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The results of the palynological analysis from core-shoe samples in borehole DAPGEO-02 (Delft), interval: 364.10-414.64 m

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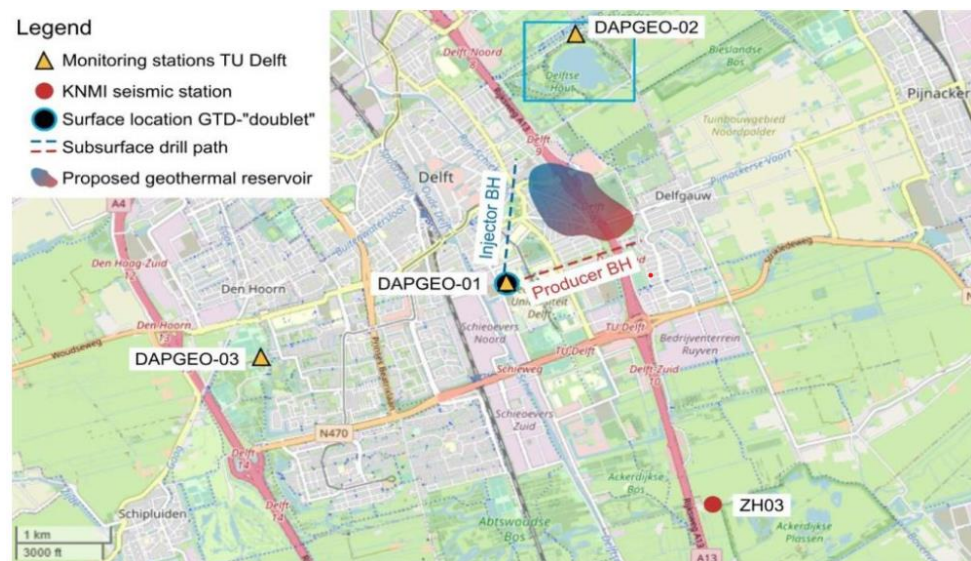
- Enclosure 1: Palynological interpretations of borehole DAPGEO-02
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1 Introduction

TU Delft, Aardyn, Shell and EBN are taking an important step forward in the energy transition and intend to instal a geothermal source on the TU Delft campus, under the name Geothermal Delft (Delft Aardwarmte Project- DAP). This source will provide both the campus and a number of neighbourhoods in Delft with sustainable heat. A unique project in which research and industry come together at a crucial moment in the energy transition.

Seismic monitoring stations, in most cases of the KNMI, are already in place in a large part of the Netherlands. However, in the area around Delft there was a white spot on this point. Recently, the municipality of Delft and the Delfland Water Board (Hoogheemraadschap Delfland) granted permits to Delft University of Technology for the installation of a seismic monitoring station in the vicinity of Delftse Hout in the northwest of Delft. A seismic monitoring station is installed on site and around parking lot P3 on Tweemolentjeskade on behalf of Delft University of Technology in 2022.

Figure 1: Location map Delft with position of the monitoringstations (borehole DAPGEO-02)



The seismic monitoring station in the Delftse Hout is one of four stations that will map in detail the possible vibrations from those geothermal wells. Measurements are made to a depth of 200 to 500 meters in the subsurface, with a measuring point at every 50 meters depth. Sample cores are also taken from the boreholes in order to study the nature of the successions.

This report presents the results of the palynological analysis from core shoe samples in the monitoring borehole DAPGEO-02, interval 364.1-414.64 m. The given age estimate for the selected succession was Paleogene. The aim of the present study is to provide accurate biostratigraphical age assessments. The palynological results will serve as part of a (standard) framework for consistent (litho)stratigraphic interpretation and correlation in the area. In situ core samples are very rare in the current stratigraphic interval.

Figure 2: (a+b+c): Details of the borehole DAPGEO-02 (500 m) location



a



b



c

2 Material & Methods

2.1 Abbreviations

Standard abbreviations in use by TNO-GSN are listed in Table 1.

Table 1: Used abbreviations in this report.

