Netherlands Enterprise Agency

Geotechnical Survey Dating Analyses - Archaeological Assessment

Ten noorden van de Waddeneilanden Wind Farm Zone

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RVO Approval for Publication

Document Characteristics

Version	Title	Date of Publication	Reference Contractor	Reference RVO
V2	Ten noorden van de Waddeneilanden Wind Farm Zone Geotechnical Survey – Dating Analyses – Archaeological Assesment	3 December 2021	Fugro Netherlands Marine B.V.	WOZ2200195

Approval

Approval for public disclosure	Position
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Ten noorden van de Waddeneilanden Wind Farm Zone – Dutch Sector, North Sea

Dating Analyses – Archaeological Assessment

P906609/08 | 02 | 3 December 2021

Final

Rijksdienst voor Ondernemend Nederland

Rijksdienst voor Ondernemend Nederland

Document Control

Document Information

Document Title	Ten noorden van de Waddeneilanden Wind Farm Zone – Dutch Sector, North Sea
	Dating Analyses – Archaeological Assessment
Fugro Project No.	P906609
Fugro Document No.	P906609/08
Issue Number	02
Issue Status	Final
Quality Management	Refer to appendix 'Supplementary Information about Document'
Fugro Project Lead	R. de Oude / ☎ +31(0)703115375 / ✉ r.deoude@fugro.com

Client Information

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Client Document No.	WOZ2200195

Revision History

Issue	Date	Status
01	24 October 2021	Draft
02	3 December 2021	Final

BioChron

Biostratigraphy
Geochronology
Project management

Report No: 07/21 (final) **03 December 2021**

An Archaeological Assessment of

Ten Noorden van de Waddeneilanden Wind Farm Zone

Dutch Sector, North Sea

by

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Contents

1 - Executive summary

Using palynological information together with observations on the microfossils, diatoms, molluscs and plant remains a multi-disciplinary palaeoenvironmental assessment was carried out in an attempt to characterise the palaeo-landscape represented by each stratigraphic unit (as assigned by Fugro/RVO) and to determine the suitability for hominin habitation since the Eemian.

Radiocarbon dating and luminescence (OSL) dating were performed on a limited number of samples in order to confirm the age of the Naaldwijk (Zandvoort), Nieuwkoop (Hollandveen) and Boxtel (Singraven/Wierden) Formations. Elsewhere we rely on palynological evidence for prevailing climate to indicate likely ages. Palaeoenvironmental interpretations are based on all microfossil data, especially foraminifera, ostracods and diatoms.

Full results of this study are presented in the following text with a description of all the analyses for each vibrocore arranged by lithostratigraphic unit using the terminology proposed by Rijsdijk *et al.* (2005) and TNO-GSN (2021a).

Some suggestions regarding lithostratigraphic assignments are made on the basis of biostratigraphy particularly in relation to the boundary between the Boxtel Formation (Singraven Member) and the Naaldwijk Formation (Wormer Member) in vibrocore TNW047-2_VC. In other cases stratigraphic notes are provided to highlight possible re-assignments of Formation/Member boundaries.

There is some similarity in biostratigraphic assemblages between stratigraphic units (as assigned), for example between the Naaldwijk Formation (Wormer Member) and the Boxtel Formation (Singraven Member) in TNW047_2-VC and in intervals assigned to the Singraven Member in TNW069-VC and TNW109-VC. Further investigation of the relationship between these units is recommended as it is possible that some could be co-eval (i.e. lateral equivalents) rather than representing distinct intervals of time. Good evidence for marine influence in the Singraven Member (as assigned) is also worthy of further investigation.

Radiocarbon and OSL ages for the Singraven and Wierden Members (as assigned) are fairly similar. A single C14 age for the Singraven Member falls within the earliest Holocene. The Wierden Member could be very latest Pleistocene (if the oldest parts of the OSL age ranges from two samples are considered) as is inferred from published data. Stratigraphic notes are provided in the text to highlight where boundary adjustments or re-assignments could be considered.

A summary of the archaeological potential of each stratigraphic unit encountered is provided.

A brief summary of the radiocarbon dating method appears in Appendix 1. Dating certificates are presented in Appendix 2 and calendar year calibrations and quality assurance certificates in Appendix 3. Luminescence dating methodology is discussed in Appendix 4 and reports on the diatom and macroplant analyses are provided in Appendices 5 and 6, respectively. A mollusc analysis report is in Appendix 7.

A summary of environmental interpretations for each formation is presented in Appendix 8 and detailed distributional data of all fossil types are available as charts in Appendix 9. A correlation diagram shows the lithostratigraphic units (as assigned by Fugro/RVO) together with a summary of microfossil, mollusc and diatom data. Ages obtained by C14 and OSL dating methods are also shown.

2 - Objectives and limitations

The main objective of the investigation was to carry out an archaeological assessment based on a suite of eight vibrocores from the Ten Noorden van de Waddeneilanden Wind Farm Zone in an attempt to characterise the palaeo-landscape of the Eemian-Holocene interval.

Fluvial activity dominated the sedimentary record of the North Sea Basin throughout the Pleistocene. During periods of sea level fall, large areas of potentially habitable landscape existed on the now submerged fluvial and coastal plains. The consequence of sea level fall was increased fluvial activity which cut down into earlier strata resulting in the reworking of sediments and their fossil content. Preserved sediments are patchy and lateral tracing of such deposits is difficult.

As for most of this time period the area under investigation was freshwater, brackish and coastal marine, establishing the nature of the adjacent landscape relies on material derived for the land and deposited "downstream" as marine sediments. This inevitably leads to a blurring of the coeval terrestrial signal. Nevertheless, palynological analysis can chart developments in local and regional vegetation patterns by observing the distribution of pollen and spores dispersed by wind and water which in turn can lead to conclusions about the climate. Palynology is thus the principal biostratigraphic discipline used in this study. Plants can inform about the terrestrial landscape where their remains are preserved (peats and organic rich sediments). Other fossil groups (e.g. molluscs, foraminifera, ostracods and diatoms) can also inform about aqueous environments, periods of inundation and they have all been used to some extent in this study.

3 - Material

Vibrocore samples from eight locations were provided by Fugro for analysis of palynomorphs, microfossils (ostracods, foraminifera, etc.) and diatoms. In addition, a limited number of other analyses were carried out on molluscs and macroplant remains, four were radiocarbon dated and three were the subject of luminescence (OSL) dating. Vibrocore locations are shown on the map in Figure 1 and a list of sample analyses is given in Figure 2.

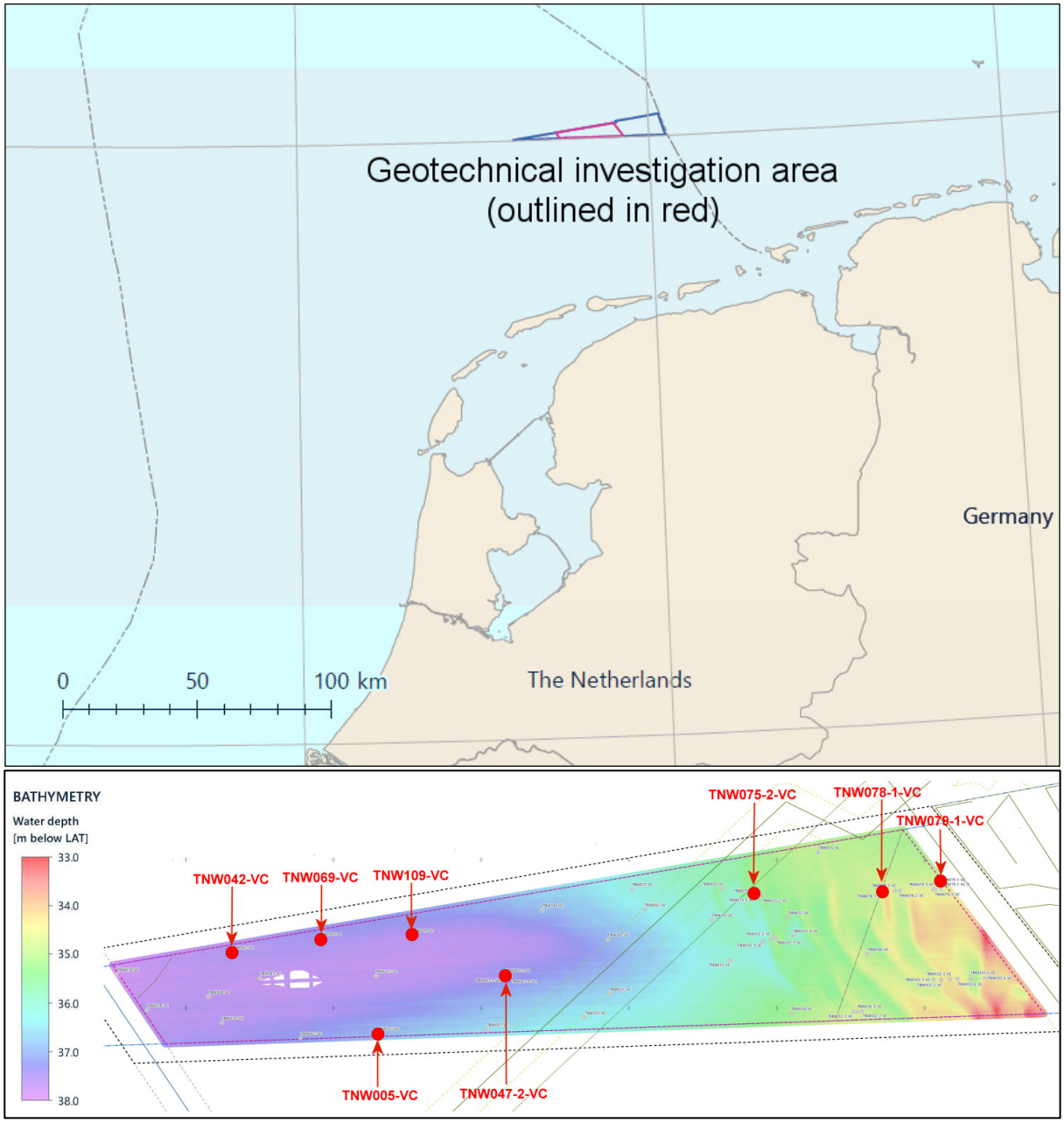

Figure 1: Map of the TNW Wind Farm Zone showing location of studied vibrocores.

(modified after RVO and Fugro)

Vibrocores	Sample depth (m)		Description	Formation	Member	Bed
	from	to				
TNW005-VC	1.54	1.59	silty fine non-calcareous SAND with closely spaced SILT laminae	Urania	Western Mud Hole	-
	1.62	1.67	clayey soft amorphous PEAT	Nieuwkoop	Hollandveen	Basal Peat
	1.85	1.90	clayey soft to firm amorphous PEAT	Nieuwkoop	Hollandveen	Basal Peat
	1.92	2.02	silty fine non-calcareous SAND (cover sand)	Boxtel	Wierden	-
	3.12	3.18	silty fine non-calcareous SAND (cover sand), with extremely close spaced laminae of dark greyish brown SILT	Boxtel	Wierden	-
	4.00	4.10	silty fine non-calcareous SAND	Boxtel	Wierden	-
	5.22	5.26	fine to medium non-calcareous SAND with extremely fine laminae of organic matter	Boxtel	Wierden	-
TNW042-VC	0.55	0.63	silty fine SAND with many SHELL and shell fragments; clams, bivalves, cockles	Urania	Western Mud Hole	-
	1.45	1.50	very dark greyish brown very organic CLAY with shell fragments; at base fine gravel sized whole shells; gastropods.	Naaldwijk	Wormer	Velsen
	1.60	1.65	very dark greyish brown very organic CLAY with shell fragments; at base fine gravel sized whole shells; gastropods.	Naaldwijk	Wormer	Velsen
	1.80	1.85	very amorpheus soft black PEAT with trace visible plant remains	Nieuwkoop	Hollandveen	Basal Peat
	1.85	1.90	very amorpheus soft black PEAT with trace visible plant remains	Nieuwkoop	Hollandveen	Basal Peat
	1.95	2.00	very sandy greyish brown non-calcareous CLAY with some organic staining	Boxtel	Singraven	-
	2.55	2.60	well sorted fine to medium grey non-calcareous SAND with closely spaced laminae of very organic black CLAY	Boxtel	Singraven	-
	3.05	3.15	well sorted fine to medium grey non-valcareous SAND (cover sand)	Boxtel	Wierden	-
TNW047_2-VC	0.60	0.65	silty fine dark grey calcareous SAND shell fragments and juvenile whole shell	Urania	Western Mud Hole	-
	1.20	1.25	interlaminated dark grey calcareous SILT and CLAY with less than 1mm laminae, pockets of greenish grey fine sand and traces of shell grit	Naaldwijk	Wormer	-
	1.65	1.70	interlaminated dark grey non-calcareous CLAY and grey fine SAND; thin to thick laminae	Naaldwijk	Wormer	-
	2.00	2.05	interlaminated and interbedded dark grey non-calcareous very soft CLAY and brown fine SAND; wavy bedding	Naaldwijk	Wormer	-
	2.50	2.55	interlaminated closely spaced dark grey non-calcareous very soft CLAY and grey fine SAND; wavy bedding	Naaldwijk	Wormer	-
	2.85	2.90	very low strength dark grey CLAY with 1 discontinuous lenticular lamination of fine sand	Boxtel	Singraven	-
	3.40	3.45	fine to medium non-calcareous SAND with laminations of soft dark grey CLAY; planar sub-horizontal bedding	Boxtel	Singraven	-
	4.00	4.05	fine to medium non-calcareous light brownish grey SAND	Boxtel	Singraven	-
	4.60	4.70	fine to medium non-calcareous brownish grey SAND with laminae of dark brown amorphous PEAT	Boxtel	Singraven	-
TNW069-VC	1.00	1.05	greyish-brown silty fine SAND with shell fragments; thin discontinuous silty laminae.	Urania	Western Mud Hole	-
	1.50	1.55	soft non-calcareous dark grey CLAY with extremely closely to closely laminae of fine SAND; wavy bedding on mm-scale.	Boxtel	Singraven	-
	2.00	2.05	soft non-calcareous dark grey CLAY; interval with predominantly CLAY; sparse very thin laminae of silty fine SAND; lenticular wavy bedding	Boxtel	Singraven	-
	2.50	2.55	soft non-calcareous dark grey CLAY with extremely closely to closely laminae of silty fine SAND; lenticular|wavy bedding	Boxtel	Singraven	-
	3.20	3.25	dark grey extremely low strengh CLAY with extremely closely to closely laminae of fine SAND; lenticular wavy bedding	Boxtel	Singraven	-
	3.80	3.85	fine SAND with very thin CLAY laminae and a few centimeters thick PEAT layer	Boxtel	Singraven	-
	4.15	4.20	fine to medium SAND with extremely closely to very closely spaced laminae of very soft dark grey CLAY	Boxtel	Singraven	-

Figure 2a: Samples analysed, lithological descriptions and lithostratigraphic assignments

Vibrocores	Sample depth (m)		Description	Formation	Member	Bed
	from	to				
TNW075_2-VC	1.00	1.10	fine to medium non-calcareous (light)grey SAND with shell-fragments	Naaldwijk	Zandvoort	-
	2.95	3.05	fine to medium non-calcareous (light)grey SAND with shell-fragments	Naaldwijk	Zandvoort	-
	3.20	3.25	stiff very dark grey calcareous CLAY with trace mica, with few fine-gravel sized pockets of organic SILT	Eem	Brown Bank equiv.	-
	3.70	3.75	stiff very dark grey calcareous CLAY with trace mica, with few fine-gravel sized pockets of organic SILT	Eem	Brown Bank equiv.	-
	4.30	4.35	stiff very dark grey calcareous CLAY with trace mica, with thin bed of organic SILT	Eem	Brown Bank equiv.	-
	4.40	4.45	silty fine grey calcareous SAND with trace of fine to medium shell fragments	Eem	-	-
TNW078_1-VC	0.60	0.65	sity fine calcareous SAND with shell fragments and whole shells	Naaldwijk	Wormer	-
	1.10	1.15	sity fine calcareous SAND with extremely close spaced planar, horizontal, wavy laminae of dark grey CLAY; wavy bedding	Naaldwijk	Wormer	-
	1.90	1.95	sity fine calcareous SAND with extremely closely spaced wavy laminae of dark grey CLAY; wavy bedding	Naaldwijk	Wormer	-
	2.60	2.65	sity fine calcareous SAND with (extremely) closely spaced thick laminae thin beds of dark grey CLAY; subhorizontal, parallel, wavy bedding	Naaldwijk	Wormer	-
	3.23	3.33	slightly amorphous spongy black PEAT with intact PLANT and WOOD remains	Nieuwkoop	Hollandveen	-
TNW079_1-VC	0.45	0.50	very stiff dark grey CLAY with laminae and lenses of black SILT with mica; probably detritical organic	Eem	Brown Bank equiv.	-
	0.65	0.70	very stiff dark grey CLAY with laminae and lenses of black SILT with mica; probably detritical organic	Eem	Brown Bank equiv.	-
	0.85	0.90	very stiff dark grey CLAY with laminae and lenses of black SILT with mica; probably detritical organic	Eem	Brown Bank equiv.	-
	1.30	1.35	very stiff dark grey CLAY with laminae and lenses of black SILT with mica; probably detritical organic	Eem	Brown Bank equiv.	-
	2.15	2.25	fine to coarse calcareous organic black SAND with shell fragments and whole SHELL; subangular medium to coarse GRAVEL	Eem	-	-
TNW109-VC	2.42	2.47	very soft dark grey CLAY with closely spaced laminae of fine SAND ; wavy bedding	Boxtel	Singraven	-
	2.95	3.00	very soft dark grey CLAY with closely spaced laminae of fine SAND; wavy bedding	Boxtel	Singraven	-
	3.45	3.50	soft dark grey CLAY with closely spaced laminae of fine SAND; lenticular bedding	Boxtel	Singraven	-
	3.95	4.00	fine light grey SAND with very thin (deformed?) laminae of soft dark grey CLAY; possibly cryoturbated?	Boxtel	-	-
	4.67	4.72	silty fine dark grey SAND	Boxtel	-	-
	4.95	5.03	silty fine greyish brown SAND with parallel thin laminae of SILT; possibly organic.	Boxtel	Wierden	-
	5.20	5.30	silty fine greyish brown SAND with parallel laminae amorphous detritical PEAT; possibly organic.	Boxtel	Wierden	-
	5.33	5.40	silty fine greyish brown SAND with parallel laminae amorphous detritical PEAT; possibly organic.	Boxtel	Wierden	-+A34:G59

Figure 2b: Samples analysed, lithological descriptions and lithostratigraphic assignments

The benefits of palynology in providing geochronology and palaeoenvironment interpretations were demonstrated in previous reports on wind farm zones offshore The Netherlands (Athersuch *et al.,* 2020a, 2020b). Consequently, this was the principal biostratigraphic method used in the present study.

Published palynological schemes are mostly from onshore study sites and tend to be based mainly on pollen rather than non-pollen palynomorphs such as marine dinoflagellate cysts and freshwater algae. Published zonations include the Eemian to Weichselian zones (Zagwijn 1961, 1974a; de Jong, 1988) and Late Glacial to Holocene zones (Van der Hammen 1951, 1971). These are summarized by Zagwijn and Van Staalduinen (1975). Suggested ties to published zones are made in some instances in the present study.

At the request of the client calcareous microfossil analyses were performed on the majority of samples and the results proved most useful in the overall interpretation. Diatoms were also present in sufficient numbers in about half the samples to provide valuable salinity and palaeoenvironmental estimates. Where available, molluscs were also studied by an expert on Quaternary molluscs and these contributed significantly to the interpretation. A few plant remains were also studied by a specialist. Radiocarbon analyses were undertaken on five samples and luminescence dating on three others and provide useful confirmation of the age of some lithostratigraphic units.

4 - Lithostratigraphy

4.1 - Introduction

Lithostratigraphic units in each of the vibrocores were provided at the outset of this study by RVO/Fugro. These assignments have by and large been confirmed but in a few cases the biostratigraphic data suggest some minor boundary depth changes or possible re-assignments could be made, subject to further investigation. Generally we have not changed any of the lithostratigraphic assignments but make notes in the text as to where adjustments could be considered.

Appendix 8 provides a summary of the environmental interpretations made for each of the assigned stratigraphic unit in each vibrocore based on evidence from all of the fossil groups studied. These comments are further summarised below to provide an overview of each unit in the study area, prefaced by descriptions taken largely from the Dinoloket online resource TNO-GSN (2021a).

In this report we have followed as far as possible the terminology proposed by Rijsdijk *et al.* (2005) and TNO-GSN (2021a).

Figure 3 depicts the lithostratigraphic units sampled in each of the studied vibrocores.

Formation	Member/Bed	TNW 005-VC	TNW 042-VC	TNW 047_2-VC	TNW 069-VC	TNW 075-2-VC	TNW 078_1-VC	TNW 079_1-VC	TNW 109-VC
Urania	Western Mud Hole								
Southern Bight	Terschellingerbank								
Naaldwijk	Wormer								
	Velsen								
	Zandvoort								
Nieuwkoop	Hollandveen								
Boxtel	Singraven								
	Wierden								
Woudenberg									
Eem	Brown Bank								

Figure 3: Summary of the formations sampled in studied vibrocores.

*(**Note:** the Southern Bight and Woudenberg Formations were not sampled during this study.)*

4.2 - Lithostratigraphic Units

Urania Formation, Western Mud Hole Member
The Urania Formation and Western Mud Hole Member consist of low-energy open marine muddy sediments of Holocene age (Rijsdijk *et al.*, 2005).

Study findings: this formation represents a period of coastal lagoon and outer estuarine or shallow marine deposition. Marsh and wetlands occurred locally and there were forested uplands.

Naaldwijk Formation, Wormer and Zandvoort Members
The Naaldwijk Formation is highly variable lithologically. The Wormer Member typically consists of grey fine to medium-grained calcareous shelly sand and/or silt, clay with organic and discontinuous peat layers. Deposition occurred in nearshore, coastal, tidal and mudflat settings (TNO-GSN, 2021d). The Velsen Bed within the Wormer Member consists of dark grey organic-rich clay, often rooted with reeds and containing gastropods, deposited in lagoonal or brackish settings (TNO-GSN, 2021e). The Zandvoort Member typically consists of grey to brownish grey fine to medium-grained shelly sand with localised clay laminae intercalations. Deposition is inferred to be shoreface and nearshore sand-prone settings (TNO-GSN, 2021g).

Study findings: The Wormer Member sampled in two localities contains freshwater, brackish and marine microfossils indicating near-coastal environments with increasing marine influence upwards. The Velsen beds sampled at one location in the distal area were deposited in freshwater to brackish environments. The depositional environment of the Zandvoort Member could not be ascertained due to low sample coverage.

Nieuwkoop Formation, Hollandveen Member, Basal Peat Bed
The Nieuwkoop Formation is of Holocene (and locally late Weichselian) age and consists of brown to black peat and may be locally clayey. The Hollandveen Member is characterised by reed, sedge, woody and moss peat deposited in coastal marsh, swamp and lacustrine settings (TNO-GSN, 2021b).

Study findings: At all locations this formation is characterised by fresh to brackish water marshes and wetlands with woodlands in the surrounding landscape.

Boxtel Formation, Singraven Member
The Singraven Member typically consists of grey to yellow fine to medium-grained sand including grey loam, grey clay and sometimes peat and mud layers. In the eastern Netherlands it is descibed as occurring in small-scale rivers, brooks and channels, with associated deposits of swamp peat and overbank silt and clay (TNO-GSN, 2021f). Inferred age is Holocene to Weichselian (Schokker *et al.*, 2007). The pollen content of the Singraven Formation (as originally defined) indicates a mostly Holocene age (Van der Hammen, 1971). Pollen diagrams for the Singraven Formation are presented by Wijmstra and De Vin (1971).

Study findings: The Singraven Member provides evidence of fresh to brackish water wetlands with ponds and lakes but with some marine influence indicated by diatom analyses. Similar to Naaldwijk but with increased fluvial activity. Deposition is suggested to have occurred partly due to infilling of incised valley features, first with reworked fluvial sands and subsequently by marine-influenced silts and clays.

Boxtel Formation, Wierden Member
The Wierden Member of the Boxtel Formation is described as light brown to yellowish brown very fine to medium-grained sand, deposited as 'coversand' under periglacial, aeolian conditions during the late Weichselian *(*Schokker *et al., 2007;* TNO-GSN, 2021c). The Wierden Member is equated with the late glacial Dryas stadials and Allerød/Bølling interstadials (Van der Hammen, 1971). Pollen diagrams including data

from the Wierden Member (e.g. at the Wierden and Usselo localities in the eastern Netherlands) are shown by Van der Hammen (1951).

Study findings: The Wierden Member differs from the Singraven Member in that it contains inter-dune freshwater marshes, ponds and lakes but away from any marine influence.

Eem Formation, Brown Bank Member

The Eem Formation has a varied lithological character, consisting of fine to medium-grained shelly sand, and dark grey to greenish grey, mostly calcareous, clay or silt. Shell layers and organic-rich layers may also occur. It occurs widely in the offshore area and in former glacial basins as shallow freshwater, brackish coastal and fully marine deposits (TNO-GSN 2021h) and deposited during MIS (Marine Isotope Stage) 5. The Brown Bank Member often overlies the Eemian marine sediments, and is also varied lithologically. It may consist of greyish brown to greyish green silty clays with interbedded sands. It can be periodically desiccated, cryoturbated but typically deposited in brackish, lagoonal and/or fluvio-lacustrine settings (TNO-GSN 2021i). Age is Early Weichselian, assumed to equate with MIS 5d-a.

Study findings: The Brown Bank Member was sampled only in two proximal locations. It represents an estuarine to nearshore setting with a landscape of heather and raised peat bogs and some forested areas. Marginal marine influence is detected but with poorly developed microfaunas, including reworked forms. Undifferentiated Eem Formation was sampled at only one proximal location where there was some evidence of a marine setting.

5 - Biostratigraphy

5.1 - Palynology

5.1.1 - Introduction

Samples were prepared for palynology by PLS Ltd. (UK). All samples were treated with various acids, notably HF (to dissolve mineral matter), HCl (to remove carbonates) and HNO_3 (to breakdown organic matter). Residues were sieved using 10 µm mesh cloth. Two fractions were mounted in Norland Adhesive, one containing the oxidised portion and a second unoxidized residue as a control, and to use for examination of organic matter (kerogen). Counts were made of all palynomorphs, including reworked forms, with the aim of obtaining a sum of 300 to 400 (or more) palynomorphs per sample, which was achieved in the majority of instances. Even though no 'exotic spike' (e.g. *Lycopodium* spores) was added to the preparations, the counts are considered sufficiently high in most cases to form a basis for reliable interpretation. Where counts are significantly lower (i.e. ≤100), no detailed interpretation is attempted.

5.1.2 - Archaeological potential

Of the fossil groups studied herein palynomorphs are of greatest archaeological interest as they reflect the palaeo-vegetation in the local and regional landscape and provide strong indications as to whether the site was terrestrial/freshwater (i.e. above wave base) or was submerged under shallow marine waters at the time of deposition. In the latter case habitation and the chances of finding hominin occupation markers are likely to be limited. The vegetation patterns also provide an indication of climate which in turn assists in dating by comparison with published and newly applied zonation schemes. Non-quantitative counts of charred fragments were made but these are generally infrequent, with no indication that they had a human origin.

5.2 - Microfossils

5.2.1 - Introduction

Forty-seven samples were prepared and analysed for microfossils. Each sample was washed through a 125µm sieve and the residue dried at 100°C. The dried residue was then examined for microfossils under a reflected light microscope. Where the number of specimens was excessive, counts were made on a fraction of the residue and the total in the entire sample was calculated. Biostratigraphic distribution charts are provided in Appendix 9.

5.2.2 - Environments

Foraminifera and/or ostracods were present in most samples where they were very useful in determining the depositional environment. Ostracods recovered in this study are particularly sensitive environmental indicators of fresh (e.g. *Limnocythere, Darwinula* and *Iliocypris*), brackish (e.g. *Loxoconcha elliptica* and *Cytheromorpha fuscata*) or marine conditions. Amongst the marine forms some are typical of nearshore environments strongly influenced by freshwater (e.g. *Palmoconcha guttata* and *Pontocythere elongata*) while others (e.g. *Carinocythereis whitei)* characterize sublittoral environments. There are also similar preferences/tolerances amongst the foraminifera. For instance, forms of *Ammonia* with umbilical plugs tend to indicate more the marine aspect of brackish environments such as outer reaches of estuaries, whereas forms without this feature are typical of less saline environments as found in inner estuaries. Miliolids are marine but often associated with outer estuaries.

5.2.3 - Archaeological potential
Foraminifera and ostracods are often useful proxies for a range of supra-tidal and marine environments but in high-energy nearshore environments much of this information is destroyed.

5.3 - Molluscs

5.3.1 - Introduction
With the exception of one sample (TNW042-VC, 0.55m-0.63m), which was identified in advance by the client, mollusc specimens were selected from washed residues prepared for microfossils. Molluscs were recovered (often as fragments) from 16 samples. Identifications and environment preferences provided by Frank Wesselingh of Naturalis Biodiversity Centre, Leiden (The Netherlands) are presented in Appendix 7.

5.3.2 - Ages
Holocene *in situ* and partially *in situ* associations indicate water depths of >15m. Some species are indicative of specific interglacials (notably *Bittium reticulatum* in the Eemian) while others are Arctic in their present day distribution and indicate glacial episodes (e.g. *Cyrtodaria curriana, Hiatella arctica* and *Portlandia arctica*). Species with cold preservation type (typically dissolution pits but otherwise fine surface details and preserved periostracum) probably derive from MIS 5a/c but could also be earliest Holocene. Much of the material recovered comprises Eemian marine species reworked in a fluvial environment. Some species indicate freshwater (e.g. *Pisidium, Ecrobia* and *Sphaerium*) while others prefer brackish conditions (e.g. *Peringia ulvae* and *Cerastoderma glaucum*).

5.3.3 - Environments
Whilst the majority of specimens are marine in origin, in most cases they have been transported and/or reworked in high energy environments. A full listing of the environmental preferences of molluscs mentioned in the text is presented in Appendix 7.

