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Neogene stratigraphy of the Langenboom locality (Noord-Brabant, the Netherlands)

E. Wijnker[1,*], T.J. Bor[2], F.P. Wesselingh[3], D.K. Munsterman[4], H. Brinkhuis[5], A.W. Burger[6], H.B. Vonhof[7], K. Post[8], K. Hoedemakers[9], A.C. Janse[10] & N. Taverne[11]

1 Laboratory of Genetics, Wageningen University, Arboretumlaan 4, 6703 BD Wageningen, the Netherlands.
2 Prinsenweer 54, 3363 JK Sliedrecht, the Netherlands.
3 Naturalis, P.O. Box 9517, 2300 RA Leiden, the Netherlands.
4 TNO B&O – National Geological Survey, P.O. Box 80015, 3508 TA Utrecht, the Netherlands.
5 Palaeocecology, Inst. Environmental Biology, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, the Netherlands.
6 P. Soutmanlaan 18, 1701 MC Heerhugowaard, the Netherlands.
7 Faculty Earth and Life Sciences, Vrije Universiteit, de Boelelaan 1085, 1081 EH Amsterdam, the Netherlands.
8 Natuurmuseum Rotterdam, P.O. Box 23452, 3001 KL Rotterdam, the Netherlands.
9 Minervastraat 23, B 2640 Mortsel, Belgium.
10 Gerard van Voornestraat 165, 3232 BE Brielle, the Netherlands.
11 Snipweg 14, 5451 VP Mill, the Netherlands.
* corresponding author. Email: erik.wijnker@wur.nl

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Abstract

The locality of Langenboom (eastern Noord-Brabant, the Netherlands), also known as Mill, is famous for its Neogene molluscs, shark teeth, teleost remains, birds and marine mammals. The stratigraphic context of the fossils, which have been collected from sand suppletions, was hitherto poorly understood. Here we report on a section which has been sampled by divers in the adjacent flooded sandpit 'De Kuilen' from which the Langenboom sands have been extracted. The studied section covers part of the marine Miocene Breda Formation and Pliocene Oosterhout Formation, and is topped by fluvial Quaternary deposits of presumably the Beegden Formation. The Breda Formation (15 - 18 m below lake surface) in this section is, based on organic walled dinoflagellate cysts, of an early-middle Tortonian age. The Oosterhout Formation (7 - 15 m below lake surface) comprises two depositional sequences, the lower of which (12 - 15 m below lake surface) presumably is the source of most Langenboom fossils. Combined dinoflagellate cyst and benthic mollusc indicators point to an early Zanclean – early Piacenzian age for this lower cycle. Its basal transgressive lag and (to lesser extent) top comprise reworked Tortonian taxa as well. Dinoflagellate cysts and a single benthic mollusc point to a Piacenzian age for the upper Oosterhout Formation sequence (7 - 12 m below lake surface).

Keywords: Breda Formation, Mill, Miocene, North Sea Basin, Oosterhout Formation, Pliocene.

Introduction

In the past twenty years, a fossil site near the village Langenboom (municipality Mill en Sint Hubert, Noord-Brabant, the Netherlands) developed into one of the most important localities of marine Neogene vertebrate fossils in northwestern Europe (Ahrens, 2003, 2004, 2005; Burger, 2006; Foekens, 2006; De Vos & Wijnker, 2006; Wijnker, 2005). It has been extensively sampled since the mid-1990s, especially by amateur collectors. Fossils are collected at sand depots where the sediments, excavated from various depths in the adjacent flooded sandpit 'De Kuilen', are dumped before further processing. The stratigraphic origin of the faunas is poorly understood and subject of debate (Janse, 1985; Wesselingh, 1986; Cadée, 1988; Ahrens, 2003, 2004). Various taxa have been reported with conflicting age estimates (ranging from Miocene to early Quaternary). Through this study we intend to elucidate the stratigraphic context of the fossils from the Langenboom locality. We describe the section of Langenboom based on a sampling campaign executed by scuba divers in the summer of 2005. Organic walled dinoflagellate cysts (dinocysts) are used for age estimates which are corroborated by macrofossils. In addition, we include an overview of fossils found *in-situ* by scubadivers. Based on these investigations we review the stratigraphic origin of the *ex-situ* found fossils.