CO	Core sample
SC	Sidewall core sample
OC	Outcrop
CU	Cuttings sample
m	Meter
ft	Feet
LOD	Last Occurrence Datum
LCOD	Last Common Occurrence Datum
FOD	First Occurrence Datum
FCOD	First Common Occurrence Datum
NL	Lower North Sea Group
NM	Middle North Sea Group
NU	Upper North Sea Group
GSN	Geological Survey of the Netherlands

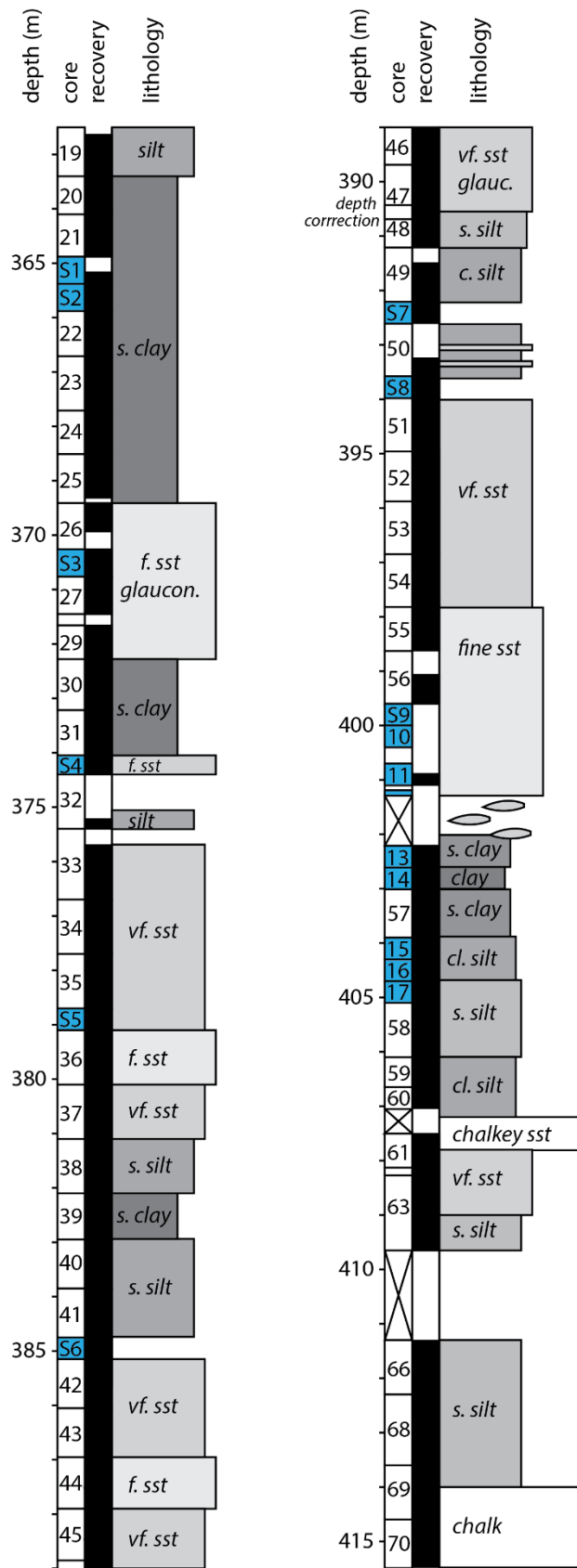
2.2 Samples

Approximately 50 core-shoe samples of borehole DAPGEO-02 (coordinates: X: 85834.6, Y: 449059.0 (RD)) were collected by Hemmo Abels (TU-Delft) and sent to TNO-the Geological Survey of the Netherlands. A first batch of eleven core samples is selected for palynological analysis in December 2022 (see Table 2). For the lithological description see Figure 3.

Table 2: Selection of core-shoe samples DAPGEO-02

Depth (m)	Type
364.10	CO
370.76	CO
372.95	CO
377.70	CO
382.95	CO
386.05	CO
389.69	CO
393.66	CO
401.10	CO
412.33	CO
414.64	CO

Figure 3: Simplified lithological description (TU-Delft)



2.3 Sample processing

The samples were processed at the TNO-GSN laboratory in December 2022 by Nico Janssen using the standard sample processing procedures, which involves HCl and HF treatment, and sieving over a 18 µm mesh sieve.

2.4 Palynological analysis

The microscopy analysis was done according to standard procedures. The associations on the microscope slides are counted until a total of ca 200 sporomorphs and dinoflagellate cysts (palynomorphs) is reached. The miscellaneous categories (*Botryococcus*, inner chambers of foraminifers, Tasmanaceae, etc.) are also calculated, but kept outside the total sum of palynomorphs. The remainder of the slide is thereafter scanned for any (rare) dinocyst species which are simply noted as “present” (+ symbol on the distribution chart).

Diagnostic species are discussed in the report, a complete distribution chart including all species found is given as appendix.

2.5 Taxonomy

For the dinoflagellate cyst taxonomy the so-called “Lentin and Williams” index is followed (Fensome et al., 2019).

2.6 Age-interpretation

The age interpretation is based on the LOD's and FOD's of dinoflagellate cysts.

