DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE **RAPPORT 2023/16**

Paleocene – Oligocene microfossil and palynological biostratigraphy of the wells DGU 38.1203 and DGU 38.1204, island of Fur, Denmark

Emma Sheldon, Kasia Śliwińska & Karen Dybkjær

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Contents

1. Summary

Microfossil and palynological biostratigraphy was carried out on samples from 2 wells, DGU 38.1203 and DGU 38.1204, both located on Fur, in order to ascertain which lithological units they should be assigned to.

In well DGU 38.1203, samples 14–15 m to 40–41 m are assigned to the Viborg Formation. The Lillebælt Clay Formation (Beds L4–lower L5) is represented by samples 42–43 m & 48–49 m. The Knudshoved Member of the Røsnæs Clay Formation is present from 50–51 to 53–54 m. Sample 55–56 m is assigned to the Fur Formation based on microfossils and the Knudshoved Member of the Røsnæs Clay Formation based on palynomorphs. The Fur Formation is represented by samples 57–58 m to 59–60 m.

In well DGU 38.1204 all samples are assigned to the Fur Formation, apart from the lowest two samples, 44–45 m and 47–48 m, which represent the Stolle Klint clay.

2. Introduction

13 cuttings samples from the DGU 38.1203 borehole from Blegagervej and 12 cuttings samples from the DGU 38.1204 borehole, Langstedvej, Fur, were examined for their microfossil and palynomorph content for biostratigraphic purposes in order to assign them to lithological units. Both wells were drilled using the air-lift method and each sample represent 1 m.

The following samples were analysed:

DGU 38.1203

13 samples were studied for both microfossils and palynology: 14–15 m, 25–26 m, 35–36 m, 40–41 m, 42–43 m, 48–49 m, 50–51 m, 51–52 m, 53–54 m, 55–56 m, 57–58 m, 58–59 m and 59–60 m.

DGU 38.1204

12 samples were studied for microfossils: 12–13 m, 17–18 m, 20–21 m, 22–23 m, 26–27 m, 28–29 m, 30–31 m, 34–35 m, 38–39 m, 43–44 m, 44–45 m and 47–48 m.

9 samples were studied for palynology: 12–13 m, 17–18 m, 20–21 m, 28–29 m, 30–31 m, 38–39 m, 43–44 m, 44–45 m and 47–48 m.

3. Materials and Methods

Selected samples from the wells DGU 38.1203 and DGU 38.1204 were analysed with respect to their microfossil and palynological content. The samples were selected in cooperation with NIRAS based on their lithology.

For the DGU 38.1203 well, all samples were analysed for microfossils (foraminifera, large, pyritised diatoms, large radiolaria, miscellaneous microfossils) and palynomorphs (enclosure 1).

For the DGU 38.1204 well, palynomorphs and siliceous microfossils (diatoms, silicoflagellates and radiolaria in the fine fraction) were analysed for all samples (enclosure 2). The lowest two samples were also analysed for microfossils from the large fraction, as fossils from the fine fraction are lacking.

The samples were prepared for microfossils (>63 µm) by soaking them overnight in warm water and a small amount of washing-up liquid, and then gently washing them through a 63 µm sieve. They were then dried at 40^{O}C overnight. The prepared samples were analysed using a Leica M205C microscope.

Palynological slides were prepared from 22 samples (13 samples from DGU 38.1203 and 9 from DGU 38.1204). Between 20 and 28 grams of sediment were dried and powdered. In order to remove calcium carbonate, sediments were treated with HCl and washed at 60ºC with citric acid. Subsequently, all residues were oxidized (1-4 minutes in HNO_3), followed by a heavy liquid ($ZnCl_2$) separation and swirling. The samples were first sieved on 20 µm meshes. Slides were made from a small fraction of the residue mounded in gelatine-jelly and studied under transmitted-light microscope.

The siliceous microfossil (diatoms and silicoflagellates) slides from the fine fraction were prepared by removing organic material from the sample with H_2O_2, boiling it, cooling it, then adding HCl. The sample was then cleaned with distilled water then allowed to settle; this part of the process was repeated several times. The sample was pipetted onto a glass coverslip, dried, mounted onto a glass slide with Naphrax, then heated to set it. The prepared slides were examined using a Leica DM2500P microscope.

A brief description of the microfossil, palynomorph and siliceous microfossil content of each sample, along with biostratigraphic, chronostratigraphic and lithostratigraphic interpretation and lithological notes is provided in the results section with a stratigraphic summary chart for each well (enclosures 1 and 2). Siliceous microfossil distribution is also provided for the DGU 38.1204 well (enclosure 2), in order to compared with the results of Pedersen & Surlyk (1983) and Mitlehner (1996) who studied diatoms and silicoflagellates from nearby sections.

