Geologische Dienst Nederland
Princetonlaan 6
3584 CB Utrecht
P.O. Box 80015
3508 TA Utrecht
The Netherlands

www.tno.nl

T +31 88 866 42 56

TNO report

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Palynostratigraphy of four wells in the Zuiderzee Low area: updating the stratigraphy of the former Breda Fm.

Date	30 January 2023
Author(s)	Dr. Sander Houben
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Contents

1 Introduction

Miocene strata in the Netherlands comprise a series of often glauconite-bearing fine sand, silt- and claystones deposited in a marine environment. Historically these strata are lithostratigraphically contained in the Veldhoven Formation of the Middle North Sea Group and the Breda Formation and Oosterhout Formation of the Upper North Sea Group (Van Adrichem Boogaert and Kouwe, 1995). Thick accumulations (up to 700 m) of Miocene strata are confined to major syn-depositional basins, the most prominent being the Roer Valley Graben in the provinces of Noord-Brabant and Limburg (Munsterman et al., 2019), and the offshore North Sea Basin (De Bruin et al., 2015). In contrast, in much of the Dutch onshore, only a thin Miocene sequence is present. The Zuiderzee Low (Figure 1) is another potential locus for thicker accumulations of Miocene strata, as it is known as an 'Early Tertiary basinal low' in the Central Netherlands onshore (eastern Noord-Holland, Flevoland and northwestern Gelderland, Duin et al., 2006). For this region, modern biostratigraphic data are not available. Consequently, the stratigraphic architecture of the Miocene and Pliocene is poorly understood, hampering the development of a specific geological model for Miocene strata in this area.

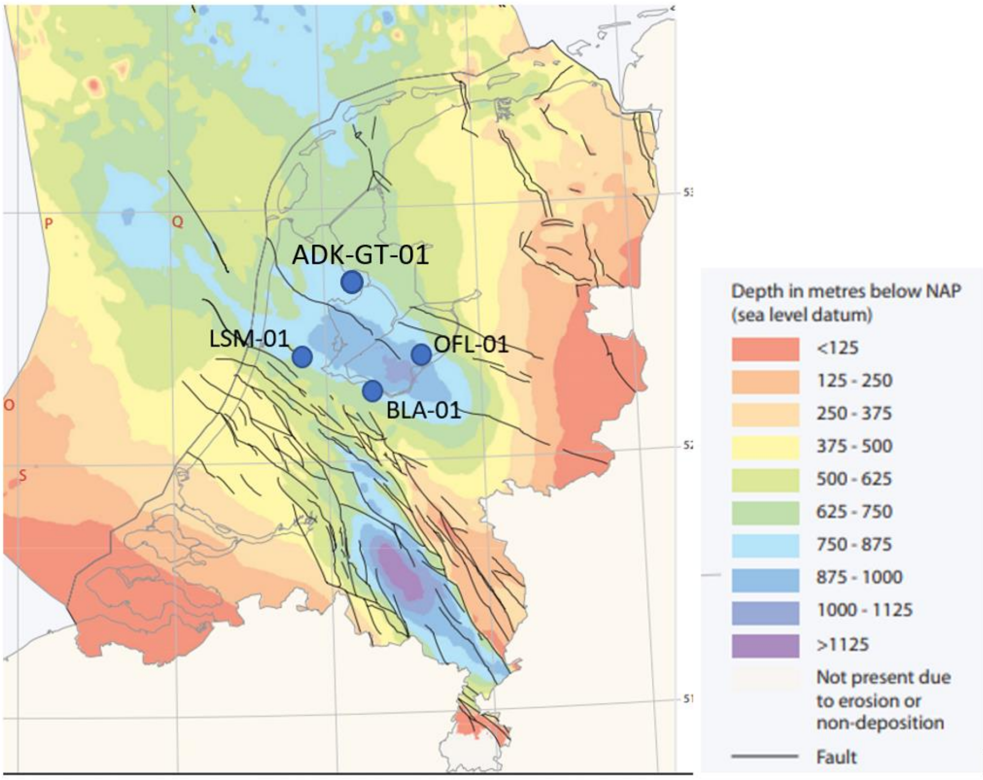

Figure 1: Map displaying the depth of the base of the Upper North Sea Group (=base Breda Fm., after Duin et al., 2006). The Zuiderzee Low is clearly displayed as a depocenter for Upper North Sea Group deposits. The location of the four investigated wells is given.

Chronostratigraphic (age) control is of particular importance because the lithostratigraphic nomenclature for the Miocene of the Netherlands has recently been revised. The former Breda Fm. is now subdivided into two Formations; the Middle Miocene Groote Heide and Upper Miocene Diessen Fm. respectively (Munsterman et al., 2019). This subdivision is based on lithological characteristics but is also strongly rooted in the seismo/sequence stratigraphic framework developed for the Roer Valley Graben, where four major unconformities are observed. These concern:

1. The **Savian Unconformity** (Late Oligocene – Chattian). This unconformity occurs within the **Veldhoven Formation**.
2. The **Early Miocene Unconformity** (EMU, Burdigalian). This unconformity corresponds to the top of the **Veldhoven Fm.** and the base of the **Groote Heide Fm.**
3. The **Middle Miocene Unconformity** (MMU, Serravalian-Tortonian). This unconformity corresponds to the top of the Groote Heide Fm. and the base of the Diessen Fm.
4. The **Late Miocene Unconformity** (latest Tortonian-Messinian). This unconformity corresponds to the top of the Diessen Fm. and the base of the (Pliocene) Oosterhout Fm.

Although this unconformity-based framework has only been mapped in detail in the Roer Valley Graben, it is expected to have a regional character and it can be traced far into the Dutch and Danish offshore area (De Bruin et al., 2015). In this report, palynology-based chronostratigraphic (age) breakdowns are provided for four wells in the Zuiderzee Low area; Andijk-Geothermie-1 (ADK-GT-01), Blaricum-1 (BLA-01), Oost Flevoland-1 (OFL-01) and Landsmeer-1 (LSM-01). The results of the study are expected to elucidate how the Miocene-Pliocene interval is stratigraphically developed in and around the Zuiderzee Low basin. This facilitates a genetic comparison with the Roer Valley Graben. It also shows if, and how application of the updated lithostratigraphic framework *sensu* Munsterman et al. (2019) can be achieved outside the Roer Valley Graben. This project was carried out as part of the Warming-Up Project and the GeoInformation Program of the Geological Survey of the Netherlands.

Dit project is mede uitgevoerd als onderdeel van het Innovatieplan WarmingUP. Dit is mede mogelijk gemaakt door subsidie van de Rijksdienst voor Ondernemend Nederland (RVO) in het kader van de subsidieregeling Meerjarige Missiegedreven Innovatie Programma's (MMIP), bij RVO bekend onder projectnummer TEUE819001. WarmingUP geeft invulling aan MMIP-4 – Duurzame warmte en koude in gebouwde omgeving en levert daarmee een bijdrage aan Missie B – Een CO_2-vrije gebouwde omgeving in 2050.