Geological setting

The 'De Kuilen' pit at Langenboom is situated in the south-eastern part of the Netherlands, on the southern fringe of the North Sea basin, in the northwestern part of the Lower Rhine Embayment (Fig. 1). Since the Oligocene, tectonic activity has been increasing in this region, both because of the Alpine orogeny and the accelerated widening of the northern Atlantic (Ziegler, 1980). This resulted in a mosaic of NW-SE trending blocks, which show differential vertical and horizontal movements. The main structures are the Ruhr Valley Graben that has been particularly strongly subsiding during the Pliocene and Pleistocene, and the Peel Horst with generally less subsidence and some uplift during the same time interval. Both structures contain smaller blocks that experienced different subsidence histories (van Rooijen et al., 1984). Practically all tectonic units are tilting to the NE, which means that the youngest and also the thickest deposits on a block are to be expected in the NE part close to the bounding fault. Tectonic activity resulted in differentiation in facies and sedimentation during parts of the Neogene and influenced the position of the coastline (Fig. 1). The Langenboom site is located on an uplifted and rather narrow fault block that forms part of the Peel Fault Block. The bordering faults are located about one km from the pit in both SW and NE direction (Fig. 2).

The greenish brown glauconite- and mica-rich loamy fine sands of the Breda Formation (Westerhoff, 2003), that form the base of the studied section, are well known from boreholes in the vicinity of Langenboom where they occur up to a depth of circa 2 m above NAP (= Dutch Ordnance Level), which is about