For DGU well 38.1203, the NSP (planktonic microfossils) and NSB (benthic microfossils) zonations of King (1989) are both applied as fossils that lived in the photic zone (planktonic=P) and at the sea-bed interface (benthic=B) are analysed. For the DGU 38.1204 well, the NSP zonation is supplemented by the silicoflagellate zonation of Perch-Nielsen (1976), is applied as only planktonic microfossils were analysed from this well. Taxonomic descriptions are referred to Ulleberg (1974), Perch-Nielsen (1986), Mitlehner (1996) and Bidgood et al. (1999). For palynology, the zonation schemes of Heilmann-Clausen (1988), van Simaeys *et al*. (2005) and Köthe (1990; 2003) are applied. Dinocyst nomenclature and taxonomy, unless stated otherwise, follows that cited in Williams *et al.* (2017), with the exception of the subfamily Wetzelielloideae for which we follow the taxonomic concepts of in Bijl *et al.* (2016).

Biostratigraphic slides and palynological residues have been retained by GEUS for future reference.

4. Results

A brief description of the palynomorph and microfossil or diatom and silicoflagellate content, including important (marker) species and a chronostratigraphic and lithostratigraphic interpretation is given here for each sample. See also enclosures 1 and 2.

Borehole DGU 38.1203

14–15 m

Microfossils

Common calcareous benthic foraminifera were present, including *Stilostomella longiscata*, *Plectofrondicularia budensis*, *Ceratobulimina contraria*, *Turrilina alsatica*, *Glandulina aequalis*, *Quinqueloculina* spp. and *Nodosaria adolphina*. Ostracod spp. are rare.

Other: Transparent yellow and white rounded quartz grains, some pyrite.

Microfossil Zone

NSP9b / NSB7a

Palynomorphs

Saccate pollen and non-saccate pollen are present. Black wood particles are sporadic. Dinocysts are common and diverse. The presence of *Areosphaeridium diktyoplokum* (entire clypeate process terminations – typical for the Oligocene taxa; (Śliwińska, 2019)), *Cerebrocysta bartonensis*, *Enneadocysta pectiniformis*, *Glaphyrocysta semitecta*, *Phthanoperidinium comatum*, *Wetzeliella gochtii*, and *Rhombodinium draco* is typical for the upper part of the Viborg Formation, of earliest Oligocene age (Śliwińska *et al.*, 2012). Some reworked Eocene dinocysts are present.

Dinoflagellate Zone

D13 (Köthe, 1990, 2003) or NSO2 (Van Simaeys *et al.,* 2005)

Age

Earliest Oligocene (earliest Rupelian)

Lithostratigraphy

Viborg Formation

25–26 m

Microfossils

Calcareous benthic foraminifera are common and include *Nodosaria adolphina*, *Stilostomella hirsuta*, *Stilostomella longiscata*, *Melonis affine*, *Nodosaria* spp., *Quinqueloculina* spp., *Pullenia bulloides*, *Laevidentilina emaciata* and *Turrilina alsatica*. Radiolaria and planktonic foraminfera are rare.

Notes: Transparent clear and yellow rounded sand grains, rare glauconite, some pyrite.

Microfossil Zone

NSP9b / NSB7a

Palynomorphs

Saccate and non-saccate pollen and rare spores are present. Dinocysts are common and diverse. Black wood particles are sporadic. *Areosphaeridium diktyoplokum* (entire clypeate process terminations – typical for the Oligocene taxa (Śliwińska, 2019)) are present. *Cerebrocysta bartonensis* and *Phthanoperidinium comatum*, typical of the Viborg Formation, of earliest Oligocene age (Śliwińska *et al.*, 2012) are present. Some reworked Eocene dinocysts are present.

Dinoflagellate Zone

D12nc (Köthe, 1990, 2003) or NSO1 (Van Simaeys *et a*l., 2005)

Age

Earliest Oligocene (earliest Rupelian)

Lithostratigraphy

Viborg Formation

35–36 m

Microfossils

Calcareous benthic foraminifera from the Early Oligocene are common and include *Cancris subconicus*, *Laevidentilina emaciata*, *Stilostomella longiscata*, *Gyroidina soldanii girardana*, *Triloculina* spp., *Quinqueloculina* spp., *Plectofrondicularia budensis*, *Glandulina aequalis*, *Ceratobulimina contraria* and *Melonis affine*. Fish teeth and minute siliceous diatoms are also present.

The tiny planktonic foraminifera *Acarinina pentacamerata* and *Subbotina patagonica* and the calcareous benthic foraminfera *Cancris* sp. A (King) and *Turrilina brevispira* are considered to be reworked from the Early Eocene.