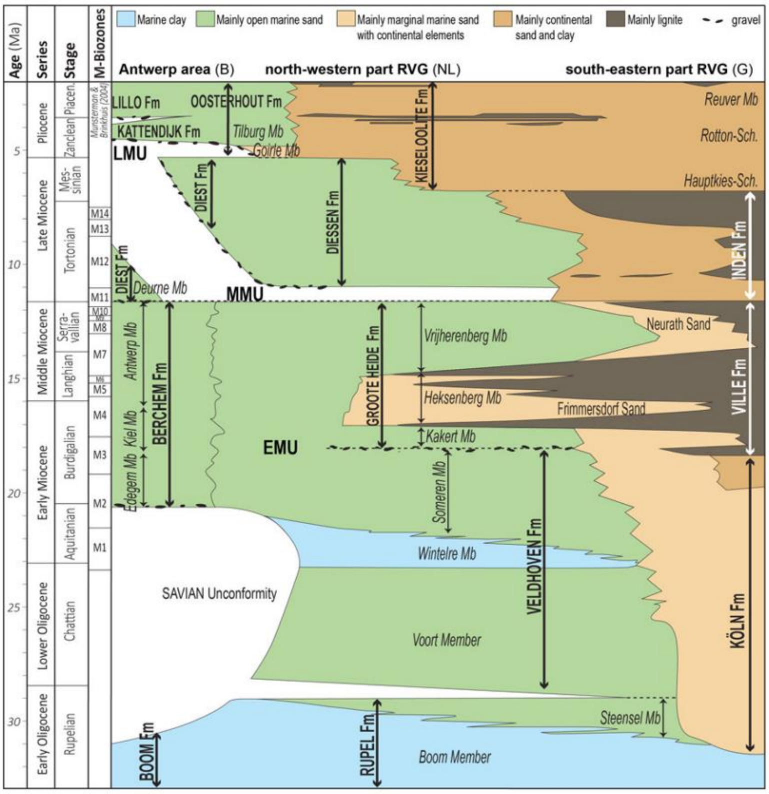

Figure 2: Stratigraphic chart for the Oligocene-Miocene strata of the Roer-Valley Graben after Munsterman et al. (2019).

2 Material and Methods

2.1 Abbreviations

Table 1 Standard abbreviations used by the TNO-Biostratigraphy team

CO	Core sample
SC	Sidewall core sample
CU	Cuttings sample
AL	Air-lifted sample
m	Meter
ft	Feet
LOD	Last Occurrence Datum
LCOD	Last Common Occurrence Datum
FOD	First Occurrence Datum
FCOD	First Common Occurrence Datum
EMU	Early Miocene Unconformity
LMU	Late Miocene Unconformity
MMU	Mid-Miocene Unconformity
DC	Dinocyst
SP	Sporomorph (pollen and spores)

2.2 Samples

Table 2 Sampled wells and intervals

Well	**Interval (m MD)**	**# samples**
ADK-GT-01	605 – 1000	11
BLA-01	400 – 950	12
LSM-01	550 – 940	9
OFL-01	400 – 1110	15

2.3 Palynological preparation

Palynology is the study of acid-resistant organic matter from sedimentary rocks. Organic matter is classified into 1) palynomorphs; organic microfossils within a certain size range 2) palynodebris; all other organic material such as plant-tissue, wood fragments, structureless organic matter, etc. Within the palynomorph category, two groups are considered the most important: marine dinoflagellate cysts (dinocysts), and pollen and spores of land-plants. In this study we primarily rely on dinocysts, resting stages of unicellular and predominantly marine algae called dinoflagellates. These have a well-documented taxonomy (Williams et al., 2017) and their stratigraphic ranges are well-known (see section 2.5).

All samples were processed by TNO at the Utrecht University Laboratory. 35% hydrochloric acid and 30% hydrofluoric acid were used for carbonate and silicate digestion respectively. The resultant kerogens were sieved over a 15 mm mesh. Slides were mounted in glycerine jelly and sealed with a cover slip.

2.4 Palynological analysis

Analysis was performed quantitatively. The study focuses on organic-walled dinoflagellate cysts. Other palynomorph categories (pollen, spores, algae) were considered in larger taxonomic complexes.

2.5 Palynostratigraphic interpretation

Due to the nature of the recovered material (cuttings), the chronostratigraphically latest (youngest) occurrences LODs are used for biostratigraphic interpretation, this is to circumvent the effects of downhole contamination. A complete record of the palynomorph distribution for each well is provided in Appendix A-C.
The biostratigraphic interpretation follows a number of key publications, including their zonal schemes; DeVerteuil and Norris (1996, Miocene, Figure 3), Munsterman & Brinkhuis (2004, Miocene Zonation, Figure 3), Van Simaeys et al. (2005, Oligocene Zonation, Figure 4) and Bujak and Mudge (1996, Paleocene-Eocene Zonation, Figure 5).

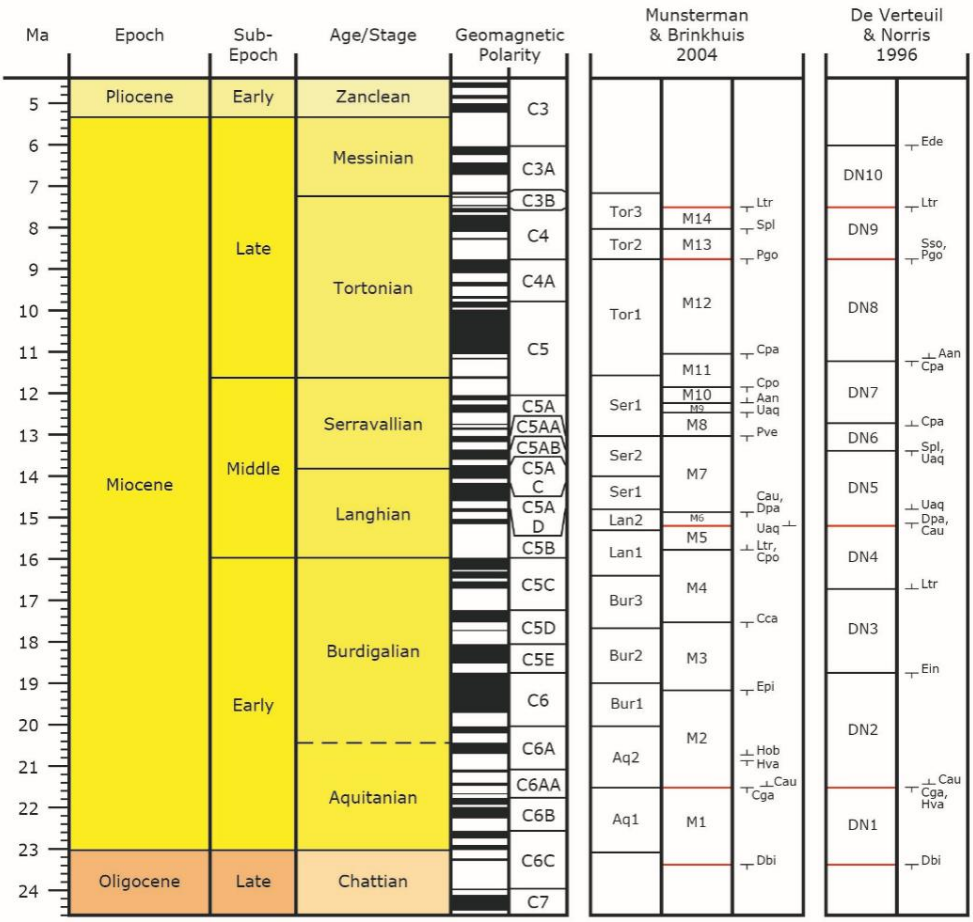

Figure 3: Dinoflagellate zonation for the Miocene after Munsterman & Brinkhuis (2004), recalibrated to the GTS sensu Ogg et al., 2016. The Miocene dinoflagellate cyst zones are referred to as the M-zones.