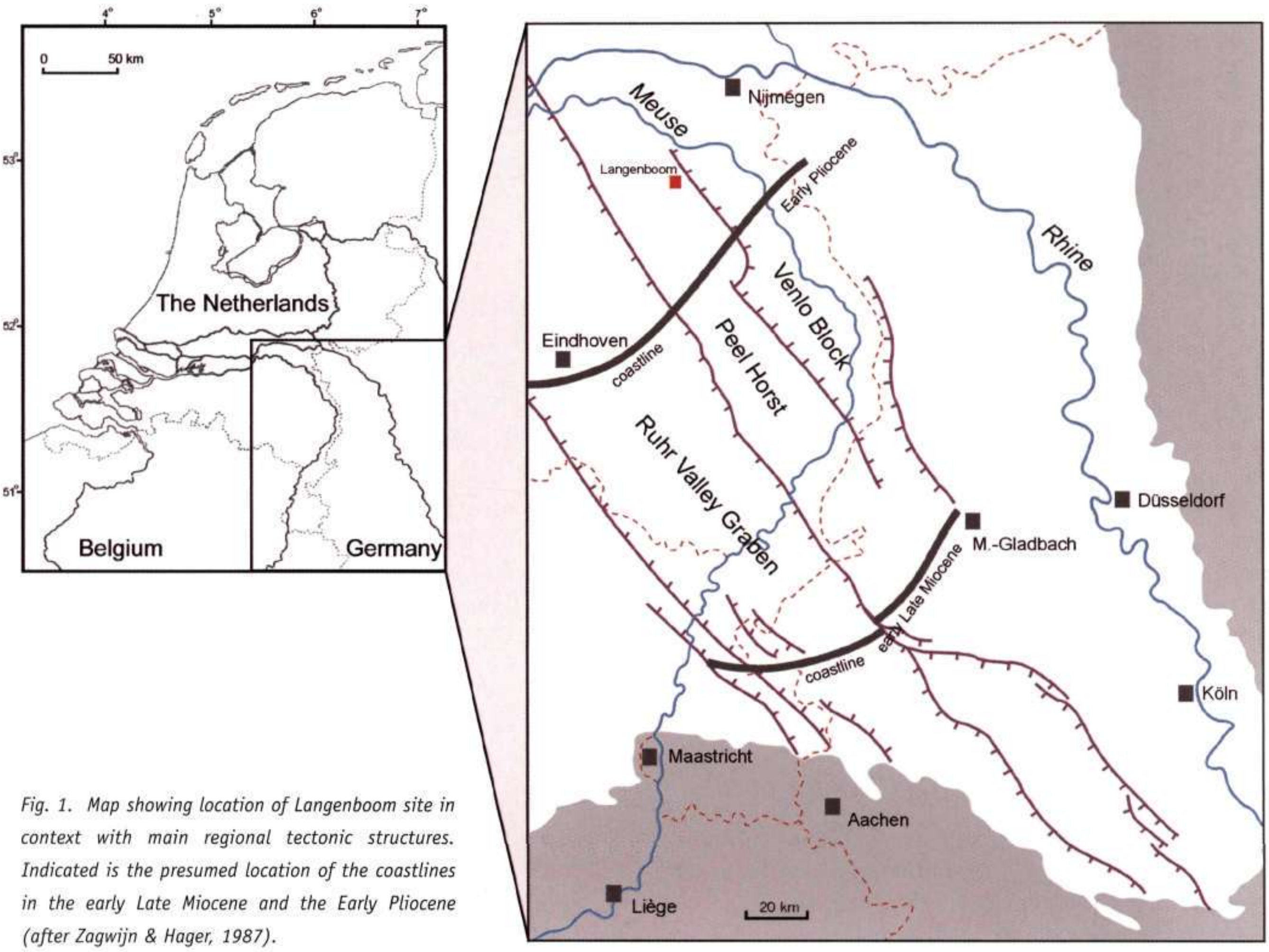

Fig. 1. Map showing location of Langenboom site in context with main regional tectonic structures. Indicated is the presumed location of the coastlines in the early Late Miocene and the Early Pliocene (after Zagwijn & Hager, 1987).