5.4 - Diatoms

5.4.1 - Introduction
Forty-seven samples were analysed for diatoms of which twenty-one failed to yield sufficient numbers of specimens for environmental interpretation and were set aside. Full accounts of the preparation and counting methodologies are given in Appendix 5 and are not repeated here. Identification and environmental interpretations were provided by Annemarie Clarke and Nick Kneebone of APEM. The analytical results are included in the biostratigraphic distribution charts in Appendix 9.

5.4.2 - Environments
Diatoms are extremely sensitive to salinity and consequently are good indicators of water salinity. In this study in order to aid interpretation of general trends observed in the cores salinity is expressed as three categories - marine, brackish and freshwater.

5.4.3 - Archaeological potential
The abundance of diatoms in marginal marine to freshwater provides clear evidence of the nature of the prevailing aqueous environments for the Boxtel and younger formations.

5.5 - Macroplants

5.5.1 - Introduction

The material examined for this study comprised five samples of plant remains all from the Nieuwkoop Basal Peat. The main objective of this analysis was to recover macroplant remains and identify them to species level where possible in order to determine the nature of the environment of deposition and the character of the surrounding landscape at the time of deposition. Macroplant analysis and interpretation was performed by Jackaline Robertson of AOC.

All plant macrofossils, including wood fragments, were examined at magnifications of x10 and up to x450 where necessary to aid identification. Plant identifications were confirmed using modern reference material and seed atlases. Wood fragments larger than 4mm were selected for species identification. Species identifications were confirmed by analysing the transverse, tangential and radial sections at x70-x450 magnification and using keys and texts.

5.5.2 - Environments

Preservation of the macroplant assemblages was brought about in waterlogged, anaerobic conditions. The macroplant assemblages were small in both number and species diversity. Preservation of the remains ranged from poor to excellent but most were categorised as adequate to good. The plant taxa in all of the samples studied comprised both woodland and weed taxa indicative of damp environments. Further details are provided in Appendix 6.

5.5.3 - Archaeological potential

Macroplants are extremely useful in archaeological interpretations as they provide important information about the paleo-vegetation in the landscape. In this study only a few samples were suitable for study, all from the Nieuwkoop Basal Peat Unit, which limited their overall potential.

6 - Radiocarbon dating

6.1 - Introduction

Three samples of wood/peat remains were selected by Fugro from the Nieuwkoop Formation (Hollandveen Member) in vibrocores TNW005-VC, TNW042-VC and TNW078_1-VC. In addition two samples from the Boxtel Formation (Singraven Member) were identified as possibly providing confirmatory dates in TNW047-2-VC. Suitable material was hand-picked from microfossil sample residues and radiocarbon (^{14}C) dating undertaken by Beta Analytic Inc.

6.2 - Results

Figure 7 presents the results of the radiocarbon dating. Conventional and calendar year calibrated radiocarbon ages resulting from the High-Probability Density method and $\delta^{13}C$ values for selected samples are displayed. Being terrestrial in origin no local reservoir corrections were required. Beta nos. are the unique international laboratory references.

Borehole	Sample depth (m)		Sample material	Stratigraphy			Beta no.	$\delta^{13}C$ (‰)	Conventional age (yrs BP)	Calendar year BP calibration range	Probability
	from	to		Formation	Member	Bed					
TNW005-VC	1.85	1.90	Peat	Nieuw koop	Hollandveen	Basal Peat	595771	-28.6	9820 ± 30	11264 - 11192	95.4%
TNW042-VC	1.85	1.90	Peat	Nieuw koop	Hollandveen	Basal Peat	595772	-29.3	9020 ± 30	10242 - 10171	95.4%
TNW078_1-VC	3.23	3.33	Wood	Nieuw koop	Hollandveen	-	595773	-25.4	9450 ± 30	10765 - 10578	95.4%
										10987 - 10984	0.3%
TNW047-2-VC	2.85	2.90	Ostracods	Boxtel	Singraven	-	605164	n/a	10090 ± 30	11177-10806	95.4%
	3.40	3.45									

Figure 7: Table showing results of radiocarbon dating (High-Probability Density method)

*(**Note:** samples from TNW047-2-VC were combined to provide enough material for analysis)*

6.3 - Archaeological potential

The dates obtained provide confirmation of the date of the Hollandveen Member (including the basal peat) and the Singraven as Early Holocene.

7 - Luminescence dating

7.1 - Introduction

Three cores were selected by Fugro and sent in their liners to the University of Durham Luminescence Laboratory where they underwent the standard procedure for Optically Stimulated Luminescence (OSL) dating. Details of the methodology are presented in a separate report in Appendix 4.

7.2 - Results

Using the measured parameters, the Naaldwijk Formation (Zandvoort Member) was dated at 9408 ± 501 years in TNW075_2-VC. The Boxtel Formation (Wierden Member) was dated at 11039 ± 920 years in TNW109-VC and 11234 ± 635 years in TNW005-VC. Very similar dates were achieved from estimation and modelling.

Lab code	Borehole	Sample depth		Formation (Member)	De (Gy)	Modelled Moisture			Measured Moisture		
		from	to			Water content	Dose rate (Gy/ka)	Age (ka)	Water content	Dose rate (Gy/ka)	Age (ka)
L4	TNW075_2-VC	2.95	3.05	Naaldwijk (Zandvoort)	8.79 ± 0.12	19.4 ± 5	0.939 ± 0.048	**9.362 ± 0.499**	19.9 ± 5	0.934 ± 0.048	**9.408 ± 0.501**
L5	TNW005-VC	4.00	4.10	Boxtel (Wierden)	11.47 ± 0.26	20.4 ± 5	0.979 ± 0.05	**11.713 ± 0.65**	16.2 ± 5	1.021 ± 0.053	**11.234 ± 0.635**
L6	TNW109-VC	5.20	5.30	Boxtel (Wierden)	10.79 ± 0.72	21.7 ± 5	0.969 ± 0.048	**11.136 ± 0.927**	20.8 ± 5	0.977 ± 0.049	**11.039 ± 0.92**

7.3 - Archaeological potential

The dates obtained suggest the age of both the Naaldwijk Formation (Zandvoort Member) and the Boxtel (Wierden Member) as Early Holocene.

8 - Vibrocore summaries

This section presents a tabulated summary of the biostratigraphic interpretations together with radiocarbon and luminescence dates for each vibrocore. We recommend that this section of the report is read in conjunction with the summary charts and correlation chart in Appendix 9.

Location: TNW005-VC

Urania Formation, Western Mud Hole Member

Palynology: 1.54m-1.59m
The sample matrix contains numerous organic fragments, but is also rich in palynomorphs. The preservation of the observed palynomorphs is generally good. Besides dominant pollen and spores, some freshwater indicators are present, mostly waterlily (*Nymphaea* sp.) basal cells and *Pediastrum*. Very few marine indicators and reworked elements are observed.

Pollen of tree taxa make up most of the pollen assemblage. Pine (*Pinus*) is most numerous, followed by birch (*Betula*) and hazel (*Corylus*). Some oak (*Quercus*) and elm (*Ulmus*) pollen is also present. Pollen of various herbaceous taxa also make up a considerable portion of the assemblage. These are mostly pollen of grasses (Poaceae), but also of sedges (Cyperaceae) and of the *Sparganium*-type *sensu* Beug (bur-reed-type, including lesser bulrush and various species of bur-reed).[1] In addition, spores of ferns of the *Dryopteris*-type (including various species of wood ferns) and marsh fern (*Thelypteris*) are commonly or rarely present. Pollen of common bulrush (*Typha latifolia*) and waterlily is sporadically present.

This assemblage likely represents a local marshland vegetation type with open freshwater, and forests present in the continental upland landscapes. Assuming that the tree pollen assemblage reflects regional vegetation this sample is consistent with the later part of the Boreal stage. The assemblage is highly similar to that of the underlying basal peat bed, which suggests that eroded older peat is likely present in this sample. Minimal marine influence is present suggesting that the sample was deposited before the main phase of Holocene sea level rise.

Microfauna: 1.54m-1.59m
Poor microfauna dominated by the brackish water ostracod *Cyprideis torosa* accompanied, on the one hand, by the freshwater ostracod *Limnocythere inopinata* (rare) and, on the other, by the marine species *Palmoconcha guttata* and echinoid fragments. This mixed assemblage suggests short distance transport or reworking by way of bioturbation of freshwater taxa into a marine environment.

Diatoms: 1.54m-1.59m
Too few specimens to make a viable count.

Molluscs: 1.54m-1.59m
Few shells, mixed preservation with marine species including *Spisula subtruncata* (dominant), *Chamelea striatula, Varicorbula gibba* (both well-preserved), *Cerastoderma edule* (worn) and a corroded, paired *Pisidum casertanum* forma *plicatum* (freshwater).

[1] Because the pollen morphological distinguishing characteristics of these various species are hard to discern in this material, these taxa are grouped. As the habitats in which these species occur are similar, this grouping has no implications for the ecological interpretation.

This assemblage suggests freshwater specimens reworked into marine below FWWB (Fairweather Wave Base).

Nieuwkoop Formation, Hollandveen Member, Basal Peat Bed

Palynology: 1.62m-1.67m, 1.85m-1.90m
The assemblage of sample 1.62m-1.67m is highly similar to that of 1.54m-1.59m, both in observed taxa and their relative abundances. The overall preservation is again good. Minor differences are that both oak and elm are slightly less frequent in this sample. Noteworthy is the possible observation of a beaked tasselweed/widgeon grass (*Ruppia cf. maritima*) pollen grain. This is a salt-tolerant aquatic herb that grows on fresh organic-rich clay soils, for example in salt marshes (Weeda *et al.*, 1991).

Sample 1.85m-1.90m has a very different palynomorph assemblage. The matrix contains numerous organic fragments, but palynomorphs are only moderately abundant. Preservation is generally fair. Pollen and spores make up almost the entire assemblage; only few freshwater indicators are observed, marine and reworked elements are absent. Charred fragments are relatively common.

The pollen and spores assemblages are composed largely of herbaceous taxa. Sedges and grasses are most common but a few pollen of bur-reed-type and meadowsweet occur, as well as several spores of horsetail (*Equisetum*) and wood fern-type. Of the tree pollen birch is most frequent, but pine and willow (*Salix*) are also present. Worth mentioning is the presence of a single pollen grain of great burnet (*Sanguisorba officinalis*). This herb grows in open and wet grasslands, river banks and eutrophic peatland (Weeda *et al.*, 1987). It is a characteristic herb in lateglacial pollen records (Hoek 1997). The pollen assemblage likely represents a sedge peatland or open marshland with sedges.

Assuming that the tree pollen assemblage reflects the continental regional vegetation, sample 1.62m-1.67m is most consistent with the early part of the Boreal stage. Based on the tree pollen assemblage, but also taking into account the observed herbaceous taxa, sample 1.85m-1.90m is most consistent with the lateglacial to preboreal stages. This is in good agreement with the radiocarbon age obtained.

Microfauna: 1.62m-1.67m, 1.85m-1.90m
Both samples from this interval contained only a few mollusc fragments and gypsum crystals. No microfauna was recovered.

Diatoms: 1.62m-1.67m, 1.85m-1.90m
The most abundant taxa in the assemblage were *Thalassiosira decipiens* (9.6%), *Thalassiosira eccentrica* (6.7%) and *Aulacoseira italica* (6.7%). *Thalassiosira* taxa are indicative of a marine-brackish environment, whereas *Aulacoseira italica* is a fresh-brackish species. Freshwater taxa account for a large proportion of the assemblage, despite the two most abundant individual taxa being marine. Overall, the diatom assemblage indicates a shallow, estuarine or brackish water environment. Only fragments were recovered from 1.85m-1.90m.

Macroplants: 1.62m-1.67m, 1.85m-1.90m
The assemblage of the upper sample comprised large numbers of sedge fruits and less common bulrush seeds, both of which plants typically favour damper habitats. Other finds included birch fruits, unspecified wood, Apiaceae (carrot family) fruits and unidentified plant stems. The presence of freshwater sponges in both samples indicates that freshwater was present at this location during this period.

Radiocarbon dating: 1.85m-1.90m
A single sample of peat was dated at between 11264 and 11192 cal yrs BP (95.4% probability) indicating an Early Holocene age.

Boxtel Formation, Wierden Member

Palynology: 1.92m-2.02m, 3.12m-3.18m, 5.22m-5.26m
Sample 1.92m-2.02m contains a fairly rich assemblage of pollen, spores and NPP (Non-Pollen Palynomorphs). The dominant tree pollen types are pine and birch, as noted in the overlying samples, with an additional presence of *Alnus* (alder) which is assumed to be reworked. Pollen from herbs and shrubs includes several specimens of *Juniperus* (juniper), various Asteraceae (composite herbs), Ericaceae (heathers), Poaceae (grass) and others such as *Galium* type (bedstraw). Pollen from aquatic plants includes several occurrences of *Myriophyllum* (water milfoil) and *Menyanthes* (bogbean). Spores consist mainly of *Dryopteris* type and *Sphagnum* (peat moss), with only low numbers of freshwater algae present. An unusual presence of common presumed xylem rings (woody plant tissue) was also noted. Very rare marine taxa were recorded which are presumed reworked. The overall assemblage does not differ significantly from that found overlying in the samples assigned to the Nieuwkoop / Hollandveen peats, although there is an increased presence, for example of Ericaceae pollen and *Sphagnum* spores, suggesting a lateglacial age. It is likely that the studied sample is close to, or spans the boundary between the Nieuwkoop and Boxtel Formations (as is suggested by the lithological log).

Samples 3.12m-3.18m and 5.22m-5.26m have very similar palynological assemblages with tree pollen dominated by a mix of birch and pine with additional *Salix* (willow). There is undoubtedly some reworked tree pollen, for example *Alnus*, *Picea* (spruce) and *Carpinus* (hornbeam). Herbs and shrubs are represented mainly by grass, sedge and heather in more or less equal proportions. Pollen from aquatic plants occurs sporadically whereas spores are represented by *Dryopteris* type and peat moss. The main feature in both samples is the frequent presence of freshwater algae (*Pediastrum*), which becomes more abundant in the lower of the two samples. Rare marine taxa are assumed to be reworked.

The frequent presence of *Pediastrum* confirms strong freshwater influences at the site of deposition. This may be due to freshwater runoff (i.e. a fluvial source) and/or the presence of open water (i.e. lakes and ponds). The latter commonly occur as inter-dune lakes at the present time in many coastal areas of northwest Europe. This does not rule out an aeolian origin for the sands but suggests that the pollen and algae are derived from fine-grained sediments or organic-rich beds within the studied intervals. A similar interpretation is reached by Crombé *et al.* (2020) in a study of 'coversand' from NW Belgium.

The palynological data in the latter two samples show many of the same characteristics seen in the onshore pollen diagrams of Van der Hammen (1951) even though these are from close to 200km to the south of the TNW locality. However, an exact match with the published records is not possible, except to say that the studied samples are likely to be of lateglacial age (i.e. within the intervals represented by the Dryas stadials and Allerød / Bølling interstadials). This is within or close to the age range indicated by OSL dating.

Microfauna: Interval not sampled.

Diatoms: Interval not sampled.

OSL dating: 4.00m-4.10m: A single sample was dated as 11234 ± 635 years

Location: TNW042-VC

Urania Formation, Western Mud Hole Member

Palynology: Interval not sampled.

Microfauna: 0.55m-0.63m
A single sample from this formation yielded very abundant specimens of the foraminifera *Ammonia* (with umbilical boss), *Elphidium williamsoni* and miliolids together with several specimens of the marine ostracod species *Palmoconcha guttata* and *Pontocythere elongata* as well as echinoid fragments. This suggests a nearshore, possibly outer estuarine setting.

Diatoms: Interval not sampled.

Molluscs: 0.55m-0.63m
Abundant shells and fragments, dominated by well-preserved *Spisula subtruncata* and other mainly worn marine species including *Spisula solida, Chamelea striatula, Abra alba, Macoma balthica, Nucula nitidosa, Peringia ulvae, Cultellus pellucidus, Tellina tenuis, Ensis* cf *minor* and *Turritella communis.* Specimens of *Cerastoderma glaucum* were bluish and worn. This is a mostly *in situ* marine assemblage from between Fairweather Wave Base (FWWB) and Storm Wave Base (SWB), but close to latter with some reworked coastal brackish species.

Naaldwijk Formation, Wormer Member, Velsen Bed

Palynology: 1.45m-1.50m, 1.60m-1.65m
Numerous organic fragments make up the matrix of both samples 1.45m-1.50m and 1.60m-1.65m. The palynological assemblages are highly similar and are composed mostly of pollen and spores. Freshwater indicators (e.g. *Pediastrum* and waterlily basal cells) are common, marine indicators very rare and reworked elements absent. Preservation of the palynomorphs in both samples is generally good. In the pollen and spores assemblages of both samples tree pollen is abundant, consisting mostly of pine but birch and hazel are also common, with oak, willow and elm present in moderate numbers. Because willow is pollinated by insects, its pollen is generally not distributed far from the parent plant in large numbers. Therefore, relatively small numbers of pollen, as occurs in these samples, can be interpreted as indicating a local presence of willow trees. Of the herbaceous taxa, pollen of grasses is the most abundant, and bur-reed-type and sedge pollen are common. Some pollen of the aquatic waterlily (*Nymphaea*) is present. In addition, in sample 1.60-1.65 m also some pollen of marsh herbs purple loosestrife (*Lythrum* cf. *salicaria*) and likely common water-plantain (*Alisma*) are observed. Spores of the wood fern-type and marsh fern are present in consistent numbers.

The overall assemblage likely represents marshland vegetation with open water (waterlilies) and grasses (reed?), ferns and willow trees/shrubs. Trees were present in the upland landscapes. Assuming that the tree pollen reflects regional vegetation, these samples are consistent with the Boreal stage of the Holocene. The dominant signal indicates a predominantly freshwater setting although a few marine indicators are observed

Microfauna: 1.45m-1.50m, 1.60m-1.65m
Iliocypris ?gibba and *Limnocythere inopinata* and opercula of the freshwater mollusc *Bithynia*. In addition, the upper sample at 1.45m-1.50m contained a significant number

of reworked specimens of the foraminifer *Ammonia* (with umbilical boss) while the lower sample had a single possibly *in situ* specimen.
Diatoms: 1.45m-1.50m, 1.60m-1.65m
Both samples were dominated by freshwater taxa, with brackish taxa making a minor contribution and marine taxa poorly represented. The assemblages suggest a predominantly freshwater, relatively shallow environment, with minor brackish and marine influence.

Molluscs: 1.45m-1.50m, 1.60m-1.65m
Both samples were dominated by opercula of the freshwater mollusc *Bithynia tentaculata* indicating flowing water or an open lake. The upper sample also yielded single specimens of a freshwater unionoid bivalve and the marine species *Spisula subtruncata* suggesting proximal reworking.

Nieuwkoop Formation, Hollandveen Member, Basal Peat Bed

Palynology: 1.80m-1.85m, 1.85m-1.90m
The palynological assemblages of both samples 1.80m-1.85m and 1.85m-1.90m are very similar and are also highly comparable to those of the overlying Velsen bed. As in the overlying Velsen samples, pollen and spores dominate the assemblage and freshwater indicators (waterlily basal cells) are common. However, *Pediastrum* was only rarely observed in these samples. Preservation of the palynomorphs is good in both samples.

Similar to the overlying samples, tree pollen of pine is most common, followed by that of birch and hazel. Some pollen of oak, elm and willow is also present. Of the herbaceous taxa, pollen of grasses and sedges are the most common, followed by that of bur-reed-type. In sample 1.85m-1.90m a few pollen of the marsh taxa common bulrush, possibly water plantain (*Alisma* cf. *plantago-aquatica*) and of the *Persicaria maculosa*-type (including wetland taxa like pale persicaria and water pepper) are observed. Some pollen of the aquatic plant waterlily is present. Spores of marsh fern and the wood fern-type seem to be more common in these samples than in the two overlying Velsen samples.

No marine indicators were found in the basal peat bed samples. However, the overall strong similarity between studied samples suggests that eroded basal peat material is likely also present in the overlying Velsen bed samples.

Microfauna: 1.80m-1.85m, 1.85m-1.90m
A single operculum of the freshwater mollusc *Bithynia* was recovered in the upper of the two samples, indicating a freshwater source.

Diatoms: 1.80m-1.85m, 1.85m-1.90m
Both samples were dominated by freshwater taxa, with brackish taxa making a minor contribution and no marine taxa represented. The assemblages suggest a predominantly freshwater, relatively shallow environment, with some brackish influence.

Macroplants: 1.80m-1.85m, 1.85m-1.90m
The macroplant assemblage in both samples consisted of wood fragments, plant stems and peat which are all poorly preserved, suggesting that the samples experienced periods of aeration. Aeration is confirmed by the presence of insect eggs and beetle fragments in the upper sample. Birch fruits and bracts were recorded in the upper sample, but not the lower. The composition of the lower assemblage indicates that the surrounding landscape included woody plants and peat. The presence of bryozoans (upper sample) and freshwater sponges (both samples) suggests influence from freshwater to brackish water.

Radiocarbon dating: 1.85m-1.90m
A single sample of peat was dated at between 10242 and 10171 cal years BP (95.4% probability) indicating an Early Holocene age.

Boxtel Formation, Singraven Member

Palynology: 1.95m-2.00m, 2.55m-2.60m
Sample 1.95m-2.00m has an assemblage similar in many respects to those present in the overlying studied intervals (e.g. common birch), although pine pollen is much more common. As noted above, willow pollen is well-represented and again suggests that these trees were growing close to the site of deposition, in a wetland or river margin setting. Other tree pollen such as alder and hazel are more difficult to account for as these are not expected to occur in the earliest part of the Holocene or lateglacial (i.e. latest Weichselian). The likelihood is that these are reworked occurrences.

Sample 2.55m-2.60m has a similar overall pollen composition but is marked by an increased presence of freshwater algae (*Botryococcus* and *Pediastrum*) and also fungal filaments (hyphae) and waterlily base cells. The latter were noted by Van Geel (2010) as commonly occurring at the lateglacial to Holocene transition in lake sediments from northeastern Europe.

Microfauna: 1.95m-2.00m, 2.55m-2.60m
Single specimens of the freshwater ostracods *Cyclocypris ovum* and *Candona* sp. were recovered together with rare specimens of the foraminifer *Ammonia* sp. from the upper of two samples from this interval of the Boxtel Formation. This indicates the influence of freshwater. The lower sample was barren.

Diatoms: 1.95m-2.00m, 2.55m-2.60m
This sample was dominated by freshwater taxa, with brackish taxa making a minor contribution and marine taxa very poorly represented, and most probably reworked. The assemblages suggest a predominantly freshwater, relatively shallow environment, with minor brackish influence. The lower sample was barren.

Boxtel Formation, Wierden Member

Palynology: 3.05m-3.15m (separate sand and clay samples)
The clast and matrix samples both yielded broadly simlar assemblages. These are comparable to the overlying two studied samples with a dominant presence of pollen from pine, birch and willow (but with additional presumed reworked content (e.g. oak, alder and hazel pollen and rare marine taxa). Spores from wood fern, marsh fern and peat moss also occur. Deposition is most likely to have occurred in a wetland marsh or similar setting away from marine influence.

Location: TNW047_2-VC

Note: stratigraphic comments

There is good evidence from the diatom analyses to show that an onset of marine influence occurred at sample depth 3.40m-3.45m. Ostracods also show strong brackish and freshwater influences in the same samples and intervals. This coincides with a lithological change (clearly visible on the lithology log) at 3.40m from mainly sand below to dark grey silt above. 3.40m could therefore be considered as an alternative pick for the Boxtel, Singraven (non-marine to brackish / marine? sand deposits) to Naaldwijk, Wormer (finer grained, with marine influence) boundary. More importantly it is likely that the succession at this locality represents the infilling of an incised feature during the Early Holocene, as is typical for the Singraven Member of the Boxtel Formation according to Schokker *et al.* (2007). The initial infilling consisted of fluvial and reworked sands (in this case below 3.40m) and later with marine-influenced silt. Furthermore, this interpretation is confirmed by the seismic profile at this location. Moreover, the microfaunal and diatom assemblages seen in the Naaldwijk Formation at this location are very similar to those seen in TNW069-VC and TNW109-VC where they are assigned to the Singraven Member. The palynomorph assemblages, however, are distinctly different.

Urania Formation, Western Mud Hole Member

Palynology: 0.60m-0.65m
Preservation of the palynomorphs in this sample is variable. The assemblage is a mixture of both terrestrial and marine elements. The marine assemblage is composed of both organic linings of foraminifera (foram linings) and organic-walled dinoflagellate cysts (dinocysts). Common dinocyst taxa include *Spiniferites* spp., *Operculodinium* cf. *centrocarpum* and the protoperidinioid type 'round brown cyst'. Reworked marine and terrestrial palynomorphs are also present, including the Mesozoic pollen *Classopollis*. Freshwater indicators are practically absent. The pollen and spore assemblage is diverse, composed of both various tree and herbaceous taxa. Tree taxa include (in order of abundance) pine, oak, hazel, birch, alder and elm. A single pollen grain of beech (*Fagus*) is found. Of the herbaceous taxa, pollen of grasses is most common but the diversity of other herbs present is noteworthy. It includes plantain (*Plantago*), various daisy-family members (Asteraceae), mustard family (Brassicaceae), goosefoot family (Cheno-Amaranthaceae) and possibly a single pollen grain of bindweed (*Calystegia*). Spores of peatmoss (*Sphagnum*) and ferns are present in low numbers. The depositional setting is probably marine, proximal to the coast. Terrestrial palynomorphs are transported to this marine environment. The observed herbs are common components in coastal marsh or grassland environments. Assuming the tree pollen assemblage reflects upland vegetation, this sample is consistent with the Subboreal (i.e. the later part of the Holocene) based on the presence of beech pollen.

Microfauna: 0.60m-0.65m
The microfaunal assemblage was dominated by *Ammonia* (with umbilical boss) and *Elphidium williamsoni* with subordinate numbers of miliolids. Several marine ostracod species (*Semicytherura sella, Leptocythere pellucida, Eucythere* sp. *Robersonites tuberculatus* and *Palmoconcha guttata* were present in small numbers together with common echinoid fragments. This suggests a nearshore, possibly outer estuarine setting.

Diatoms: 0.60m-0.65m
This sample was devoid of diatoms.

Molluscs: 0.60m-0.65m
Common, mostly well-preserved sea floor below FWWB assemblage but with some worn or corroded specimens. Species include *Spisula subtruncata, Chamelea striatula, Varicorbula gibba* (all dominant), *Acanthocardia* cf *echinata, Thracia convexa, Thracia* cf *phaseolina, Euspira nitida, Tellina tenuis* and *Nucula nitidosa* (all rare).

Naaldwijk Formation, Wormer Member

Palynology: 1.20m-1.25m, 1.65m-1.70m, 2.00m-2.05m, 2.50m-2.55m
These samples all contain numerous organic fragments, but also well-preserved palynomorphs. The assemblage of the samples is comparable, but that of sample 1.20m-1.25m appears to be transitional between the overlying and underlying samples. Terrestrial palynomorphs dominate the assemblages and the freshwater indicator *Pediastrum* is common in all. In sample 1.20m-1.25m, marine palynomorphs (foram linings, dinocysts) and reworked palynomorphs are additionally present, whereas in the deeper samples these are practically absent. The pollen and spores assemblages are again largely composed of tree pollen, of which pine and hazel are most frequently observed but birch and oak are also common. Alder is only distinctly present in sample 1.20m-1.25m. Pollen of grasses, sedges and bur-reed-type are numerous in all samples, but various other herbs are also present. Notably, pollen of great reed-mace (*Typha latifolia*) is sporadically observed in all but sample 1.20m-1.25m, and waterlily is present in samples 1.20m-1.25m and 1.60m-1.65m. Spores of the wood-fern-type but also marsh fern are common in all samples, peatmoss only in sample 1.20m-1.25m. Noteworthy is the possible observation of a beaked tasselweed/widgeon grass (*Ruppia maritima*) pollen grain in sample 1.20m-1.25m. The assemblage in all samples is consistent with that of marsh vegetation with grasses (reeds?), sedges and other riparian herbs, with open water (with waterlily), but there appears to be more marine influence in the uppermost sample 1.20m-1.25m. The assemblages are comparable with those typically seen in the Boreal (Early / Mid Holocene) on the basis of abundant hazel, with sample 1.20m-1.25m more consistent with the late Boreal based on the slightly increased presence of alder.

Microfauna: 1.20m-1.25m, 1.65m-1.70m, 2.00m-2.05m, 2.50m-2.55m
The assemblage from the uppermost sample differs markedly from the other samples assigned to this formation in that it is dominated by *Ammonia* spp. (with umbilical plug).

Amongst the ostracods, specimens of the freshwater *Limnocythere inopinata* were numerous as were the brackish water species *Cyprideis torosa* and *Cytheromorpha fuscata* and the marine *Pontocythere elongata*. Brackish water foraminifera *Ammonia* (with umbilical boss) and *Elphidium williamsoni* were also numerous as were the marine miliolid foraminifera and fragments of echinoids. This assemblage appears to be transitional between typical Naaldwijk and Urania microfaunal assemblages. The assemblages from the lower three samples were very similar and comprised small numbers of the freshwater ostracod taxa *Darwinula stevensoni, Limnocythere inopinata, Iliocypris gibba* and candonids together with higher numbers of the brackish water ostracods *Cyprideis torosa* and *Cytheromorpha fuscata.*

Diatoms: 1.20m-1.25m, 1.65m-1.70m, 2.00m-2.05m, 2.50m-2.55m
The uppermost sample (1.20m-1.25m) was devoid of diatoms. While all the other samples are dominated by marine taxa, their proportion decreases towards the top of the core, whilst both brackish and freshwater taxa increase. This supports the inference from the diatom assemblage data that the environment at this location became more influenced by estuarine conditions over time. The assemblage structure indicates a dynamic, marine coastal environment.