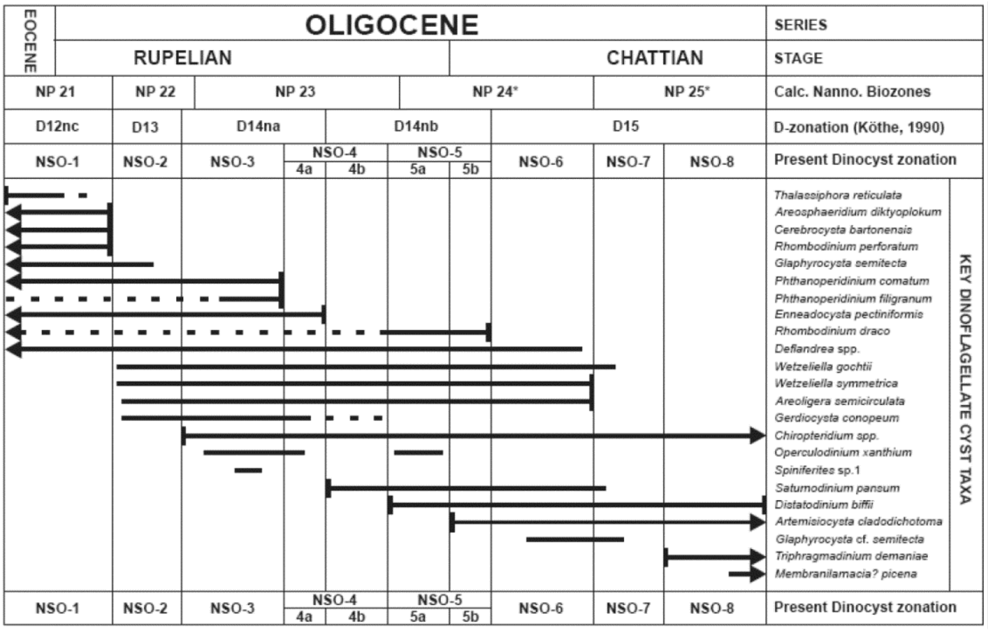

Figure 4: Dinoflagellate cyst distribution chart and zonation for the Oligocene after Van Simaeys et al. (2005). The Oligocene dinoflagellate cyst zones are referred to as the NSO-zones.

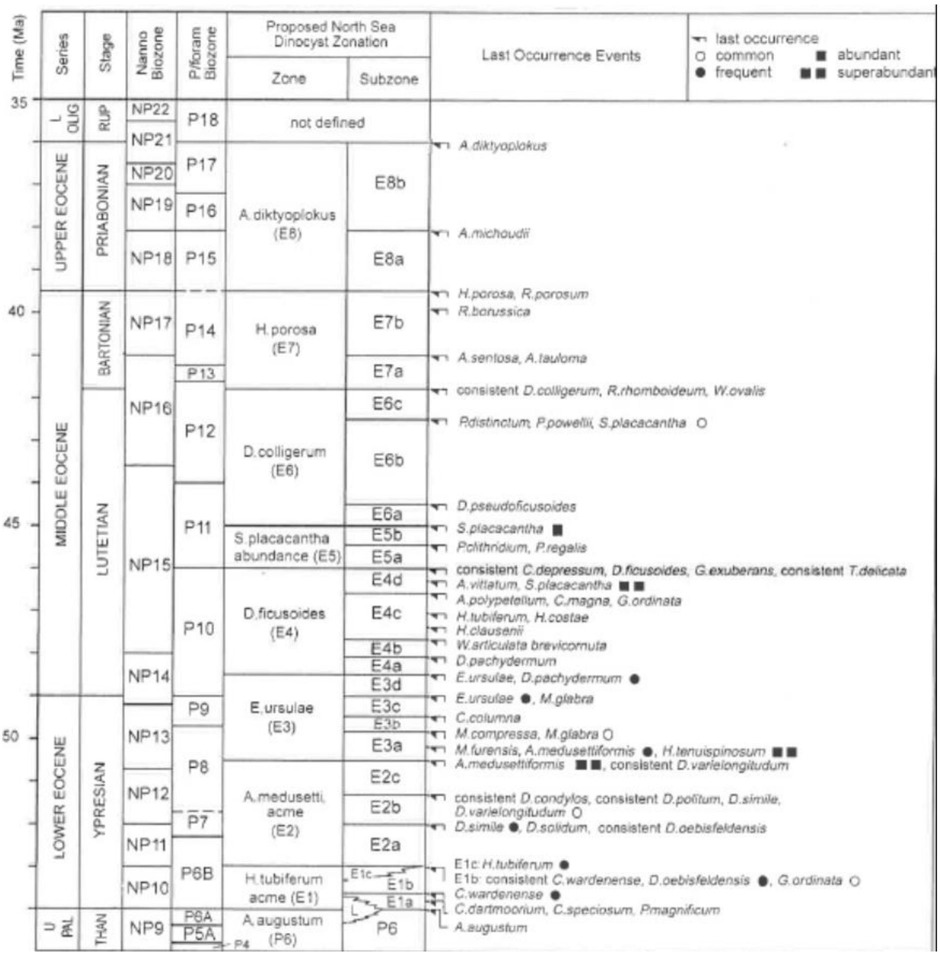

Figure 5: Dinoflagellate cyst zonation for the Eocene after Bujak and Mudge (1994).

3 Results

All studied samples yielded well-preserved palynological associations. The majority is dominated by organic-walled dinoflagellate cysts, signifying persistent marine conditions. The only exception are the more shallow samples of the sections, in which pollen and spores are dominant.

3.1 Well ADK-GT-01

Interval 510 – 550 m MD: Uncertain, likely Early Pleistocene
This interpretation is based on:

- Absence of *Barssidinium* spp.

Remark: Dinocysts are very rare and may be reworked in a predominantly fluvially-dominated setting.

Interval 605 – 650 m MD: Pliocene: Late Zanclean – Piacenzian
This interpretation is based on:

- LOD of *Barssidinium graminosum* at 605 m MD
- LOD of *Achomosphaera andalousiensis* at 605 m MD
- LOD of *Invertocysta lacrymosa* at 650 m MD
- LOD of *Heteraulacacysta* sp. at 650 m MD

Interval 700 – 775 m MD: Pliocene: Early Zanclean
This interpretation is based on:

- LOD of *Melitasphaeridium choanophorum* at 700 m MD
- LOD of *Reticulatosphaera actinocoronata* at 750 m MD
- LCOD of *Operculodinium tegillatum* at 750 m MD

Sample 800 m MD: MIddle Miocene: latest Serravalian (Zone M10)
This interpretation is based on:

- LOD of *Cannosphaeropsis passio* at 800 m MD
- LOD of *Cerebrocysta poulseni* at 800 m MD
- LOD of *Paleocystodinium golzowense* at 800 m MD
- LOD of *Systematophora placacantha* at 800 m MD
- LOD of *Labyrinthodinium truncatum* at 800 m MD
- LOD of *Impagidinium densiverrucosum* of Zevenboom 1995 at 800 m MD