Palynological interpretation is based on key-references concerning the palynostratigraphy of Paleogene to Neogene from the North Sea region such as: Bujak & Mudge (1994), De Schepper and Head (2009), De Schepper et al. (2015), Dybkjaer & Piasecki (2010), Heilmann-Clausen (1985), Köthe (2003), Kuhlmann et al. (2006), Louwye (2005), Louwye et al. (2010), Munsterman & Brinkhuis (2004), Munsterman et al. (2019), Powell (1992) and Van Simaey, Munsterman & Brinkhuis (2005). For the Miocene the dinocyst zonation scheme of Munsterman and Brinkhuis (2004) is used, recalibrated to Geological Time Scale (GTS) 2016 of Ogg et al. (2016) in Munsterman et al. (2019) (see Figure 4). The biozonation scheme for the Oligocene is sensu Van Simaey et al., 2005 (Figure 5), the standard dinocyst zonation used for the Eocene is from Bujak & Mudge (1994) (Figure 6) and finally the biozonation selected for the Paleocene is cf. Powell (1992) (Figure 7).

Figure 4: Miocene dinozonation sensu Munsterman & Brinkhuis (2004), recalibrated to the GTS sensu Ogg et al. (2016) in Munsterman et al. (2019).

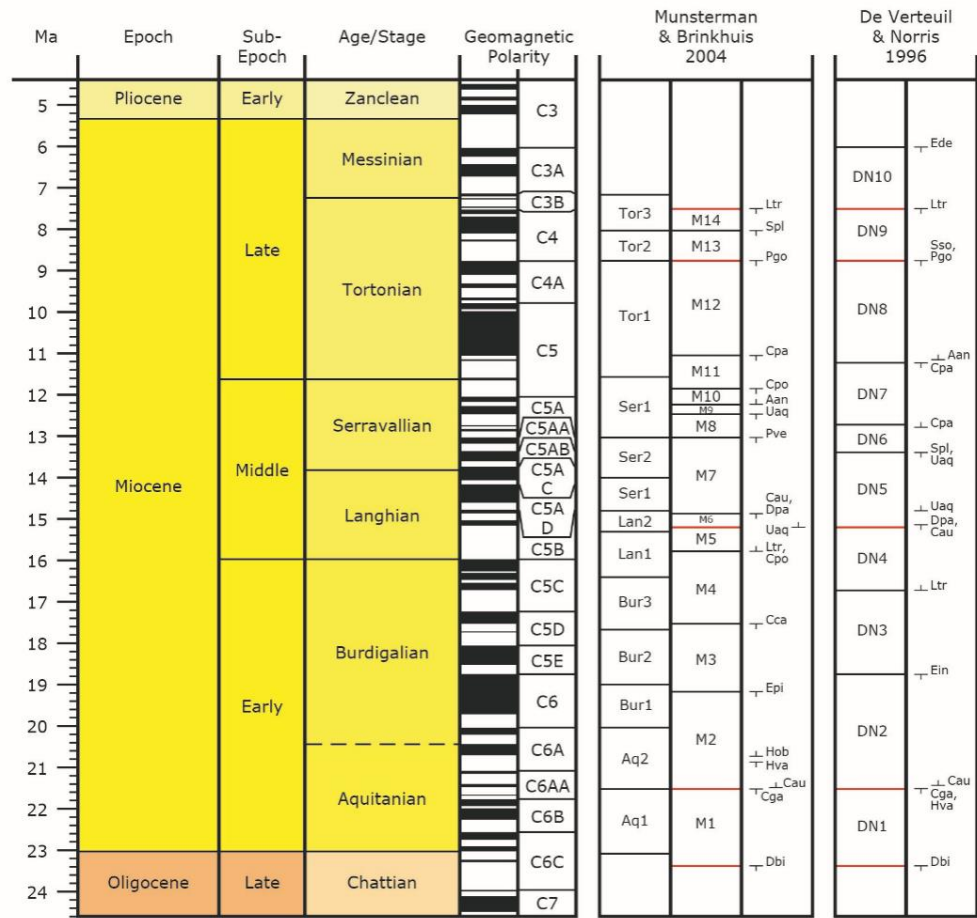


Figure 5: Ranges of dinoflagellate cysts from the North Sea Oligocene zonation scheme sensu Van Simaëys, Munsterman & Brinkhuis (2005).