Notes: Orange, yellow and transparent rounded quartz grains, some glauconite

Microfossil Zone

NSP9b / NSB7a (with reworking from NSP5b and NSB3b)

Palynomorphs

Palynomorphs are dominated by non-saccate pollen and spores. Saccate pollen are present. Dinocysts are present. Black wood particles are sporadic. The presence of *Areosphaeridium diktyoplokum* (entire clypeate process terminations – typical for the earliest Oligocene taxa; (Śliwińska, 2019)), *Cerebrocysta bartonensis*, *Enneadocysta pectiniformis*,*Glaphyrocysta semitecta*, and *Phthanoperidinium comatum* is typical for the Viborg Formation, of earliest Oligocene age (Śliwińska *et al.,* 2012). Some reworked Eocene dinocysts are present.

Dinoflagellate Zone

D12nc (Köthe, 1990, 2003) or NSO1 (Van Simaeys *et al*., 2005)

Age

Earliest Oligocene (earliest Rupelian) with reworking from the Early Eocene

Lithostratigraphy

Viborg Formation with reworked Røsnæs Formation

40–41 m

Microfossils

The microfossil assemblage includes well-preserved calcareous benthic foraminifera, shell fragments, rare planktonic foraminifera, diatoms, ostracod fragments and abundant echinoid fragments. Calcareous benthic foraminfera include *Gyroidina soldanii soldanii*, *Alabamina tangentialis*, *Gyroidina soldanii girardana*, *Cassidulina carapitana*, *Hoeglundina elegans*, *Plectofrondicularia budensis*. *Stilostomella longiscata*, *Glandulna* spp., *Lenticulina* spp., *Pullenia bulloides*, *Quinqueloculina* spp., *Stilostomella hirsuta*, *Laevidentilina emaciata*, *Nodosaria adolphina*, *Guttulina* spp., *Melonis affine*, *Pyrulina* spp., *Stilostomella spinescens* and *Pyrgo bulloides*.

Notes: Sediment dominated by glauconite and pyrite and pyrite tubes

Microfossil Zone

NSP9b / NSB7a

Palynomorphs

Palynomorphs are dominated by non-saccate pollen and spores. Black wood particles are sporadic. Saccate pollen is common. Dinocysts are present and include *Cerebrocysta bartonensis* and *Enneadocysta pectiniformis.* Some reworked Eocene dinocysts are present, including *Deflandrea oebisfeldensis*.

Dinoflagellate Zone

Possibly D12nc (Köthe, 1990, 2003) or NSO1 (Van Simaeys *et al.,* 2005)

Age

Earliest Oligocene (earliest Rupelian)

Lithostratigraphy

Viborg Formation

42–43 m

Microfossils

The microfossil assemblage is dominated by fish teeth. Rare calcareous benthic foraminifera include ?*Dentalina* / *Nodosaria* spp.. Diatom spp. are fairly common and corroded. The pyritized diatom *Coscinodiscus* spp. is rare. Large white *Cenosphaera* spp. (radiolaria) are present.

Notes: Abundant pyrite, pyrite tubes, coarse rounded sand grains

Microfossil Zone

NSP6 / NSB4

Palynomorphs

The assemblage is dominated by saccate pollen and dinocysts. The most typical dinocysts include *Cordosphaeridium funiculatum*, *Deflandrea* spp., *Hystrichokolpoma rigaudiae*, *Rottnestia*

borussica, *Spiniferites* spp. and *Paucilobimorpha spinosa* (acritarch). The assemblage contains *Wetzeliella articulata – ovalis* which are characteristic of the Lillebælt Clay Formation (Heilmann-Clausen, pers. comm).

Dinoflagellate Zone

Wetzeliella articulata – ovalis Zone (Heilmann-Clausen, 1988)

Age

Early to mid Eocene (Late Ypresian-Early Lutetian)

Lithostratigraphy

Lillebælt Clay Formation, Beds L4 and lower L5

48–49 m

Microfossils

Abundant fish teeth, rare corroded pyritized Diatom spp.

Notes: dominant dark and light green glauconite

Microfossil Zone

NSP6 / NSB4

Palynomorphs

Common and first occurrence of *Samlandia chlamydophora*, and *Wetzeliella articulata-ovalis*. The assemblage is similar to that in the sample above: dominated by saccate pollen and dinocysts. The most typical dinocyst includes *Cordosphaeridium funiculatum* and *Wetzeliella articulata – ovalis ovalis-articulata* are the most common. The sample also contains *Deflandrea* spp., *Hystrichokolpoma rigaudiae, Hystrichokolpoma cinctum, Rottnestia borussica, Samlandia chlamydophora, Spiniferites* spp., *Thalassiphora pelagica* and *Paucilobimorpha spinosa* (acritarch). *Wetzeliella ovalis-articulata* which are known to be characteristic of the Lillebælt Clay Formation (Heilmann-Clausen, pers. comm).

Dinoflagellate Zone

Wetzeliella articulata – ovalis Zone (Heilmann-Clausen, 1988)

Age

Early to mid Eocene (Late Ypresian-Early Lutetian)

Lithostratigraphy

Lillebælt Clay Formation, Beds L4 and lower L5

50–51 m

Microfossils

Fish teeth, rare *Cenosphaera* spp. (radiolaria).