Molluscs: 1.20m-1.25m
Common shells with a somewhat mixed preservation, but mostly well-preserved sea floor below FWWB assemblage dominated by *Spisula subtruncata* with *Varicorbula gibba, Chamelea striatula* and rare *Nucula nitidosa, Tellina fabula, Spisula* cf *solida* and *Euspira nitida.*

Boxtel Formation, Singraven Member

Palynology: 2.85m-2.90m, 3.40m-3.45m, 4.00m-4.05m, 4.60m-4.70m
The pollen assemblages in these four samples are not significantly different from those present in the overlying Naaldwijk Formation interval. Similar features include a common presence of pine, birch, hazel and oak pollen with lesser numbers of alder and willow. Distributions of herbaceous pollen and spores also show similar trends. One significant difference is an increased presence of freshwater algae and fungal bodies relative to the overlying section. This is probably an indication of increased fluvial activity during sand deposition and the presence lower energy pond or small lakes, represented by clay laminae. The pollen floras are most comparable with the Boreal stage (local pollen zone E of Wijmstra and De Vin (1971) in the Singraven Formation in the eastern Netherlands). This falls within the Early Holocene but would be slightly younger than the age indicated by radiocarbon (see below).

Microfauna: 2.85m-2.90m, 3.40m-3.45m, 4.00m-4.05m, 4.60m-4.70m
The uppermost of the four samples from this formation was virtually identical to the samples from the overlying Naaldwijk Formation. The sample from 3.40m-3.45m yielded common specimens of the brackish water ostracods *Cyprideis torosa* and *Cytheromorpha fuscata*. The lower two samples were devoid of microfossils.

Diatoms: 2.85m-2.90m, 3.40m-3.45m, 4.00m-4.05m, 4.60m-4.70m
The upper two samples are dominated by marine taxa but influenced by estuarine conditions. The assemblage structure indicates a dynamic, marine coastal environment. The lower two samples were devoid of diatoms.

Molluscs: 3.40m-3.45m
Three well preserved *Pisidium* spp. possibly *P. henslowanum* and *P. casertanum* forma *plicatum.* Fine details and periostracum are preserved although there is some shell corrosion. These are probably *in situ* and indicative of (running?) freshwater.

Radiocarbon dating: 2.85m-2.90m, 3.40m-3.45m
Ostracods from both of these samples were combined to provide enough material for radiocarbon dating. The resulting date was 11177-10806 cal yrs BP (95.4% probability) indicating an Early Holocene age.

Location: TNW069-VC

Note: stratigraphic comments

As noted in the section on vibrocore TNW047_2-VC, there is an abundance of marine diatoms within the Boxtel Formation, Singraven Member as assigned in TNW069-VC. These predominate at and above sample 3.80m-3.85m. Furthermore, brackish ostracods are consistently present at and above sample 3.20m-3.25m. This interval consists mainly of clay according to the lithology log. The assemblages are consistent with the infilling of an incised feature with marine-influenced sediments during the Early Holocene.

Urania Formation, Western Mud Hole Member

Palynology: 1.00m-1.05m
Preservation of the palynomorphs in this sample is variable, but generally fair. The assemblage is dominated by pollen and spores. Freshwater indicators are present, marine and reworked elements are only sporadically observed. Tree pollen makes up the majority of the pollen and spore assemblage. Pollen of pine and hazel are most frequently observed, with birch and oak also common. Some elm and alder is present. Pollen of grasses is the most frequent of the herbaceous taxa, but that of sedges, bur-reed-type and the goosefoot family is also common. Spores of the wood fern-type are also common. Single pollen grains of yellow pond lily (*Nuphar* cf. *lutea*), possibly beaked tasselweed / widgeon grass and meadowsweet (*Filipendula*) are observed. The overall assemblage likely reflects marsh vegetation with grasses (reed?), sedges and other wetland herbs. The tree pollen assemblage is consistent with that of the Early Holocene Boreal stage based primarily on the very high numbers of hazel pollen recorded. Minor marine or coastal / brackish influence is suggested by the rare presence of foram tests and dinocysts.

Microfauna: 1.00m-1.05m
Low numbers of the brackish ostracods *Cyprideis torosa* and *Cytheromorpha fuscata* in the single sample from this formation indicate a brackish lagoonal or estuarine setting.

Diatoms: 1.00m-1.05m
This sample was devoid of diatoms.

Molluscs: 1.00m-1.05m
A few grey blue and brownish cream, mixed preservation shells were recovered from this sample. These included *Cerastoderma edule, Peringia ulvae* and *Spisula subtruncata.* The best-preserved specimens (*Cerastoderma, Peringia*) suggest a marine setting above FWWB.

Boxtel Formation, Singraven Member

Palynology: 1.50m-1.55m, 2.00m-2.05m, 2.50m-2.55m, 3.20m-3.25m, 3.80m-3.85m, 4.15m-4.20m
The assemblages in the six samples studied follow more or less the same pattern as observed in the Singraven Member in the previously described vibrocore, TNW047-VC. Similar distributions of tree pollen (pine, birch, hazel, oak, willow) and non-tree pollen (grasses and sedges etc.) as well as pollen from aquatic plants and fern/moss spores are evident. The TNW069-VC interval also shows an increased presence of freshwater algae and fungal bodies, with a low but consistent presence of marine taxa also occurring. Similarity with the Holocene, Boreal stage is indicated and with deposition occurring in a freshwater-influenced setting. If the Holocene age is correct, it cannot be ruled out that

some of the marine content could be *in situ*, indicating possible tidal or coastal influences.

Microfauna: 1.50m-1.55m, 2.00m-2.05m, 2.50m-2.55m, 3.20m-3.25m, 3.80m-3.85, 4.15m-4.20m
Six samples from this formation yielded a variety of different microfaunal assemblages. The uppermost sample from 1.50m-1.55m was very similar to the overlying Urania Formation sample. The sample from 2.00m-2.05m yielded several different freshwater ostracod species, *Darwinula stevensoni, Limnocythere inopinata, Metacypris cordata*, together with higher numbers of brackish species *Cyprideis torosa* and *Cytheromorpha fuscata* and low numbers of marine forms, *Palmoconcha laevata*, ?*Asterigerina* sp. and fragments of echinoids. At 2.50m-2.55m and 3.20m-3.25m assemblages were similar but less diverse and with fewer specimens. The samples from 3.80m-3.85m and 4.15m-4.20m were barren of microfossils apart from a few mollusc fragments at the lower depth.

Diatoms: 1.50m-1.55m, 2.00m-2.05m, 2.50m-2.55m, 3.20m-3.25m, 3.80m-3.85m
The diatom assemblages between 1.50m-1.55m and 3.80m-3.85m were dominated by the marine *Cymatosira belgica* and the marine-brackish *Delphineis minutissima*. *Navicula perminuta* (brackish-marine to brackish, benthic) was also relatively common in the upper the samples, while *Thalassiosira decipiens* (marine-brackish) and *Thalassiosira proschkinae* (marine-brackish, brackish-marine) were abundant in the lower two samples, respectively. This could indicate a slight decrease in marine conditions, or possibly a shallowing of the environment in the upper three samples, as an increase in a benthic form could indicate a greater prevalence of shallow habitat. The sample from 4.15m-4.20m was devoid of diatoms.

Location: TNW075_2-VC

Note: stratigraphic comments

The various fossil groups studied show a degree of marine influence in all of the studied samples below 3.20m-3.25m a feature which is consistent with the assignment to the Eem Formation, including the Brown Bank Member. The lowermost sample studied has an increased abundance of marine microfossils and (mainly intertidal) mollusc shells: this is a possible indication that the Eem Formation proper is present at the base of the studied interval. This section probably broadly equates to MIS 5, including possibly MIS 5e at the base.

Naaldwijk Formation, Zandvoort Member

Palynology: 1.00m-1.10m
Very few palynomorphs are present in this sample, the preservation of which is highly variable. Mostly, some pollen of pine, spruce (*Picea* sp.), grasses and sedges have been observed, and some fern spores. In addition, some very vague remains of the type *Halodinium* sp. are present. The sample is too poor for proper counts so no inferences can be made. The observed palynomorphs are present in the sediments below, so it is possible that these are reworked from the underlying deposits.

Microfauna: 1.00m-1.10m
The single sample from this formation was barren of microfauna.

Diatoms: 1.00m-1.10m
This sample was devoid of diatoms.

OSL dating: 2.95m-3.05m
A single sample at the base of the Zandvoort Member was dated as 9408 ± 501 years.

Eem Formation / Brown Bank Member (equivalent)

Palynology: 3.20m-3.25m, 3.70m-3.75m, 4.30m-4.35m, 4.40m-4.45m
The four samples have highly comparable assemblages, except on one point: the lowermost sample 4.40m-4.45m contains numerous remains of the dinocyst *Halodinium*, in sample 4.30m-4.35m only some are observed and in the two overlying samples this type is absent. This palynomorph is associated with estuarine to shallow marine (intertidal to near shore) settings (Head, 1993). In these two lowermost samples, freshwater indicators and reworked and marine elements are also more common. The pollen and spores assemblages are dominated by pollen of pine. In addition, pollen of spruce, alder, birch, hazel, oak and hornbeam (*Carpinus*) are common. Also pollen of holly (*Ilex*) is present sporadically. Pollen of herbaceous taxa largely consists of grasses and sedges, but the presence of common heather (*Calluna vulgaris*) and other undifferentiated types of heather (Ericaceae) is noteworthy. In addition, spores of peatmoss are abundantly present and fern spores are common. Notably, in all samples pollen of the herb common bistort (*Polygonum bistorta*) are sporadically present. This is a herb that occurs on moist organic soils and is currently found in wet meadows and along streams (Weeda *et al.,* 1985).

The abundant presence of peatmoss in the assemblage is indicative of raised bog landscapes, in which heather, grasses and sedges are also common components. Some forested (park landscape) areas were likely present besides open landscapes with bog and heather. The distinct presence of the estuarine to shallow marine palynomorph

Halodinium in the lowermost samples, however, points to a coastal setting with perhaps a raised bog in the proximity. The common presence of tree taxa in association with common heather and herbs is consistent with the final phase of the Eemian and earliest interstadials of the early Weichselian (Amersfoort/Brørup) (Behre, 1989; Zagwijn, 1989). The latter, in particular pollen zones EWII and EWIV of Zagwijn (1961), also contain frequent *Dryopteris*-type and peatmoss (*Sphagnum*) spores, with *Polygonum bistorta*, as observed in the present study.

Microfauna: 3.20m-3.25m, 3.70m-3.75m, 4.30m-4.35m, 4.40m-4.45m
Foraminifera were rare and comprised specimens of *Elphidium* spp., miliolids and echinoid fragments. The miliolids in particular were stained brown and appear reworked.

Diatoms: 3.20m-3.25m, 3.70m-3.75m, 4.30m-4.35m, 4.40m-4.45m
These samples were devoid of diatoms.

Molluscs: 4.30m-4.35m, 4.40m-4.45m
Some shells, mixed preservation from worn to well-preserved and dominated by *Scrobicularia subtruncata* and also contained *S. plana*. The lower sample also yielded *Mytilus edulis, Kurtiella bidentata, Spisula* cf. *solida* and *Nucula nitidosa.* The assemblage from the upper sample is indicative of a marine setting below FWWB and of brackish water whereas the lower assemblage suggests a position around or above FWWB.

Location: TNW078_1-VC

Naaldwijk Formation, Wormer Member

Palynology: 0.60m-0.65m, 1.10m-1.15m, 1.90m-1.95m, 2.60m-2.65m
All four samples from the Wormer Member are rich in organic fragments but also in palynomorphs, which are generally well preserved. The assemblages are dominated by pollen and spores, but marine indicators (foram linings, dinocysts) and freshwater indicators (mostly *Pediastrum*) are also common. Reworked elements are present.

The pollen and spores assemblages have common pine, alder, birch, hazel and oak, and some elm and willow is present. Note that alder peaks in sample 1.10m-1.15m, and willow in sample 2.60m-2.65m. The herbaceous assemblage is characterised by grasses, sedges and of bur-reed type. Pollen of the goosefoot family (Cheno-Amaranthaceae) is also consistently present. Spores of the wood fern-type are common, those of marsh fern and peatmoss less so. Interesting is the presence of beaked tasselweed (*Ruppia maritima*) in all samples. This pioneer aquatic plant is typically found in brackish water over an organic-rich clayey soil, nowadays in wetlands close to the coast (Weeda *et al*., 1991). Some waterlily was also present in these waters. The notable presence of willow in sample 2.60m-2.65m probably indicates that these wetland trees grew nearby. Increasing presence of marine indicators in the upper samples suggest a growing marine influence at the site of deposition. These samples are probably representative of the late Boreal to Atlantic (Mid / Late Holocene) stages based on the high counts of hazel and then alder pollen.

Microfauna: 0.60m-0.65m, 1.10m-1.15m, 1.90m-1.95m, 2.60m-2.65m
The uppermost sample is characterised by abundant foraminifera *Ammonia* spp. (with umbilical boss) and miliolids and *inter alia* the ostracod *Pontocythere elongata*. The underlying three samples are quite dissimilar in that in contrast they yielded numerous *Ammonia* spp. (without boss), *Elphidium williamsoni* and the ostracod *Cyprideis torosa* suggesting that there was a change in environment from brackish to more marine conditions near the top of this interval.

Diatoms: 0.60m-0.65m, 1.10m-1.15m, 1.90m-1.95m, 2.60m-2.65m
The shallowest sample (0.60m-0.65 m) was too sparse to provide a full count, with only 63 valves found over three transects. Data from this sample is presented on the distribution chart, but not detailed in this report, apart from in basic terms for considering potential similarity of this sample. All samples are dominated by marine taxa, with brackish and freshwater taxa making only a minor contribution to the assemblages. There is an indication of a slight increase in brackish taxa towards the upper samples. A similar pattern was observed in 0.60m-0.65m, but here brackish taxa are relatively more abundant due to the occurrence of *Planothidium delicatulum* in high numbers. The assemblages suggest a consistently coastal marine environment, with only minor estuarine influence and possibly a minor increase in brackish conditions in shallower samples.

Molluscs: 0.60m-0.65m
Common shells and fragments with mixed preservation, mostly reasonably well preserved but many grey to creamy grey, some bluish. The best preserved specimens in the assemblage belong to *Chamelea striatula* which are dominant. Other species present include *Cultellus pellucidus, Spisula subtruncata, Varicorbula gibba, Euspira nitida, Peringia ulvae* and *Acteon tornatilis*. *Mytilus edulis, Scrobicularia plana, Kurtiella bidentata, Spisula* cf. *solida* and *Nucula nitidosa* were rare. This assemblage contains species with differing ecologies (*Scrobicularia* versus *Chamelea* faunas) indicating an *in situ* fully marine seafloor association above SWB or one that has been transported only a short distance with reworked brackish coastal taxa.

Nieuwkoop Formation, Hollandveen Member

Palynology: 3.23m-3.33m
The palynomorphs in this sample are moderately well preserved and the assemblage is notably different from the ones overlying it. Pollen and spores again dominate the assemblage, but marine and reworked elements are practically absent, whereas freshwater indicators (waterlily basal cells) are very abundant. The tree pollen assemblage also differs distinctly in that it is dominated by pollen of pine and birch, and some hazel is present. Also, the herbaceous assemblage is less diverse: mostly grasses, sedges and some fern spores are present. Pollen of waterlily is present in small numbers, but the considerable presence of the basal cells indicates that the local environment was open water. The high counts of birch and pine with low counts of hazel and absence of alder suggest an early Boreal, Holocene age for this sample. This is slightly younger than the age inferred by radiocarbon dating (see below).

Microfauna: 3.23m-3.33m
This sample was devoid of microfauna.

Diatoms: 3.23m-3.33m
This sample was devoid of diatoms.

Macroplants: 3.23m-3.33m
The macroplant assemblage was formed mostly of large quantities of wood fragments and plant stems. Preservation of the wood fragments was variable and only one large piece was identifiable as pine. Other plant finds included sedge fruits, and peat was also present.

Radiocarbon dating: 3.23m-3.33m
A single sample of wood from this formation was dated between 10765 and 10578 cal yrs BP (95.4% probability) and 10987-10984 (0.3% probability) indicating an Early Holocene age.

Location: TNW079_1-VC

Note: stratigraphic comments

The lowermost sample studied has an increased presence of marine microfossils and (mainly intertidal) mollusc shells: this is a possible indication that the Eem Formation proper is present at the base of the studied interval. This studied section probably broadly equates to MIS 5, including possibly MIS 5e at the base.

Eem Formation, Brown Bank Member (equivalent)

Palynology: 0.45m-0.50m, 0.65m-0.70m, 0.85m-0.90m, 1.30m-1.35m
The upper four samples studied are rich in organic fragments as well as in palynomorphs. In the upper two samples the preservation is variable, in the lower two preservation is good. The palynomorph assemblage is dominated by pollen and spores. Freshwater indicators (*Pediastrum* mostly) are common, and marine and reworked indicators are present in low numbers. For the upper three samples, the pollen and spores assemblages are highly comparable whereas sample 1.30-1.35m differs distinctly. In the upper three samples, pollen of pine is dominant with several spruce grains also present. Deciduous trees including alder, birch, hornbeam, hazel and oak are fairly common. In addition, pollen of heather (*Calluna*) and related types are relatively abundant besides that of grasses and sedges. Some pollen of common bistort (*Polygonum bistorta*) is observed in all three. Spores of peatmoss are also abundantly present, and spores of the wood fern-type are common. In contrast, in sample 1.30-1.35m pollen of hazel and oak are by far the most common tree taxa, co-occurring with pine, birch and elm. Grasses, sedges and bur-reed-type are the most common herbaceous pollen types. A single possible pollen grain of the brackish-water plant tasselweed/wigeon grass has been observed.

The assemblages in the upper three samples highly resemble that seen in vibrocore TNW075-VC so, as previously noted, are consistent with the final phase of the Eemian and earliest interstadials of the early Weichselian (Amersfoort/Brørup). It is perhaps significant that Zagwijn (1961) noted the rare presence of *Polygonum bistorta* within his zone EWIV, linked to the Brørup interstadial. Local vegetation likely included open landscapes with heather and raised bogs as well as forested parts. Minimal marine or brackish influence is also suggested. The high counts of hazel and oak and the absence of spruce and hornbeam in sample 1.30m-1.35m, however, are more consistent with Eemian stages E3 or E4a (Zagwijn, 1989). The pollen assemblage in this sample reflects marshland vegetation locally, and mixed oak forests in the upland areas. Again, minor marine influence is possible.

Microfauna: 0.45m-0.50m, 0.65m-0.70m, 0.85m-0.90m, 1.30m-1.35m
All four samples contained low numbers of reworked foraminifera and a single reworked ostracod. Echinoid fragments and sponge spicules were also occasionally present but it is not possible to know if these were also reworked. The lowermost sample studied has an increased presence of marine microfossils. This is a possible indication that the Eem Formation proper is present at the base of the studied interval.

Diatoms: 0.45m-0.50m, 0.65m-0.70m, 0.85m-0.90m, 1.30m-1.35m
These samples were devoid of diatoms.

Molluscs: 1.30m-1.35m
This sample yielded only a few fragments of molluscs including *Spisula subtruncata*; blue-grey with ?gypsum-manganese, badly worn and/or corroded. An environmental interpretation cannot be made.

Eem Formation (undifferentiated)

Palynology: 2.55m-2.65m
This sample is very poor in palynomorphs and contains little organic material. Preservation of the palynomorphs present is variable. On the whole, the material is too poor to obtain a reliable count and only basic analysis could be done. Palynomorphs that were observed generally include pollen of pine and some spruce and grasses, as well as several dinocysts (*Spiniferites*). A single *Halodinium* sp. has been observed in the slide. Due to the low counts no inferences can be made although affinity with the Eemian and some marine influence seems likely.

Microfauna: 2.55m-2.65m
This sample was barren other than for a few mollusc fragments.

Diatoms: 2.55m-2.65m
This sample was devoid of diatoms.

Molluscs: 2.55m-2.65m
This sample contained common grey blue, worn to very worn shells and fragments. A few cream grey *Spisula* sp. were less worn. *Dosinia lupinus* was dominant, *Laevicardium crassum, Spisula subtruncata, Acanthocardia* sp. were also present and *Bela* cf *nebula*, *Macoma balthica* and *Spisula solida* were rare. Multiple reworking of marine faunas is suggested.

Location: TNW109-VC

Note: stratigraphic comments

Within the Boxtel Formation as assigned in this vibrocore there is a clear distinction in the diatom records with an abundance of marine forms at and above sample 3.95m-4.00m. This also coincides with the rare but consistent presence of brackish and freshwater ostracods, and a change from mostly sand to clay at 3.90m according to the lithology log. To reflect these observations the upper boundary of the Wierden Member has been picked to include sample 4.67m-4.72m in the following text and on the accompanying distribution charts.

Boxtel Formation, Singraven Member

Palynology: 2.42m-2.47m, 2.95-3.00m, 3.45m-3.50m, 3.95m-4.00m
All four samples have assemblages very similar to those described from the Singraven Member in the other vibrocores in this study. These are characterised by a mixed tree pollen assemblage with frequent pine, birch and hazel with lesser oak, willow and elm. Non-tree taxa are dominated by grass and sedge pollen but with a fairly diverse complement of other herbs including aquatics. Ferns are characterised by wood-fern type and marsh fern. A mix of freshwater taxa occur including *Pediastrum* and water lily base cells, although a minor but consistent marine presence is noted. On the basis of frequent *Corylus*, the samples are likely to be of Holocene age, relating to the Boreal stage.

Microfauna: 2.42m-2.47m, 2.95m-3.00m, 3.45m-3.50m, 3.95m-4.00m
All four samples yielded similar poorly diverse microfaunas including a rare specimens of the brackish ostracod (*Cytheromorpha fuscata*) and brackish foraminifera (*Ammonia* spp., *Elphidium williamsoni* and *Haynesina germanica*) with echinoid fragments. Rare freshwater ostracods (*Darwinula stevensoni* and *Limnocythere inopinata*) occurred at 2.95m-3.00m and a single charophyte oogonium (fresh-brackish water) was recovered from 3.45m-3.50m.

Diatoms: 2.42m-2.47m, 2.95m-3.00m, 3.45m-3.50m, 3.95m-4.00m
These samples are dominated by the marine *Cymatosira belgica*, marine-brackish *Delphineis minutissima* and *Navicula perminuta*, the marine to marine-brackish *Paralia sulcata* and the marine *Minidiscus* spp. A predominantly coastal marine environment is indicated.

Molluscs: 2.42m-2.47m, 3.45m-3.50m
The upper sample yielded shells with mixed preservation, from worn to fine details preserved, mostly glassy-grey. *Spisula subtruncata* (well-preserved) and *Chamelea striatula* were dominant and *Varicorbula gibba* was present with rare specimens of *Scrobicularia plana* and *Euspira nitida*. This is a mixed marine and brackish water assemblage from below FWWB. Sample 3.45m-3.50m contained only a single worn fragment of *Chamelea striatula.*

Boxtel Formation, Wierden Member

Palynology: 4.67m-4.72m, 4.95m-5.03m, 5.33m-5.40m
Sample 4.67m-4.72m has an assemblage broadly similar to that in the overlying interval. The lower two samples show a marked increase in pine pollen and much reduced numbers of oak and hazel pollen. The latter two may well be reworked. The non-tree and pollen from aquatic plants shows little change from the overlying intervals.

Fern spores (wood-fern type) show a minor increase whereas freshwater algae (*Pediastrum*) show a minor decrease down-section. Water lily base cells are again well-represented. Marine content is very negligible and likely to be reworked. The closest match with published records is with the lateglacial Allerød interstadial, the later part of zone II as shown by Van der Hammen (1951) in the Wierden and Usselo B sections in the northeastern Netherlands. This is within the age range indicated by OSL dating (see below).

Microfauna: 4.67m-4.72m, 4.95m-5.03m, 5.33m-5.40m
Of these three samples the upper two were barren of microfauna and the lowermost one yielded only a single charophyte oogonium of fresh to mildly brackish water origin and a few mollusc fragments.

Diatoms: 4.67m-4.72m, 4.95m-5.03m, 5.33m-5.40m
The upper and lower samples are dominated by the planktonic brackish-fresh to fresh-brackish *Cyclotella atomus*, the brackish-fresh *Cyclotella meneghiniana*, the planktonic freshwater taxon *Stephanodiscus hantzschii* and the fresh-brackish *Aulacoseira italica*. A predominantly freshwater environment is indicated. The sample from 4.95m-5.03m yielded too few specimens to make a viable count.

Molluscs: 5.33m-5.40m
A slightly worn *Chamelea striatula* was recovered from this sample. This is a marine species but no further environmental interpretations can be made.

OSL dating: 5.20m-5.30m
A single sample was dated as 11039 ± 920 years.

9 - Archaeological potential

Urania Formation, Western Mud Hole Member
The Urania Formation where studied invariable contains evidence for some degree of marine inundation, although areas with freshwater conditions also occurred. Palynology suggests Urania deposition occurred at some localities (e.g. TNW005-VC and TNW069-VC) during the Early Holocene, Boreal stage, which is before the main period of Holocene sea level rise. It is certainly possible, therefore, that some land suitable for habitation may have been present at this time.

Naaldwijk Formation, Wormer and Zandvoort Members
The Naaldwijk Formation is a known source for many artefacts, animal bones etc. that show that significant areas of the North Sea could have been inhabited when the Naaldwijk was deposited. Many items, however, are lacking stratigraphic context and may be reworked from the older Pleistocene (Hijma *et al.*, 2012; Pieters *et al*., 2020). One OSL date of close to 9500 years BP for the base of the formation was obtained in this study. This date falls within the Boreal stage of the Early Holocene and is in agreement with the pollen records in several sampled intervals. One section (TNW078_1-VC) appears to be slightly younger (late Boreal to Atlantic stage, Early to Mid Holocene). The Naaldwijk Formation was deposited before the main phase of Holocene sea level rise and therefore probably largely suitable for habitation. Even so, there would have been extensive boggy and wetland areas. The pollen and spores obtained are all from 'wild' species, with no evidence of any cultivated plants.

Nieuwkoop Formation, Hollandveen Member, Basal Peat Bed
As indicated for the Naaldwijk Formation, the peat-rich Nieuwkoop Formation would very probably also have been suitable for habitation, although with extensive boggy and wetland areas present. Despite rising relative sea levels, direct inundation from sea water would have been minimal or absent. The plant macrofossil evidence includes a fairly large piece of pine wood and various birch fossils, suggesting that at least some of these trees were growing close to the sites of deposition. *Cenococcum* spores are potentially linked with mycorrhiza, the fungal soil networks that allow many woodland trees to thrive. Potentially useful plants are indicated by the presence of Apiaceae fruits at one locality (TNW005-VC). Apiaceae are the carrot family which includes several potential root crops as well as several plants with herbal and medicinal uses. Relatively frequent charred fragments were also noted at the TNW005-VC locality, although not sufficient to clearly indicate a human presence.

Boxtel Formation, Singraven Member
Interpretation of the Singraven Member as the sediment infilling of an incised landscape has a potential bearing on its suitability for habitation. Incised valleys offer potential sites for habitation by providing a degree of shelter, as well as a source of freshwater in small rivers and lakes. The sediments became progressively marine and therefore any settled areas would eventually have become inundated. Infilling of valley features with sediment fill offers the potential for burial and preservation of artefacts. Based on the inferred ages of the studied sections, it is possible that the valleys were formed at the very end of the Pleistocene, possibly resulting from a minor sea level fall during the Late Dryas stage, and then infilled at the onset of the Holocene.

Boxtel Formation, Wierden Member
There is a strong likelihood that the Wierden Member would have provided suitable land for habitation as the landscape probably contained dunes and associated freshwater lakes and ponds.

Eem Formation, Brown Bank Member
Habitation of the TNW locality during the Eemian (i.e. MIS 5e) is possible, although the area would have been subject to marine inundation. More likely is that drier, hinterland areas were inhabited where mixed dryland forests would have been present. During deposition of the Brown Bank Member (MIS 5d-a) sea levels would have been variable but generally lower allowing potential habitation on exposed land areas.

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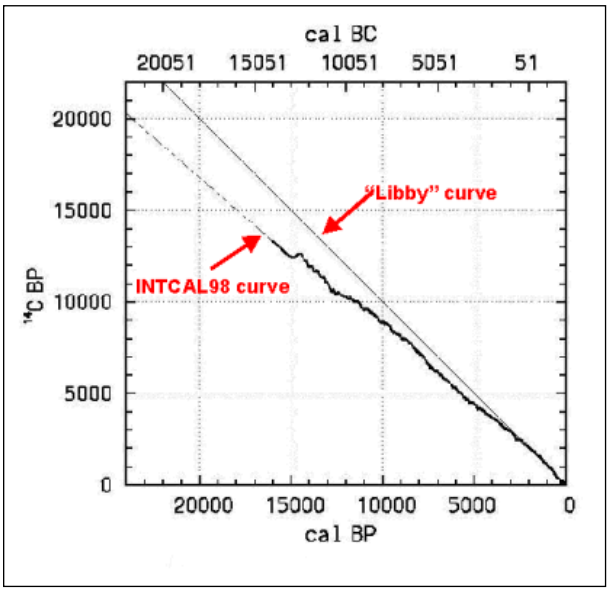
Appendix 1 - Radiocarbon (^{14}C) dating

Method

The radiocarbon method of dating was first developed by a group led by Willard F.Libby in 1949, since when it has been used mainly as an archaeological tool. ^{14}C is an unstable isotope of carbon which is created from ^{14}N in the upper atmosphere. Carbon (both ^{14}C and ^{12}C) rapidly oxidises to CO_2 and disperses in the atmosphere. It is then absorbed by all living organisms via photosynthesis (in the case of plants) or through the food chain (in the case of animals). Because ^{14}C is an unstable isotope it is constantly decaying, but the proportion of ^{14}C in living organisms stays relatively constant over time through continued metabolic uptake. In life the $^{14}C/^{12}C$ ratio therefore remains in equilibrium with the atmosphere. However, upon death there is no further uptake of carbon and the ^{14}C decays to ^{12}N with a half-life of 5,730 years. Measurement of the amount of ^{14}C remaining in a dead organism will therefore give the date of its death. Using this method the maximum detectable age is no greater than 50,000 years but over 40,000 years dates are unreliable. In addition, material from the last 300 years gives unreliable ages mainly due to the widespread burning of fossil fuels. More recently, the explosion of nuclear bombs both of which have artificially increased the amount of ^{14}C in the atmosphere and since 1950 it is not possible to provide a date using this method. Since 1977 the use of AMS (Atomic Mass Spectrometry) has enabled the use of very small quantities (10mg) of material.