Sample 835 m MD: Middle Miocene: early Langhian (Zones M5-6)
This interpretation is based on:

- LOD of *Apteodinium spiridoides* at 835 m MD
- LOD of *Cousteaudinium aubryae* at 835 m MD
- LOD of *Distatodinium paradoxum* at 835 m MD
- LOD of *Paleocystodinium ventricosum* at 835 m MD
- LCOD of *Systematophora placacantha* at 835 m MD

Interval 850 - 875 m MD: Early Miocene: Burdigalian (Zone M3) to Aquitanian (Zone M2, base)
This interpretation is based on:
- LOD of *Cordosphaeridium cantharellum* at 850 m MD
- LOD of *Homotryblium vallum* at 875 m MD

Interval 955 - 1000 m MD: Middle Eocene: early Lutetian Zone E4
This interpretation is based on:
- LOD of *Diphyes colligerum* at 955 m MD
- LOD of *Dracodinium/Wetzeliella varielongitudum* at 955 m MD
- LOD of *Hystrichosphaerdium tubibeferum* at 955 m MD
- Absence of *Eatonicysta ursulae*

Remarks: The *in-situ* Eocene flora is very sparse. The large majority of encountered palynomorphs is caved from overlying strata. This may support the inference of the Brussels Sand Mb., which is generally palynologically poor. The flora does contain Upper Eocene (Priabonian) but lacks definite Lower Oligocene (Rupelian, notably *Chiropteridium* spp.) elements. This suggests the Asse Mb. is developed, and the Rupel Fm. is absent in the interval that is not currently sampled (i.e, between 875 and 955 m MD).

3.2 Well OFL-01

Sample 400 - 440 m MD: Uncertain, likely Pleistocene
This interpretation is based on:
- Absence of *Barssidinium* spp.

Remark: Dinocysts are very rare. Those that are present suggest a Pleistocene rather than Pliocene age.

Interval 500-550 m MD: Early Pliocene (Early Zanclean, not zoned)
This interpretation is based on:
- LOD *Reticulatosphaera actinocoronata* at 500 m MD

Interval 610 – 660 m MD: Late Miocene (late Tortonian to Messinian, post-Zone M14)
This interpretations is based on:
- LOD *Impagidinium densiverrucosum* at 610 m MD

Interval 710 – 760 MD: Late Miocene (Tortonian) Zone M12 and M13
This interpretation is based on:
- LOD of *Systematophora placacantha* at 710 m MD
- LOD of *Sumatradinium druggi* at 760 m MD
- Absence of *Cannosphaeropsis passio*

Interval 810 - 860 m MD: Middle Miocene (Langhian) Zones M5-M6
This interpretation is based on :
- LCOD of *Systematophora placacantha* at 810 m
- LOD *Coustodinium aubreyae* at 810 m
- LOD *Distatodinium paradoxum* at 810 m
- LOD *Apteodinium spiridoides* at 860 m

Interval 910 – 990 m MD: Early Miocene (mid Burdigalian) Zone M3, or older
This interpretation is based on:
- LOD *Cordosphaeridium cantharellum* at 910 m

Sample 1040 Oligocene: Chattian Zones NSO-6 – NSO-8, or older
This interpretation is based on:
- LOD *Chiropteridium galea* at 1040 m

Sample 1110: Middle Eocene (Bartonian, Zone E7 or older)
This interpretation is based on:
- *LOD Heteraulacacysta porosa*

Remark: The Rupelian is present between 1110 and 1040 since caved (down-hole contamination) specimens of *Wetzeliella gochtii* are observed in the sample at 1110 m. Presence of Eatonicysta ursulae suggests reworking of Ypresian and lower Lutetian strata at this level.

3.3 Well BLA-01

Sample 400 m CU: Uncertain, likely Early Pleistocene
This interpretation is based on:
- Abundant Ericaceae
- Absence of Pliocene dinoflagellate cysts (e.g., *Barssidinium* spp.)
- Presence of *Operculodinium israelianum* at 400 m MD

Sample 450 – 500 m CU: Pliocene: Piacenzian, or older
This interpretation is based on:
- LOD of *Barssidinium* spp. at 450 m MD
- LOD of *Melitasphaeridium choanophorum* at 500 m MD

Interval 550 – 600 m: Late Miocene (late Tortonian, Zone M13)
This interpretation is based on:
- LOD of *Hystrichosphaeropsis obscura* at 550 m MD
- LOD of *Reticulatosphaera actinocoronata* at 550 m MD
- LOD of *Systematophora placacantha* at 550 m MD

Sample 650 m MD: Late Miocene (mid Tortonian, Zone M12)
This interpretation is based on:
- LOD *Paleocystodinium golzowense*
- FCOD of *Achomosphaera andalousiensis*

Interval 700-800 m MD: Middle Miocene (Serravalian to earliest Tortonian Zone M9-M11)
This interpretation is based on:
- LOD *Cannosphaeropsis passio* at 700 m
- Absence of *Unipontidinium aquaductus* at 800 m

Remark: older Middle Miocene strata (e.g., Langhian) were not sampled, but possibly present between 800 and 850 m MD.

Interval 850 – 900 m MD: Early Miocene (mid Burdigalian, Zone M3), or older
This interpretation is based on:
- LCOD *Cordosphaeridium cantharellum* at 850 m MD
- LOD *Coustodinium aubreyae* at 850 m MD
- LOD *Apteodinium spiridoides* at 850 m MD

Sample 950 m MD: Early Miocene (late Aquitanian to early Burdigalian, base Zone M2), or older
This interpretation is based on:
- LOD *Ectosphaeropsis picena* at 950 m MD
- LOD *Homotryblium vallum* at 950 m MD

3.4 Well LSM-01

Sample 550 m: Uncertain, likely Early Pleistocene (Gelasian, not zoned)

This interpretation is based on:
- LOD of *Habibacysta tectata* at 550 m MD
- Presence of *Ulmus glabra*
- Absence of Pliocene elements

Sample 600 m: Pliocene: late Zanclean - Piacenzian
This interpretation is based on:
- LOD of *Barssidinium* spp.

Interval 650 - 700 m: Early Pliocene: Early Zanclean
This interpretation is based on:
- LOD of *Reticulatosphaera actinocoronata* at 650 m MD

Interval 750 – 800 m: Middle Miocene (Langhian, Zone M5-6)
This interpretation is based on:
- LOD *Cousteaudinium aubryae* at 750 m MD
- FOD *Unipontedinium aquaductum* at 800 m MD

Remark: The presence of *Impagidinium densiverrucosum* at 750 m is ascribed to downhole contamination. This suggests a (thin) Tortonian succession is present between 750 m and 700 m depth.

Sample 850 - 900 m: Oligocene (mid-Rupelian, NSO-4)
This interpretation is based on:
- LOD *Enneadocysta pectiniformis* at 850 m MD
- LOD *Distatodinium biffii* at 850 m MD
- LOD *Chiropteridium galea* at 900 m MD

Sample 940 m: Oligocene (early Rupelian, NSO-3)
This interpretation is based on:
- LOD *Phthanoperidinium comatum* (DC)
- LCOD *Histiocysta* spp. (DC)

Remark: An Eocene (Priabonian or older) age is unlikely since *Areosphaeridium diktyoplokus* was not encountered.