Notes: Yellow, fine-grained sediment (clay?), glauconite, transparent quartz sand, white, hard spheroids, flat cream coloured objects

Microfossil Zone

NSP6 / NSB4

Palynomorphs

Dinocysts are the dominant group of palynomorphs. The sample includes an acme of *Areoligera senonensis* complex sensu Eaton (1976). The sample yields the last occurrence of *Alisocysta heilmannii, Rottnestia borussica,* and *Wetzeliella meckelfeldensis*. The highest stratigraphic occurrence of *Glaphyrocysta ordinata* is seen in this sample.

Dinoflagellate Zone

Wetzeliella mackelfeldensis Zone - equivalent to Subzone 6b, observed in the Knudshoved Member (lower part) (Heilmann-Clausen, 1988).

Age

Early to mid Eocene (Early Ypresian)

Lithostratigraphy

Knudshoved Member of the Røsnæs Clay Formation

51–52 m

Microfossils

Rare fish teeth and faecal pellets

Notes: Transparent and yellowish quartz sand, rounded, glauconite, pyrite spheres

Microfossil Zone

NSP6 / NSB4

Palynomorphs

Black wood particles are sporadic. Dinocysts are the most dominant group of palynomorphs. The sample yields *Achomosphaera crassipellis*, *Alisocysta heilmannii, Areoligera senonensis* complex sensu Eaton (1976), *Cordosphaeridium gracile*, *Glaphyrocysta ordinata*, *Hystrichosphaeridium tubiferum*, *Rottnestia borussica* and *Wetzeliella meckelfeldensis*.

Dinoflagellate Zone

Wetzeliella mackelfeldensis Zone - equivalent to Subzone 6b, observed in the Knudshoved Member (lower part) (Heilmann-Clausen, 1988).

Age

Early to mid Eocene (Early Ypresian)

Lithostratigraphy

Knudshoved Member of the Røsnæs Clay Formation

53–54 m

Microfossils

Rare fish teeth, siliceous diatoms and ?*Rhabdammina* spp. (agglutinated foraminifera).

Notes: Glauconite, white and transparent / translucent sand grains. No pyrite

Microfossil Zone

NSP6 / NSB4

Palynomorphs

Dinocysts are the most dominant group of palynomorphs. Black wood particles are sporadic. The sample yields *Achomosphaera crassipellis*, *Alisocysta heilmannii, Areoligera senonensis* complex sensu Eaton (1976), *Cordosphaeridium gracile*, *Glaphyrocysta ordinata*, *Hystrichosphaeridium tubiferum*, *Rottnestia borussica, Wetzeliella* sp. and *Wetzeliella meckelfeldensis*.

Dinoflagellate Zone

Wetzeliella mackelfeldensis Zone - equivalent to Subzone 6b, observed in the Knudshoved member (lower part) (Heilmann-Clausen, 1988).

Age

Early to mid Eocene (Early Ypresian)

Lithostratigraphy

Knudshoved Member of the Røsnæs Clay Formation

55–56 m

Microfossils

Pyritised diatoms include *Coscinodiscus morsianus moelleri* (common), *Coscinodiscus morsianus morsianus*, Diatom spp., and rare *Trinacria regina*, *Trinacria excavata* and ?*Arachnodiscus indicus*. The microfossil assemblage also contains fish teeth, bone fragments and common ?*Cenosphaera* spp. (radiolaria).

Notes: Yellow, white, glassy, translucent sand, rounded, pyrite tubes, some glauconite

Microfossil Zone

NSP4 / NSB2

Palynomorphs

Numerous black wood fragments are present. Dinocysts are the most dominant palynomorph group (often fragmented) and are dominated by *Spiniferites* spp. and *Microdinium – Membranosphaera*

complex. Other observed dinocysts include *Apectodinium quinquelatum*, *Cordosphaeridium cantharellus* and *Wetzelliella meckelfeldensis*

Dinoflagellate Zone

Wetzeliella mackelfeldensis Zone - equivalent to Subzone 6b, observed in the Knudshoved Member (lower part) (Heilmann-Clausen, 1988).

Age

Late Paleocene / Early Eocene

Lithostratigraphy

Fur Formation (microfossils)

Knudshoved Member of the Røsnæs Clay Formation (palynology)

57–58 m

Microfossils

The microfossil assemblage comprises the pyritized diatoms *Fenestrella antiqua* (common), *Coscinodiscus morsianus moelleri* (common), *Trinacria regina* (common), *Trinacria excavata* and Diatom spp. along with faecal pellets, fish teeth and bone fragments

Notes: Tuff, pyrite and glauconite are present

Microfossil Zone

NSP4 / NSB2

Palynomorphs

Black wood fragments are present. Dinocysts are the most dominant group, but non-saccate pollen and spores are also common. The assemblage yields e.g. common *Deflandrea oebisfeldensis* and *Microdinium – Membranosphaera* complex. *Spiniferites* spp. and *Achomosphaera* spp. *Paucilobimorpha spinosa* (acritarch) is present but rare.

