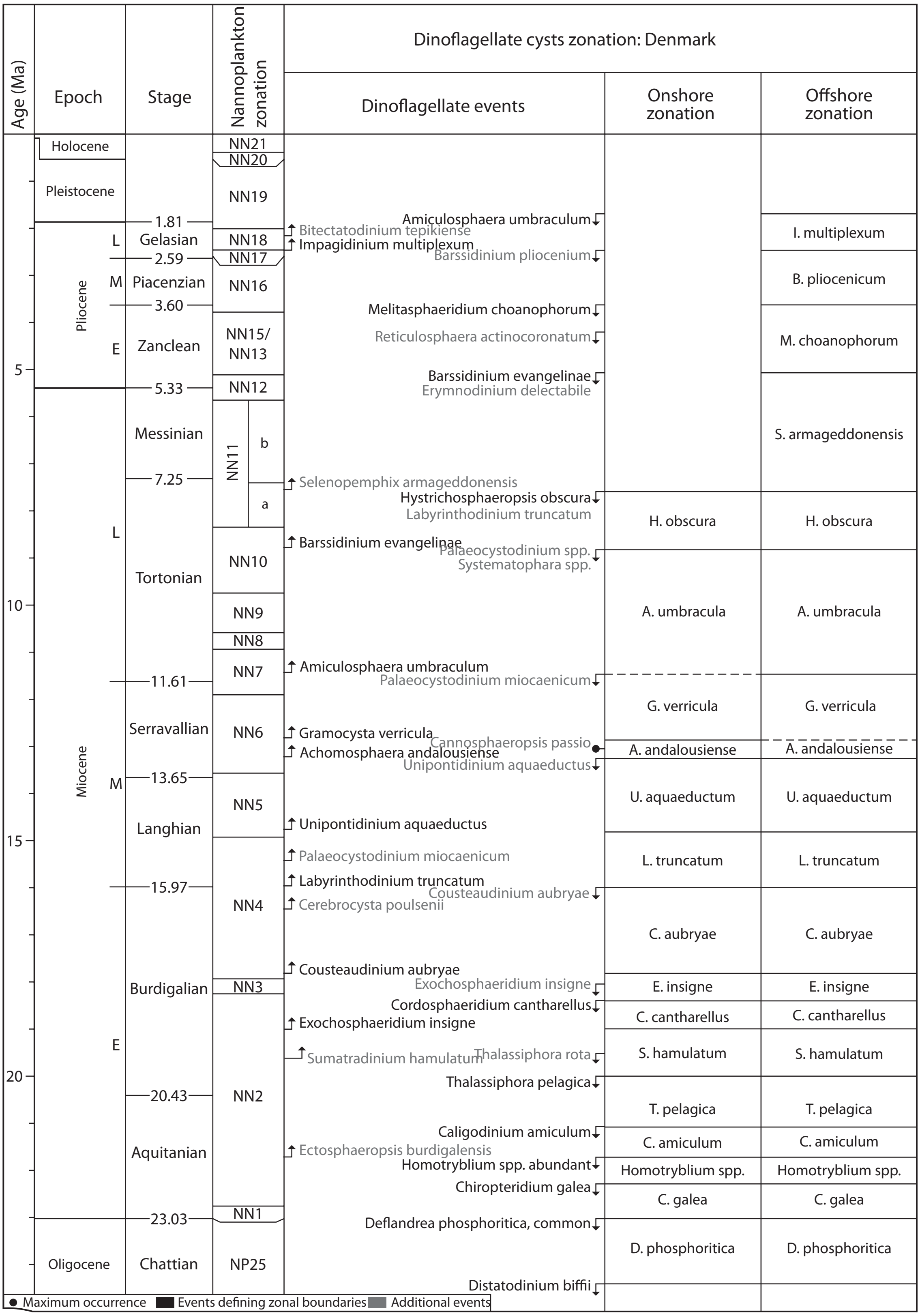

Figure 3: Dinocyst zonation (Dybkjær & Piasecki 2010). The species names shown in black marks the events (first or last occurrences, or abundance occurrences) defining the zonal boundaries. The species names shown in grey are additional stratigraphic usefull events.