Calendar year calibration

The results of ^{14}C dating have traditionally been quoted in "conventional radiocarbon years", typically in years BP (before present) where the "present" is 1950. The initial assumption that the concentration of atmospheric ^{14}C has been constant as measured in 1950 has been shown to be incorrect. Dating annual tree growth rings of known historical age has demonstrated that in the past there have been short term variations in atmospheric ^{14}C levels. Tree ring dating has been used to construct a probabilistic calibration curve extending back to 11,857 calendar years BP. This method is not without its own inaccuracies and has limited precision, but it does provide dates in terms of calendar years. Extension of the calibration curve further back to about 24,000 calendar years BP has been achieved using U-Th decay series dates from marine organisms (principally corals). The INTCAL calibration curve thus constructed has been accepted by international consent.

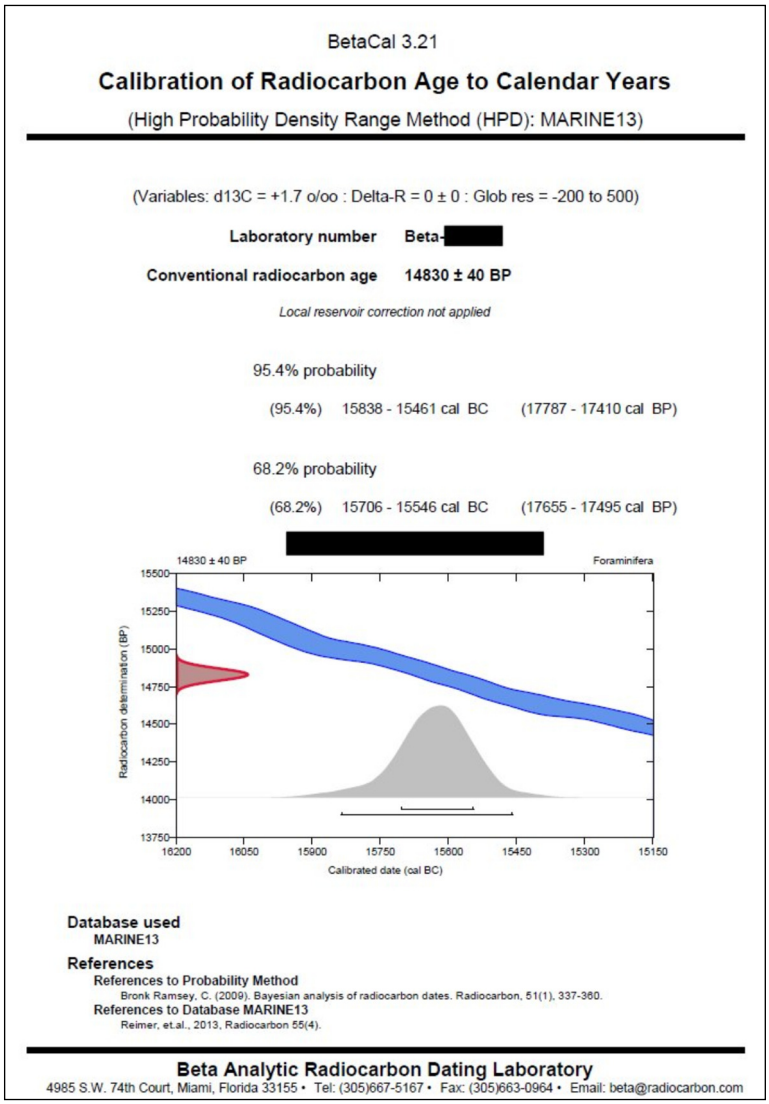


Comparison of the original curve calculated by Libby and the calibrated INTCAL curve.
(*From Stuiver et al. 1998*)

There are two main methods used for calculating calendar age ranges (cal BP) from the calibration curve. In the past we have provided intercept ages which conveniently provided a single date with a known error for each sample. However, it has become common practice in recent years to use the High-Probability Density (HPD) range method which uses probability densities in an attempt to enhance precision. Results are graphically represented by a shaded grey area on the plot and by percentage values reported next to each range.

A full explanation of the method can be found at *www.radiocarbon.com/calendar-calibration-carbon-dating.htm.*

By convention radiocarbon dates (years BP) from the laboratory are reported with the associated 1σ and 2σ errors. However, it should be borne in mind that an error of ±1σ means that there is a 1 in 3 chance of the age NOT falling within the range of uncertainty. This improves to 1 in 20 for a ±2σ error but a date should never be used without reference to its associated errors as if they were absolutely known with no uncertainty. Samples which are beyond the range of ^{14}C dating cannot be calibrated and are typically displayed as >43,500yrs BP.



Example of a radiocarbon calibration - HPD method

(from Beta Analytic)

Marine reservoir age
The average difference between a radiocarbon date of a terrestrial organism such as a tree and a marine shell of the same age is about 400 radiocarbon years. This difference which is called the reservoir age is caused both by the delay in exchange rates between atmospheric CO_2 and oceanic bicarbonate, and the dilution effect caused by mixing surface waters with upwelling deep waters which are very old. A local reservoir correction factor must therefore be applied to conventional radiocarbon dates based on the remains of marine organisms.

Reworking
For practical purposes ^{14}C dating records the time of death of an organism and not the point at which it is finally entombed in sediment. Reworking of older material into younger sediments frequently occurs and can dramatically increase their ^{14}C age. Therefore, specimens for analysis are selected with great care and, to any doubtful material, discarded.

Appendix 2 - Radiocarbon dating certificates and quality assurance reports

Beta Analytic, Inc.
4985 SW 74th Court
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Tel: 305-667-5167
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ISO/IEC 17025:2017-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

John Athersuch — Report Date: July 13, 2021

BioChron — Material Received: June 23, 2021

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes	
Beta - 595771	**TNW(A) TNW005 1.85-1.90**	**9820 +/- 30 BP**	IRMS δ13C: -28.6 o/oo

(95.4%) 9315 - 9246 cal BC (11264 - 11195 cal BP)

Submitter Material: PEAT
Pretreatment: (organic sediment) acid washes
Analyzed Material: Organic sediment
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 29.45 +/- 0.11 pMC
Fraction Modern Carbon: 0.2945 +/- 0.0011
D14C: -705.50 +/- 1.10 o/oo
Δ14C: -708.02 +/- 1.10 o/oo (1950:2021)
Measured Radiocarbon Age: (without d13C correction): 9880 +/- 30 BP
Calibration: BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

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REPORT OF RADIOCARBON DATING ANALYSES

John Athersuch — Report Date: July 13, 2021

BioChron — Material Received: June 23, 2021

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes	
Beta - 595772	**TNW(A) TNW042 1.85-1.90**	**9020 +/- 30 BP**	IRMS δ13C: -29.3 o/oo

(95.4%) 8293 - 8222 cal BC (10242 - 10171 cal BP)

Submitter Material:	PEAT
Pretreatment:	(organic sediment) acid washes
Analyzed Material:	Organic sediment
Analysis Service:	AMS-Standard delivery
Percent Modern Carbon:	32.53 +/- 0.12 pMC
Fraction Modern Carbon:	0.3253 +/- 0.0012
D14C:	-674.66 +/- 1.22 o/oo
Δ14C:	-677.44 +/- 1.22 o/oo (1950:2021)
Measured Radiocarbon Age:	(without d13C correction): 9090 +/- 30 BP
Calibration:	BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

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REPORT OF RADIOCARBON DATING ANALYSES

John Athersuch — Report Date: July 13, 2021

BioChron — Material Received: June 23, 2021

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes	
Beta - 595773	**TNW(A) TNW078 3.23-3.33**	**9450 +/- 30 BP**	IRMS δ13C: -25.4 o/oo

(95.1%)	**8816 - 8629 cal BC**	**(10765 - 10578 cal BP)**
(0.3%)	**9038 - 9035 cal BC**	**(10987 - 10984 cal BP)**

Submitter Material: WOOD
Pretreatment: (wood) acid/alkali/acid
Analyzed Material: Wood
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 30.84 +/- 0.12 pMC
Fraction Modern Carbon: 0.3084 +/- 0.0012
D14C: -691.62 +/- 1.15 o/oo
Δ14C: -694.25 +/- 1.15 o/oo (1950:2021)
Measured Radiocarbon Age: (without d13C correction): 9460 +/- 30 BP
Calibration: BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

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Quality Assurance Report

This report provides the results of reference materials used to validate radiocarbon analyses prior to reporting. Known-value reference materials were analyzed quasi-simultaneously with the unknowns. Results are reported as expected values vs measured values. Reported values are calculated relative to NISTSRM-1990C and corrected for isotopic fractionation. Results are reported using the direct analytical measure percent modern carbon (pMC) with one relative standard deviation. Agreement between expected and measured values is taken as being within 2 sigma agreement (error x 2) to account for total laboratory error.

Report Date: July 13, 2021
Submitter: Dr. John Athersuch

QA MEASUREMENTS

Reference 1

Expected Value:	0.44 +/- 0.10 pMC
Measured Value:	0.46 +/- 0.03 pMC
Agreement:	Accepted

Reference 2

Expected Value:	129.41 +/- 0.06 pMC
Measured Value:	129.43 +/- 0.35 pMC
Agreement:	Accepted

Reference 3

Expected Value:	96.69 +/- 0.50 pMC
Measured Value:	97.58 +/- 0.28 pMC
Agreement:	Accepted

COMMENT: All measurements passed acceptance tests.

Validation: Digital signature on file

Date: July 13, 2021

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REPORT OF RADIOCARBON DATING ANALYSES

John Athersuch — Report Date: October 11, 2021

BioChron — Material Received: October 06, 2021

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes	
Beta - 605164	**TNW047 2.85m-2.90m & 3.40m-3.45m**	**10090 +/- 30 BP**	IRMS δ13C: NA

(95.4%) 9228 - 8857 cal BC (11177 - 10806 cal BP)

Submitter Material: Ostracods
Pretreatment: (shell) none
Analyzed Material: Shell
Analysis Service: AMS-PRIORITY delivery
Percent Modern Carbon: 28.48 +/- 0.11 pMC
Fraction Modern Carbon: 0.2848 +/-
D14C: -715.23 +/- 1.06 o/oo
Δ14C: -717.67 +/- 1.06 o/oo (1950:2021)
Measured Radiocarbon Age: (without d13C correction): NA
Calibration: BetaCal4.20: HPD method: MARINE20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB. References for calendar calibrations are cited at the bottom of calibration graph pages.

Beta Analytic
TESTING LABORATORY

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ISO/IEC 17025:2017-Accredited Testing Laboratory

Quality Assurance Report

This report provides the results of reference materials used to validate radiocarbon analyses prior to reporting. Known-value reference materials were analyzed quasi-simultaneously with the unknowns. Results are reported as expected values vs measured values. Reported values are calculated relative to NISTSRM-1990C and corrected for isotopic fractionation. Results are reported using the direct analytical measure percent modern carbon (pMC) with one relative standard deviation. Agreement between expected and measured values is taken as being within 2 sigma agreement (error x 2) to account for total laboratory error.

Report Date: October 11, 2021
Submitter: Dr. John Athersuch

QA MEASUREMENTS

Reference 1

Expected Value:	0.44 +/- 0.10 pMC
Measured Value:	0.42 +/- 0.03 pMC
Agreement:	Accepted

Reference 2

Expected Value:	96.69 +/- 0.50 pMC
Measured Value:	97.02 +/- 0.28 pMC
Agreement:	Accepted

Reference 3

Expected Value:	41.14 +/- 0.10 pMC
Measured Value:	40.98 +/- 0.17 pMC
Agreement:	Accepted

COMMENT: All measurements passed acceptance tests.

Validation: Chris Patrick
Digital signature on file

Date: October 11, 2021

Appendix 3 - Radiocarbon calendar year calibrations

BetaCal 4.20

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -28.6 o/oo)

Laboratory number **Beta-595771**

Conventional radiocarbon age **9820 ± 30 BP**

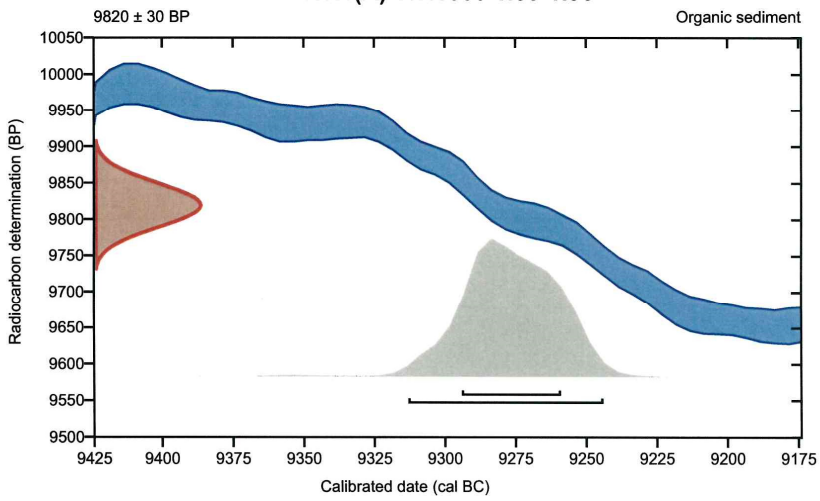
95.4% probability

(95.4%) 9315 - 9246 cal BC (11264 - 11195 cal BP)

68.2% probability

(68.2%) 9296 - 9261 cal BC (11245 - 11210 cal BP)

TNW(A) TNW005 1.85-1.90



Database used

INTCAL20

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL20

Reimer, et al., 2020, Radiocarbon 62(4):725-757.

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BetaCal 4.20

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -29.3 o/oo)

Laboratory number **Beta-595772**

Conventional radiocarbon age **9020 ± 30 BP**

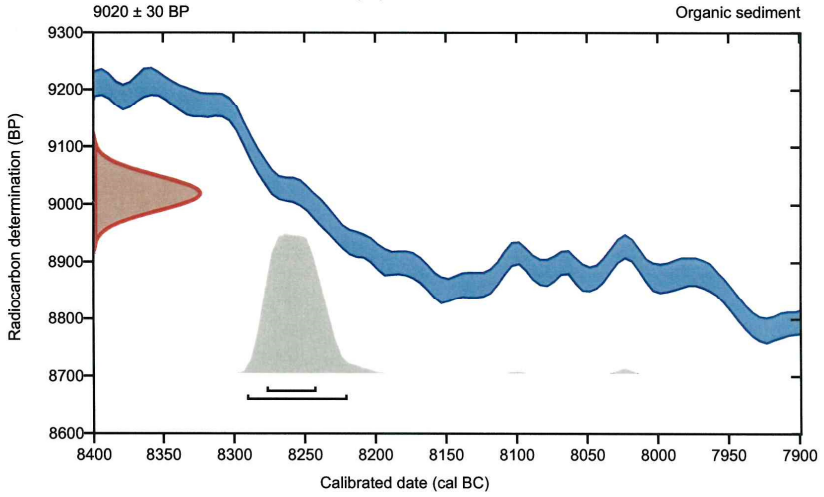
95.4% probability

(95.4%) 8293 - 8222 cal BC (10242 - 10171 cal BP)

68.2% probability

(68.2%) 8279 - 8244 cal BC (10228 - 10193 cal BP)

TNW(A) TNW042 1.85-1.90



Database used

INTCAL20

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL20

Reimer, et al., 2020, Radiocarbon 62(4):725-757.

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BetaCal 4.20

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -25.4 o/oo)

Laboratory number **Beta-595773**

Conventional radiocarbon age **9450 ± 30 BP**

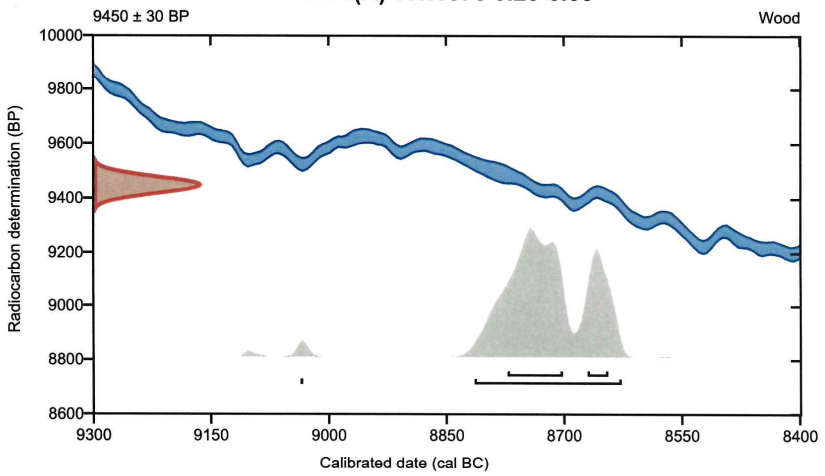
95.4% probability

(95.1%)	8816 - 8629 cal BC	(10765 - 10578 cal BP)
(0.3%)	9038 - 9035 cal BC	(10987 - 10984 cal BP)

68.2% probability

(51.6%)	8774 - 8704 cal BC	(10723 - 10653 cal BP)
(16.6%)	8672 - 8646 cal BC	(10621 - 10595 cal BP)

TNW(A) TNW078 3.23-3.33



Database used

INTCAL20

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL20

Reimer, et al., 2020, Radiocarbon 62(4):725-757.

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BetaCal 4.20

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): MARINE20)

(Variables: d13C = N/A : Delta-R = 0 ± 0)

Laboratory number **Beta-605164**

Conventional radiocarbon age **10090 ± 30 BP**

Local reservoir correction not applied

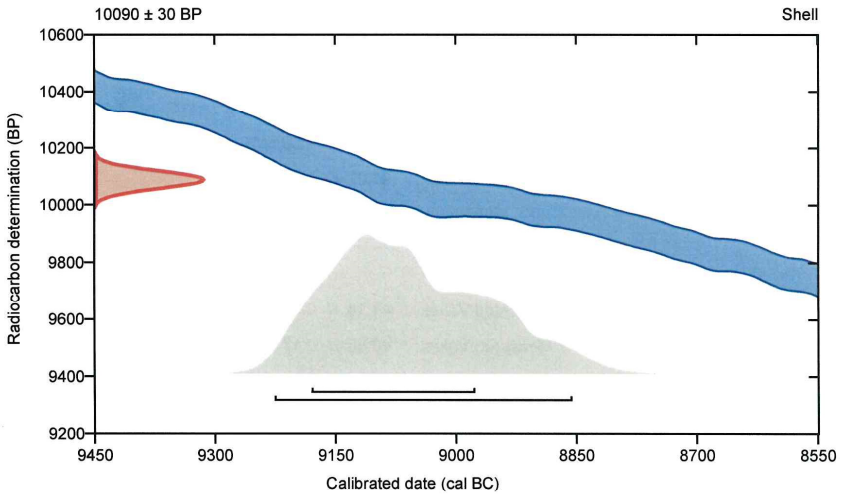
95.4% probability

(95.4%) 9228 - 8857 cal BC (11177 - 10806 cal BP)

68.2% probability

(68.2%) 9182 - 8978 cal BC (11131 - 10927 cal BP)

TNW047 2.85m-2.90m & 3.40m-3.45m



Database used

MARINE20

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database MARINE20

Heaton, et al., 2020, Radiocarbon 62(4);779-820.

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Appendix 4 - Luminescence dating report (E. Andrieux, Durham University Luminescence Laboratory)

Methodology

Sampling and sample preparation

The material used for the dating was subsampled from three core liners and prepared under subdued red-light conditions in the Durham University Luminescence Laboratory (DLL). L4 (DLL2181) was taken from TNW075_2-VC, 2.95m-3.05m, L5 (DLL2182) was taken from TNW005-VC, 4.00m-4.10m, and L6 (DLL2183) was taken from TNW109-VC, 5.20m-5.30m. The core was previously opened and halves were exposed to light. The outer 2mm of light-exposed sediment was therefore removed before sampling. The sediment in contact with the liner was not sampled to avoid barrel smearing effects. This material was later used for environmental dose rate measurements. The sampled sediment was treated with hydrochloric acid (1M HCl) and hydrogen peroxide (H_2O_2) to remove carbonate and organic matter respectively. The samples were wet sieved to isolate the 150-200µm sediment fraction size. Quartz was then extracted from the selected sediment fraction size by using density separations at 2.62 and 2.70 g/cm^3 and a subsequent HF acid etch (23M HF for 60 minutes, followed by a 10M HCl rinse). The samples were then re-sieved to remove acid-soluble fluorides and any grains that had been significantly reduced in size by etching.

Luminescence measurements

Equipment

Luminescence measurements were performed on 9mm aliquots using a Riso reader TL/OSL-DA-20 automated dating system equipped with a 90Sr/90Y beta source for irradiations. The optical stimulation of the samples was carried out using a blue (470nm) light emitting diode (LED) and infra-red (IR) stimulation with an IR (870nm) laser diode. The luminescence emissions were detected through a Hoya U-340 filter (7.5mm) using a photomultiplier tube.

Equivalent dose determination

Equivalent dose (De) determination was carried out using the Single-Aliquot Regenerative-dose (SAR; Murray and Wintle, 2000, 2003; Table S1). A five-point SAR protocol was used to bracket the expected palaeodoses with an additional recycling point to check for uncorrected sensitivity changes. A number of additional regeneration points were also included to monitor the quality of the data generated (1) a zero dose point to measure recuperation and thermal transfer; (2) a repeat measurement of the initial regeneration dose to calculate the recycling ratio, which tests the internal consistency of the growth curve and thus the applicability of the SAR protocol; (3) a second repeat of the initial regeneration dose followed by a room temperature IR bleach and subsequent OSL measurement to calculate the IR depletion ratio, which allows contaminating feldspar grains to be detected (Duller, 2003). Preheat temperatures were determined using dose recovery preheat plateau tests (Murray and Wintle, 2003). Several preheating regimes yielded measured to given dose ratios within two standard errors of unity for all samples, which demonstrates the overall robustness of the SAR method. Of these regimes we adopted a 200°C, 10s for preheat with a second preheat of 160°C, 10s.

A dose recovery test was performed on the samples using a given dose of 10Gy. Recovery doses were within 5% of the given dose demonstrating that the protocol used in this study was adequate and can successfully measure a known irradiation dose prior to any thermal treatment.

The dose response curves were fitted with a saturating exponential function. All the measured discs are dominated by the fast-OSL component, for which the SAR procedure was developed (Galbraith *et al.*, 1999). The D_e values for individual aliquots were calculated by projecting the sensitivity-corrected natural luminescence intensity onto the dose response curve. D_e values were estimated from the initial 0.2 s of OSL decay, and the last 0.3 s of the signal was subtracted as background. The standard error associated with each individual D_e determination was estimated by Monte Carlo simulation. Curve fitting, D_e determination and Monte Carlo simulations were performed using version 4.31.9 of the Luminescence Analyst software (Duller, 2007).

D_e values were only accepted when (1) the natural signal could be distinguished from the background signal (determined using Luminescence Analyst 'sig. >3 sigma above BG' rejection criterion); (2) the recycling ratio was within 10% of unity; (3) the recuperation on zero dose was lower than 5%; (4) the IR-depletion ratio was lower than two standard errors below unity; (5) the error on D_e was less than 30%.

Dose rate determination

The environmental dose rate consists of alpha, beta and gamma components, since the overlying water completely shields the ocean floor sediments from cosmic rays. Uranium, Thorium and Potassium contents in the samples were measured using a Canberra high-resolution gamma spectrometer fitted with a Germanium detector and converted to dose rates using Guérin *et al.* (2011) conversion factors. These values were corrected for i) 150-200 µm grain size attenuation factors from Guérin *et al.* (2012), ii) etch attenuation factors (Bell, 1979) and iii) for water content.

The water content of the sediment was measured after sampling at different intervals within each liner by Fugro. These provide useful comparison points however they are not directly measuring the moisture levels of each of the sampled areas. The water content was therefore modelled considering saturation in water, using particle density, grain size, and the overburden densities of sediments, following Lowick and Preusser (2009). These modelled water contents were then corrected for sediment compaction using a linear compaction model.

Results

The modelling results for the water content yield results of 19.4, 20.4 and 21.7% for samples L4, L5 and L6 respectively, which is very close to the values measured after sampling. An associated error of 5% was also added to take into account past changes.

Twelve 9mm aliquots replicas were measured for each sample, all of them passed the rejection criteria for the samples measured. L4 and L5 displayed less than 8% of data overdispersion (OD) suggesting that the samples are very homogeneous and little to no mixing for these samples is expected (Fig 1, Fig 2). L6 has 15% OD, but this overdispersion is caused by an outlier replica (see Fig 3). Equivalent doses centred around the mean for each sample are presented in figures 1, 2 and 3 in abanico plots.

The dose rates (derived from Uranium, Thorium and Potassium content) and the luminescence sensitivity of these samples are very comparable, which is generally attesting of similar sources of sediment (Sawakuchi *et al.*, 2020).

Given the low overdispersion of the samples, the skewness and kurtosis of the data, the Average Dose Model (Guérin *et al.*, 2017) was deemed the most adequate to calculate the burial doses of each sample and used in subsequent age calculations. Doses and ages are presented in Table 1, both for the modelled and the measured water contents.

Lab code	Vibrocore	Sample depth		Formation (Member)	D_e (Gy)	Modelled Moisture			Measured Moisture		
		from	to			Water content	Dose rate (Gy/ka)	Age (ka)	Water content	Dose rate (Gy/ka)	Age (ka)
L4	TNW075_2-VC	2.95	3.05	Naaldwijk (Zandvoort)	8.79 ± 0.12	19.4 ± 5	0.939 ± 0.048	**9.362 ± 0.499**	19.9 ± 5	0.934 ± 0.048	**9.408 ± 0.501**
L5	TNW005-VC	4.00	4.10	Boxtel (Wierden)	11.47 ± 0.26	20.4 ± 5	0.979 ± 0.05	**11.713 ± 0.65**	16.2 ± 5	1.021 ± 0.053	**11.234 ± 0.635**
L6	TNW109-VC	5.20	5.30	Boxtel (Wierden)	10.79 ± 0.72	21.7 ± 5	0.969 ± 0.048	**11.136 ± 0.927**	20.8 ± 5	0.977 ± 0.049	**11.039 ± 0.92**

Table 1: Equivalent doses (D_e), Dose rates and Ages for the samples L4, L5 and L6 using modelled and measured water contents.