Dinoflagellate Zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988).

Age

Late Paleocene / Early Eocene (latest Thanetian–early Ypresian)

Lithostratigraphy

Fur Formation

58–59 m

Microfossils

The microfossil assemblage comprises the pyritized diatoms *Fenestrella antiqua*, *Coscinodiscus morsianus moelleri, Trinacria regina*, *Thalassiosiropsis wittiana*, *Stephanogonia danica*, *Odontotropsis cristata* and Diatom spp. and common faecal pellets.

Notes: Tuff, pyrite, glauconite and volcanic glass are present

Microfossil Zone

NSP4 / NSB2

Palynomorphs

Black wood fragments are sporadic. The palynomorphs are dominated by non-saccate pollen and spores. Dinocysts are common and are dominated by *Deflandrea oebisfeldensis.* Glaphyrocysta ordinata and *Microdinium – Membranosphaera* complex are present.

Dinoflagellate Zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988).

Age

Late Paleocene / Early Eocene (latest Thanetian–early Ypresian)

Lithostratigraphy

Fur Formation

59–60 m

Microfossils

The microfossil assemblage comprises the pyritized diatoms *Fenestrella antiqua*, *Coscinodiscus morsianus moelleri*, and Diatom spp., fish teeth and faecal pellets.

Notes: transparent, volcaninc glass, glauconite, tuff, pyritised tubes and framboids

Microfossil Zone

NSP4 / NSB2

Palynomorphs

Black wood fragments are sporadic. The palynomorphs are dominated by non-saccate pollen and spores. Dinocysts are common and are dominated by *Deflandrea oebisfeldensis. Glaphyrocysta ordinata*, *Thalassiophora delicata* and the *Microdinium – Membranosphaera* complex are also present.

Dinoflagellate Zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988).

Age

Late Paleocene / Early Eocene (latest Thanetian–early Ypresian)

Lithostratigraphy

Fur Formation.

Borehole DGU 38.1204

12–13 m

Siliceous microfossils (fine fraction)

The assemblage includes abundant *Cenosphaera* spp. (radiolaria), *Naviculopsis danica* and *Corbisema hastata globulata* (silicoflagellates) with a low diversity, fairly high abundance diatom assemblage including *Coscinodiscus morsianus morsianus*, *Hemiaulus frigidus*, *Pterotheca aculeifera*, *Stephanogonia danica*, *Stephanopyxis horridus*, *Stephanopyxis turris* and *Trinacria excavata*. *Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone. The *Naviculopsis danica* silicoflagellate subzone of the *Naviculopsis constricta* Zone is assigned to the Knudeklint Member of the Fur Formation (Pedersen and Surlyk 1983).

Palynomorphs

The slide is dominated by silicoflagellates. Palynomorphs are dominated by spores and non-saccate pollen. A few dinocysts are present, these include: *Glaphyrocysta ordinata* (most common), *Hystrichosphaeridium tubiferum*, and *Oligosphaeridium complex*. *Wetzelielloideae* (neither *Wetzeliella astra* nor *Wetzeliella meckelfeldensis*) are not observed.

Dinoflagellate zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988)

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

17–18 m

Siliceous microfossils (fine fraction)

The medium diversity, high abundance siliceous microfossil assemblage includes abundant *Cenosphaera* spp. and present *Peridium longispinum* (radiolaria) and *Corbisema hastata globulata Naviculopsis danica* and *Dictyocha praecanteris* (silicoflagellates). The diatom assemblage is similar to that above, though *Stephanogonia danica*, *Stephanopyxis horridus* and *Trinacria excavata* were not noted. Also present are the diatoms *Coscinodiscus morsianus morsianus, Hemiaulus elegans*, *Hemialus morsianus*, *Paralia siberica laevis*, *Omphalotheca jutlandica* and *Solium excsculptum*. *Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

The slide is dominated by silicoflagellates. Palynomorphs are dominated by saccate pollen, spores and non-saccate pollen. Only very few dinocysts are present, e.g. *Glaphyrocysta ordinata* (most common).