The *Cordosphaeridium cantharellus* Zone, 339 m – 285 m

Dinocyst zonation

This interval is referred to the *Cordosphaeridium cantharellus* Zone (Dybkjær & Piasecki 2010) due to the first occurrence of *Exochosphaeridium insigne* in the sample at 336–339 m and the last occurrence of *Cordosphaeridium cantharellus* in the sample at 282–285 m (Enclosure 1).

Dinocyst assemblage

The dinocyst assemblage is very sparse in the lower part of the interval, up to about 294 m. In the upper part of the interval the assemblage becomes more rich and diverse. The assemblage is dominated by *Cleistosphaeridium placacanthum*, *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp. In the upper part of the interval, from 294 m, *Apteodinium australiense* and *A.* cf. *australiense* also dominates, while *A. tectatum*, *Cordosphaeridium cantharellus*, *Dapsilidinium pseudocolligerum* and *Spiniferites pseudofurcatus* are common (Enclosure 2)

Severe caving is indicated by the presence of e.g. *Achomosphaera andalousiense*, *Cerebrocysta poulsenii*, *Habibacysta tectata*, *Labyrinthodinium truncatum*, *Palaeocystodinium miocaenicum*/*minor* and *Unipontodinium aquaductum*. In addition, reworking of Jurassic, Cretaceous and Palaeogene deposits is indicated by the presence of *Gonyaulacysta jurassica*, *Chatangiella* spp., *Deflandrea* spp., *Glaphyrocysta pastielsii* and *Wetzeliella gochtii* (Enclosure 1).

Age

Burdigalian (Early Miocene) (Fig. 3).

Depositional environment

The lower part of the interval, up to and including the sample at 300–303 m, comprises a very limited *in situ* dinocyst assemblage and the freshwater algae *Pediastrum* occurs in high numbers (Enclosure 1). These observations indicate a nearshore marine depositional environment strongly influenced by freshwater run-off from land. This is supported by abundant wood-particles and non-saccate and bisaccate pollen. The upper part of the interval, represented by the samples at 291–294 m and 288–291 m, is characterised by distinctly more diverse and abundant dinocyst assemblages and few freshwater algae. This interval is interpreted as representing a marine depositional setting with minor freshwater influx.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, the lower part of this interval (up to 292 m) is correlated with the Danish Bastrup Formation, while the upper part is correlated with the Arnum Formation (Fig. 2).

The *Exochosphaeridium insigne* Zone, 285 m – 246 m

Dinocyst zonation

This interval is referred to the *Exochosphaeridium insigne* Zone (Dybkjær & Piasecki 2010) due to the last occurrence of *Cordosphaeridium cantharellus* in the sample at 282–285 m and the first occurrence of *Cousteaudinium aubryae* combined with the last occurrence of *E. insigne* in the sample at 243–246 m (Enclosure 1). The occurrences of *C. aubryae* in the samples at 264–267 m and 255–258 m are here interpreted as due to caving and the occurrences of *E. insigne* in the samples at 237–240 m and 228–231 m are interpreted as the result of reworking, as the range of these two species in previous studies do not overlap (Dybkjær & Piasecki 2010). However, the results from the present study may indicate that overlap can occur.

Dinocyst assemblage

The dinocyst assemblage is relatively rich and diverse. The assemblage is dominated by *Apteodinium tectatum*, *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp., while *A.* cf. *australiense*, *Cleistosphaeridium placacanthum*, *Dapsilidinium pseudocolligerum* and *Spiniferites pseudofurcatus* are common (Enclosure 2).

Severe caving is indicated by the presence of e.g. *Cannosphaeropsis passio*, *Cerebrocysta poulsenii*, *Cousteaudinium aubryae*, *Habibacysta tectata*, *Labyrinthodinium truncatum*, *Palaeocystodinium miocaenicum*/*minor* and *Unipontodinium aquaductum*. In addition, reworking of Jurassic, Cretaceous and Palaeogene deposits is indicated by the presence of *Cribroperidiunium* spp., *Chatangiella* spp., *Apectodinium* spp., *Deflandrea* cf. *heterophlycta*, *Deflandrea* spp. and *Wetzeliella* spp. (Enclosure 1).

Age

Burdigalian (Early Miocene) (Fig. 3).

Depositional environment

This interval is characterised by a diverse and abundant dinocyst assemblage and relatively few freshwater algae, however with an increasing abundance upwards, especially of *Pediastrum*. The interval is interpreted as representing a marine depositional setting with minor, but upwards increasing, freshwater influx.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, the major part of this interval is correlated with the Danish Arnum Formation. The uppermost part (from 252 m) is correlated with the Odderup Formation (Fig. 2).