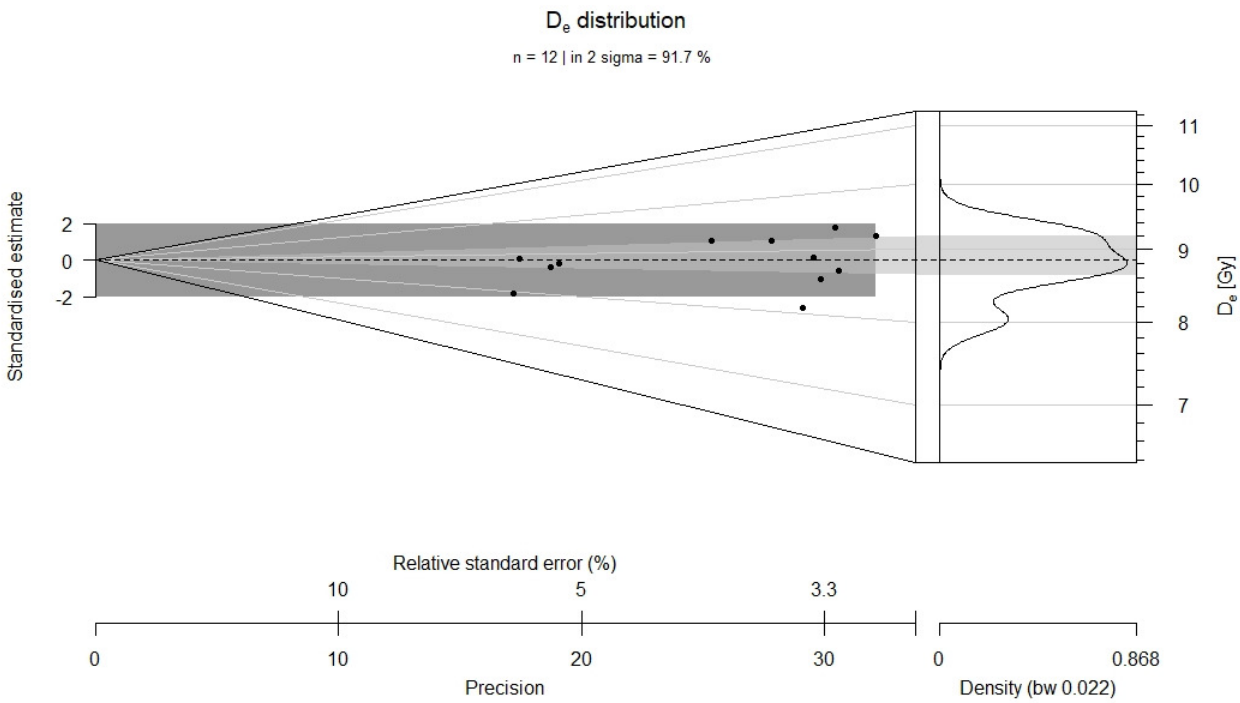

Figure 1: Abanico Plot showing the equivalent doses (D_e) of sample L4

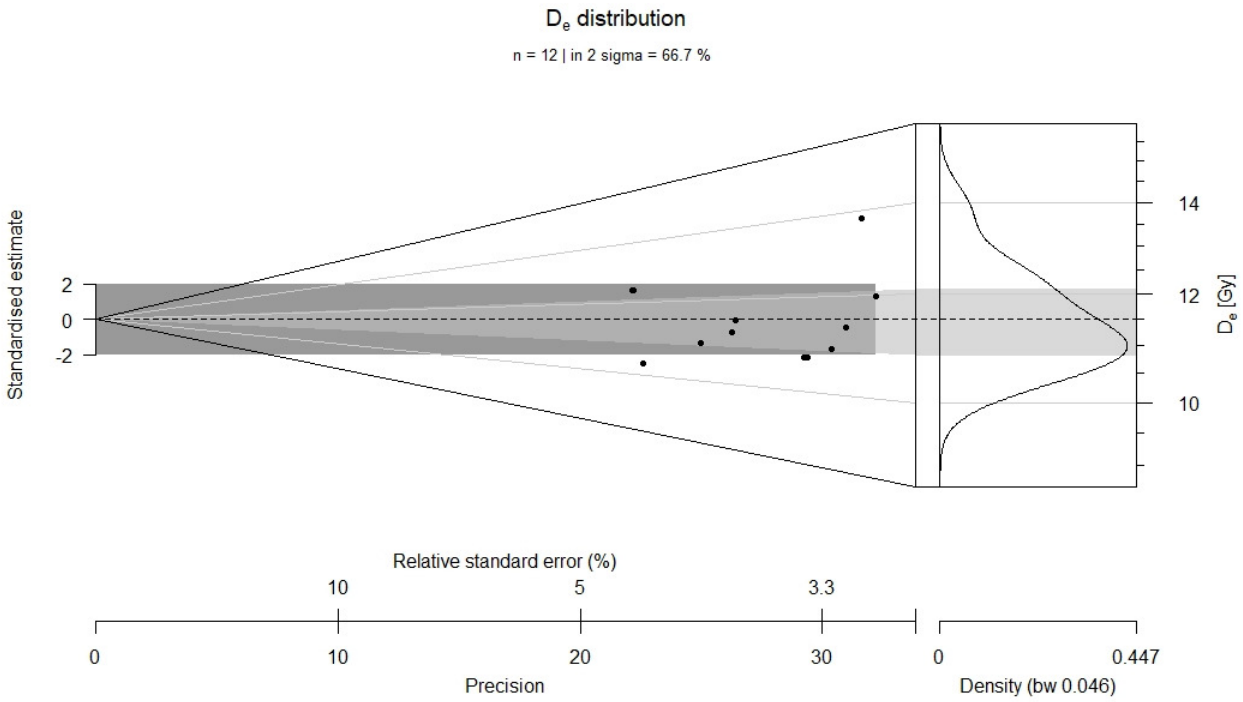

Figure 2: Abanico Plot showing the equivalent doses (D_e) of sample L5

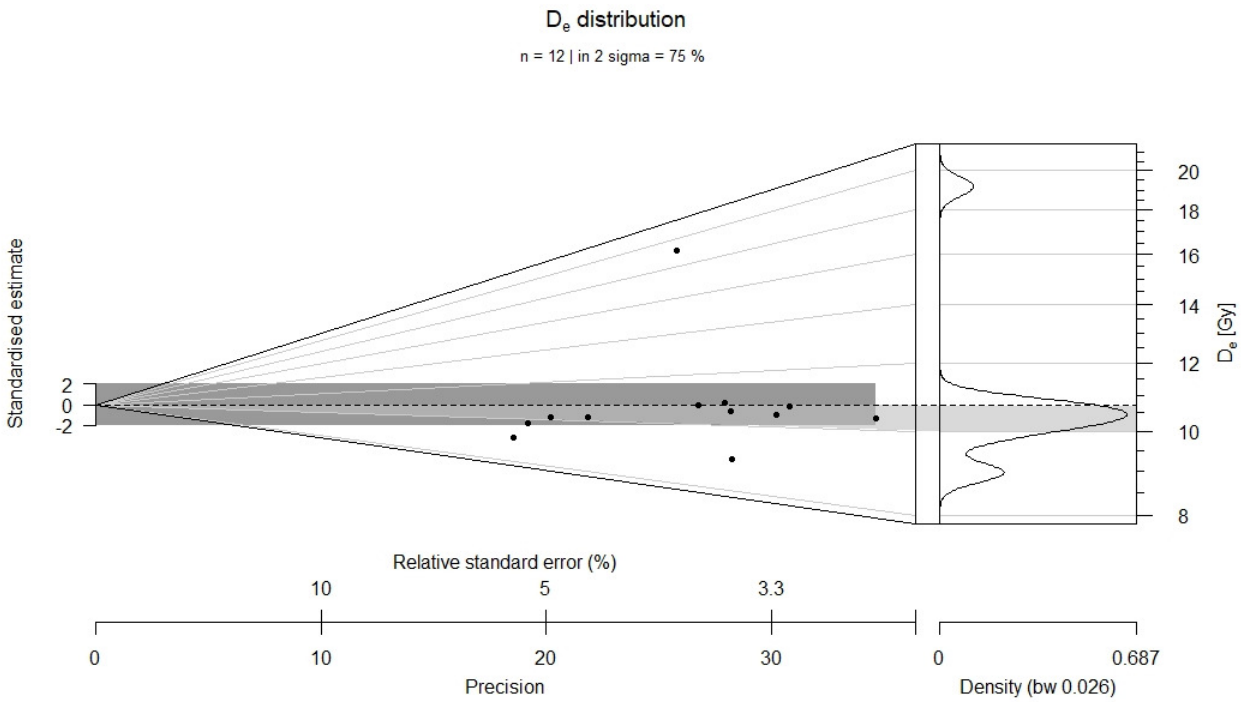

Figure 3: Abanico Plot showing the equivalent doses (D_e) of sample L6

References

Bell, W.T., 1979. Attenuation factors for the absorbed radiation dose in quartz inclusions for thermoluminescence dating. Anc. TL 8, 1-12.

Duller, G.A.T., 2003. Distinguishing quartz and feldspar in single grain luminescence measurements. Radiat. Meas. 37, 161-165.

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Murray, A.S., Wintle, A.G., 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. Radiat. Meas. 37, 377-381.

Sawakuchi, André O., Fernanda C.G. Rodrigues, Thays D. Mineli, Vinícius R. Mendes, Dayane B. Melo, Cristiano M. Chiessi, and Paulo C.F. Giannini 2020. "Optically Stimulated Luminescence Sensitivity of Quartz for Provenance Analysis" Methods and Protocols 3, no. 1: 6.

Appendix 5 - Diatom report

Biochron Sediment Core analysis - Diatoms

APEM ref: P6308
October 2021

Dr Annemarie Clarke, Nick Kneebone

Client:	**BioChron Ltd**
Address:	**17 The Bothy** **Ottershaw Park** **Chobham Road** **Ottershaw** **Surrey** **KT16 0QG**
Project reference:	**P6308**
Date of issue:	**October 2021**

Project Director:	**David Hall**
Project Manager:	**Nick Kneebone**

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Contents

1 Introduction

APEM was contracted to undertake the sample preparation, analysis and subsequent reporting of 47 sediment core samples from vibrocores off the coast of The Netherlands. It was considered likely that the samples would represent both freshwater and marine palaeoenvironments. This report presents the results of the diatom identification from all viable samples, and an interpretation of the changes in key diatom taxa over time. The possible environmental conditions likely to have influenced the assemblages are discussed.

2 Methods

2.1 Sample preparation

The sediment samples were cleaned using the hot peroxide (H_2O_2) method. Approximately 0.1g of core material was transferred to a beaker where ca. 20 ml of 30% H_2O_2 was added. Samples were then heated at 90 (± 5) °C until all organic material was oxidised. The samples were then cooled in a fume cupboard and a few drops of 1 M hydrochloric acid (HCL) added to remove any remaining H_2O_2 and any carbonates present. Beaker sides were washed down with distilled water, and the contents transferred to sterilin tubes for the washing process. Samples were washed manually to minimise damage to the diatom valves, being left undisturbed to settle out for a period of 24 hrs (minimum) between each wash. Disposable pipettes (one per sample) were used to remove the supernatant to approximately 5 mm above the sample surface. Distilled water was then added vigorously as a wash. The samples were washed four times in total. Clay was removed during the last wash by adding a few drops of 1% ammonia solution to the sample with any fine sediment remaining in suspension then being decanted off with the supernatant.

The cleaned material was stored in labelled sterilin tubes prior to slide preparation. Diatom slides were prepared using thickness 0 coverslips of 19 mm diameter, mounted with Naphrax on unwashed microscope slides. Each sample was manipulated with its own disposable Pasteur pipette. Cleaned samples were homogenized by shaking, and an aliquot removed and diluted to an acceptable concentration where fine particles were just visible in suspension. Two coverslips per sample were flooded with this homogenized suspension and evaporated at room temperature in a specially set aside area. Any suspensions severely clumped after evaporation were washed again and re-settled. Prior to permanent mounting the density of diatom valves was checked by examining a coverslip (placed face down on a slide, using a new slide for each coverslip) at 400 × magnification for densities in the region of 30 valves per field of view. Suspension concentration was adjusted as necessary to obtain this density (or as close to as possible given the constraints of sample quality) which equates to ca. 15 valves per field of view at 1000 × magnification. Coverslips with suitable valve densities were mounted with Naphrax, using a hotplate in a fume cupboard as the heat source. Two slides per sample were prepared and labelled.

2.2 Sample analysis

Slides were enumerated on a high power light microscope using a 1000 × oil immersion lens and phase contrast illumination. A minimum of 300 diatom valves were enumerated per sample. A consistent approach to broken or corroded valves was adopted to avoid over-counting. Where more than half a valve of a pennate diatom was found, it was counted as one

valve; central fragments of centric diatoms were counted as one valve. Valves were identified to the lowest taxonomic level possible, and relative abundances of all taxa present were recorded. Samples were enumerated by tallying all diatoms visible within a field of view before moving along a vertical traverse to the next field of view. Where taxa were only partially visible at the left margin, they were not included in the count. Where more than one traverse was required, they were separated by two fields of view to ensure that no diatom was counted twice. Taxa lists and abundance records for each sample were transferred from paper records to Excel.

Any occurrences of *Chaetoceros* sp. resting spores (not separated to species level) and *Rhizosolenia* spines (these are rarely preserved in sediment samples, so are excluded to prevent taphonomic processes from unduly influencing assemblage composition) were recorded but not included in the tally. Additional records were made for Chrysophyte cysts and phytoliths. Identification principally followed Witkowski *et al*. (2000), Snoeijs (1993), Snoeijs & Vilbaste (1994), Snoeijs & Potapova (1995), Snoeijs & Kasperovičienė (1996), Snoeijs & Balashova (1998), Krammer & Lange-Bertalot (1986-1991), Harris *et al.* (1995) and Muylaert & Sabbe (1996).

2.3 Data assessment

The raw data was transformed to percentages, and to facilitate interpretation of the diatom assemblages, each taxon was assigned two ecological codes. These were for lifeform (see Table 1) and salinity classification (see Table 2) as included in Denys (1992).

Table 1: Lifeform classification according to Denys (1992)

Numerical code	Lifeform
0	Unknown
2	Euplanktonic
3	Tychoplanktonic - epontic origin
4	Tychoplanktonic - benthic origin
5	Tychoplanktonic - both epontic and benthic origin
6	Epontic
7	Epontic & benthic
8	Benthic

Denys (1992) classified tychoplanktonic diatoms as being frequently found in the plankton, although they are derived from other attached habitats. These taxa are considered able to metabolise and reproduce in the plankton as well as in their original habitat. Epontic lifeform refers to firmly attached (e.g. epipsammic) taxa, while benthic is used to refer to those more motile, yet attached taxa such as epiphytic, interstitial and epipelic forms.
Several salinity classifications are given by Denys (1992), selection of the Van der Werff classification was based on the large number of categories, and the ease with which they could be combined.

Table 2: Salinity classification according to the system of Van der Werff (Van der Werff, 1958; Van der Werff & Huls, 1957-1974)

Numerical code	Salinity range	Alphabetical code
0	Unknown	
2	Marine	M
3	Marine to marine-brackish	M-MB
4	Marine-brackish	MB
5	Marine-brackish to brackish-marine	MB-BM
6	Brackish-marine	BM
7	Brackish-marine to brackish	BM-B
8	Brackish	B
9	Brackish to brackish-fresh	B-BF
10	Brackish-fresh	BF
11	Brackish-fresh to fresh-brackish	BF-FB
12	Fresh-brackish	FB
13	Fresh-brackish to fresh	FB-F
14	Fresh	F

To aid interpretation of general trends observed in the cores the lifeform classification was then simplified into three categories of:

- Planktonic (code 2 only),
- Tychoplanktonic (codes 3 - 5 inclusive), and
- Benthic (codes 6 - 8 inclusive).

The salinity classification was similarly simplified into three categories:

- Marine (codes 2 - 5 inclusive),
- Brackish (codes 6 - 11 inclusive), and
- Fresh (codes 12-14 inclusive).

In both cases, taxa whose ecological preferences were unknown were excluded from the simplified classification.

3 Results

Of the 47 sediment samples sent to APEM, only 26 had diatom frustules preserved. These were found in cores: TNW005-VC, TNW042-VC, TNW047_2, TNW069-VC, TNW078_1-VC and TNW109-VC. Results for these sediment cores are presented individually below. A separate Excel file contains the raw data, percentages, lifeform and salinity classifications and assemblage characterisation based on lifeform and salinity.

3.1 TNW005-VC

A single sample (1.62 - 1.67 m) from this core had preserved diatom frustules. A total of 66 taxa were identified, and 106 Chrysophyte cysts were recorded. The most abundant taxa in

the assemblage were *Thalassiosira decipiens* (9.6%), *Thalassiosira eccentrica* (6.7%) and *Aulacoseira italica* (6.7%). All three are tychoplanktonic, but while the *Thalassiosira* taxa are indicative of a marine-brackish environment, *Aulacoseira italica* is a fresh-brackish species.

Table 3: Simplified lifeform characterisation for 1.62 - 1.67 m sample from TNW005-VC

Lifeform group	**%**
Planktonic	6.1
Tychoplanktonic	40.7
Benthic	47.5

Table 4: Simplified salinity characterisation for 1.62 - 1.67 m sample from TNW005-VC

Salinity bracket	**%**
Marine	26.0
Brackish	20.7
Fresh	51.2

While the most abundant individual taxa in the core are tychoplanktonic, Table 3 shows that benthic taxa actually dominate the whole assemblage accounting for 47.5%, with tychoplanktonic taxa accounting for 40.7%. Planktonic taxa are poorly represented in the assemblage at just 6.1%. Similarly, Table 4 illustrates that freshwater taxa account for just over half of the assemblage, despite the two most abundant individual taxa being marine (in the simplified characterisation). Overall, the assemblage indicates a shallow, estuarine environment.

3.2 TNW042-VC

Five samples from this core had preserved diatom frustules. A total of 182 taxa were identified between them, with individual samples having between 59 and 89 taxa. Chrysophyte cysts were found with increasing abundance downcore, and phytoliths were found only in the deepest sample analysed (1.95 - 2.00 m).

Table 5: The most abundant diatom taxa in TNW042-VC samples

Core depth (m)	**Diatom taxa and percentage abundance**		
1.45 - 1.50	*Aulacoseira ambigua* 17.9%	*Pseudostaurosira brevistriata* 7.2%	*Staurosira construens* 4.7%
1.60 - 1.65	*Aulacoseira ambigua*	*Aulacoseira granulata*	*Aulacoseira sp.*

	9.2%	7.0%	5.7%
1.80 - 1.85	*Aulacoseira italica* 28.0%	*Epithemia adnata* 8.6%	*Aulacoseira sp.* 4.8%
1.85 - 1.90	*Aulacoseira italica* 25.9%	*Epithemia adnata* 13.3%	*Navicula veneta* 5.8%
1.95 - 2.00	*Aulacoseira italica* 14.1%	*Aulacoseira sp.* 11.5%	*Amphora copulata* 5.8%

Aulacoseira ambigua and *A. granulata* are planktonic, while *A. italica* is tychoplanktonic, as is *Staurosira construens*. *Epithemia adnata* is epontic, *Pseudostaurosira brevistriata* and *Amphora copulata* are epontic & benthic, while *Navicula veneta* is benthic. The changes noted above, suggest that an increase in planktonic production occurred at this location in the upper samples. All the above taxa are considered fresh-brackish species (freshwater in the simplified classification) apart from *N. veneta* which is brackish-fresh (brackish in the simplified classification).

Table 6: Simplified diatom lifeform classification for TNW042-VC samples

	Sample depth (m)				
Lifeform (%)	**1.45 - 1.50**	**1.60 - 1.65**	**1.80 - 1.85**	**1.85 - 1.90**	**1.95 - 2.00**
Planktonic	22.3	22.5	9.2	3.2	4.5
Tychoplanktonic	15.0	20.6	33.8	29.4	19.9
Benthic	59.2	50.0	46.8	59.9	62.2

Table 6 indicates that while all samples were dominated by benthic diatoms (composed of numerous taxa at low abundances) the samples at 1.45 - 1.50 m and 1.60 - 1.65 m had a higher proportion of planktonic taxa (principally driven by the increase in *A. ambigua*) when compared to the lower samples. Samples 1.80 - 1.85 m and 1.85 to 1.90 m show an increase in tychoplanktonic taxa compared to the other sample depths, while the deepest sample (1.95 - 2.00 m) had a greater contribution from benthic taxa.

Table 7: Simplified diatom salinity classification for TNW042-VC samples

	Sample depth (m)				
Salinity (%)	**1.45 - 1.50**	**1.60 - 1.65**	**1.80 - 1.85**	**1.85 - 1.90**	**1.95 - 2.00**
Marine	2.8	2.8	0.0	0.0	0.6
Brackish	13.8	22.2	11.1	11.0	10.9
Fresh	81.5	73.7	83.4	86.7	87.2

Table 7 shows that all sample depths were dominated by freshwater taxa, with brackish taxa making a minor contribution and marine taxa poorly represented, particularly in the three deepest samples. All assemblages suggest a predominantly freshwater, relatively shallow environment, with a minor increase in brackish and marine influence towards the higher samples. An increase in planktonic taxa was noted towards the higher samples, predominantly driven by an increase in *A. ambigua*.

3.3 TNW047_2-VC

Five samples from this core had preserved diatom frustules. A total of 136 taxa were identified between them, with individual samples having between 43 and 63 taxa. Chrysophyte cysts were rare, and a single *Chaetoceros* spp. resting spore was recorded (2.85 - 2.90 m).

As Table 8 (below) indicates, assemblage structure in terms of the dominant taxa is relatively consistent throughout the core. *Cymatosira belgica* is a marine, tychoplanktonic diatom, widespread on Atlantic coasts today, and also found in the Western Baltic Sea. It is heavily silicified, and robustly shaped, and often preserves well. *Delphineis minutissima* is another widespread coastal taxon, common in the littoral zone, marine-brackish in salinity tolerances and considered epontic. *Planothidium delicatulum* is a widespread epontic diatom, frequently found on sandy, littoral sediments, and classified as brackish. *Navicula perminuta* is considered a cosmopolitan species, brackish-marine to brackish in salinity tolerance and epontic and benthic in lifeform. *Navicula salinicola* is a marine-brackish cosmopolitan benthic taxon. The increase in abundance of *Planothidium delicatulum* in the upper two samples could indicate slightly more brackish/estuarine conditions during the period represented by these samples.

Table 8: The most abundant diatom taxa in TNW047_2-VC samples

Core depth (m)	**Diatom taxa and percentage abundance**		
1.65 - 1.70	*Cymatosira belgica* 16.8%	*Delphineis minutissima* 12.1%	*Planothidium delicatulum* 9.8%
2.00 - 2.05	*Cymatosira belgica* 24.1%	*Delphineis minutissima* 16.9%	*Planothidium delicatulum* 15%
2.50 - 2.55	*Cymatosira belgica* 23.3%	*Delphineis minutissima* 23.0%	*Navicula perminuta* 9.6%
2.85 - 2.90	*Cymatosira belgica* 38.2%	*Delphineis minutissima* 18.2%	*Navicula perminuta* 5.7%
3.40 - 3.45	*Cymatosira belgica* 50.3%	*Delphineis minutissima* 12.6%	*Navicula salinicola* 3.9%

Table 9: Simplified diatom lifeform classification for TNW047_2-VC samples

	Sample depth (m)				
Lifeform (%)	**1.65 - 1.70**	**2.00 - 2.05**	**2.50 - 2.55**	**2.85 - 2.90**	**3.40 - 3.45**
Planktonic	1.3	1.6	3.2	4.1	4.2
Tychoplanktonic	32.4	29.1	32.2	49	61.9
Benthic	63.5	67.8	62.9	45.9	32.9

Table 9 (above) shows that all assemblages were dominated by either tychoplanktonic or benthic diatoms. Planktonic diatoms are not common, particularly in samples 1.65 - 1.70 m and 2.00 - 2.05 m. Tychoplanktonic diatoms dominate the deeper samples of 2.85 - 2.90 m and 3.40 - 3.45 m. An increase in benthic taxa can be seen from the lower samples to the higher samples. Assemblage structure indicates a turbulent, marine coastal environment.

Table 10 (below) indicates that while all samples are dominated by marine taxa, their proportion decreases towards the top of the core, whilst both brackish and freshwater taxa increase. This supports the inference from the diatom assemblage data that the environment at this location became more influenced by estuarine conditions over time.

Table 10: Simplified diatom salinity classification for TNW047_2-VC samples.

	Sample depth (m)				
Salinity (%)	**1.65 - 1.70**	**2.00 - 2.05**	**2.50 - 2.55**	**2.85 - 2.90**	**3.40 - 3.45**
Marine	38.1	44.4	62.0	74.5	79.0
Brackish	32.1	36.3	28.4	16.2	16.1
Fresh	28.3	19.1	8.6	8.6	4.2

3.4 TNW069-VC

Diatom frustules were found in five samples from this core. A total of 133 taxa were identified between them, with individual samples having between 58 and 70 taxa. Chrysophyte cysts were rare, three *Rhizosolenia* spines were recorded in the sample at 2.00 - 2.05 m, and similarly few *Chaetoceros* spp. resting spores were recorded in the bottom two samples (3.20 - 3.25m and 3.80 - 3.85m).

Table 11: The most abundant diatom taxa in TNW069-VC samples

Core depth (m)	**Diatom taxa and percentage abundance**		
1.50 - 1.55	*Cymatosira belgica* 41.2%	*Delphineis minutissima* 18.9%	*Navicula perminuta* 6.6%
2.00 - 2.05	*Cymatosira belgica* 22.1%	*Delphineis minutissima* 14.4%	*Navicula perminuta* 7.4%
2.50 - 2.55	*Cymatosira belgica* 26.3%	*Delphineis minutissima* 20.3%	*Navicula perminuta* 8.4%
3.20 - 3.25	*Cymatosira belgica* 38.7%	*Delphineis minutissima* 20.4%	*Thalassiosira decipiens* 3.5%
3.80 - 3.85	*Delphineis minutissima* 20.4%	*Cymatosira belgica* 38.7%	*Thalassiosira proschkinae* 5.3%

As with core TNW047_2-VC, Table 11 indicates that the diatom assemblages present were dominated by the marine, tychoplanktonic *Cymatosira belgica* and the marine-brackish, epontic *Delphineis minutissima*. *Navicula perminuta* (brackish-marine to brackish; epontic and benthic) was also relatively common in the upper three samples, while *Thalassiosira decipiens* (marine-brackish, tychoplanktonic) and *Thalassiosira proschkinae* (marine-brackish, brackish-marine, tychoplanktonic) were abundant in the lower two samples respectively. This could indicate a slight decrease in marine conditions, or possibly a shallowing of the environment in the upper three samples, as an increase in a benthic form could indicate a greater prevalence of shallow habitat.

Table 12: Simplified diatom lifeform classification for TNW069-VC samples

	Sample depth (m)				
Lifeform (%)	**1.50 - 1.55**	**2.00 - 2.05**	**2.50 - 2.55**	**3.20 - 3.25**	**3.80 - 3.85**
Planktonic	2.5	5.4	3.1	3.5	6.5
Tychoplanktonic	54.1	39.4	44.1	51.8	41.7
Benthic	42.8	52.9	50.3	43.1	49.8

In common, again, with core TNW047_2-VC, planktonic taxa made only a minor contribution to the assemblages present in this core (Table 12). Instead, tychoplanktonic and

benthic taxa dominate, with benthic taxa more common at sample depths 2.00 - 2.05, 2.50 - 2.55 and 3.80 - 3.85 m, and tychoplankton dominant in the 1.50 - 1.55 and 3.20 - 3.25 m samples. Overall, however, the contribution made by these two lifeform groups is relatively similar throughout the core.

Table 13: Simplified diatom salinity classification for TNW069-VC samples.

	Sample depth (m)				
Salinity (%)	**1.50 - 1.55**	**2.00 - 2.05**	**2.50 - 2.55**	**3.20 - 3.25**	**3.80 - 3.85**
Marine	72.3	57.4	65.0	77.6	71.7
Brackish	19.5	32.4	25.6	14.7	21.5
Fresh	7.5	9.0	8.4	6.1	5.3

As shown in Table 13, marine taxa dominated all samples, with brackish taxa comprising the next most common group, while freshwater taxa consistently contributed between 5 and 10%. Brackish taxa showed an increase at sample depths 2.00 - 2.05, 2.50 - 2.55 and 3.80 - 3.85 m (the same depths were benthic taxa became more prevalent), while marine taxa had a higher proportion in samples 1.50 - 1.55 and 3.20 - 3.25 m, where tychoplanktonic taxa were more common. It is possible that at the depths where benthic, brackish taxa increased in overall abundance, available habitat for these taxa had increased, possibly suggesting a shallowing of the environment, or indicating an increased estuarine environment.

3.5 TNW078_1-VC

Diatom frustules were found in four samples from this core, however the shallowest sample (0.60 - 0.65 m) was too sparse to provide a full count, with only 63 valves found over three transects. Data from this sample is presented in the Excel sheet, but not included in this report, apart from in basic terms for considering potential similarity of this sample. A total of 71 taxa were found between the three samples, with individual samples having between 32 and 45 taxa. Chrysophyte cysts were not found, and very few *Chaetoceros* sp. resting spores or *Rhizosolenia* spines were recorded.

Table 14: The most abundant diatom taxa in TNW078_1-VC samples

Core depth (m)	**Diatom taxa and percentage abundance**		
1.10 - 1.15	*Cymatosira belgica* 33.9%	*Delphineis minutissima* 21.7%	*Paralia sulcata* 7.0%
1.90 - 1.95	*Cymatosira belgica* 71.9%	*Rhaphoneis amphiceros* 5.1%	*Catenula adhaerens* 4.5%
2.60 - 2.65	*Cymatosira belgica* 44.1%	*Delphineis minutissima* 23.2%	*Rhaphoneis amphiceros* 7.0%

Table 14 shows that all samples were dominated by the marine, tychoplanktonic *Cymatosira belgica*, the marine-brackish epontics *Delphineis minutissima* and *Rhaphoneis amphiceros*. The marine to marine-brackish tychoplankton *Paralia sulcata* was abundant in the sample from 1.10 - 1.15 m, while the brackish-marine epontic *Catenula adhaerens* was notable in the sample from 1.90 - 1.95 m. These taxa would indicate a marine coastal environment.

Table 15: Simplified diatom lifeform classification for TNW078_1-VC samples

	Sample depth (m)		
Lifeform (%)	**1.10 - 1.15**	**1.90 - 1.95**	**2.60 - 2.65**
Planktonic	1.0	0.0	1.3
Tychoplanktonic	47.6	75.1	50.8
Benthic	50.5	24.6	47.6

In common with the other marine sediment cores, Table 15 indicates that the planktonic contribution to all the assemblages from this core is minor. The assemblages are dominated approximately 50:50 by tychoplanktonic and benthic taxa, apart from sample depth 2.00 - 2.05 m, where the tychoplanktonic proportion is ca. 75%, driven by the high occurrence of *Cymatosira belgica* and near disappearance of *Delphineis minutissima* (epontic) in this particular sample. The sparse sample (0.60-0.65 m) was dominated by benthic diatoms, followed by tychoplanktonic, with freshwater diatoms forming only a minor component. This is driven by *Rhaphoneis amphiceros* being the dominant taxon in the sample.

Table 16: Simplified diatom salinity classification for TNW078_1-VC samples.

	Sample depth (m)		
Salinity (%)	**1.10 - 1.15**	**1.90 - 1.95**	**2.60 - 2.65**
Marine	83.7	89.8	87.9
Brackish	10.9	7.3	5.7
Fresh	4.8	2.2	5.7

As shown in Table 16, all samples are dominated by marine taxa, then brackish taxa, with freshwater taxa comprising only a minor contribution. There is an indication of a slight increase in brackish taxa towards the upper samples. A similar pattern was observed in the sparse sample, with the increase in brackish taxa further pronounced, due to the occurrence of *Planothidium delicatulum* in relatively high numbers. The assemblages suggest a consistently marine environment, with only a minor estuarine influence.

3.6 TNW109-VC

Diatom frustules were found in six samples from this core. A total of 178 taxa were identified between them, with individual samples having between 34 and 82 taxa. Chrysophyte cysts were present in the bottom two samples, while *Chaetoceros* spp. resting spores were found sporadically in low numbers, and a single *Rhizosolenia* spine was recorded in a single sample. Samples 2.95 - 3.00 m, 3.45 - 3.50 m and 3.95 - 4.00 m were well preserved, while that at 4.67 - 4.72 m had many fragmented valves.

As shown in Table 17 (below) a change in dominant taxa occurs in this core, with the upper four samples dominated by the marine tychoplankton *Cymatosira belgica*, marine-brackish epontics *Delphineis minutissima* and *Navicula perminuta*, the marine to marine-brackish tychoplankton *Paralia sulcata* and the marine tychoplankton *Minidiscus* spp. In contrast, the lower two samples are dominated by the planktonic brackish-fresh to fresh-brackish *Cyclotella atomus*, the brackish-fresh tychoplankton *Cyclotella meneghiniana*, the planktonic freshwater taxon *Stephanodiscus hantzschii* and the fresh-brackish tychoplanktonic *Aulacoseira italica*. The differences in these dominant taxa indicate a change in diatom assemblage, from a freshwater environment in the two lower samples to a marine environment in the upper four samples.