Dinoflagellate zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

20–21 m

Siliceous microfossils (fine fraction)

Cenosphaera spp. (radiolaria) are present, along with *Corbisema hastata globulata*, *Naviculopsis danica* and the last occurrence of *Naviculopsis constricta* (silicoflagellates). The co-occurrence of *Naviculopsis constricta* and *Naviculopsis danica* in this and underlying samples indicates the *Naviculopsis danica* subzone of the *Naviculopsis constricta* silicoflagellate Zone (Perch-Nielsen 1976). The high abundance and diversity diatom assemblage is similar to that above, although *Coscinodiscus morsianus morsianus, Paralia siberica laevis* and *Solium exsculptum* are not noted. *Stephanogonia danica* and *Hemiaulus elegans* are present, along with *Hemiaulus hostilis*, *Hemiaulus orthoceras* and *Trinacria regina. Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

The slide is dominated by silicoflagellates. The palynomorph assemblage is impoverished and dominated by saccate pollen, spores and non-saccate pollen. Only very few dinocysts are present, e.g. *Glaphyrocysta ordinata.*

Dinoflagellate zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

22–23 m

Siliceous microfossils (fine fraction)

The siliceous microfossil assemblage is very similar to that in the overlying sample. In the diatom assemblage, *Solium exsculptum* is noted again, *Trinacria regina* is not seen and *Hemiaulus pungens* is present. *Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

26–27 m

Siliceous microfossils (fine fraction)

Silicoflagellates and radiolaria are as in the overlying samples, with the addition of the silicoflagellate *Corbisema glezerae*. The diatom assemblage is of lower diversity than in the overlying samples, and dominated by *Stephanopyxis* spp. and *Pterotheca* spp. The last occurrence of *Actinoptychus senarius* is found in this sample. This species was only seen in the Knudeklint Member of the Fur Formation in Mitlehner (1996). *Falsebria ambigua* (Ebridian) is abundant.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

28–29 m

Siliceous microfossils (fine fraction)

Silicoflagellates and radiolaria are as in the previous sample, although without *Corbisema glezerae*. The diatom assemblage is also similar to that of the previous sample, with the addition of rare *Trinacria regina tetragona*. *Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

The slide is dominated by silicoflagellates. The palynomorph assemblage is impoverished and dominated by saccate pollen, spores and non-saccate pollen.

Dinoflagellate zone

Indeterminate

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

30–31 m

Siliceous microfossils (fine fraction)

Silicoflagellates and radiolaria are as in the previous samples. The diatom assemblage increases in diversity, though is still dominated by *Stephanopyxis*, spp., *Pterotheca* spp. and *Opephora gemmata*, and includes common *Hemiaulus morsianus* and *Hemiaulus elegans*. *Hemiaulus curvatulus* is also present and was noted in the Knudeklint Member in Mitlehner (1996). *Falsebria ambigua* (Ebridian) is abundant.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

The slide is dominated by silicoflagellates. Palynomorphs rare and dominated by spores and non-saccate pollen. Wood fragments are present. Few dinocysts are present, these include: *Glaphyrocysta ordinata* (most common). No Wetzelielloideae are observed.

Dinoflagellate zone

Deflandrea oebisfeldensis Zone (approximately equivalent to Subzone 5b) observed in the Fur Formation from near the ash layer -19b to the top of the formation (Heilmann-Clausen, 1988)

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

34–35 m

Siliceous microfossils (fine fraction)

Silicoflagellates and radiolaria are as above. The fairly low diversity diatom assemblage is dominated by *Stephanopyxis* spp., *Pterotheca* spp., and *Rhizosolenia* spp. *Paralia siberica* increases in abundance from this sample and down. *Rhizosolenia clavigera* is also present. *Falsebria ambigua* (Ebridian) is abundant.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

38–39 m

Siliceous microfossils (fine fraction)

Silicoflagellates and radiolaria are as in the overlying sample. In addition, the silicoflagellate *Dictyocha* cf. *fibula* (which is only seen in the Knudeklint Member in Mitlehner 1996) is present (highest occurrence). The diatom assemblage is fairly low diversity, dominated by *Pterotheca* spp. and *Stephanopyxis* spp. *Paralia siberica laevis* is abundant. *Actinoptychus senarius* is present and *Stephanogonia danica* is absent, characteristics of the Knudeklint Member (Mitlehner 1996). *Falsebria ambigua* (Ebridian) is present.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

The slide is dominated by silicoflagellates. Black and brown wood fragments are common. Palynomorphs are more common than in the sample at 30-31 m and are dominated by spores and non-saccate pollen. Dinocysts are common and diverse and include *Deflandrea oebisfeldensis*, *Microdinium – Membranosphaera* complex, *Spiniferites* spp., *Apectodinium* sp., *Apectodinium augustum*, and *Microdinium ornatum.*

Dinoflagellate zone

Possibly *Apectodinium augustum* zone/Subzone D5a (base of the Fur Formation to near the ash layer number -19b by Gry (1941) sensu Heilmann-Clausen (1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member

43–44 m

Siliceous microfossils (fine fraction)