The *Cousteaudinium aubryae* Zone, 246 m – 231 m

Dinocyst zonation

This interval is referred to the C*ousteaudinium aubryae* Zone (Dybkjær & Piasecki 2010) due to the combined first occurrence of *Cousteaudinium aubryae* and last occurrence of *E.*

insigne in the sample at 243–246 m and the last occurrence of *Cousteaudinium aubryae* in the sample at 228–231 m (Enclosure 1).

Dinocyst assemblage

The abundance and diversity of dinocysts are generally lower than in the interval below. The assemblage is dominated by *Polysphaeridium zoharyi* and *Spiniferites* spp., while *Apteodinium tectatum*, *Hystrichokolpoma rigaudiae* and *Operculodinium centrocarpum* are common (Enclosure 2).

The presence of *Labyrinthodinium truncatum* and *Palaeocystodinium miocaenicum*/*minor* is interpreted as being a result of caving during the drilling process. In addition, reworking of Palaeogene deposits is indicated by the presence of *Diphyes ficusoides*, *Deflandrea* spp. and *Wetzeliella* spp. (Enclosure 1). In addition, the presence of *Exochosphaeridium insigne* within this interval is here interpreted as the result of reworking of deposits referred to the dinocyst zone immediately below this one.

Age

Burdigalian (Early Miocene) (Fig. 3).

Depositional environment

This interval is characterised by a sparse dinocyst assemblage. The abundances of dinocysts and freshwater algae are about equal, with an increasing abundance of the freshwater algae *Pediastrum* upwards. The interval is interpreted as representing a marine depositional setting with a relatively high and upwards increasing freshwater influx. This is supported by high abundances of wood particles, cuticle and bisaccate pollen.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, this interval is correlated with the Danish Odderup Formation (Fig. 2).

The *Labyrinthodinium truncatum* Zone, 231 m – 186 m

Dinocyst zonation

This interval is referred to the *Labyrinthodinium truncatum* Zone (Dybkjær & Piasecki 2010) due to the last occurrence of *Cousteaudinium aubryae* in the sample at 228–231 m and the first occurrence of *Unipontodinium aquaductum* in the sample at 183–186 m (Enclosure 1). Due to severe caving, the first occurrence of *Labyrinthodinium truncatum* which define the lower boundary of this zone, cannot be pointed out in the present study.

Dinocyst assemblage

The abundance and diversity of dinocysts are generally low within this interval. The assemblage is dominated by *Apteodinium tectatum*, *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum*, *Spiniferites pseudofurcatus* and *Spiniferites* spp., while *Apteodinium tectatum*, *Cleistosphaeridium placacanthum*, *Dapsilidinium pseudocolligerum*, and *Lingulodinium machaerophorum* are common (Enclosure 2).

The presence of *Achomosphaera andalousiense* and *Habibacysta tectata* is interpreted as being a result of caving during the drilling process. In addition, reworking of Jurassic and Palaeogene deposits is indicated by the presence of e.g. *Cribroperidinium* spp., *Alicocysta* spp., *Areoligera gippingensis*, *Cordosphaeridium cantharellus*, *Deflandrea* spp. and *Diphyes* spp. (Enclosure 1).

Age

Langhian (Middle Miocene) (Fig. 3).

Depositional environment

This interval is characterised by a rather sparse dinocyst assemblage and high relative abundances of freshwater algae, especially *Pediastrum*. The interval is interpreted as representing a nearshore marine depositional setting with a high freshwater influx. This is supported by high abundance of wood particles, cuticles and non-saccate and bisaccate pollen.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, this interval is correlated with the Danish Odderup Formation (Fig. 2).

The *Unipontodinium aquaductum* Zone, 186 m – 132 m

Dinocyst zonation

This interval is referred to the *Unipontodinium aquaductum* Zone (Dybkjær & Piasecki 2010) due to the first occurrence of *Unipontodinium aquaductum* in the sample at 183–186 m and the first occurrence of *Achomosphaera andalousiensis* in the sample at 129–132 m. The location of the upper boundary is further supported by the last occurrence of *Unipontodinium aquaductum* in the sample at 132–135 m (Enclosure 1).