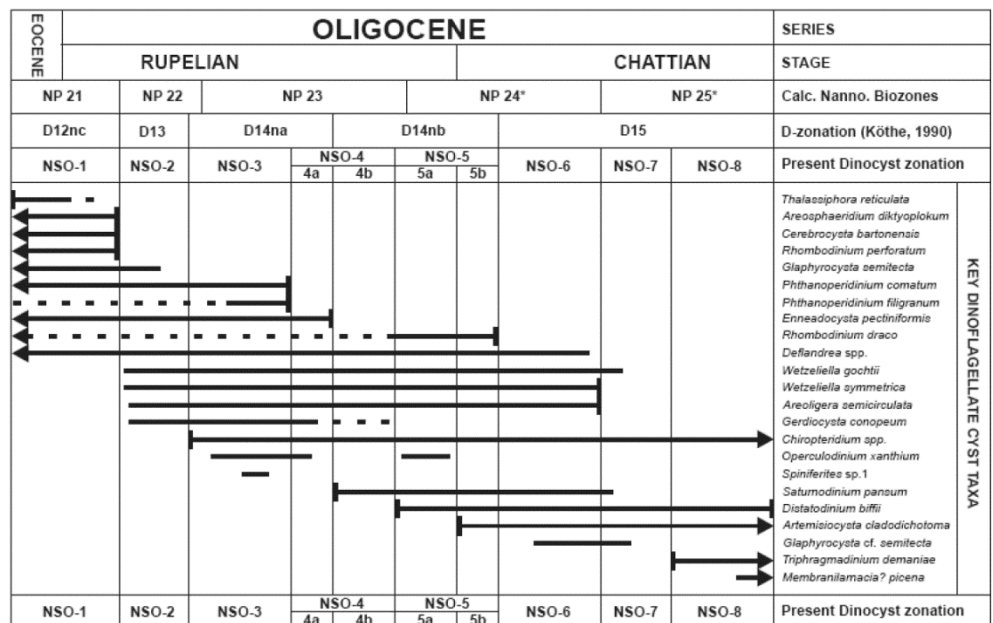
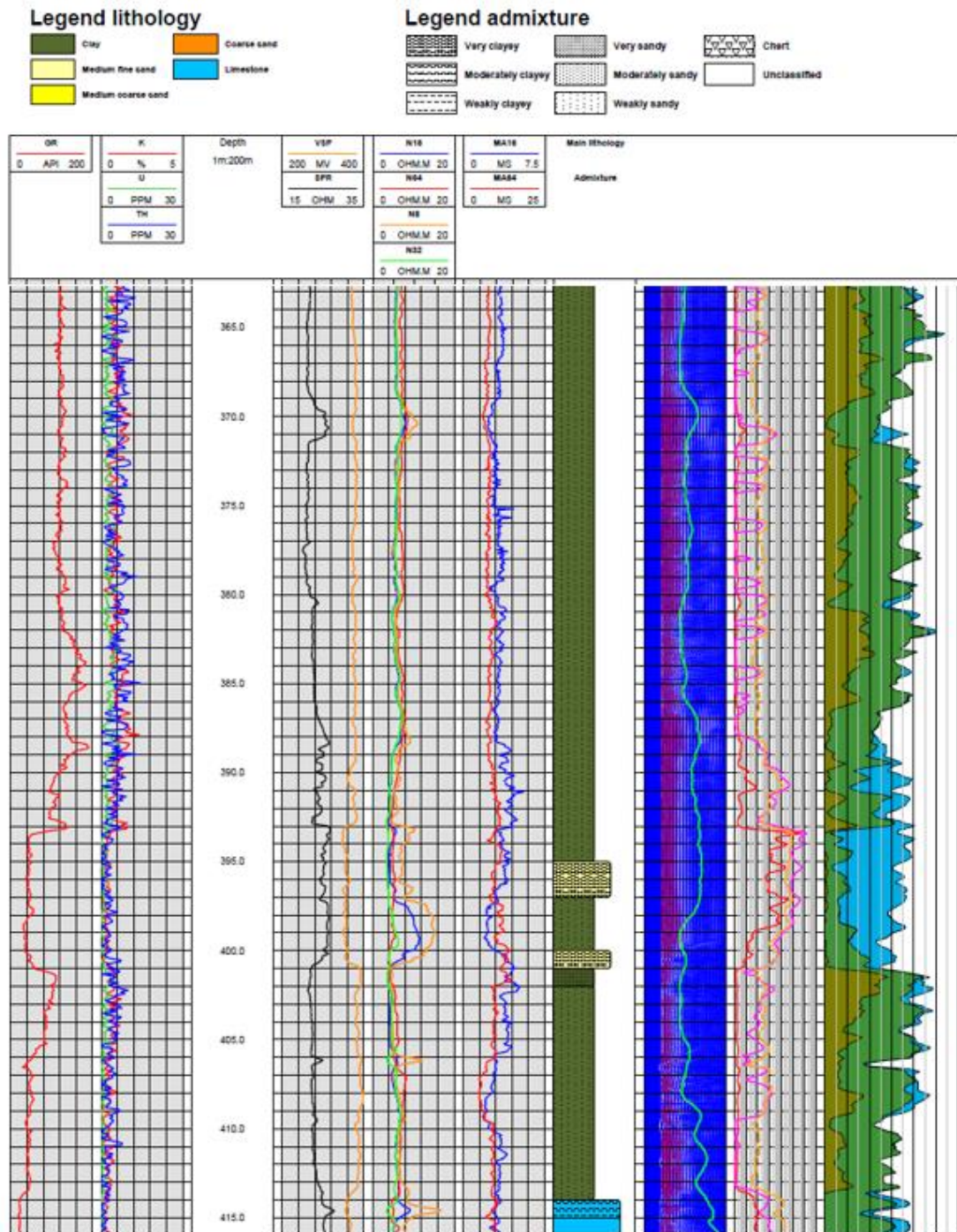