Cenosphaera spp. (radiolaria) are present. The silicoflagellate assemblage is diverse, including *Corbisema inermis crenulata* and *Naviculopsis foliacea tumida*. *Corbisema inermis crenulata* is seen in the Knudeklint Member in Mitlehner (1996). The lowest occurrences of *Corbisema hastata globulata, Dictyocha* cf *fibula*, *Naviculopsis danica* and *Naviculopsis constricta* occur in this sample and are indicative of the *Naviculopsis danica* silicoflagellate subzone (Perch-Nielsen 1976). Diatom diversity is high and includes *Aulacodiscus singiliewskyanus*, *Coscinodiscus morsianus moelleri* and *Coscinodiscus radiatus*. *Hemiaulus febriatus* is also present, it is seen in the Knudeklint Member in Mitlehner (1996). *Actinoptychus senarius* increases in abundance compared with the overlying sample and *Stephanogonia danica* is not seen: these are characteristics of the Knudeklint Member in Mitlehner (1996). *Falsebria ambigua* (Ebridian) is abundant.

Microfossil Zone

NSP4

Silicoflagellate zone

Naviculopsis constricta Zone, *Naviculopsis danica* subzone

Palynomorphs

Pollen and spores are present. Dinocysts are rare but moderately diverse; the most common taxa include *Deflandrea oebisfeldensis*, *Spiniferites* sp., *Apectodinium* sp., and *Apectodinium augustum*. A single specimen of *Thalassiphora pelagica* is observed. *Thalassiphora pelagica* is typically associated with the Røsnæs Clay, therefore it is possibly caved. The sample is dominated by aggregates of amorphous organic matter.

Dinoflagellate zone

Apectodinium augustum zone/Subzone D5a (base of the Fur Formation to near the ash layer number -19b by Gry (1941) sensu Heilmann-Clausen (1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Fur Formation, Knudeklint Member (microfossils)

Stolle Klint clay (palynomorphs)

44–45 m

Siliceous microfossils (fine fraction)

The assemblage contains rare *Stephanopyxis turris* and *Pterotheca aculeifera* (diatoms).

Microfossils

Common *Cenosphaera* spp. (radiolaria)

Microfossil Zone

middle to upper NSP4 (and NSB2), NS13 (King 2016)

Palynomorphs

The slide is dominated by amorphous organic matter. Pollen and spores are present. Dinocysts are rare but the assemblage is moderately diverse. The most common taxa include *Apectodinium* sp., *Apectodinium augustum*, *Deflandrea oebisfeldensis*, and *Spiniferites* spp. A single specimen of *Thalassiphora pelagica* is observed. This species is typically associated with the Røsnæs Clay, therefore it is possibly caved.

Dinoflagellate Zone

Apectodinium augustum zone/Subzone D5a (base of the Fur Formation to near the ash layer number -19b by Gry (1941) sensu Heilmann-Clausen (1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Stolle Klint clay

47–48 m

Siliceous microfossils (fine fraction)

Rare *Stephanopyxis turris*

Microfossils

The microfossil assemblage comprises the pyritized diatoms *Coscinodiscus morsianus moelleri*, Diatom spp. and *Fenestrella antiqua* and common *Cenosphaera* spp. (radiolaria).

Microfossil Zone

middle to upper NSP4 (and NSB2)

Palynomorphs

Pollen and spores are present. Aggregates of amorphous organic matter are present but are less common than in the samples above. Dinocysts are rare, and moderately diverse. The most common taxa include *Apectodinium augustum* (common), *Apectodinium* sp. (common), *Deflandrea oebisfeldensis*, and *Spiniferites* spp.

Dinoflagellate Zone

Apectodinium augustum zone/Subzone D5a (base of the Fur Formation to near the ash layer number -19b by Gry (1941) sensu Heilmann-Clausen (1988).

Age

Late Thanetian-Early Ypresian

Lithostratigraphy

Stolle Klint clay

Note

The laminated clay which is now known as the Stolle Klint clay (Heilmann-Clausen 1995), was later linked with the *Apectodinium augustum* acme (Schmitz et al. 2004), which could be assigned to the *Apectodinium augustum* zone/Subzone D5a. However, in this study we notice that *Apectodinium augustum* and other species of the *Apectodinium* genus are common but not abundant in the DGU borehole 31.1204 in samples 44-45 m and 38-39 m. This may suggest that the studied succession is either more complete than the sections studied previously for palynology, or that the interval from 44 to 38 m of the DGU 38.1204 borehole consist of heavily disturbed sediments, comprising both the Fur Formation and the Stolle Klint clay.

5. Summary

DGU 38.1203

Samples 14–15 m to 40–41 m are assigned to the Viborg Formation.

The Lillebælt Clay Formation (Beds L4–lower L5) is represented by samples 42–43 m & 48–49 m.

The Knudshoved Member of the Røsnæs Clay Formation is present from 50–51 to 53–54 m.

Sample 55–56 m is assigned to the Fur Formation based on microfossils and the Knudshoved Member of the Røsnæs Clay Formation based on palynomorphs.