Dinocyst assemblage

The abundance and diversity of dinocysts are very high within this interval. The assemblage is dominated by *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp., while *Cleistosphaeridium placacanthum*, *Dapsilidinium pseudocolligerum*, *Labyrinthodinium truncatum*, *Lingulodinium machaerophorum*, *Palaeocystodinium miocaenicum*/*minor* and *Polysphaeridium zoharyi* are common (Enclosure 2).

The presence of *Achomosphaera andalousiense* and *Barssidinium evangelineae* are interpreted as being a result of caving during the drilling process. In addition, reworking of Jurassic and Palaeogene deposits are indicated by the presence of e.g. *Cribroperidinium* spp., *Gonyaulacysta helicoidea*, *Areosphaeridium dictyoplokus*, *Charlesdowniae* spp. and *Deflandrea* spp. (Enclosure 1).

Age

Langhian to early Serravallian (Middle Miocene) (Fig. 3).

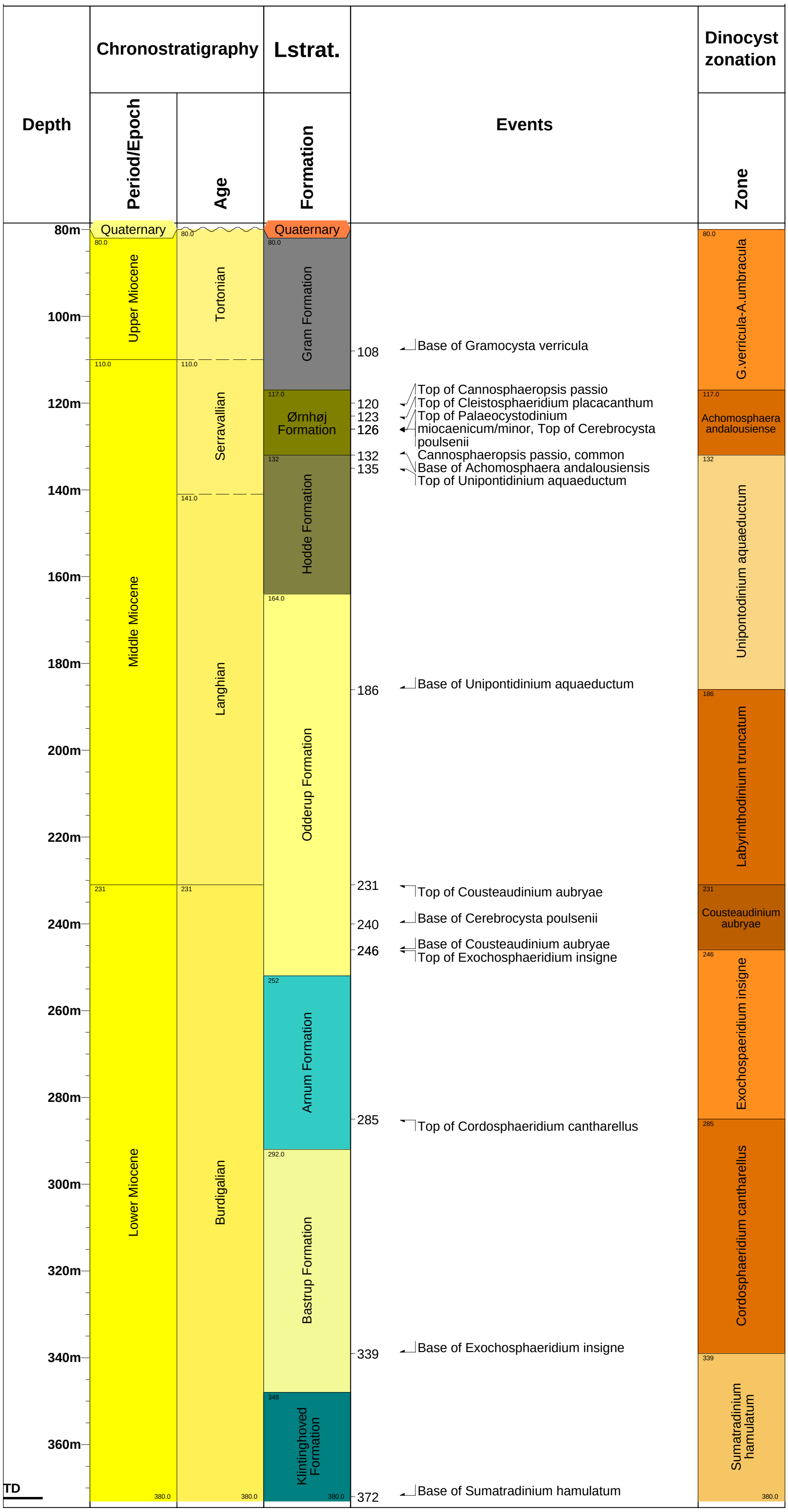

Figure 4: Stratigraphic summary for the Westerlangstedt-BR1 borehole.

Depositional environment

This interval is characterised by a rich and diverse dinocyst assemblage, while the abundance of freshwater algae generally is low. In a few samples, at 174 m and 135 m, however, relatively high abundances of *Pediastrum* were found. The interval is interpreted as representing a fully marine depositional setting with a generally low, but somewhat variegating freshwater influx.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples, the lower part of this interval (up to 164 m) is correlated with the Danish Odderup Formation, while the upper part is correlated with the Hodde Formation (Fig. 2).