Figure 7: Paleogene biozonation sensu Powell, 1992



2.7 Logs of borehole DAPGEO-02 (Vardon et al., 2022)



3 Results

The palynomorph (spores, pollen and dinoflagellate cysts) recovery is very rich in the interval 364.10-393.66 m (8 cores). The preservation is very good, comprising crystal clear palynomorphs. The association in sample 401.10 m is poor in palynomorphs. Rich in dinoflagellate cysts is also the microflora from sample 412.33 m. The calcareous sample at 414.64 m is totally barren, lacking any spores, pollen and dinoflagellate cysts.

In general, reworking is very low (< 1 % of the total sum palynomorphs), except in the association of sample 393.66 m, where palynomorphs originating from the Mesozoic comprise 3 % of the total sum. The association in the sample 393.66 m also contains a minor freshwater-tolerant component (3 % *Pediastrum*).

3.1 Sample/interval 364.10 m: Late Miocene, latest Tortonian, post SNSM14 Zone

The dating is based on:

- LOD *Hystrichosphaeropsis obscura*

Remarks: Marker species indicative for older zones in the Miocene are absent. *Reticulosphaera actinocoronata* is also present.

Facies

The palynological association is dominated (61 %) by bisaccate pollen of Gymnosperms. These have a very high buoyancy in both air and water, hence may be transported over long distances (recorded even in deep oceans). The marine component primarily consists of the dinoflagellate cysts *Spiniferites* spp. (24 %) and

Operculodinium centrocarpum sensu Wall & Dale, 1966 (43 %). These indicate shallow but open-marine conditions.

Prominently featured in the assemblage are *cold tolerant* dinoflagellate cysts, containing 17 % of the total sum dinoflagellate cysts. Such elevated abundances are well-known from coeval strata in the Roer Valley and Venlo Graben (Donders et al., 2008). They represent a strong cool phase during the late Tortonian.

3.2 Sample/interval 370.76 m: late Miocene, late Tortonian, Zone SNSM14

The dating is based on:

- LOD *Gramocysta verricula*
- LOD *Labyrinthodinium truncatum*

Remarks: *Invertocysta lacrymosa* is present. Rare occurrences of reworking from the Eocene-early Oligocene are recorded.

Facies

The assemblage is dominated by dinoflagellate cysts (88 %). The most abundant taxon of the dinoflagellate cysts is *Lingulodinium machaerophorum* (66 % of the dinocysts), indicating (warm) coastal (shallow) marine conditions, perhaps with low-salinity influence.

3.3 Sample/interval 372.95 m: late Miocene, late Tortonian, Zone SNSM13

The dating is based on:

- LOD *Systematophora placacantha*

Remarks: The LOD of *Sumatradinium soucouyantiae*, here present, is recorded in DN8 (mid-Tortonian) sensu De Verteuil & Norris, 1996 (Virginia, Maryland).

Facies

The marine component is 95 % of the total sum palynomorphs. Compared to the overlying sample at 370.76 m, the number of *Lingulodinium machaerophorum* is decreased (15 %) and *Spiniferites* spp. increased to 58 % of the dinocysts. Conditions: (shallow to) open marine.

3.4 Sample/interval 377.70 m: late Miocene, early Tortonian, Zone SNSM12

The dating is based on:

- LOD of *Palaeocystodinium golzowense*

Remarks: *Barssidinium evangelinae*, *Sumatradinium druggii* and *Sumatradinium soucouyantiae* are present. Minor reworking is recorded from the Valanginian and Eocene-early Oligocene.