The Fur Formation is represented by samples 57–58 m to 59–60 m.

The results are summarised in enclosure 1.

DGU 38.1204

Samples 12-13 m to 38-39 m are assigned to the Knudeklint Member of the Fur Formation

Sample 43-44 m is assigned to the Knudeklint Member of the Fur Formation based on microfossils and the Stolle Klint clay based on palynomorphs

Samples 44–45 m and 47–48 m represent the Stolle Klint clay.

The results are summarised in enclosure 2.

6. References

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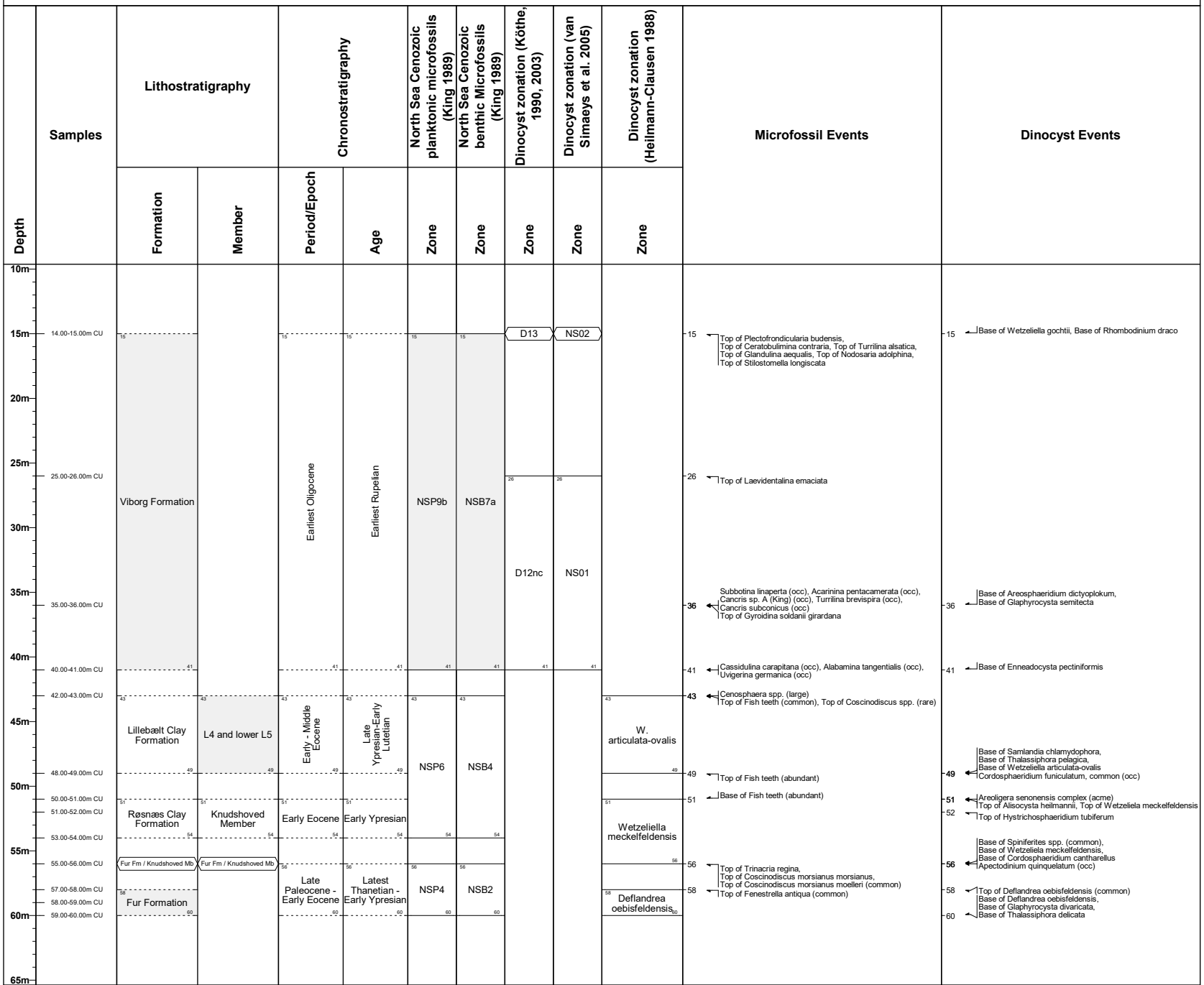
Well Name : 38.1203

Interval : 10.00m - 65.00m
Scale : 1:250
Chart date: 11 May 2023

Enclosure 1
Microfossils & Palynology
Kasia Sliwinska & Emma Sheldon

GEUS



Well Name : 38.1204

Interval : 10.00m - 50.00m
Scale : 1:250
Chart date: 11 May 2023

Enclosure 2
Siliceous Microfossils & Palynology
Emma Sheldon & Kasia Sliwinska

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