The *Achomosphaera andalousiense* Zone, 132 m – 117 m

Dinocyst zonation

This interval is referred to the *Achomosphaera andalousiense* Zone (Dybkjær & Piasecki 2010) due to the first occurrence of *Achomosphaera andalousiense* in the sample at 129–132 m and the last occurrence of *Cannosphaeropsis passio* in the sample at 17–20 m (Enclosure 1), see further the discussion concerning the location of the base of the *Gramocysta verricula* Zone, p. 16.

Dinocyst assemblage

The abundance and diversity of dinocysts are very high within this interval. The assemblage is dominated by *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp., while *Habibacysta tectata*, *Labyrinthodinium truncatum*, *Lingulodinium machaerophorum*, *Mini dino 4* KD, *Spiniferites pseudofurcatus* and *Spiniferites solidago* are common (Enclosure 2).

The presence of *Barssidinium evangelineae* is interpreted as being a result of caving, while reworking of Jurassic deposits is indicated by the presence of *Cribroperidinium* spp. (Enclosure 1).

Age

Serravallian (Middle Miocene) (Fig. 3).

Depositional environment

This interval is characterised by a rich and diverse dinocyst assemblage, while freshwater algae occur very sporadic. The interval is interpreted as representing a fully marine depositional setting.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples this interval is correlated with the Danish Ørnhøj Formation (Fig. 2).