Table 17: The most abundant diatom taxa in TNW109-VC samples

Core depth (m)	**Diatom taxa and percentage abundance**		
2.42 - 2.47	*Cymatosira belgica* 41.9%	*Delphineis minutissima* 19.4%	*Paralia sulcata* 7.6%
2.95 - 3.00	*Cymatosira belgica* 35.7%	*Navicula perminuta* 20.8%	*Delphineis minutissima* 19.9%
3.45 - 3.50	*Cymatosira belgica* 33.9%	*Delphineis minutissima* 28.8%	*Navicula perminuta* 8.9%
3.95 - 4.00	*Cymatosira belgica* 50.2%	*Delphineis minutissima* 16.4%	*Minidiscus* spp. 3.5%
4.67 - 4.72	*Cyclotella atomus* 12.5%	*Cyclotella meneghiniana* 9.6%	*Stephanodiscus hantzschii* 7.7%
5.35 - 5.40	*Stephanodiscus hantzschii* 13.7%	*Cyclotella meneghiniana* 10.2%	*Aulacoseira italica* *10.3%*

Table 18: Simplified diatom lifeform classification for TNW109-VC samples

	Sample depth (m)

Lifeform (%)	2.42 - 2.47	2.95 - 3.00	3.45 - 3.50	3.95 - 4.00	4.67 - 4.72	5.35 - 5.40
Planktonic	1.0	0.9	2.5	0.9	25.0	25.9
Tychoplanktonic	58.1	46.6	40.8	65.9	20.5	24.9
Benthic	40.0	50.3	55.1	31.5	46.8	39.3

As shown in Table 18 (above), planktonic taxa contribute only a small component of the overall assemblage in each of the upper four samples. In the lower two, however, they account for ca. 25% of the assemblage: the highest contribution recorded in all samples analysed. Tychoplanktonic taxa are more prevalent in the upper four samples, while benthic taxa remain relatively constant over the whole core. The change from planktonic to tychoplanktonic occurs at the same depth that the change in dominant taxa occurs, possibly indicating a change from a freshwater to marine environment.

Table 19 (below) illustrates the substantial change in salinity tolerance for the dominant taxa, with marine taxa accounting for between ca. 70% and 87% of the upper four assemblages, but only ca. 2% of the lower two samples. In contrast, freshwater taxa account for only ca. 1.5% to 5% of the upper four samples, and between ca. 64% and 74% of the bottom two samples. Brackish taxa show variation throughout the core, with their two lowest abundance samples (2.42 - 2.47 m and 3.95 - 4.00 m) coinciding with increases in marine taxa. The changes observed in the assemblages suggest a change through time from a predominantly freshwater environment to a coastal marine one.

Table 19: Simplified diatom lifeform classification for TNW109-VC samples

	Sample depth (m)					
Salinity (%)	**2.42 - 2.47**	**2.95 - 3.00**	**3.45 - 3.50**	**3.95 - 4.00**	**4.67 - 4.72**	**5.35 - 5.40**
Marine	86.7	70.5	75.9	84.5	1.9	1.9
Brackish	7.6	25.5	18.0	12.6	29.2	20.8
Fresh	4.8	2.5	4.4	1.6	64.1	73.8

3.7 Summary

A summary of each sample is provided in Table 20. The diatom assemblages present in the cores are indicative of marine, brackish and freshwater environments. Overall, planktonic taxa are not well represented and this may, in many samples, be a reflection of taphonomic processes. Many common and abundant marine planktonic taxa such as *Chaetoceros* spp., *Rhizosolenia* spp., *Skeletonema* spp. and some *Thalassiosira* spp. are very lightly silicified and do not preserve well in sediments, particularly in either energetic environments or well-oxygenated sediments. Accordingly, care should be taken not to assume that the assemblages recorded are considered as true reflections of the whole diatom community present.

Core TNW005-VC is the only core considered possibly indicative of a shallow estuarine environment or brackish water lagoon, although this is based on a single sample depth and so should be considered with caution.

Core TNW042-VC contains assemblages indicative of a shallow, freshwater environment. Marine and brackish water taxa show a slight increase in abundance in the upper samples, possibly indicating a marginally greater marine influence. The increase in planktonic taxa in these samples was, however, driven by the freshwater *Aulacoseira ambigua* suggesting that freshwater conditions dominated.
Cores TNW047_2-VC, TNW069-VC and TNW078_1-VC were all similar in terms of containing diatom assemblages indicative of coastal marine environments. The dominant taxa are all common littoral taxa of the present Western Baltic, North Sea and Atlantic coasts.

Core TNW109-VC was the only core where the diatom assemblages indicated a clear change of environment. The two lower samples (4.67 - 4.72 m and 5.35 - 5.40 m) were indicative of a shallow freshwater environment, with a relatively high planktonic component, while the four higher samples indicated a coastal marine environment, similar to that recorded in the three cores discussed above, with a high tychoplanktonic and benthic component.

Table 20: Summary of vibrocores

Core	Sample depth (m)	Environmental interpretation	Comments
TNW005-VC	1.62 - 1.67	Shallow, estuarine or brackish water environment	Many fragmented valves and some dissolution. Above Boxtel formation
TNW042-VC	1.45 - 1.50	Shallow freshwater environment, increasing planktonic representation, some marine/brackish influence	
TNW042-VC	1.60 - 1.65	Shallow freshwater environment, increasing planktonic representation, some marine/brackish influence	
TNW042-VC	1.80 - 1.85	Shallow freshwater environment, minor brackish influence, greater benthic and tychoplanktonic representation	Many fragmented valves and some dissolution
TNW042-VC	1.85 - 1.90	Shallow freshwater environment, minor brackish influence, greater benthic representation, reduced tychoplanktonic & planktonic contribution	
TNW042-VC	1.95 - 2.00	Shallow freshwater environment, minor marine/brackish influence, greater benthic representation, further reduced tychoplanktonic & planktonic contribution	Many fragmented valves, many initial valves of *Aulacoseira* spp.

Core	Sample depth (m)	Environmental interpretation	Comments
TNW047_2-VC	1.65 - 1.70	Coastal marine environment, greater freshwater component than deeper samples	Well preserved valves
TNW047_2-VC	2.00 - 2.05	Coastal marine environment, greater freshwater component than deeper samples	
TNW047_2-VC	2.50 - 2.55	Coastal marine environment	
TNW047_2-VC	2.85 - 2.90	Coastal marine environment	
TNW047_2-VC	3.40 - 3.45	Coastal marine environment	Within Boxtel formation
TNW069-VC	1.50 - 1.55	Coastal marine environment, increase in marine tychoplanktonic taxa	
TNW069-VC	2.00 - 2.05	Coastal marine environment, increase in benthic, brackish taxa - possible increase in benthic habitat	
TNW069-VC	2.50 - 2.55	Coastal marine environment, increase in benthic, brackish taxa - possible increase in benthic habitat	
TNW069-VC	3.20 - 3.25	Coastal marine environment, increase in marine tychoplanktonic taxa	Many fragmented valves
TNW069-VC	3.80 - 3.85	Coastal marine environment, increase in benthic, brackish taxa - possible increase in benthic habitat	

Core	Sample depth (m)	Environmental interpretation	Comments
TNW078_1-VC	0.60 - 0.65	Coastal marine environment, possible minor increase in brackish taxa	Slide too sparse to count, assessment on 63 valves. Many broken fragments and some dissolution
TNW078_1-VC	1.10 - 1.15	Coastal marine environment, slight increase in brackish taxa	
TNW078_1-VC	1.90 - 1.95	Coastal marine environment	
TNW078_1-VC	2.60 - 2.65	Coastal marine environment	
TNW109-VC	2.42 - 2.47	Coastal marine environment, high tychoplanktonic and benthic component	Sparse slide, some dissolution
TNW109-VC	2.95 - 3.00	Coastal marine environment, high tychoplanktonic and benthic component	Well preserved, within Boxtel formation
TNW109-VC	3.45 - 3.50	Coastal marine environment, high tychoplanktonic and benthic component	Very well preserved, within Boxtel formation
TNW109-VC	3.95 - 4.00	Coastal marine environment, high tychoplanktonic and benthic component	Good preservation, within Boxtel formation
TNW109-VC	4.67 - 4.72	Shallow, freshwater environment, minor brackish influence, high planktonic component	Many broken fragments, within Boxtel formation
TNW109-VC	5.35 - 5.40	Shallow, freshwater environment, minor brackish influence, high planktonic component	Boxtel formation

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Appendix 6 - Macroplant report (Jackaline Robertson, AOC)

TNW: Environmental Analysis

AOC project no 25956

August 2021

AOC Archaeology Group

ARCHAEOLOGY | HERITAGE | CONSERVATION

TNW:
Environmental Analysis

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Date of report	Revision/Amendment	Author	Approved	Date
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Factual Data

Five sediment samples collected from a series of vibrocores were submitted for environmental analysis. The vibrocores were extracted from North Sea sediments off the coast of the Netherlands. At time of writing this report no further site information was available. The main objective of this report was to identify any surviving macroplant remains towards understanding the development of the surrounding landscape at time of deposition.

Methodology

The sediment samples were gently disaggregated by hand in the laboratory by a process designed to retrieve fragile ecofactual finds (cf. Kenward *et al.*, 1980). The samples were processed in their entirety and the wash-overs were fed through a stack system of 4.0mm, 2.0mm 1.0mm and 300 µm sieves. The

waterlogged samples have been retained in sample tubes in distilled water and are currently in cold storage (below 5°C).

All plant macrofossils were examined at magnifications of x10 and up to x450 where necessary to aid identification. Plant identifications were confirmed using modern reference material and seed atlases (Cappers *et al* 2006; Cappers and Neef 2012; Cappers and Bekker 2013; Schulz 2018; Tomlinson 1985). Nomenclature for plants follows Stace (2010).

Wood fragments larger than 4mm were selected for species identification. Species identifications were confirmed by analysing the transverse, tangential and radial sections at x70-x450 magnification and using keys and texts (Schweingruber 1990; Hather 2000).

Results

The results are presented in Table 1 *The macroplant and wood assemblage*.

The plant assemblage

Preservation of the macroplant assemblage was facilitated through waterlogged, anaerobic conditions. The macroplant assemblage was small in both number and species diversity. Preservation of the remains ranged from poor to excellent but most were categorised as adequate to good. The plant taxa fell into two categories of (1) woodland and (2) weeds. Other finds included fragments of peat, *Cenococcum* spores (mycorrhizal fungi), insect remains and aquatic creatures.

Woodland material was noted in all five samples some of which was identified as fruits and bracts of birch (*Betula* sp) along with pine (*Pinus* sp) roundwood. A large piece of pine roundwood was recovered from sample 3.23-3.33 and was cut on one end but it is likely this damage occurred when the vibrocore sample was originally collected. None of the remaining wood fragments could be identified as they were either too small or too poorly preserved.

The weeds comprised undifferentiated Apiaceae (carrot family), sedge (*Carex* sp) and bulrush (*Typha* sp). These plants probably grew locally and were not dispersed too far from their original source (Birks and Birks, 1980, 68). The macroplant assemblage is low in both species diversity and relative abundance throughout the vibrocore samples. Given the small size of the assemblage the conclusions presented below while somewhat speculative suggest environmental change in the catchment area in the form of reduced water levels and periodic drying, resulting in aeration of the sediments.

The macroplant results for the five samples are briefly summarised below by number and depth

TNW005-VC, Sample 1.62-1.67m

Description: The sediment (58.1g) was described as a soft clayey amorphous peat.

Macroplant: The macroplant assemblage was composed of large numbers of sedge followed by bulrush, plant stems and wood fragments. Other finds included peat, *Cenococcum* spores, earthworm capsules, insect eggs and freshwater sponges.

Discussion: Both sedge and bulrush typically favour damper habitats as do some tree species although none of the wood fragments could be identified. The presence of the freshwater sponges indicates that freshwater was present in this location during this period.

TNW005-VC, Sample 1.85-1.90m

Description: The sample (61.9g) was formed of a soft to firm clay amorphous peat.

Macroplant: The largest inclusions within the sample were small pieces of peat. Other finds included birch, wood, Apiaceae fruits and plant stems. The presence of *Cenococcum* sp spores, beetles, earthworm capsules, insect eggs and freshwater sponges were noted.

Discussion: The macroplant assemblage is formed of species that tend to favour damper environments and the presence of freshwater sponges indicates that freshwater was present.

TNW042-VC, Sample 1.80-1.85m

Description: The sediment (64.8g) was described as a very amorphous soft black organic peat.

Macroplant: The macroplant assemblage was dominated by birch, wood fragments and plant stems. Other finds comprised small fragments of peat, *Cenococcum* sp spores, beetles, earthworm capsules, insect eggs, Bryozoans sp and freshwater sponges.

Discussion: The composition of the macroplant assemblage indicates that the surrounding landscape was formed of both woodland and peat. This was the only sample from which Bryozoans sp were collected. Some of these animals survive exclusively in freshwater but others can thrive in more brackish water.

TNW042-VC, Sample 1.85-1.90m

Description: The sample (32.0g) was formed of a very amorphous soft black organic peat.

Macroplant: The macroplant assemblage was small and consisted of wood fragments, plant stems and peat which were all poorly preserved.

Discussion: The small size and poor preservation of the macroplant assemblage coupled with the absence of any insect or aquatic remains perhaps indicates that this sample experienced periods of aeration.

TNW078_1-VC, Sample 3.23-3.33m

Description: This was the largest sediment sample (385.2g) and while noticeably more dried out than the previous four deposits a large piece of roundwood was present. The sediment was a marginally amorphous peat.

Macroplant: The macroplant assemblage was formed of large quantities of wood fragments and plant stems. Preservation of the wood fragments was variable and only the larger roundwood was identifiable as pine. This piece of pine roundwood appeared to have been cut at one end but it is likely this occurred when the sample was extracted from the core. The woodland material was composed of buds, roundwood and wood fragments. Other plant finds included sedge, and peat was also present. Beetle remains were observed.

Discussion: The presence of the pine and sedge indicates that this deposit while still damp was perhaps more acidic.

Discussion

The woodland

Wood remains were noted in all five deposits and the species identified were birch and pine. Birch normally favours damper habitats whereas pine usually grows in more acidic soils (Stace 2010, 582; Linford, 2009). Both these tree species would have been able to grow in the damp peaty environment present at this site.

The weeds

Sedge and bulrush thrive in damp habitats including wetland and meadows. Both species would have been able to colonise the acidic peat land of this area. It is also probable that the plant stems were sedge and bulrush, but this could not be confirmed. Apiaceae (carrot family) plants are found in a range of habitats including coastal areas and waste ground. Its presence within a single sample suggests it was able to temporarily grow within this landscape.

Other finds

The *Cenococcum* sp spores and peat were both natural inclusions within the sediment. The concentration of aquatic animals within TNW005-VC samples 1.62-1.67m, 1.85-1.90m and TNW042-VC sample 1.80-1.85m suggests the presence of fresh or brackish water. The absence of any aquatic creatures and a decline in the insect population in TNW042-VC samples 1.85-1.90m and

TNW078_1 VC sample 3.23-3.33m perhaps indicates a change in the local environment, when the sediment had experienced periods of aeration.

Comparison sites

Earlier work on other mire communities in Europe including sites in the Netherlands, Scotland, Germany and France have demonstrated that plant taxa both adapt and even contribute to environmental changes within their immediate landscape (Birks and Birks, 1980). The macroplant assemblage from this current site along with two nearby sites previously studied demonstrate that the plant species able to thrive were those which could more easily adapt to environmental changes affecting water levels.

Conclusion

Given the small size of the macroplant assemblage no further work is recommended. If material is required for C14 dating the pine roundwood from sample TNW078_1-VC sample 3.23-3.33m is suitable. While the remaining wood fragments from TNW005-VC samples 1.62-1.67m, 1.85-1.90m and TNW042-VC 1.80-1.85m could not be identified if they are required for dating the larger pieces of wood are available. There was no suitable material for dating recorded in sample TNW042-VC 1.85-1.90m. The macroplant assemblage while restricted in number and diversity, remained relatively consistent and is representative of plants that grew locally. This suggests the surrounding landscape was composed of acidic peat bogs which experienced some periods of flooding by freshwater along with periods of aeration.

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Vibrocore			**TNW005-VC**	**TNW005-VC**	**TNW042-VC**	**TNW042-VC**	**TNW078-VC**
Sample			1.62-1.67	1.85-1.90	1.80-1.85	1.85-1.90	3.23-3.33
Weight (g)			58.1	61.9	64.8	32.0	385.2
% Analysed			100	100	100	100	100
Species	**Name**	**Part**					
Woodland							
Betula sp.	Birch	Fruit(s)		*	***		
Betula sp.	Birch	Bract(s)			*		
Pinus sp.	Pine	Roundwood					*
Wood	Wood	Bud scale(s)			*		*
Wood	Wood	Frag(s)	**	*	***	*	***
Wood	Wood	Roundwood(s)					**
Weeds							
Apiaceae sp.	Carrot	Fruit(s)		*			
Carex sp.	Sedge	Nutlet(s)	***				*
Typha sp.	Bulrush	Seed(s)	**				
Plant stem	Stem	Frag(s)	*	*	***	***	***
Unknown	Indet	Achene/fruit/seed	*	*	*		
Other							
Cenococcum sp.		Spore(s)	**	*	*		
Peat		Frag(s)	***	***	****	***	**
Insect							
Beetle		Frag(s)		*	***		*
Earthworm		Capsule(s)	*	*	*		
Insect		Egg(s)	**	**	**		
Aquatic creatures							
Bryozoans sp	Moss animals	Larvae			***		
cf. Freshwater sponge	Aquatic	Animal(s)	**	***	***		

Key:*=<10, **=10-29, ***=30-100, ****>100

Appendix 7 - Mollusc report (Frank Wesselingh, Naturalis)

Borehole	Depth	Formation	Member (Bed)	Description	Dominant	Occur	Rare but important	Remarks
TNW005	1.54-1.59	Urania	Western Mud Hole	Few shells, mixed preserved marine species and corroded Pisidum including pair	Spisula subtruncata	Pair Pisidum casertanum forma plicatum	Chamelea striatula, Varicorbula gibba (well preserved), Cerastoderma edule (worn)	Mixed faunas with proximal reworked freshwater into mixed bFWWB marine
TNW042	0.55-0.63	Urania	Western Mud Hole	Abundant shells and fragments, dominated by fine preserved Spisula subtruncata and other marine species, but other shells worn	Spisula subtruncata	Spisula solida, Chamelea striatula, Abra alba, Macoma balthica, Nucula nitidosa, Peringia ulvae, Cultellus pellucidus, Tellina tenuis, Ensis cf minor	Turritella communis, Cerastoderma glaucum (bluish, worn)	Mostly in situ marine, between FWWB and SWB, but close to latter; some reworked coastal brackish species
	1.45-1.50	Naaldwijk	Wormer (Velsen)	Few shells and fragments; well preserved Bithynia opercula and pearly Freshwater mussel fragment (with periostracum), one Spisula valve	Bithynia tentaculata (opercula)		Unionoidea indet., Spisula subtruncata	Proximally reworked freshwater assemblage; running water or open lake. Spisula from marine interval
	1.60-1.65	Naaldwijk	Wormer (Velsen)	Few well preserved bithynid opercula	Bithynia tentaculata (opercula)	none	none	Proximally reworked freshwater (running water or open lake)
TNW047	0.60-0.65	Urania	Western Mud Hole	Common shells, mostly well preserved but some worn or corroded specimens	Spisula subtruncata, Chamelea striatula, Varicorbula gibba	none	Acanthocardia cf echinata, Thracia convexa, Thracia cf phaseolina, Euspira nitida, Tellina tenuis, Nucula nitidosa	Mostly sea floor assemblage below FWWB
	1.20-1.25	Naaldwijk	Wormer	Common shells, somewhat mixed preservation, but mostly well preserved	Spisula subtruncata	Varicorbula gibba, Chamelea striatula	Nucula nitidosa, Fabulina fabula, Spisula cf solida, Euspira nitida	Mostly sea floor assemblage below FWWB
	3.40-3.45	Boxtel	Singraven	Three well preserved sphaeriid clams	Pisidum sp.	none	none	Fine details and periostracum preserved, some shell corrosion; in situ freshwater, possibly running freshwater. Species identification required for environmental details. Likely P henslowanum, P casertanum forma plicatum
TNW069	1.00-1.05	Urania	Western Mud Hole	Some shells; grey blue and brownish cream, mixed preservation	none	Cerastoderma edule	Peringia ulvae, Spisula subtruncata	The best preserved fraction (Cerastoderma, Peringia) suggests marine above FWWB
TNW075	4.30-4.35	Eem	Brown Bank equivalent	Some shells, mixed preservation from worn to fine details preserved, mostly glassy-grey	Spisula subtruncata	none	Scrobicularia plana	Mixed marine bFWWB and brackish water
	4.40-4.45	Eem		Some shells, mixed preservation, Macoma and Spisula partially very well preserved	Spisula subtruncata	none	Macoma balthica, ?Abra alba (or Scrobicularia plana)	Partially mixed, in situ component marine around or above FWWB
TNW078	0.60-0.65	Naaldwijk	Wormer	Common shells and fragments, mixed preservation, mostly reasonable well preserved, dominant grey to cream grey, some bluish; mixed ecology (Scrobicularia versus Chamelea faunas, the latter best preserved)	Chamelea striatula	Cultellus pellucidus, Spisula subtruncata, Varicorbula gibba, Euspira nitida, Peringia ulvae, Acteon tornatilis	Mytilus edulis, Scrobicularia plana, Kurtiella bidentata, Spisula cf. solida, Nucula nitidosa	In situ or proximal reworked marine sea floor association, above SWB, full marine with reworked brackish coastal assemblage
TNW079	1.30-1.35	Eem	Brown Bank equivalent	Very few shells fragments; blue-grey with ?gypsum-manganese; strongly worn and/or corroded.	Spisula subtruncata	none	none	uncertain interpretation
	2.55-2.65	Eem		Common shells and fragments; grey blue, worn to very worn;a few cream grey Spisula less worn	Dosinia lupinus	Laevicardium crassum, Spisula subtruncata, Acanthocardia indet.	Bela cf nebula, Macoma balthica, Spisula solida	Multiple reworked marine faunas
TNW109	2.42-2.47	Boxtel	Singraven	Some shells, mixed preservation from worn to fine details preserved, mostly glassy-grey	Spisula subtruncata well preserved, Chamelea striatula	Varicorbula gibba	Scrobicularia plana, Euspira nitida	Mixed marine bFWWB and brackish water
	3.45-3.50	Boxtel	Singraven	One worn fragment of Chamelea striatula				uncertain interpretation
	5.33-5.40	Boxtel	Wieden	One slightly worn Chamelea striatula				Reworked specimen originates from marine bFWWB settings but reworking may indicate transgressive, tidal or fluvial environments
n.b. proximal reworking indicates either short-distance within habitat transport or reworking by bioturbation. (b)FWWB = (below) Fair Weather Wave Base, SWB = Storm Wave Base								

Appendix 8 -Summary of environmental interpretations

The following table is a summary of the environmental interpretations of each fossil group for each stratigraphic unit studied in each vibrocore. In addition, numerical ages determined by radiocarbon (^{14}C) and luminescence (OSL) dating are shown where available.

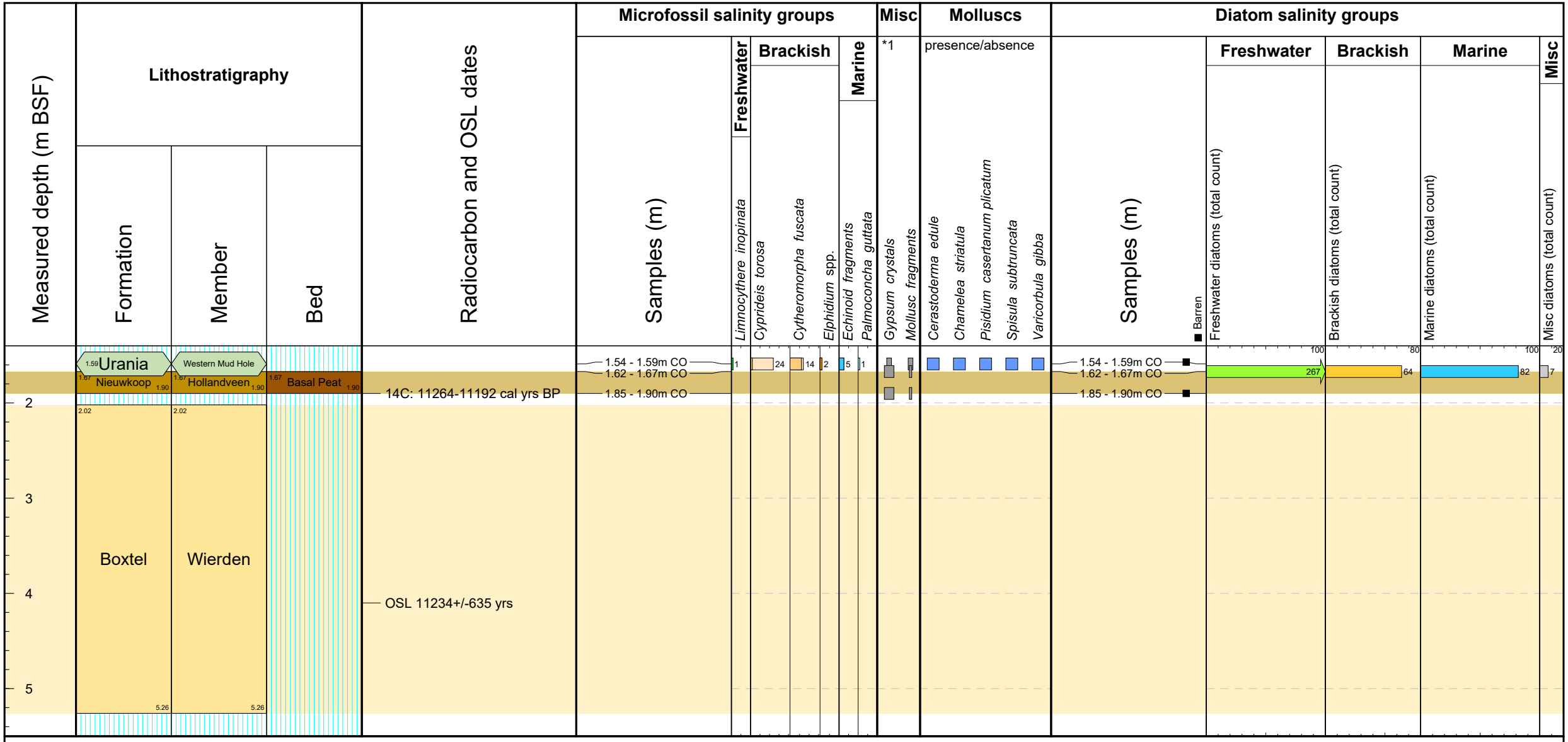
		Distal ←----------→ Proximal							
	Borehole →	TNW042-VC	TNW069-VC	TNW109-VC	TNW005-VC	TNW047-2-VC	TNW075-2-VC	TNW078-1-VC	TNW079-1-VC
Urania (Western Mud Hole)	Paly		Marsh/wetland. Minor marine or coastal / brackish influence. Boreal.		Local marshland, open freshwater. Forests in uplands. Minimal marine. Late Boreal	Probably marine, proximal to the coast. Subboreal (i.e. the later part of the Holocene)	Uncertain		
	Micro	Nearshore, possibly outer estuarine setting.	Brackish lagoonal or estuarine setting.		Brackish - freshwater, possibly reworked into marine.	Nearshore, possibly outer estuarine setting.			
	Molluscs	Marine assemblage between FWWB and SWB with some reworked coastal brackish species.	Marine above FWWB.		Freshwater reworked into marine below FWWB	Seafloor below FWWB.			
Naaldwijk	Paly	VELSEN. Freshwater marsh				Marsh vegetation with open water but more marine influence in the uppermost sample	ZANDVOORT. Uncertain	Wetland, increasingly marine influence upwards. Late Boreal to Atlantic	
	Micro	VELSEN. Freshwater				Freshwater - brackish	ZANDVOORT. Uncertain	Change from brackish to more marine conditions near the top of this interval	
	Diatoms	VELSEN. Freshwater				Dominated by marine taxa,giving way to both brackish and freshwater taxa upwards. Turbulent, marine coastal environment.		Dominated by marine taxa, with few brackish and freshwater taxa	
	Molluscs	VELSEN. Freshwater				Seafloor below FWWB		*In situ* fully marine seafloor above SWB or transported a short distance with reworked brackish coastal taxa.	
	OSL						9,408 ± 501 years		
Nieuwkoop (Hollandveen)	Paly	marshland vegetation with open water. Upland trees (late) Boreal			Sedge peatland or open marshland/salt marsh. Late Boreal to pre-boreal.			Open freshwater. Boreal	
	Micro	Freshwater						Barren	
	Diatoms	Freshwater			Shallow, estuarine or brackish water				
	Plants	Surrounding landscape woodland and peat			Freshwater			Damp woodland	
	^{14}C	10,242-10,171 cal yrs BP			11,264-11,192 cal yrs BP			10,765-10,578 cal yrs BP	

		Distal ←----------→ Proximal							
Borehole →		TNW042-VC	TNW069-VC	TNW109-VC	TNW005-VC	TNW047-2-VC	TNW075-2-VC	TNW078-1-VC	TNW079-1-VC
Boxtel (Singraven)	Paly	Wetland or river margin. Late glacial to Holocene transition.	as TNW047-VC	Similar to other vibrocores.		Similar to Naaldwijk but increased fluvial activity and lower energy ponds or small lakes. Boreal stage (local pollen zone E)			
	Micro	?Freshwater	Freshwater - brackish marginal marine in upper part	Fresh to brackish water but increasing marine influence towards the top of this interval.		Virtually identical to the overlying Naaldwijk Formation			
	Diatoms	Shallow freshwater environment, with minor brackish and marine influence.	Predominantly marine and marine brackish with significant freshwater influence.	Predominantly coastal marine.		Marine - estuarine. A turbulent, marine coastal environment.			
	Molluscs			Mixed marine and brackish water assemblage from below FWWB.		Running freshwater			
	^{14}C					11,177-10,806 cal years BP			
Boxtel (Wierden)	Paly	Wetland marsh or similar away from marine influence		Freshwater. Late glacial, Allerød interstadial.	Uppermost sample may be Nieuwkoop. fluvial or the presence of open water (i.e. lakes and ponds) likely late glacial				
	Micro			Freshwater - Brackish?					
	Diatoms			Predominantly freshwater.					
	Molluscs			Uncertain					
	OSL			11,039 ± 920 years	11,234 ± 635 years				
Eem (Brown Bank)	Paly						Estuarine to shallow marine (intertidal to near shore). raised bog landscapes. Some forested areas. Eemian and earliest interstadials of the early Weichselian		Similar to TNW075-VC. Locally open landscapes with heather and raised bogs as well as forested parts. Minimal marine or brackish influence.
	Micro						Uncertain		Uncertain
	Molluscs						Upper sample - marine setting below FWWB and of brackish water. Lower sample- around or above FWWB		Uncertain
Eem (undifferentiated)	Paly								?Marine. ?Eemian
	Micro								Barren
	Molluscs								Uncertain

Appendix 9 - Summary, correlation and biostratigraphic distribution charts

The following charts display for each vibrocore a graphical summary of all the biostratigraphic results, details of the palynology and diatom analyses and a correlation of all of the vibrocores. Charts were produced using StrataBugs v2.1.1.