Facies

Dinocysts dominate the assemblage (99 %). *Lingulodinium machaerophorum* (12 %) and *Spiniferites* spp. (68 %) still dominate the microflora. Conditions: (shallow to) open marine.

3.5 Sample/interval 382.95 m: middle Miocene, late Serravallian, Zone SNSM10



The dating is based on:

- LOD *Cerebrocysta poulsenii*
- FOD *Achomosphaera andalouisiensis*
- Remarks: The presence of *Cannosphaeropsis passio* confirms the interpretation

Facies: Dinoflagellate cysts (89 %) are dominant. The sporomorphs comprise only bisaccate pollen, no spores are recorded. *Spiniferites* spp. is most numerous with 63 % of the dinocysts. Representatives of the genus *Dapsilidinium* spp. follow with 8 %. Conditions: (shallow to) open marine.

3.6 Sample/interval 386.05 m: middle Miocene, mid Langhian, Zone SNSM6

The dating is based on:

- LOD *Cousteaudinium aubryae*
- FOD *Unipontidinium acqueductum*

Facies

The assemblage consists of 99 % dinoflagellate cysts. *Spiniferites* spp. comprise 57 %, *Lingulodinium machaerophorum* 13 %, *Operculodinium centrocarpum* 8 % and *Dapsilidinium* spp. 5 % of the total sum. Conditions: (shallow to) open marine.

3.7 Sample/interval 389.69 m: middle Miocene, early Langhian, Zone SNSM5

The dating is based on:

- FOD *Labyrinthodinium truncatum*
- FOD *Cerebrocysta poulsenii*
- Remarks: *Cousteaudinium aubryae* is also present, but *Unipontidinium acqueductum* is missing here.

Facies

Dinoflagellate cysts comprise 95 % of the total sum palynomorphs. The number of *Spiniferites* spp. is 57 %, *Systematophora placacantha* 14 %, *Lingulodinium machaerophorum* 6 % and *Cousteaudinium aubryae* 5 % of the total sum dinocysts. Conditions: (shallow to) open marine.

3.8 Sample/interval 393.66 m: early Eocene, earliest Ypresian, Zone E1a



The dating is based on:

- FCOD of *Apectodinium* spp. (24 % of the total sum dinocysts)
- LOD *Cerodinium speciosa*

Remarks

High numbers of *Apectodinium* spp. indicate a position associated closely to the Paleocene Eocene Thermal Maximum (PETM). This was a time period with a more than 5–8 °C global average temperature rise across the event (e.g., McInerney and Wing, 2011). This climate event occurred close to the boundary of the Paleocene and Eocene. The exact age and duration of the event is uncertain but it is estimated to have occurred around 55.5 million years ago. The associated period of massive carbon release into the atmosphere has been estimated to have lasted from 20,000 to 50,000 years. The entire warm period lasted for about 200,000 years.

The genera (Eocene) taxa *Dracodinium* and *Wetzeliella* are absent. Also missing is *Apectodinium augustum*. The association furthermore contains: *Areoligera* cf. *senonensis*, *Cerodinium depressum*, *Diphyes colligerum*, *Glaphyrocysta pastielsii*, *Hystrichosphaeridium tubiferum* and *Muratodinium fimbriatum*.

Facies

Dinoflagellate cysts (88 %) outnumber the sporomorphs (12 %) in the assemblage of the present core. *Spiniferites* is the most prominent genus (37 %), followed by *Apectodinium* spp. (24 %), *Homotryblium* spp. (8 %), *Hystrichosphaeridium tubiferum* (5 %), *Glaphyrocysta pastielsii* (4 %), *Areoligera* cf. *senonensis* (4 %), *Lingulodinium machaerophorum* (3 %) and *Polysphaeridium* spp. (3 %). Conditions: shallow marine. Minor freshwater influence is recorded.

3.9 Sample/interval 401.10 m: Not diagnostic

Remarks: The core sample yields a very poor assemblage of only 30 palynomorph specimens, while a minimum of 200 specimens are necessary for a reliable interpretation. Present is *Glaphyrocysta pastielsii* and *Systematophora placacantha*. Based on superposition the age is approximately around the Paleocene/Eocene boundary.

Facies

Most prominent are the open-marine genus *Spiniferites* spp. (53 %) and bisaccate pollen (23 %).