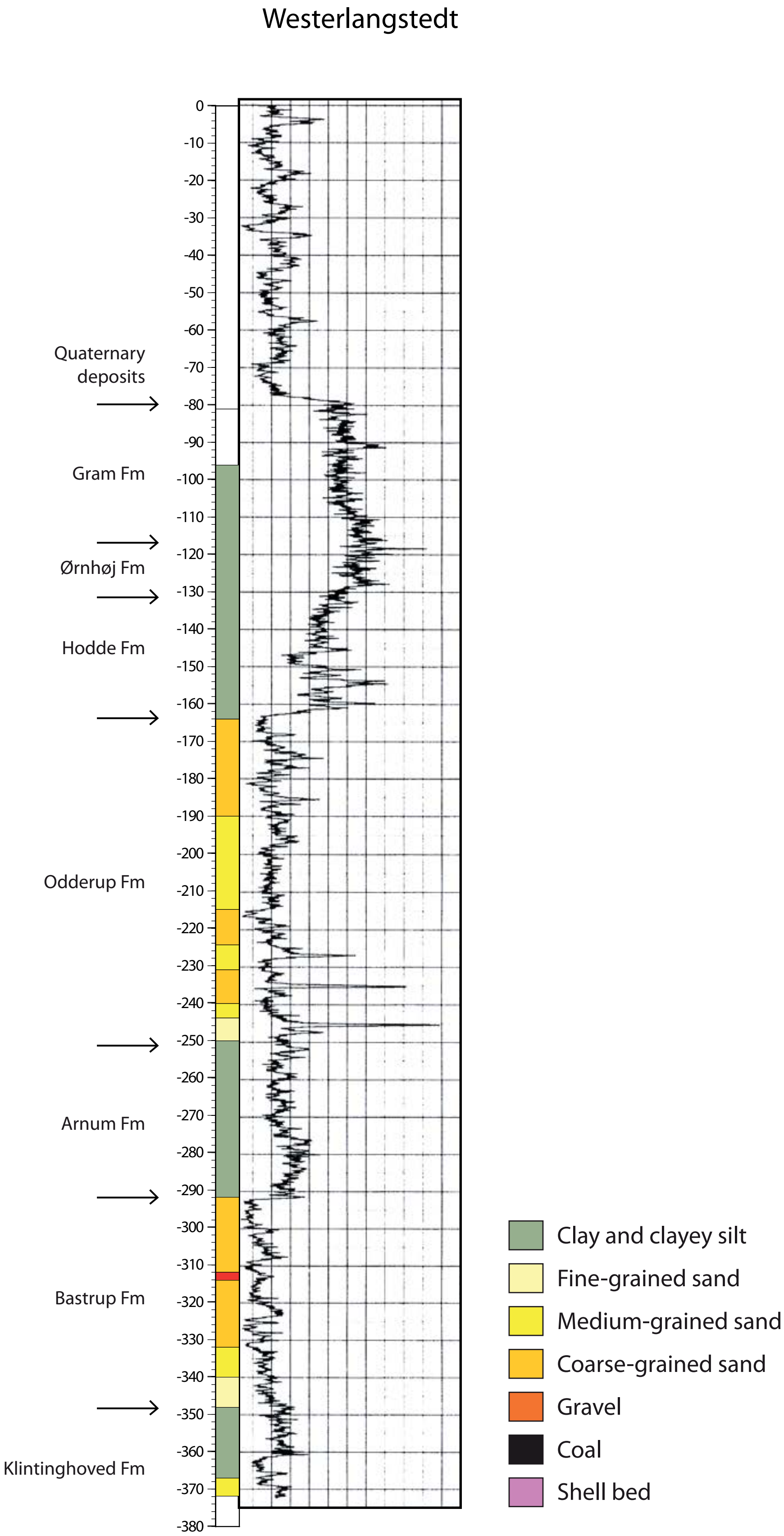

Figure 5: Correlation between the Miocene succession in the Westerlangstedt-BR1 borehole and the Danish lithostratigraphy of Rasmussen *et al.* (in press).

The *Gramocysta verricula* Zone/*Amiculosphaera umbracula* Zone, 117 m – 87 m

Dinocyst zonation

This interval is referred to the *Gramocysta verricula* and the *Amiculosphaera umbracula* Zones (Dybkjær & Piasecki 2010). The last occurrence of *Cannosphaeropsis passio* in the sample at 117–120 m is here interpreted as indicating the base of the *Gramocysta verricula* Zone. The first occurrence of *Gramocysta verricula*, defining the base of the zone, is often a problematic marker, as it is absent in offshore settings. It is thus necessary to use alternative markers, as done here. The location of the base of the *Gramocysta verricula* Zone is further supported by the last occurrence of *Cerebrocysta poulsenii* in the sample at 123–126 m and of *Cleistosphaeridium placacanthum* in the sample at 120–123 m. Sporadic occurrences of *Gramocysta verricula* were recorded from the samples at 105–108 m and 93–96 m (Enclosure 1).

Dinocyst assemblage

The abundance and diversity of dinocysts are generally high within this interval, but decreases upwards. The assemblage is dominated by *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum* and *Spiniferites* spp. and in addition *Labyrinthodinium truncatum* dominates in the sample at 90–93 m, while *Homotryblium tenuispinosum* dominates in the uppermost sample, at 87–90 m. *Achomosphaera andalousiense*, *Dapsilidinium pseudocolligerum*, *Habibacysta tectata*, *Labyrinthodinium truncatum, Lingulodinium machaerophorum* and *Operculodinium piasecki* are common (Enclosure 2).

The presence of *Barssidinium evangelineae* is interpreted as being a result of caving, while reworking of Jurassic and Palaeogene deposits is indicated by the presence of e.g. *Cribroperidinium* spp., *Oligosphaeridium patulum*, *Apectodinium* spp., *Cordosphaeridium cantharellus* and *Wetzeliella* spp. (Enclosure 1).

Age

Serravallian to Tortonian (Middle to Late Miocene) (Fig. 3).