TNW005-VC



Text Keys

*1 semi-quantitative [Default Abundance Scheme]

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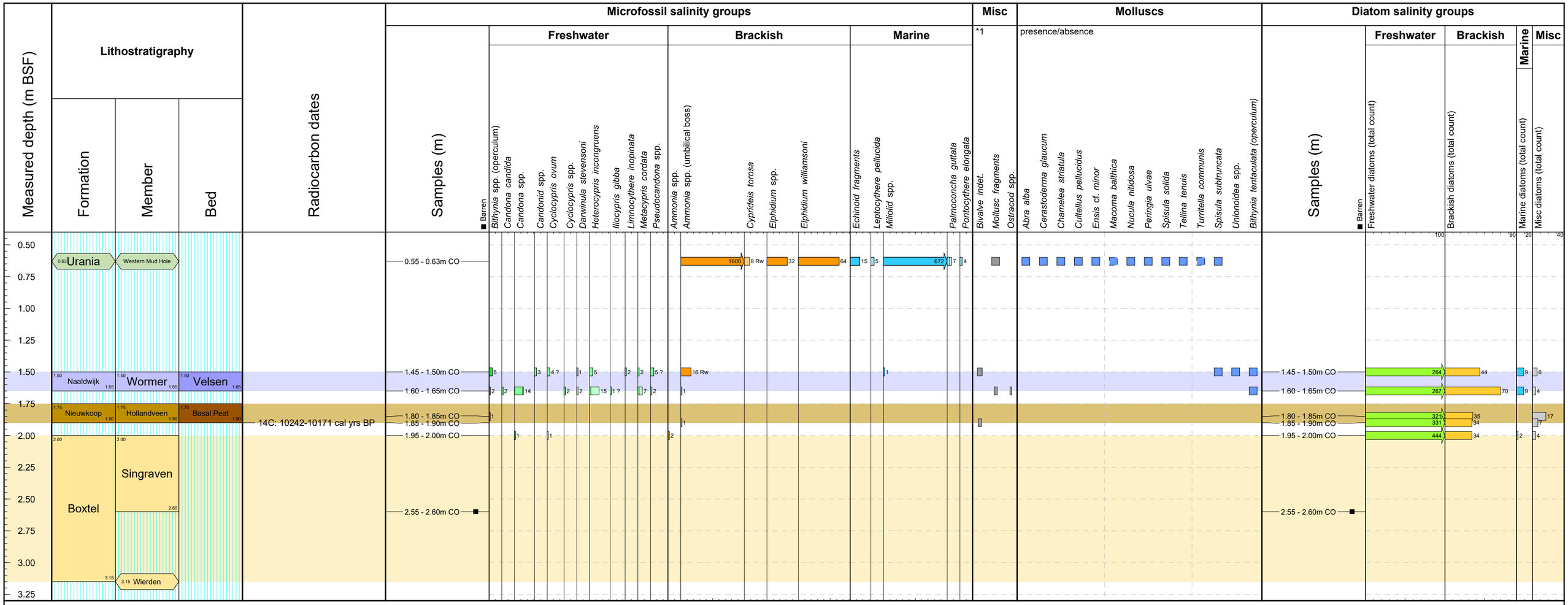

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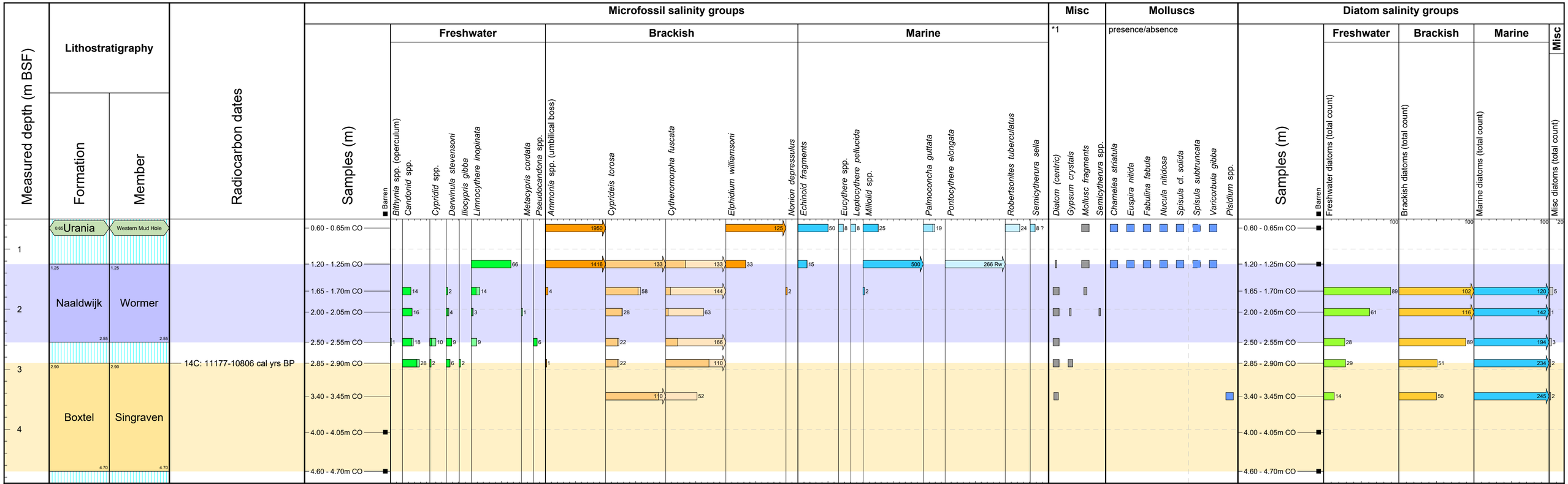

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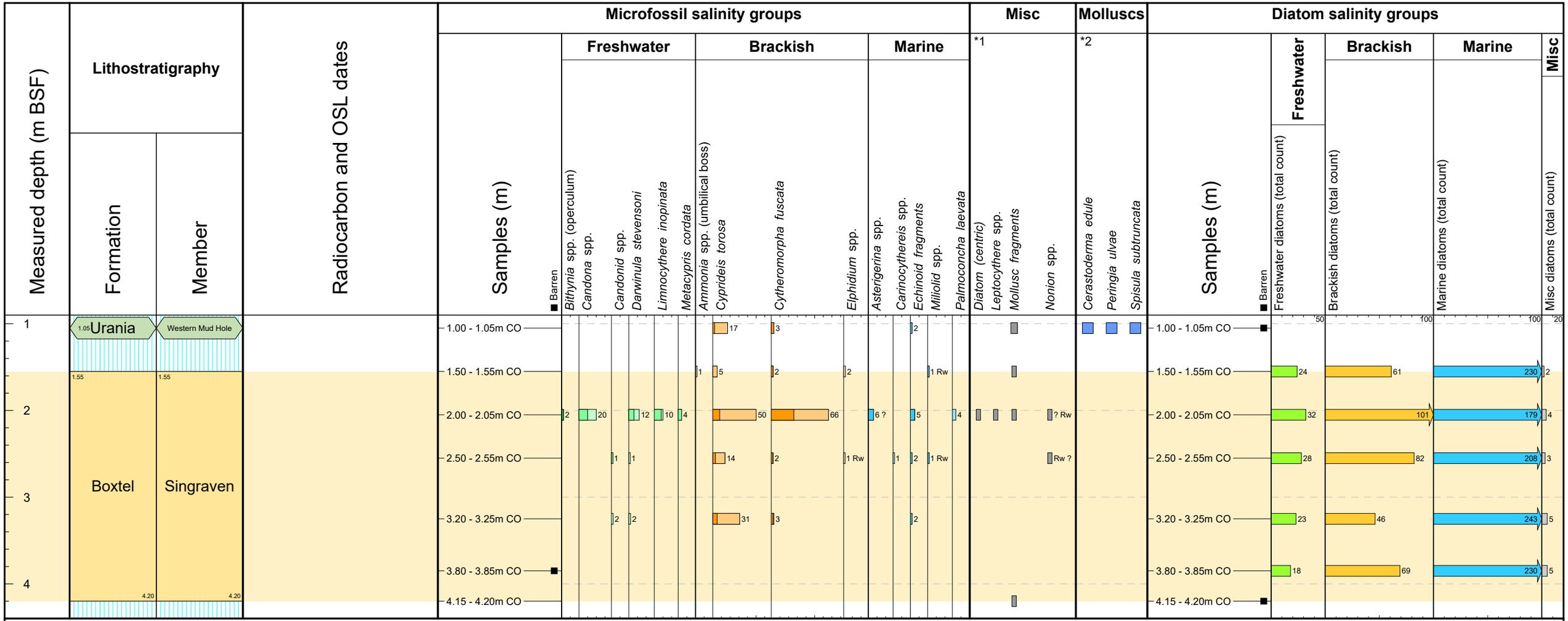

Text Keys

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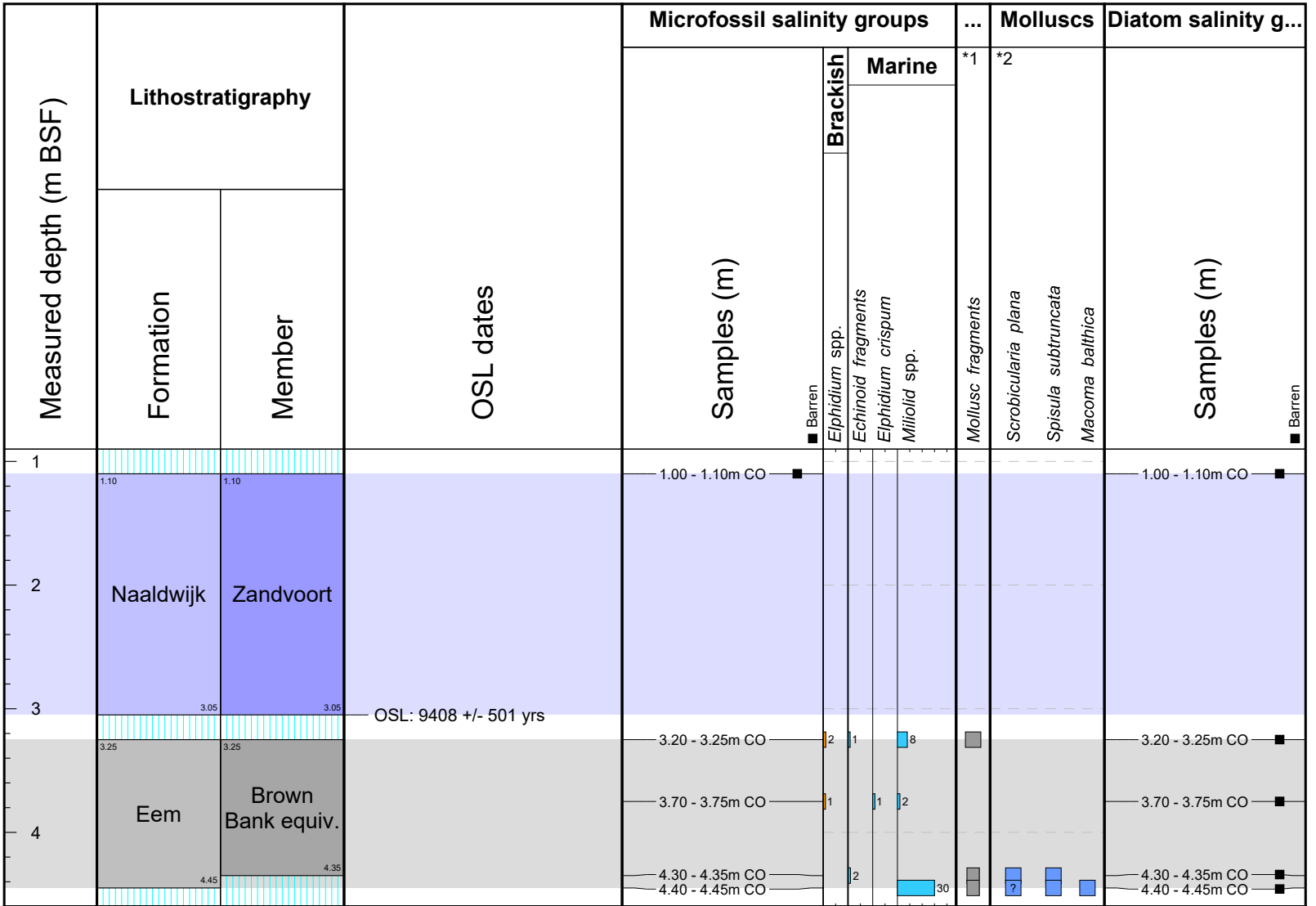

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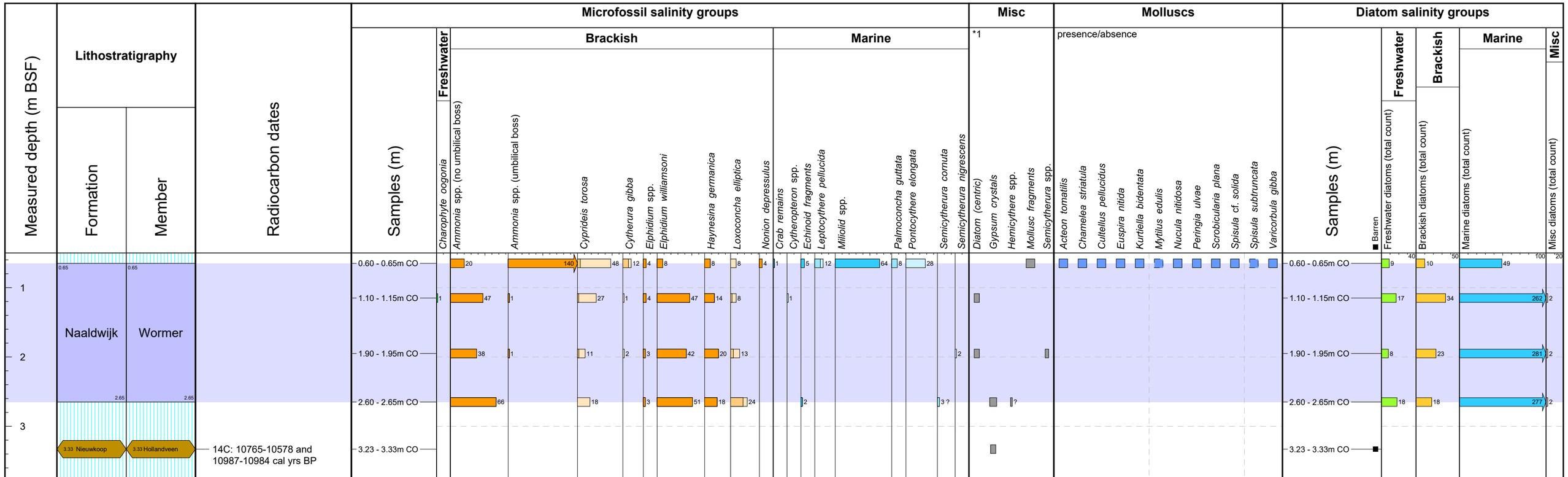

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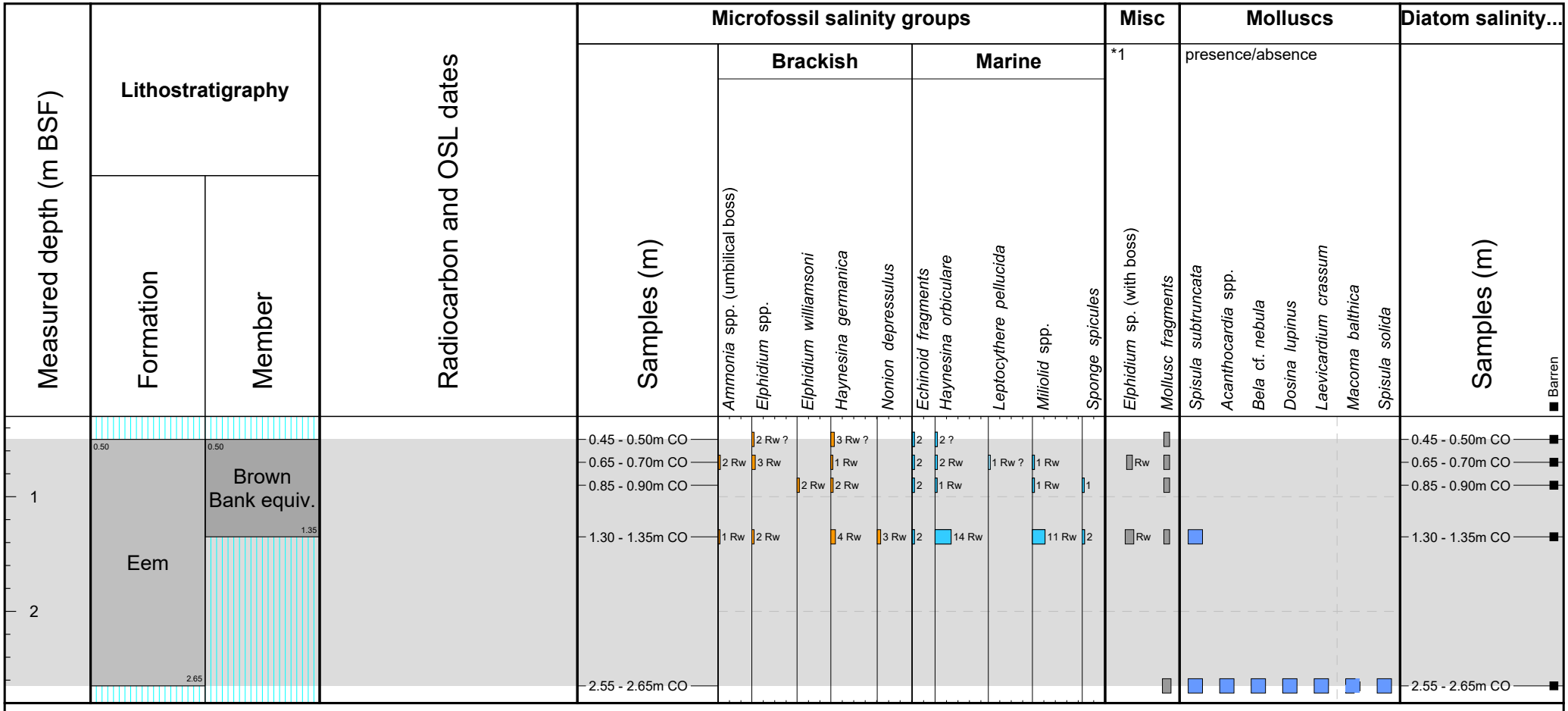

Text Keys

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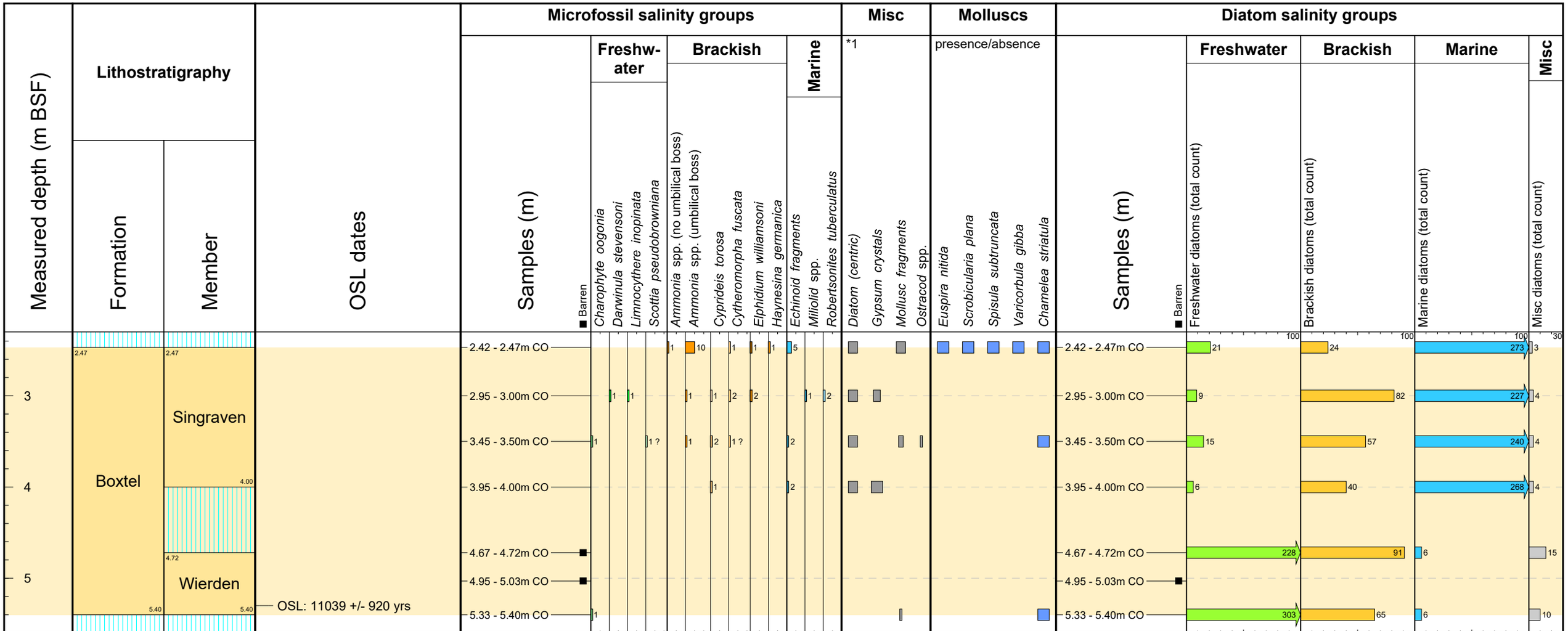

Text Keys

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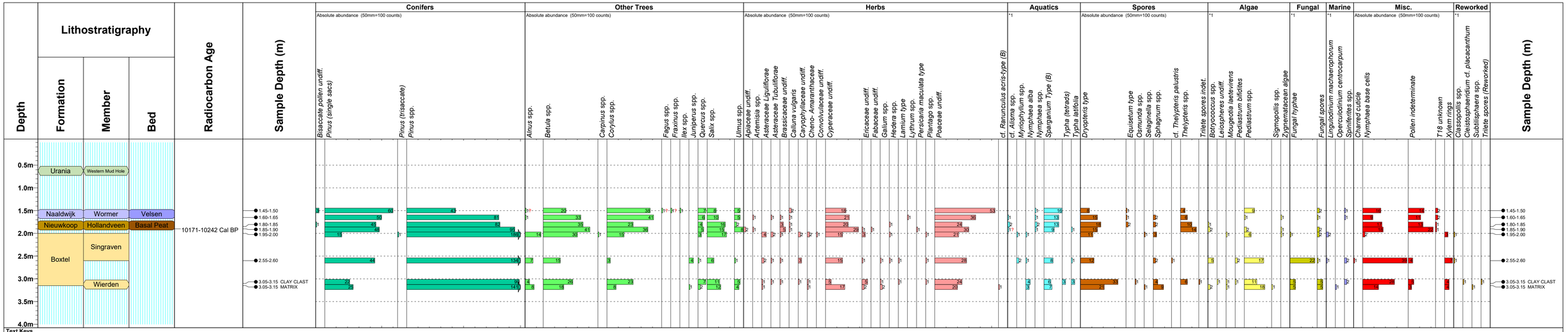
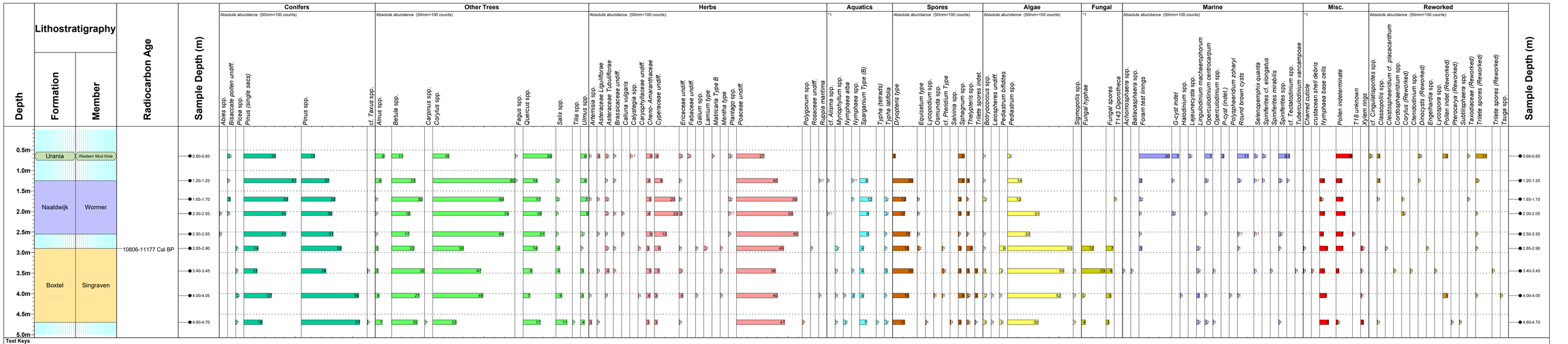
Text Keys
*1 Absolute abundance (50mm=100 counts)

TNW042-VC



Text Keys

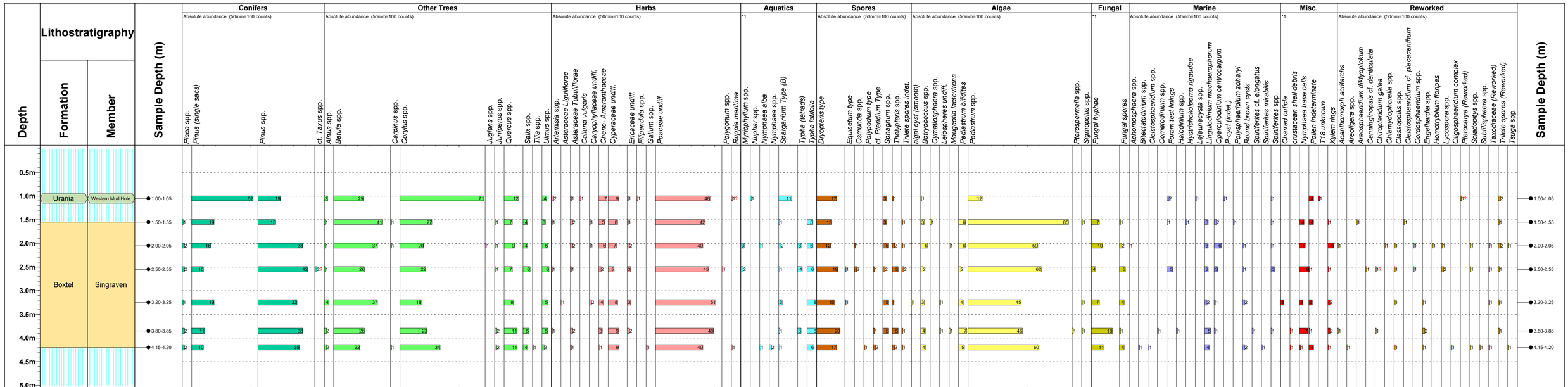
*1 Absolute abundance (50mm=100 counts)



Text Keys

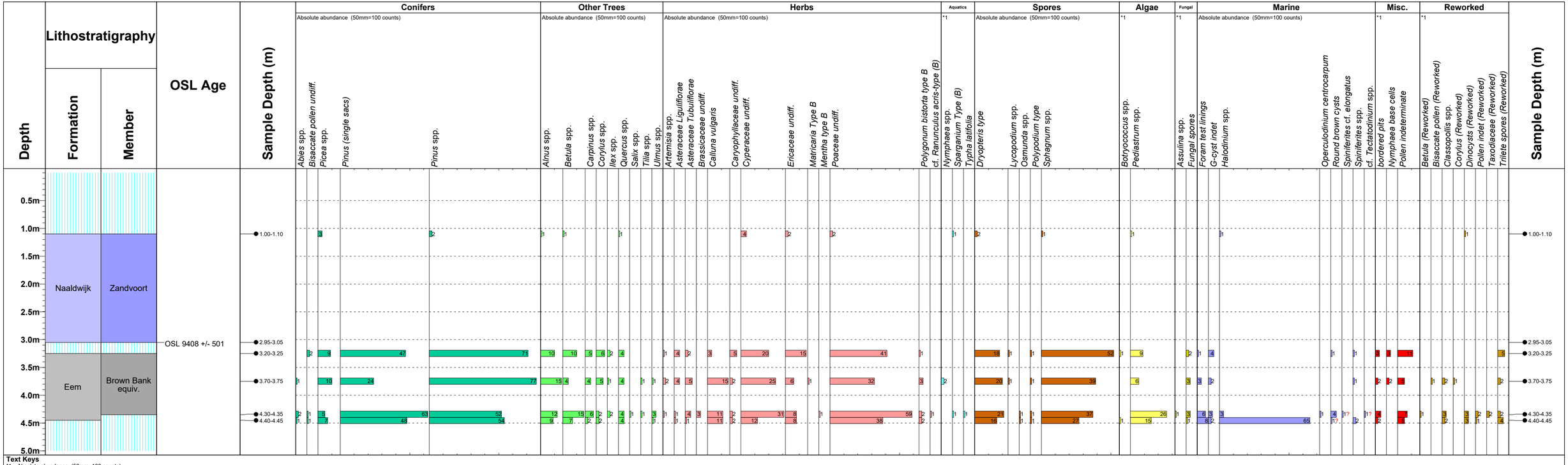
*1 Absolute abundance (50mm=100 counts)

TNW069-VC



Text Keys
*1 Absolute abundance (50mm=100 counts)

TNW075_2-VC



Text Keys

*1 Absolute abundance (50mm=100 counts)