3.10 Sample/interval 412.33 m: late Paleocene, late Thanetian, Zone P5b

The dating is based on:

- LOD *Alisocysta margarita*
- FOD *Deflandrea denticulata*

Remarks: The Zone P5b sensu Bujak & Mudge, 1994 can be correlated to Zone 4 in Heilmann-Clausen, 1985 and Zone Ama in Powell, 1992.

Facies

Dinocysts comprise 95 % of the microflora. *Spiniferites* spp. dominate (82 %) the association. Open marine conditions are interpreted.

3.11 Sample/interval 414.64 m: Not diagnostic



Remarks: No dinocysts, spores and pollen are recorded during the palynological analysis of this core sample. The lithology changed from a clastic into a carbonate deposition.

4 Conclusions, discussion and recommendations

The palynostratigraphic results of borehole DAPGEO-02 are tabulated below:

Table 3: Overview age-assessments of borehole DAPGEO-02

Depth (m - MD)	Age, Zone
364.10	late Miocene, latest Tortonian, post Zone SNSM14
370.76	late Miocene, late Tortonian, Zone SNSM14
372.95	late Miocene, late Tortonian, Zone SNSM13
377.70	late Miocene, early Tortonian, Zone SNSM12
ca. 382.95	~~~~~ (MMU)
382.95	middle Miocene, late Serravallian, Zone SNSM10
386.05	middle Miocene, mid Langhian, Zone SNSM6
389.69	middle Miocene, early Langhian, Zone SNSM5
390.5	~~~~~ (EMU+Savian+Pyrenean+ phases)
393.66	early Eocene, earliest Ypresian, Zone E1a (approx. PETM)
412.33	late Paleocene, late Thanetian, Zone P5b
ca. 414	~~~~~ (Laramide+ phase)

Based on the palynological study of borehole DAPGEO-02 the following stratigraphic conclusions are reached:

- More than half of the studied succession, interval 364.10-414.64 m, does not fit with the Paleogene, but is here interpreted as lower Neogene, Miocene (interval 364.10-390.5 m). Based on lithology, age and facies interpretation the current succession is lithostratigraphical divided into the Diessen Formation, interval 364.10-382.95 m (thickness: 18.85 m) and Groote Heide Formation, interval 382.95-390.5 m (thickness: 7.55 m). The boundary between these formations corresponds to the MMU. The latter is associated with a high peak on the gamma-ray log at c. 382.95 m (see gamma-ray log on Enclosures). The uppermost clayey interval c. 363.4-369.3 m (see lithological description) might be correlated with the Belgian Kasterlee Formation, which is dated as Zone DN10 sensu De Verteuil & Norris, 1996 (cf. post Zone SNSM14) in VandenBerghe et al., 2020. In the Netherlands the present clayey sequence (not yet differentiated in the Strat. Nomenclator NL) is recorded near the top of the Formation of Diessen e.g. in the Roer Valley Graben and in the Achterhoek. It is striking that the present Miocene deposits are thin, although stratigraphically quite complete (and hence not limited to known depocenters (RVG, Zuiderzee).
- A major unconformity is recorded at ca. 390.5 m, comprising the mid-late Eocene, Oligocene and early Miocene. Absent are the lithostratigraphic units of the Brussels Sand and Asse members belonging to the Formation of Dongen, the Rupel Formation and Formation of Veldhoven.
- A late Paleocene, Thanetian-early Eocene, Ypresian age range is interpreted within the interval c. 390.5-414 m. Based on lithology, age and facies interpretation the lithostratigraphy fits with the Landen Formation, Liessel Member (interval: c. 402-414 m) and the Oosteind (interval: c. 394-402 m) and Ieper (interval: c. 390.5-394 m) members within the Dongen Formation.

- The top of the Chalk Group is recorded at 414 m. A palynological prepared sample at 414.64 m did not yield any palynomorphs, hence was not age-diagnostic. Most probably the Formation of Ommelanden is reached, because the Paleocene Houthem Formation is palynologically more prolific.

Table 4: Lithostratigraphic classification (sensu Stratigraphic Nomenclator NL, online)

Depth (m)	Group	Formation	Member
364.10-382.95	NU	Diessen	
382.95-390.5	NM	Groote Heide	
390.5-394	NL	Dongen	leper
394-402			Oosteind
402-414		Landen	Liessel
414-	Chalk	?Ommelanden	

Recommendations

Additional palynological analyses are recommended for:

- interval 390.5-392 m, to establish the relative age of the present “top” of the leper Member, including the (maximum) chronostratigraphic extent of the hiatus
- interval 394-410 m, to accurately monitor and check the plausible development of the PETM event with reference to the changes in lithostratigraphy (basal leper, Oosteind and top Liessel members). One may also consider to run a few carbon isotope analyses.
- Interval 414-416 m, to date the top of the Chalk Group. The stratigraphy of the Chalk Group can likely be resolved by analyzing calcareous nannofossils.