Depositional environment

This interval is characterised by a rich and diverse dinocyst assemblage, however with a decreasing trend upwards. At the same time the abundance of freshwater algae increases in the upper part of the interval. The interval is interpreted as representing a fully marine depositional setting with a minor, upwards increasing influx of freshwater.

Lithostratigraphy

Based on a combination of the dinocyst stratigraphy, the geophysical log pattern and the lithology of the samples this interval is correlated with the Danish Gram Formation (Fig. 2).

Conclusion

The dinocyst zonation of Dybkjær & Piasecki (2010), developed for the Danish Miocene succession was successfully applied to the studied succession from the Westerlangstedt-BR1 borehole. The following dinocyst zones were found:
372 m – 339 m: The *Sumatradinium hamulatum* Zone (Lower Miocene)
339 m – 285 m: The *Cordosphaeridium cantharellus* Zone (Lower Miocene)
285 m – 246 m: The *Exochosphaeridium insigne* Zone (Lower Miocene)
246 m – 231 m: The *Cousteaudinium aubryae* Zone (Lower Miocene)
231 m – 186 m: The *Labyrinthodinium truncatum* Zone (Middle Miocene)
186 m – 132 m: The *Unipontodinium aquaductum* Zone (Middle Miocene)
132 m – 117 m: The *Achomosphaera andalousiense* Zone (Middle Miocene)
117 m – 87 m: The *Gramocysta verricula* Zone/*Amiculosphaera umbraculum* Zone (Middle to Upper Miocene).

Caving of Upper Miocene and Pliocene/Pleistocene material was found throughout the studied succession and also reworking of especially Jurassic and Palaeogene palynomorphs was observed.

Based on a combination of the dinocyst stratigraphy, the lithology of the samples and the geophysical log-pattern, the studied succession is correlated with the Danish lithostratigraphy defined by Rasmussen *et al*., (in press);
1) 372.4 m (TD)–348 m: The Klintinghoved Formation
2) 348 m–292 m: The Bastrup Formation
3) 292 m–252 m: The Arnum Formation
4) 252 m–164m: The Odderup Formation
5) 164 m–132 m: The Hodde Formation
6) 132 m–117 m: The Ørnhøj Formation
7) 117 m–80 m: The Gram Formation

The studied succession was inserted in a log-correlation panel striking north-south, from the Danish Rødding borehole to the Westerlangstedt borehole (Fig. 6). Except for the distinctly thicker succession in the Tinglev borehole, located within the Tønder Graben, the thicknesses of the Miocene formations in the Danish boreholes and the Westerlangstedt borehole are comparable and the correlation is straight forward.