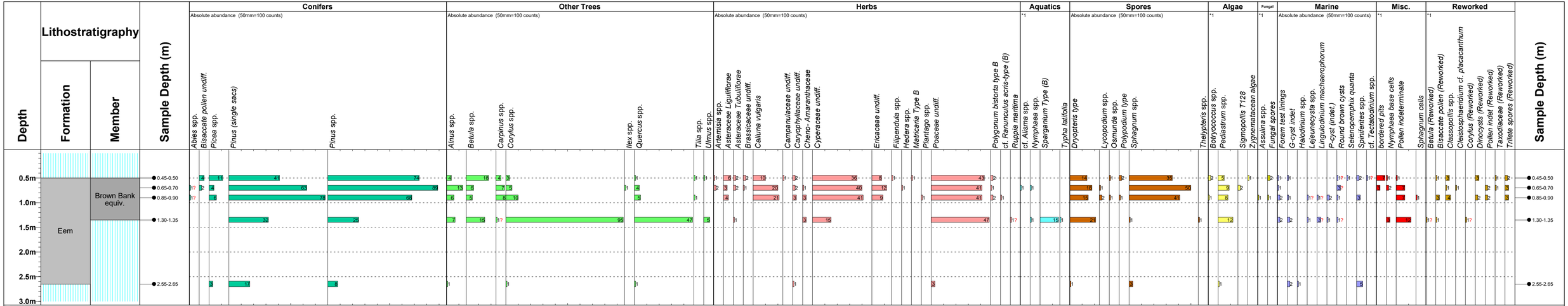
TNW078_1-VC

Text Keys

*1 Absolute abundance (50mm=100 counts)

*2 Fungal

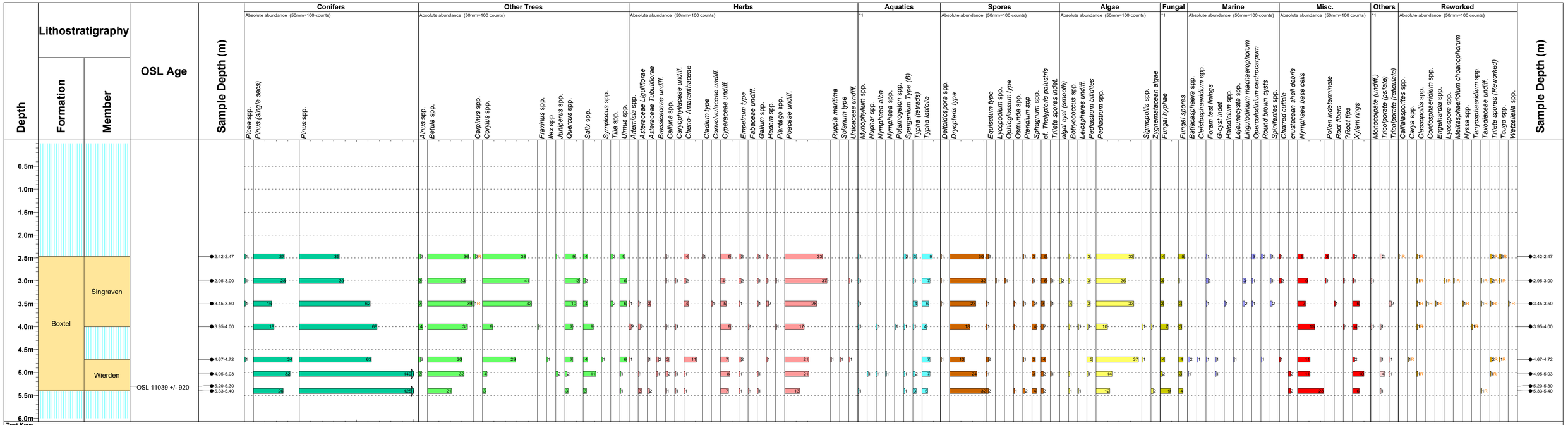
TNW079_1-VC



Text Keys

*1 Absolute abundance (50mm=100 counts)

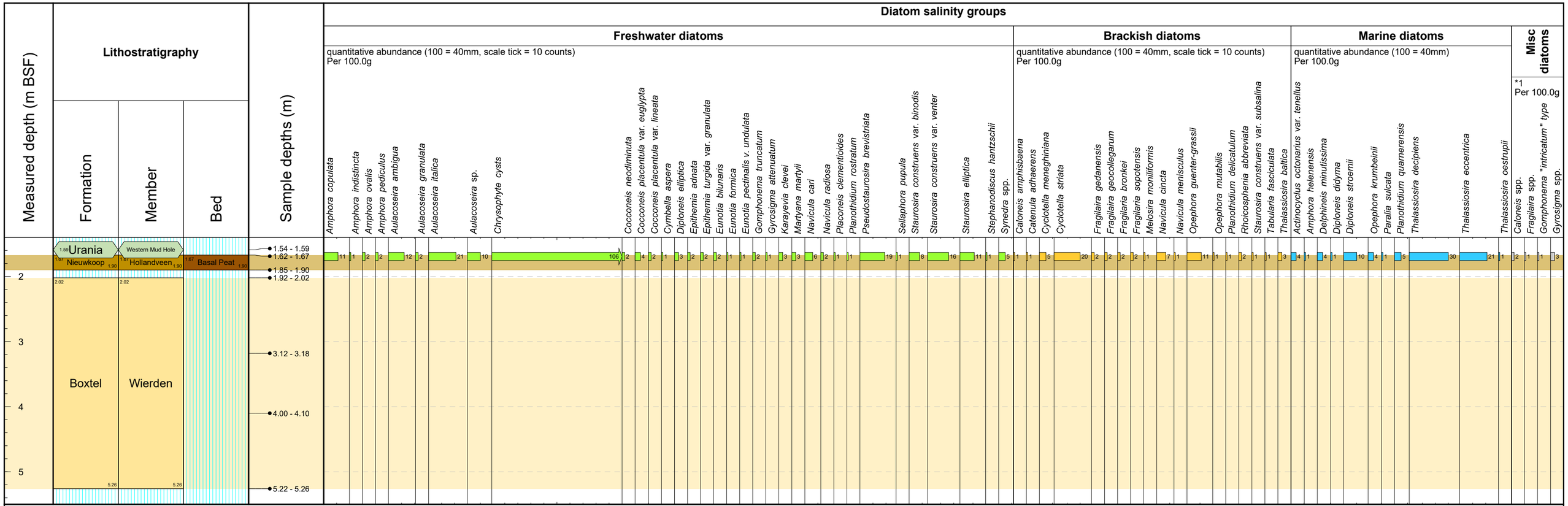
TNW109-VC



Text Keys

*1 Absolute abundance (50mm=100 counts)

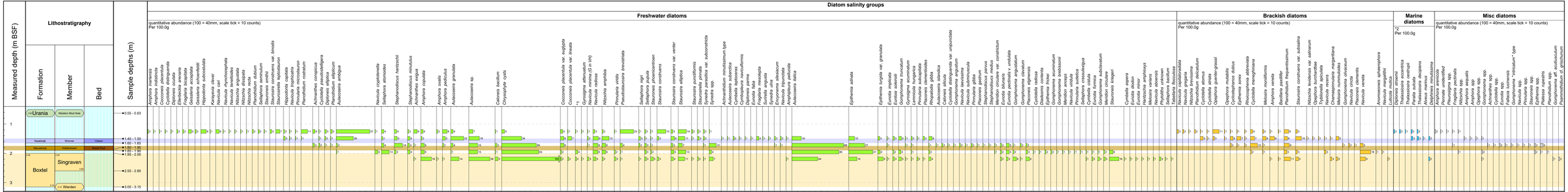
TNW005-VC



Text Keys

*1 quantitative abundance (100 = 40mm, scale tick = 10 counts)

TNW042-VC

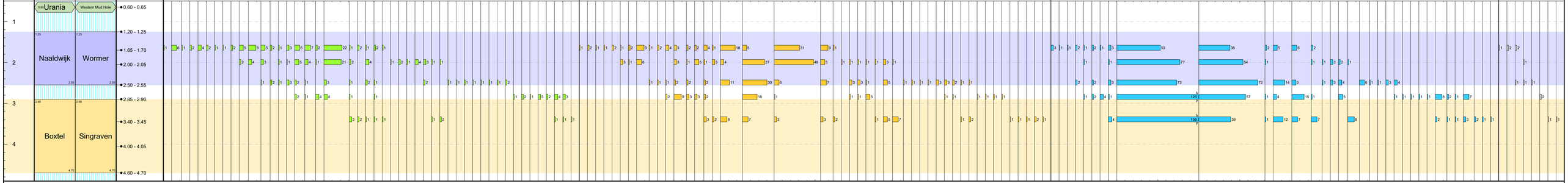


Text Keys

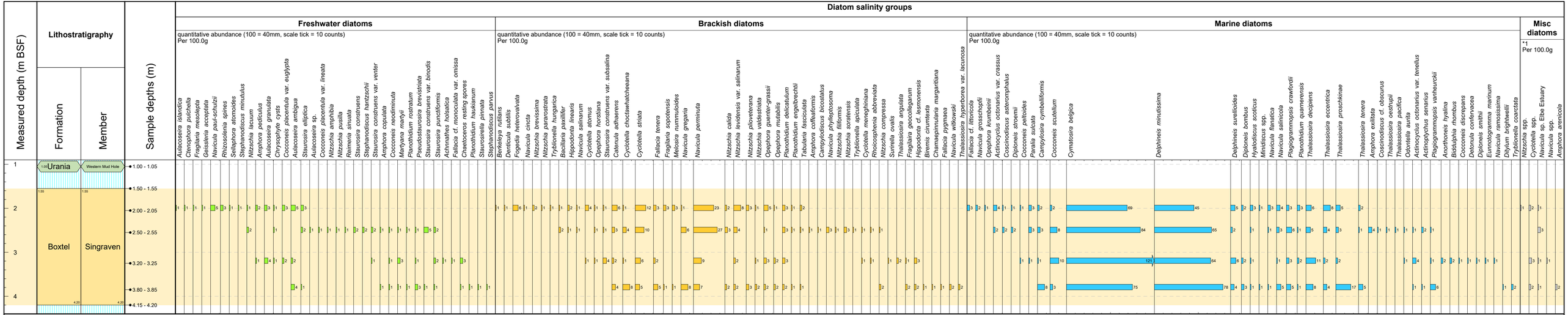
*1 *Gomphonema parvulum* var. *exilissimum*

*2 quantitative abundance (100 = 40mm, scale tick = 10 counts)

TNW047_2-VC


Diatom salinity groups
Freshwater diatoms
Brackish diatoms
Marine diatoms
Misc diatoms
Measured depth (m BSF)
Lithostratigraphy
Formation
Member
Sample depths (m)
quantitative abundance (100 = 40mm, scale tick = 10 counts)
Per 100.0g
*1
Per 100.0g
Urania
Western Mud Hole
Naaldwijk
Wormer
Boxtel
Singraven
0.60 - 0.65
1.20 - 1.25
1.65 - 1.70
2.00 - 2.05
2.50 - 2.55
2.85 - 2.90
3.40 - 3.45
4.00 - 4.05
4.60 - 4.70
Amphora ovalis
Cocconeis placentula
Eucocconeis laevis
Fragilaria nonguta
Mastogloia smithii
Planothidium lanceolata
Staurosira construens
Staurosira construens var. binodis
Staurosira construens var. venter
Amphora indistincta
Kolbesia ploenensis
Amphora pediculus
Planothidium elliptium
Staurosirella pinnata
Cocconeis neodiminuta
Karayevia clevei
Planothidium haukianum
Planothidium rostratum
Aulacoseira ambigua
Aulacoseira granulata
Aulacoseira sp.
Chrysophyte cysts
Staurosira punctiformis
Eunotia soleirolii
Karayevia kolbei
Planothidium dubium
Pseudostaurosira brevistriata
Navicula mollicula
Amphora fogediana
Cocconeis placentula var. lineata
Achnanthidium minutissimum type
Amphora copulata
Diploneis elliptica
Gomphonema acuminatum
Hippodonta costulata
Navicula hungarica
Nitzschia palea
Salligchara puguia
Chaetoceros resting spores
Navicula subminuscula
Nitzschia amphibia
Staurosira elliptica
Symedra parasitica
Hippodonta capitata
Stephanodiscus hantzschii
Stephanodiscus parvus
Actinocyclus normanii
Melosira nummuloides
Navicula enifuga
Planothidium frequentissimum
Platessa oblongella
Fragilaria bronkei
Opephora burchardiae
Staurosira construens var. subsalina
Achnanthes brevipes
Hippodonta hungarica
Fragilaria sopotensis
Navicula salinarum
Opephora guenter-grassii
Opephora mutabilis
Catenula adhaerens
Cocconeis hauerienses
Cyclotella striata
Navicula perminuta
Planothidium delicatulum
Planothidium engelbrechtii
Pseudostaurosira perminuta
Planothidium dispar
Fallacia pygmaea
Navicula gregaria
Opephora hoestana
Cyclotella meneghiniana
Nitzschia levidensis var. salinarum
Nitzschia paradoxa
Luticola mutica
Navicula microdigitoradiata
Nitzschia parvula
Tabularia fasciculata
Thalassiosira angulata
Cyclotella atomus
Navicula cincta
Nitzschia valdestriata
Paribacillus protracta
Fogedia heterovalvata
Nitzschia levidensis
Nitzschia dubia
Nitzschia exilis
Nitzschia sp.
Caloneis amphisbaena var. subsalina
Cosmoneis pusilla
Cyclostephanos dubius
Cyclotella choctawhatcheeana
Fallacia tenera
Amphora helenensis
Diploneis stroemii
Rhabdonema minutum
Plagiogrammopsis vanheurckii
Odontella aurita
Paralia sulcata
Plagiogrammopsis crawfordii
Cocconeis scutellum
Cymatosira belgica
Delphineis minutissima
Hyalodiscus scoticus
Navicula salinicola
Thalassiosira decipiens
Thalassiosira eccentrica
Actinocyclus octonarius var. tenellus
Thalassiosira oestrupii
Delphineis surirelloides
Minidiscus spp.
Opephora krumbeinii
Planothidium quarnerensis
Tryblionella coarctata
Zygoceros atlanticus
Actinoptychus senarius
Cocconeis stauroneiformis
Coscinodiscus radiatus
Thalassionema nitzschioides
Tryblionella acuminata
Campylosira cymbelliformis
Cocconeis peltoides
Dimeregramma minor
Thalassiosira pseudonana
Biddulphia rhombus
Navicula arenaria
Opephora pacifica
Amphora spp.
Navicula spp.
Planothidium spp.
Navicula aff. leptoloba
Cocconeis spp.
Cyclotella spp.
Fragilaria oldenburgiana
Gyrosigma spp.
Text Keys
*1 quantitative abundance (100 = 40mm, scale tick = 10 counts)

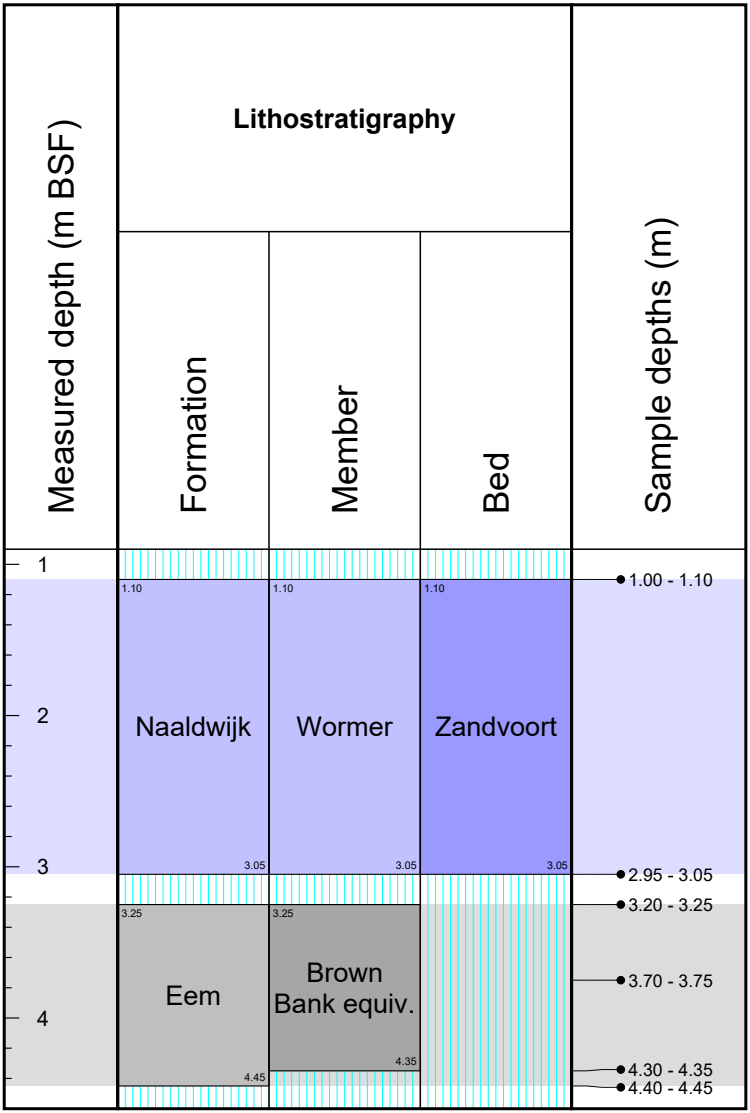
TNW069-VC



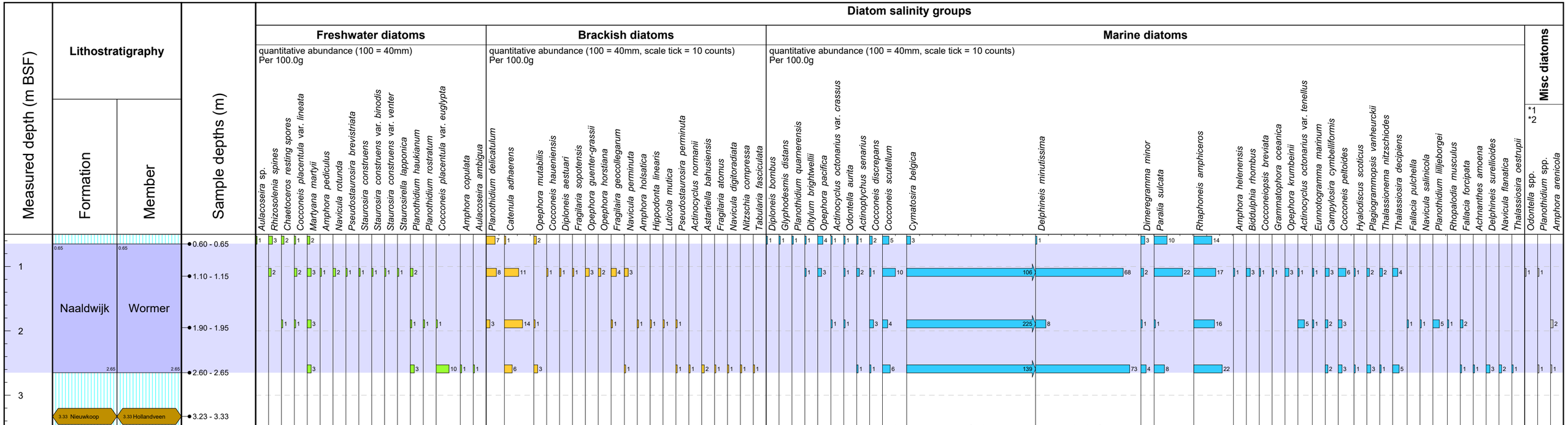
Text Keys

*1 quantitative abundance (100 = 40mm, scale tick = 10 counts)

TNW075_2-VC


Measured depth (m BSF)
Lithostratigraphy
Formation
Member
Bed
Sample depths (m)
1
2
3
4
1.10
1.10
1.10
Naaldwijk
Wormer
Zandvoort
3.05
3.05
3.05
3.25
3.25
Eem
Brown Bank equiv.
4.35
4.45
1.00 - 1.10
2.95 - 3.05
3.20 - 3.25
3.70 - 3.75
4.30 - 4.35
4.40 - 4.45

TNW078_1-VC

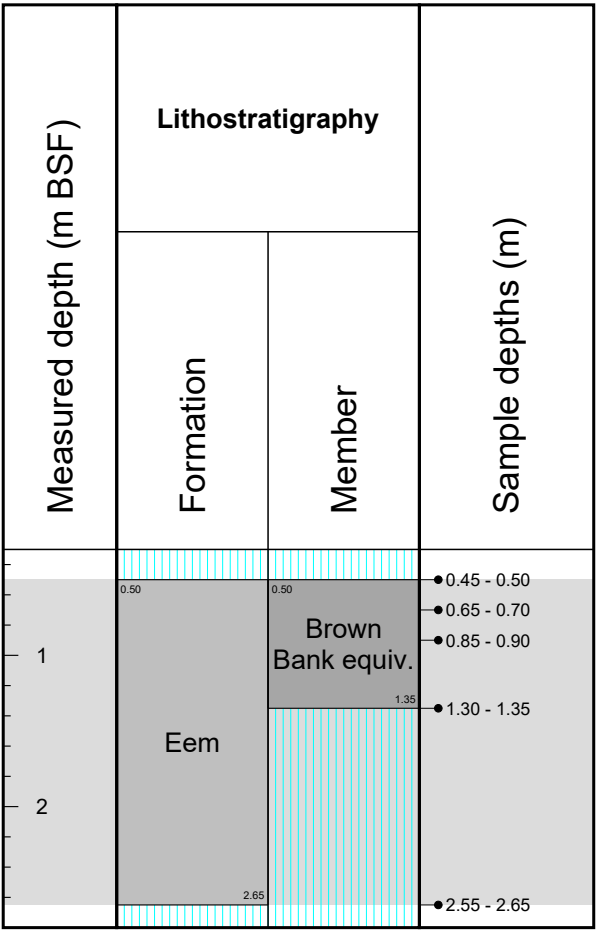


Text Keys

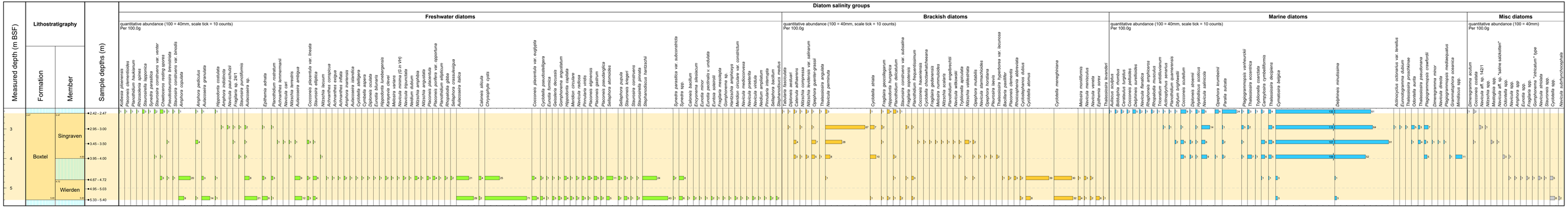
*1 quantitative abundance (100 = 40mm, scale tick = 10 counts)

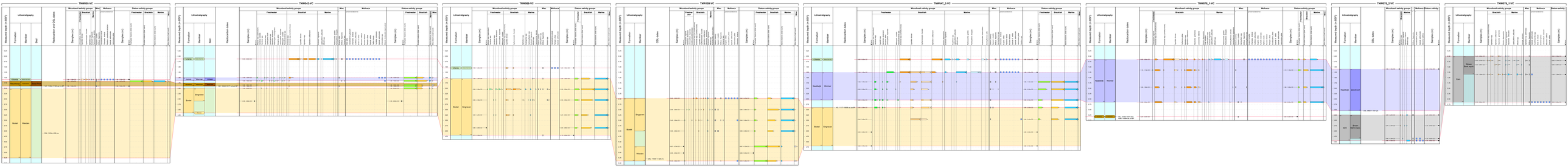
*2 Per 100.0g

TNW079_1-VC


Measured depth (m BSF)
Lithostratigraphy
Formation
Member
Sample depths (m)
1
2
0.50
0.50
Eem
Brown
Bank equiv.
1.35
2.65
0.45 - 0.50
0.65 - 0.70
0.85 - 0.90
1.30 - 1.35
2.55 - 2.65

TNW109-VC


Measured depth (m BSF)
Lithostratigraphy
Formation
Member
Sample depths (m)
Diatom salinity groups
Freshwater diatoms
Brackish diatoms
Marine diatoms
Misc diatoms
quantitative abundance (100 = 40mm, scale tick = 10 counts)
Per 100.0g
Boxtel
Singraven
Wierden
3
4
5
2.42 - 2.47
2.95 - 3.00
3.45 - 3.50
3.95 - 4.00
4.67 - 4.72
4.95 - 5.03
5.33 - 5.40
Kidbaea phoenetis
Pinnularia microstauron
Placoneis dimerobolaris
Rhizosolenia spines
Stauroneis lapponica
Stauroneis phoenicenteron
Staurosira construens var. venter
Chaetoceros resting spores
Staurosira construens var. binodis
Staurosira construens var. binodis
Amphora coffeaformis
Amphora pediculus
Aulacoseira granulata
Hippodonta costulata
Amphora inelatoncta
Navicula cincta var. rostrata
Fragilaria sp. 241
Staurosira punctiformis
Aulacoseira sp.
Epithemia adnata
Pinnularia nobilis
Navicula cincta var. minimoides
Navicula cari
Nitzschia fonseiana
Aulacoseira ambigua
Cocconeis placentula var. lineata
Staurosira elliptica
Navicula tripunctata
Navicula tripunctata (G in H9)
Navicula lanceolata
Navicula angusta
Nitzschia amphibia
Placoneis placentula
Placoneis pontica var. opportuna
Placoneis pseudanagnostidis
Rhopalodia gibba
Sellaphora crassulenegua
Aulacoseira italica
Cadosira silicula
Chrysosphyrk cysts
Cocconeis placentula var. euglypta
Cyclotella pseudostelligera
Eunotia formica
Gomphonema lagenarium
Hippodonta capitata
Meridion circulare
Navicula cincta
Navicula lanceolata
Pinnularia viridis
Placoneis elginensis
Placoneis gastrum
Placoneis pseudanagnostica
Sellaphora atomoides
Sellaphora pupula
Staurosira construens
Staurosira construens var. binodis
Staphanodiscus parvus var. hantzschii
Synedra parasitica var. subconstricta
Synedra spp.
Cocconeis scutellum
Eunotia minor
Eunotia pectinalis var. undulata
Eunotia praerupta
Fragilaria mesolepta
Gomphonema spp.
Hippodonta hungarica
Meridion circulare var. constricta
Navicula medioconvexa
Navicula pelagica
Navicula viridula
Nitzschia fonseiana
Nitzschia sinuata
Sellaphora bacillum
Staphanodiscus medius
Cyclotella striata
Fragilaria geocollegarum
Hippodonta hungarica
Pinnularia obscura var. subsalina
Staurosira construens var. subsalina
Fragilaria capucinoides
Fragilaria construens var. venter
Navicula cincta var. rostrata
Navicula lanceolata
Nitzschia fonseiana
Nitzschia sinuata
Pinnularia engelbrechtii
Navicula wellesiae
Navicula cincta var. rostrata
Nitzschia valdestriata
Opephora mutabilis
Navicula atomoides
Navicula lanceolata
Pleurosira laevis
Thalassiosira fryxellorum var. laconicae
Navicula salinicola
Placoneis clementis
Rhoicosphenia abbreviata
Cocconeis scutellum
Cyclotella atomus
Cyclotella meneghiniana
Melosira moniliformis
Navicula minuscula
Navicula veneta
Navicula salinicola
Thalassiosira levanderi
Auliscus sculptus
Biddulphia mortificus
Cocconeis dirhyncha
Cocconeis pelliculata
Delphineis surirelloides
Grammatophora marina
Rhaphoneis amphiceros
Rhopalodia musculus
Thalassionema nitzschioides
Actinocyclus octonarius var. fenestrus
Actinoptychus senarius
Diploneis smithii
Hyalodiscus scoticus
Navicula salinicola
Opephora mumbaiensis
Paralia sulcata
Plagiogrammopsis vanheurckii
Thalassionema frauenfeldii
Thalassionema nitzschioides
Trybliosnella coarctata
Caloneiphaera quinquefasciata
Thalassionema nitzschioides
Gyrosigma elongatum
Delphineis minutissima
Actinocyclus octonarius var. fenestrus
Eunotogramma dubium
Thalassiosira proschkinae
Odontella aurita
Thalassiosira pseudonana
Plagiogrammopsis cravefordii
Dimeragramma minor
Navicula cincta var. rostrata
Plagiogrammopsis mediaequatus
Grammatophora oceanica
Melosira spp.
Dimeragramma aculum
Navicula spp.
Navicula aff. sp. 142/1
Nitzschia spp.
Mastogloia spp.
Navicula cincta var. "saline salt/alkali"
Cocconeis spp.
Navicula spp.
Navicula spp.
Eunotia spp.
Fragilaria spp.
Navicula cincta var. "minutissima" type
Navicula atomoides
Stauroneis spp.
Cyclotella spp.
Navicula salinoephoraphila


TNW005-VC
TNW042-VC
TNW069-VC
TNW109-VC
TNW047_2-VC
TNW078_1-VC
TNW075_2-VC
TNW079_1-VC
Lithostratigraphy
Formation
Member
Bed
Measured depth (m BSF)
Radiocarbon and OSL dates
Radiocarbon dates
OSL dates
Samples (m)
Microfossil salinity groups
Freshwater
Brackish
Marine
Misc
Molluscs
presence/absence
Diatom salinity groups
Boxtel
Wanneperveen
Naaldwijk
Walcheren
Wormer
Singraven
Wierden
Ecim
Brown Bank equiv.

This investigation was carried out by Fugro, commissioned by RVO, an agency of the Ministry of Economic Affairs and Climate Policy.

The information in this document is valid at the time of publishing (see month/year). Updates will be published on the website https://offshorewind.rvo.nl/ at the relevant sitemap (TNW), General Information, submap Revision Log and Q & A.
In the Revision Log is indicated which versions are the latest and what the changes are in relation to previous versions. The documents can be found at the relevant sites, indicated in the List of all reports and deliverables.

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Netherlands Enterprise Agency (RVO) | February 2022