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6 Signature

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Authorisation of release

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Well Name : DAPGEO-02

Interval : 360.00m - 420.00m

Scale : 1:750

Chart date: 13 January 2023

Palynological interpretation

TNO report

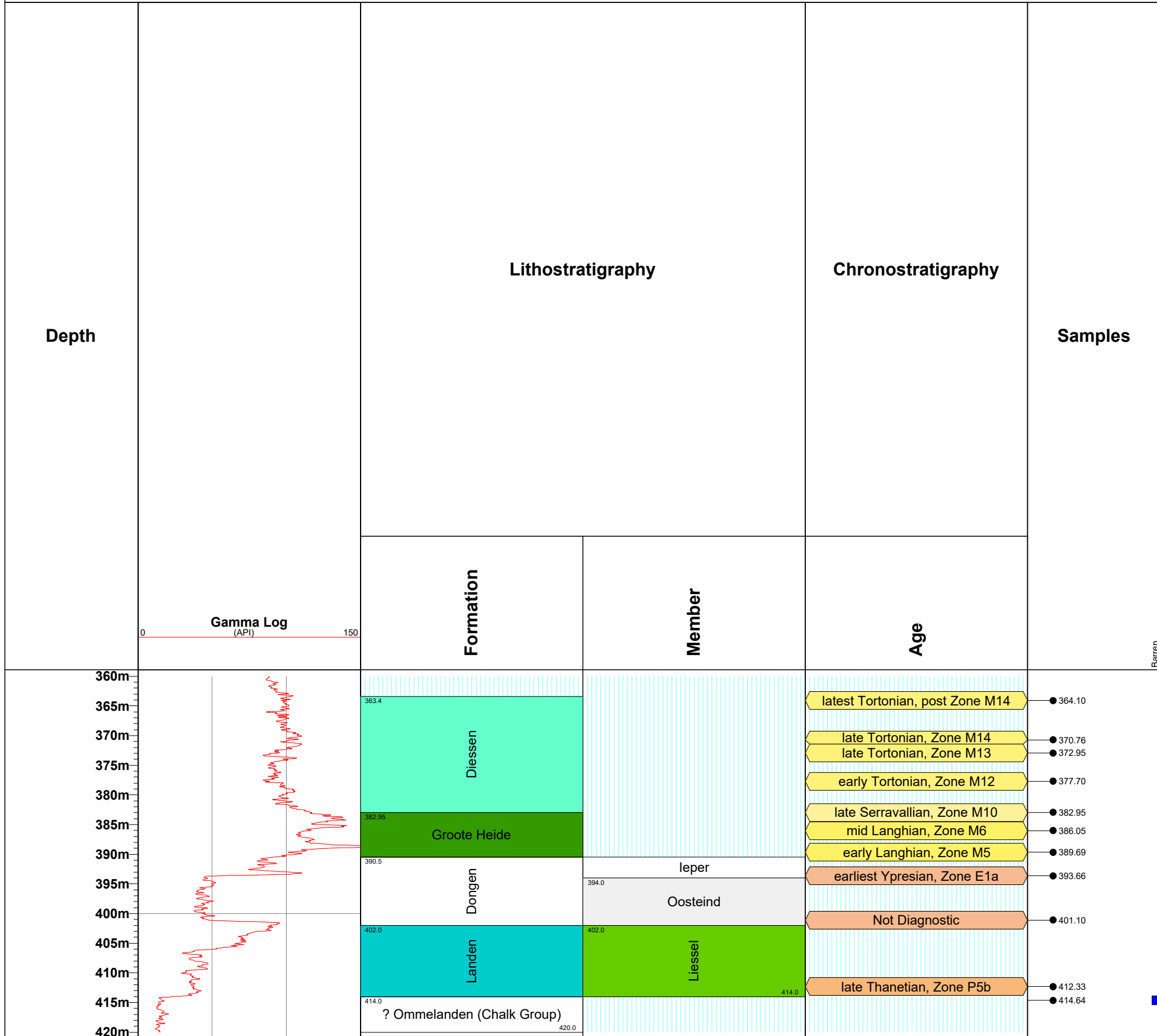
Dirk Munsterman

DAPGEO-02

TNO-NITG

Utrecht

Enclosure 1



Barren

Well Name : DAPGEO-02

Interval : 360.00m - 420.00m
 Scale : 1:750
 Chart date: 13 January 2023

Distribution chart (rel)
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DAPGEO-02