4 Discussion and conclusions

The new palynological data allow for chronostratigraphic interpretation of the investigated sections. These form the basis for identification of the regional unconformities of Munsterman et al. (2019), now for the first time in the Zuiderzee Low area. The interpretations facilitate an update of the lithostratigraphic interpretations (see Table 3-6, see also Appendix A).
In all investigated wells, unconformities are observed separating the following strata (Figure 6):

- Eocene from Oligocene (Pyrenean Unconformity)
- Oligocene from Lower Miocene (Savian Unconformity)
- Lower Miocene from Middle Miocene (mid-Burdigalian from Langhian, EMU)
- Middle Miocene from Upper Miocene (Langhian-Serravalian from Tortonian, MMU)
- Upper Miocene from Lower Pliocene (LMU)

Following the Roer-Valley Graben framework, these unconformities correspond to the formation boundaries between the Upper Oligocene – Lower Miocene Veldhoven Fm., the Lower-Middle Miocene Groote Heide Fm. and the Upper Miocene Diessen Fm. respectively (Figure 6).

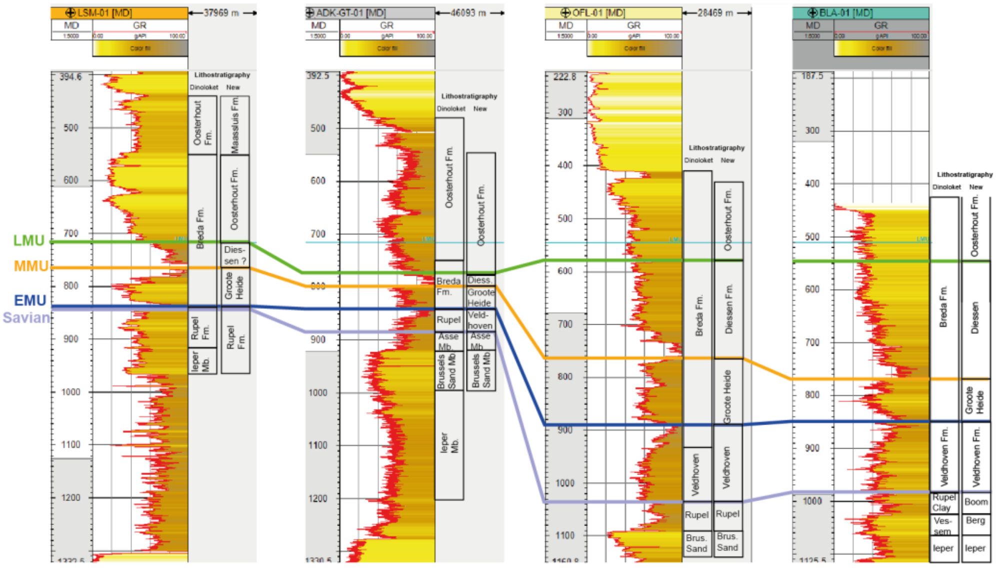

Figure 6: Figure 4: GR-correlation panel of the investigated wells. The colored lines indicate the position of the regional unconformities. Following the updated chronstratigraphic a suggestion for a revision of the lithostratigraphic nomenclature is given. A full-size version is given as an appendix to this report.

The lithostratigraphy for well **ADK-GT-01** as provided on Dinoloket follows the composite well log interpretation. In well ADK-GT-01, Middle Eocene (lower Lutetian) assemblages are encountered at 955 m and 1000 m depth. This confirms the original assignment to the Brussels Sand Mb. of the Dongen Fm. Abundant downhole contamination in those samples contains Late Eocene, but lacks Early Oligocene elements. This suggests that the Asse Mb. of the Dongen

Fm. (888 – 919 m MD) is present and that the Lower Oligocene Rupel Fm. is not developed here.
Instead, the sequence initially assigned to the Rupel Fm. (844 – 888 m MD) contains an earliest Miocene (Aquitanian) association, which warrants inclusion in the Veldhoven Fm. The highest gamma-ray values correspond to the clayey Wintelre Member. The lower values below to the Voort Member.
Middle Miocene samples was encountered at 835 m MD (Langhian) and at 800 m MD (Serravalian). This implies that the MMU (and the top of Groote Heide Fm.) is located between 775 and 800 m MD. At 775 m MD, the Lower Pliocene is encountered. Hence, the base of the Oosterhout Fm. lies somewhat deeper than the initial interpretation suggested. A thin Diessen Fm.-equivalent is encountered somewhere between 800 and 775 m MD. The above implies that Diessen and Groote Heide Fm. (e.g., the Breda Fm.) combined equate to a thickness of about 70 m.

The lithostratigraphy for well **OFL-01** as provided on Dinoloket was last updated in 2004. Generally this interpretation is consistent with the new biostratigraphic data, albeit the identification of Middle Miocene (810 – 860 m MD) and Upper Miocene (610 – 760 m MD) sequences allow for identification of the Groote Heide (580 – 765 m) and Diessen Fm. (765-910 m), respectively. The lowermost Miocene Veldhoven Fm. is indeed developed. The base of the Pliocene is also encountered substantially deeper than the base of the Oosterhout Fm. (at 550 m instead of 400 m MD). The above implies that Diessen and Groote Heide Fm. (e.g., the Breda Fm.) combined equate to a thickness of about 330 m.

The lithostratigraphy for well **BLA-01** as provided on Dinoloket was last updated in 2004. Generally this interpretation is consistent with the new biostratigraphic data, albeit the identification of Middle Miocene (700 – 800 m MD) and Upper Miocene (550– 650 m MD) sequences allow for identification of the Groote Heide (780 – 835 m) and Diessen Fm. (550 - 780 m), respectively. The lowermost Miocene, older half of Veldhoven Fm. (Wintelre and Voort Mb.) is indeed developed. The base of the Pliocene is again encountered substantially deeper than the base of the Oosterhout Fm. (at 550 m instead of 425 m MD). The above implies that Diessen and Groote Heide Fm. (e.g., the Breda Fm.) combined equate to a thickness of about 285 m.

Although the Miocene succession in well **LSM-01** is substantially thinner than in some of the other wells, it remains unclear whether it also more truncated by all the respective unconformities. Indeed, the Veldhoven Fm. is absent and Langhian strata overly Rupelian, suggesting a large, amalgamated Savian U/C and EMU associated hiatus (at ~840 m MD). A Middle Miocene (Langhian) succession is encountered at 750 and 800 m MD whereas the Lower Pliocene is encountered at 700 m MD. The presence of a few caved Tortonian specimens in the sample at 750 m MD suggests the Diessen Fm. is developed between 700 – 750 m MD. Also in this instance, the base of the Pliocene does not correspond to the base of the Oosterhout Fm. (700 vs. 550 m MD).   The above implies that Diessen and Groote Heide Fm. (e.g., the Breda Fm.) combined equate to a thickness of about 144 m.

It is clear that the base of the Diessen Fm. is consistently characterized by very high GR-values. Consequently, a (series of) progressive cleaning-upward cycle(s) are recorded. Likely this GR-maximum reflects glauconite enrichment in association with sediment starvation and/or winnowing in association with the MMU. In the more basin-ward wells (OFL-01 and BLA-01), a thick Diessen sequence with an overall cleaning/coarsening upward character is observed. In wells LSM-01 and ADK-GT-01 towards the western edge of the basin, the Diessen is truncated, thin, and the consequent coarsening upward cycle is of Pliocene rather than Miocene age.