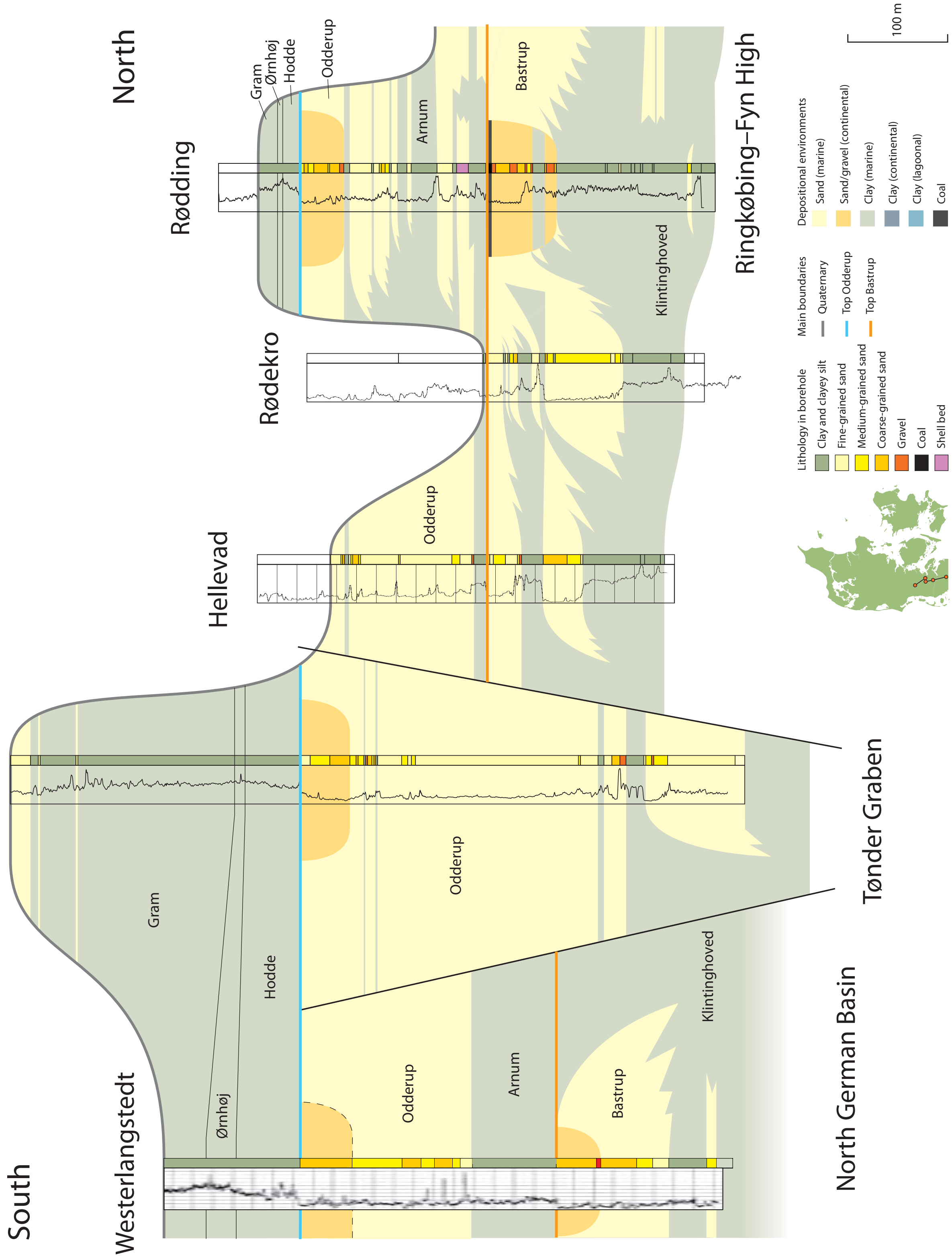

Figure 6: Log-correlation panel showing the Miocene succession in the boreholes; Rødding, Rødekro, Hellevad, Tinglev and Westerlangstedt. Notice how the Tønder Graben results in a distinct thickening of the Odderup Formation in the Tinglev borehole.

References

Dybkjær, K. & Piasecki, S., 2010: Neogene dinocyst zonation for the eastern North Sea Basin, Denmark. Review of Palaeobotany and Palynology **161**, 1–29.

Rasmussen, E.S., Dybkjær, K. & Piasecki, S., in press: Lithostratigraphy of the Upper Oligocene – Miocene succession in Denmark. Geological Survey of Denmark and Greenland Bulletin **21**.

Enclosures

Enclosure 1: Rangechart for the Westerlangstedt-BR1 borehole. The chart presents; the lithostratigraphic subdivision (based on the Danish lithostratigraphy by Rasmussen et al., in press), the chronostratigraphy, the dinocyst zonation (Dybkjær & Piasecki, 2010), the dinocyst events, the relative abundances of the recorded *in situ* and caved dinocyst species, the presumed reworked dinocysts, the freshwater algae, acritarchs and other marine algae, all in percentages of the total number of dinocysts, freshwater algae, acritarchs and other marine algae ("OM"). Occurrences marked by a "C" means that it is interpreted as being the result of caving. Occurrences marked by a "?" means that the indentification of the specimen to species or genus is questionable.

Enclosure 2: Rangechart for the Westerlangstedt-BR1 borehole, presenting the absolute abundances of *in situ* and caved dinocysts in percentage of the total number of *in situ* and caved dinocysts. Occurrences marked by a "C" means that it is interpreted as being the result of caving. Occurrences marked by a "?" means that the indentification of the specimen to species or genus is questionable.

Well Name : Westerlangstedt - BR1

Interval : 80m - 373m
Scale : 1:1000
Chart date: 04 November 2010 Karen Dybkjær
Enclosure 1

GEUS
Copenhagen

Well Name : Westerlangstedt - BR1

Interval : 80m - 373m
Scale : 1:1000
Chart date: 04 November 2010 Karen Dybkjær
Enclosure 2

GEUS
Copenhagen