It also noteworthy that the (Upper) Miocene palynological associations in all wells consistently contain a substantially smaller proportion of pollen (notably bisaccate pollen of *Pinus*) than Pliocene ones (<10% vs. ~80%). This likely signifies a progradation of the coastline by Pliocene times, perhaps in association with the LMU. It also remarkable that Miocene dinoflagellate cyst assemblages are characterized by the consistent presence of genuinely open marine taxa like *Impagidinium dispertitum* and *Nematosphaeropsis labyrinthus*. This suggests that the Miocene coast-line was quite from the study area, which was subjective to open-marine conditions.

In all investigated wells, the base of the Oosterhout Fm. lies deeper than previously interpreted. This implies that some of the sandstone-dominated lithologies previously assigned to the Breda Fm. are of Pliocene rather than Miocene age The lithostratigraphic interpretation of well-logs in this ‘shallow domain’ is often very problematic in hydrocarbon exploration wells due to a lack of detailed petrophysical and lithological logging. Consequently, the picking of lithostratigraphic boundaries (e.g., Oosterhout vs. Diessen) on well-logs alone remains problematic. Biostratigraphic analysis and/or proper sedimentary descriptions are instrumental to identify these units accurately.

Table 3: Overview of palynostratigraphic results and inferred lithostratigraphy and position of regional unconformities for well ADK-GT-01

Depth (m)	**Age/Zone**	**Corresponding Lithostratigraphy**	**Previous lithostratigraphy (sensu Dinoloket)**
510 - 550	Uncertain, Pleistocene?	Maassluis?	Oosterhout Fm.
605 – 650	Pliocene (late Zanclean-Piacenzian)	Oosterhout Fm.	Oosterhout
700 - 775	Early Pliocene (early Zanclean)	Oosterhout	Oosterhout
~~	**MMU+LMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
800	Middle Miocene (Serravalian, Zone M10)	Groote Heide Fm.	Breda Fm.
835	Middle Miocene (Langhian, Zone M5-6)	Groote Heide Fm.	Breda Fm.
~~	**LMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
850-875	Early Miocene (Aquitanian Zone M2)	Veldhoven Fm.	Rupel Clay Mb.
~~	**Savian + Pyrenean Unconformity**	~~~~~~~~~~~~	~~~~~~~~~~~~
955 -1000 m	Middle Eocene (Early Lutetian, Zone E4).	Brussels Sand Mb.	Dongen Fm.

Table 4: Overview of palynostratigraphic results and inferred lithostratigraphy and position of regional unconformities for well OFL-01

Depth (m)	**Age/Zone**	**Corresponding Lithostratigraphy**	**Previous lithostratigraphy (sensu Dinoloket)**
400 - 440	Uncertain	Oosterhout Fm. or Maassluis Fm.	Oosterhout Fm.
500 – 550	Early Pliocene (Early Zanclean)	Oosterhout Fm.	Breda Fm.
~~	**LMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
610 – 660	Late Miocene (post-zone M14)	Diessen Fm.	Breda Fm.
710 – 760	Late Miocene (Zone M12-13)	Diessen Fm.	Breda Fm.
~~	**MMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
810 – 860	Middle Miocene (Langhian, Zones M5-M6)	Groote Heide Fm.	Breda Fm.
~~	**EMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
910 – 990	Early Miocene (Burdigalian, Zone M3)	Veldhoven Fm.	Breda/Veldhoven Fm.
~~	**Savian Unconformity**	~~~~~~~~~~~~	~~~~~~~~~~~~
1040	Late Oligocene (Chattian, Zone NSO6-8)	Boom Mb.* and Berg Mb.** – Rupel Fm.	Rupel Clay Mb. – Rupel Fm.

*new name for Rupel Clay Mb. *sensu* Nomenclator
** new name for Vessem Mb. *sensu* Nomenclator

Table 5: Overview of palynostratigraphic results and inferred lithostratigraphy and position of regional unconformities for well BLA-01

Depth (m)	**Age/Zone**	**Corresponding Lithostratigraphy**	**Previous lithostratigraphy (sensu Dinoloket)**
400	Early Pleistocene?	Maassluis Fm.?	Oosterhout Fm.
450	Pliocene (Piacenzian)	Oosterhout Fm.	Breda Fm.
500	Early Pliocene (Early Zanclean)	Oosterhout Fm.	Breda Fm.
~~	**LMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
550 - 650	Late Miocene (Tortonian, Zones M13-14)	Diessen Fm.	Breda Fm.
~~	**MMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
700 - 800	Middle Miocene (Serravalian, Zone M9-11)	Groote Heide Fm.	Breda Fm.
~~	**EMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
850-950	Early Miocene (Aquitanian – Burdigalian, Zone M2-M3)	Veldhoven Fm.	Breda/Veldhoven Fm.

Table 6: Overview of palynostratigraphic results and inferred lithostratigraphy and position of regional unconformities for well LSM-01

Depth (m)	**Age/Zone**	**Corresponding Lithostratigraphy**	**Previous lithostratigraphy (sensu Dinoloket)**
550	Early Pleistocene	Maassluis Fm.	Oosterhout
600 - 700	Pliocene (Piacenzian-Zanclean)	Oosterhout Fm.	Breda Fm.
~~	**LMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
730	Late Miocene? not sampled	Diessen Fm.?	Breda Fm.
~~	**MMU**	~~~~~~~~~~~~	~~~~~~~~~~~~
750 - 800	Middle Miocene (Langhian, Zone M6)	Groote Heide Fm.	Breda Fm.
~~	**EMU + Savian**	~~~~~~~~~~~~	~~~~~~~~~~~~
850 - 900	Middle Rupelian	Rupel Fm.	Rupel Fm.
940	Early Rupelian	Rupel Fm.	Dongen Fm.

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6 Signature

Utrecht, februari 2023

TNO

Singnature of reviewer

ValidSigned by Dirk Munsterman
on 2023-03-17 15:17:29

Drs. D.K. Munsterman

Signature

ValidSigned by Alexander Houben
on 2023-02-28 09:12:55

Dr. A.J.P. Houben
Author

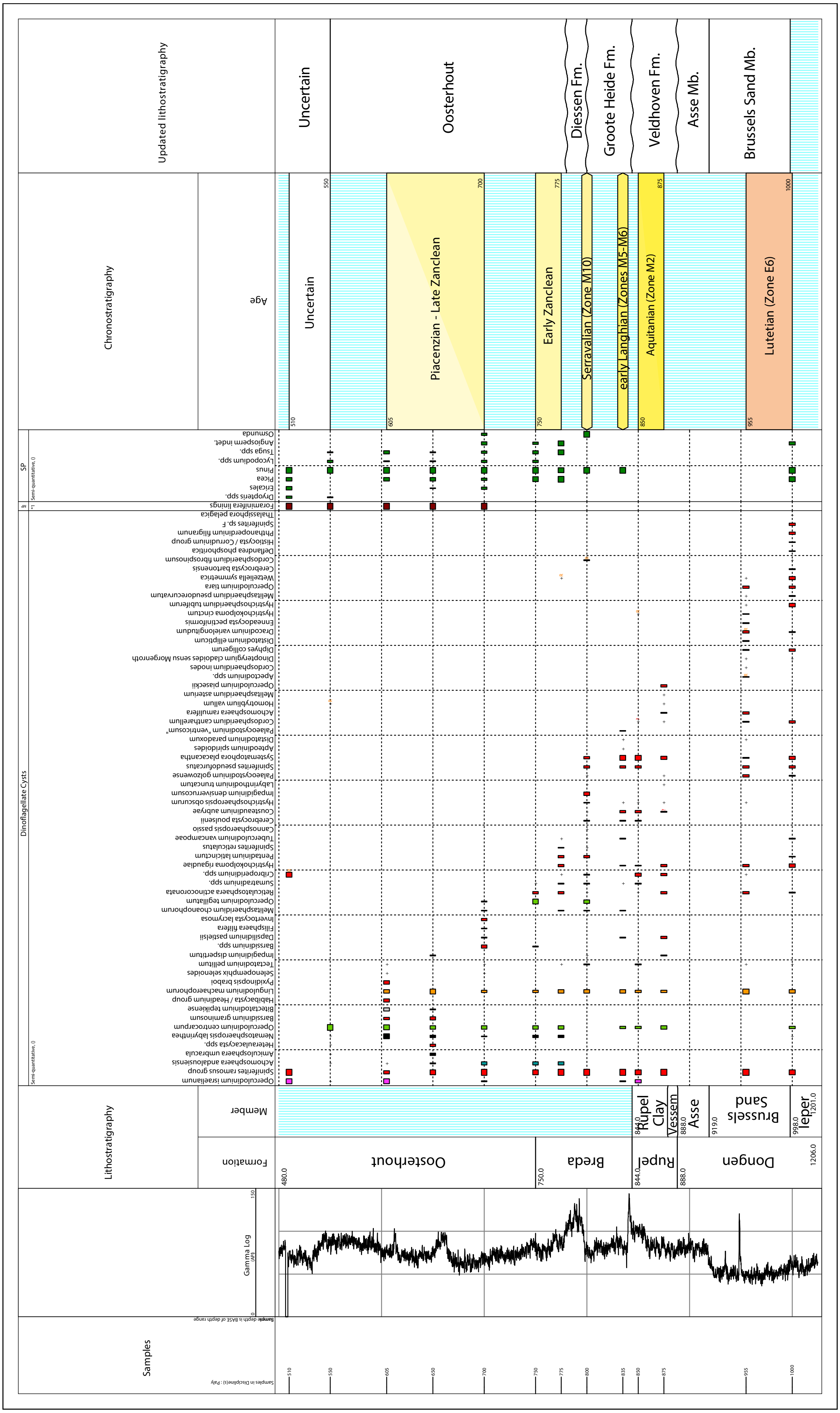
Authorization of release

ValidSigned by Denise Maljers
on 2023-02-28 09:24:27

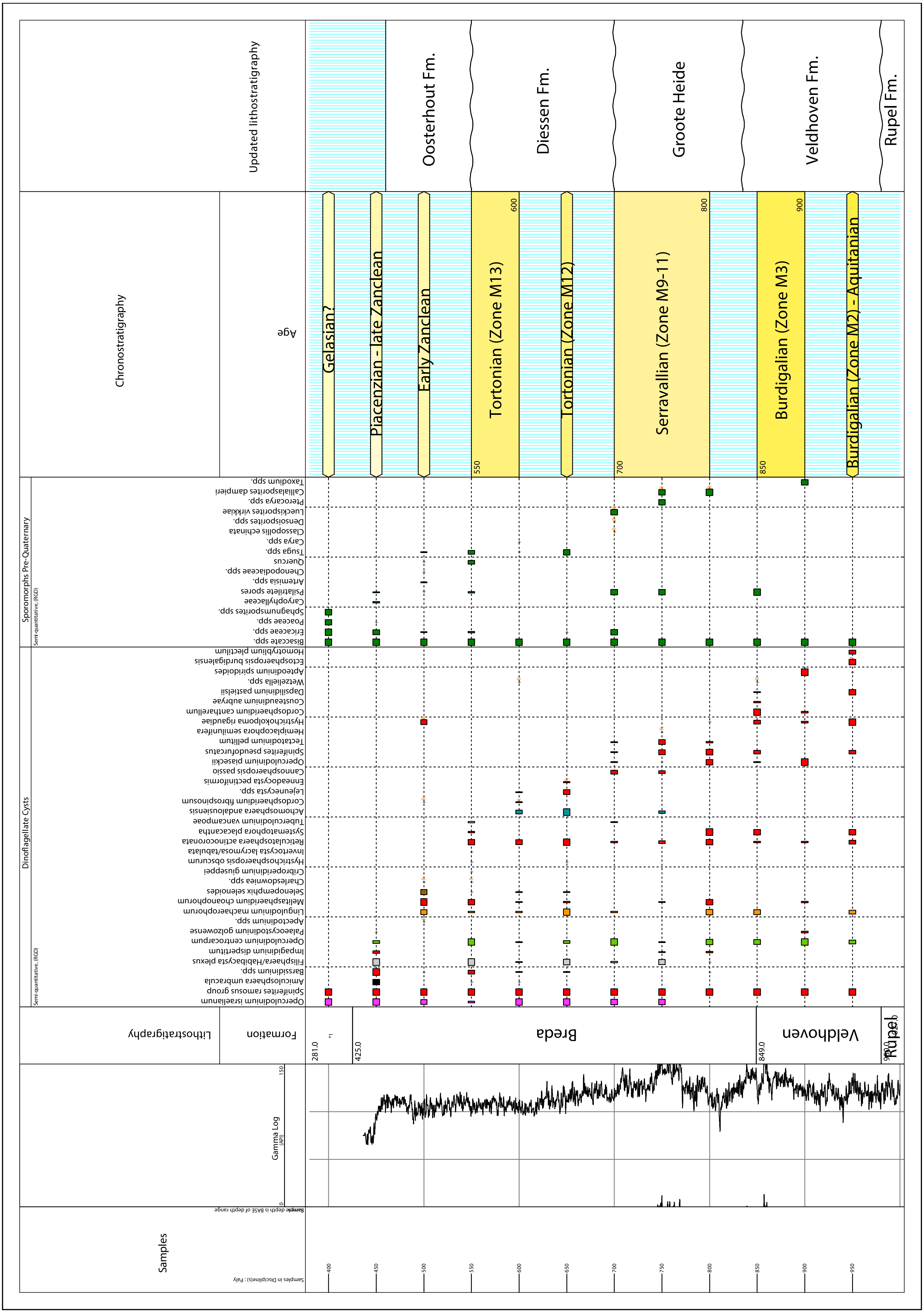
Drs. D. Maljers
Research manager

Appendices

Distribution chart well ADK-GT-01



Distribution chart well BLA-01



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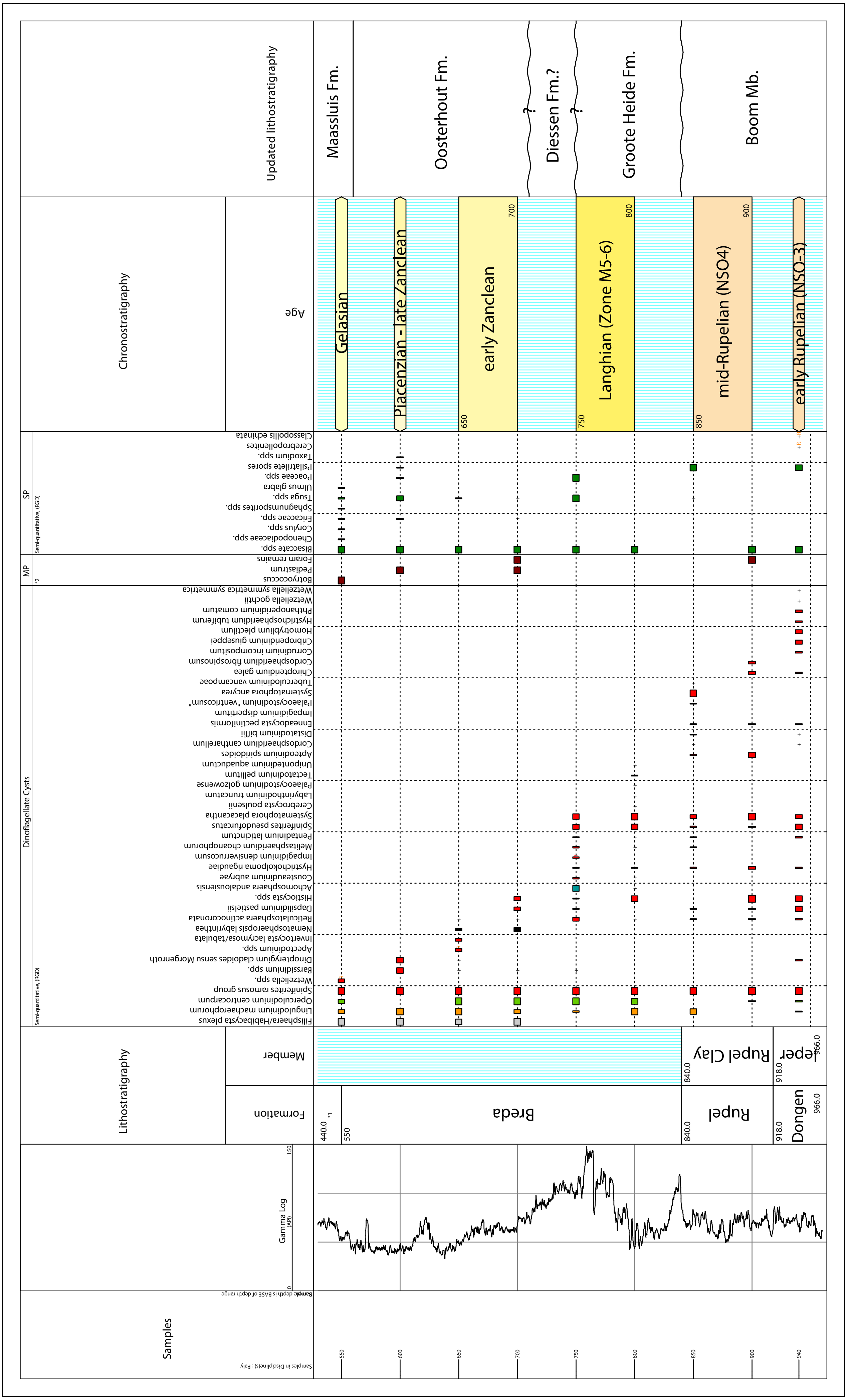

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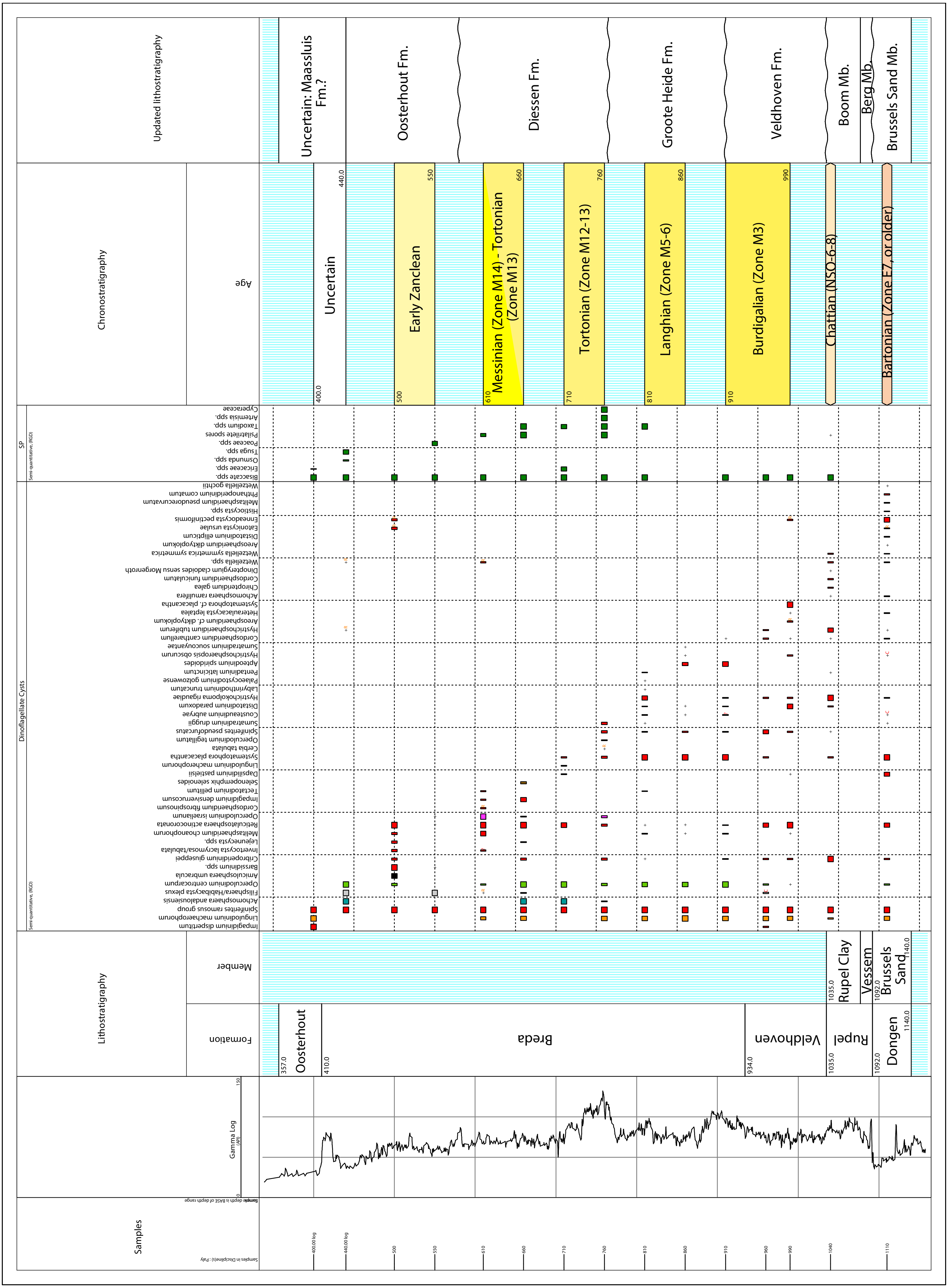

Full Size Figure 6