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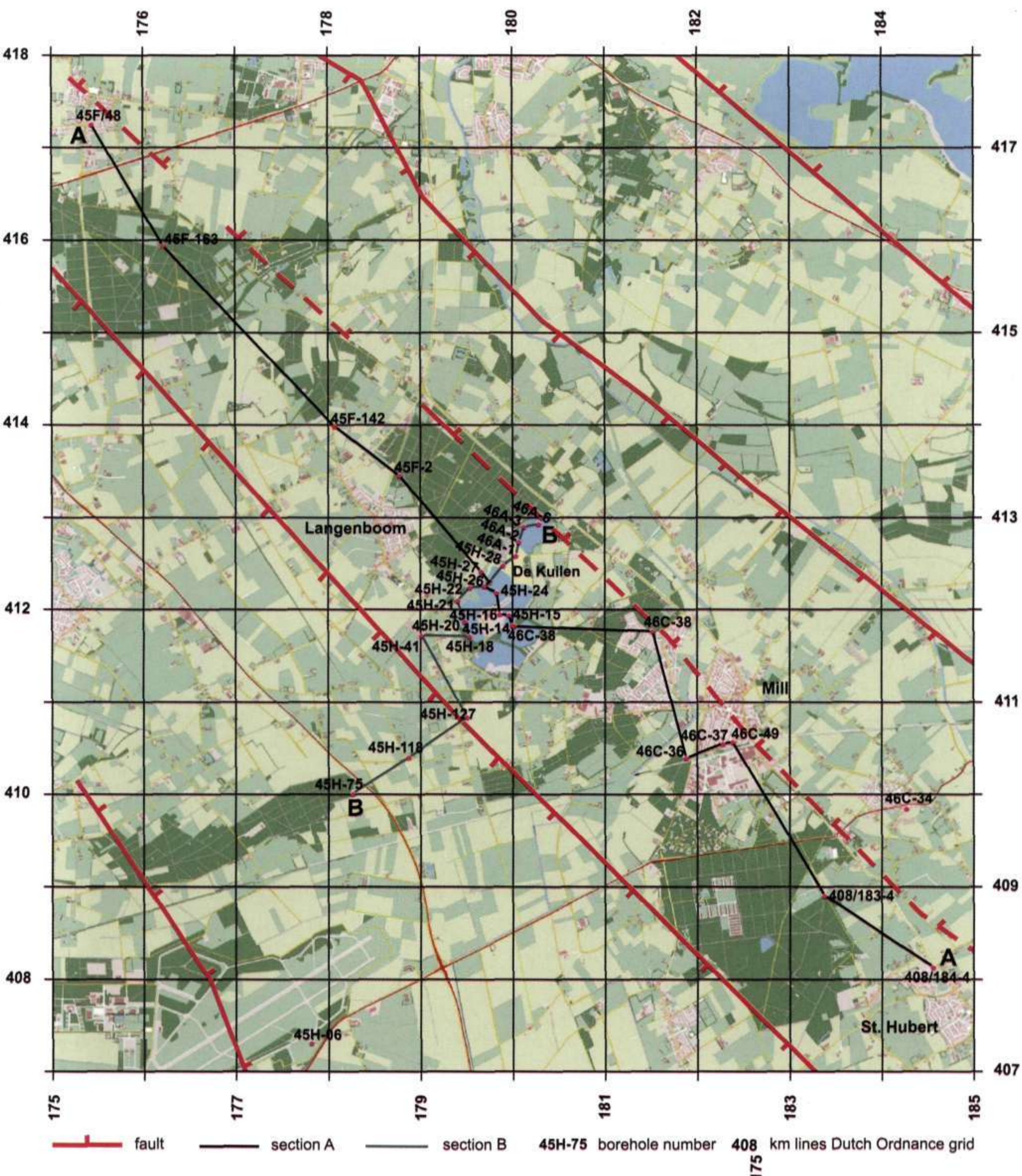

Fig. 2. Tectonic map of the surroundings of the Langenboom site. Indicated are the borehole cross-sections A and B presented in Figs 3 and 4. Borehole locations are marked by a red dot.

15 m below lake surface. The assumed coastline during the early part of the Late Miocene (during deposition of the Breda Formation at Langenboom) was some 125 km to the South of Langenboom (Zagwijn & Hager, 1987) (also see Fig. 1).

Pliocene deposits in the study area consist mainly of grey-green or green-grey fine sands with glauconite, occasionally rich in mollusc fossils, which are attributed to the Oosterhout Formation (Ebbing & De Lang, 2003). Study of the available borehole data shows that the Oosterhout Formation wedges out somewhere at the southern end of the village Mill, and dips to the northwest. The presumed coastline during the Early Pliocene must have been some 25 km to the south of the

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sandpit (Zagwijn & Hager, 1987) (Fig. 1). The toplayers of both the Oosterhout and the Breda Formation show often brownish or yellow colours due to oxidation. A change to a non-marine environment, e.g. the fluvial Pliocene Kieseloolite Formation, is not encountered on this fault block in the vicinity of Langenboom. The fluvial sands and gravels overlying the Oosterhout Formation are of a presumably Quaternary age and tentatively attributed to the Beegden Formation that includes all Quaternary Meuse deposits (Westerhoff & Weerts, 2003a). Two units of this formation seem to occur: a lower one, that is mainly brownish in colour, and a higher one, that is mainly grey in colour (see sections). Whether the lower unit should instead be attributed to the Waalre Formation (Westerhoff and Weerts, 2003b) deposited by the river Rhine, or whether both deposits are of the Meuse river is not to be said without petrographic study of the sediments. The region is covered by thin periglacial and local deposits of the Boxtel Formation (Schokker et al., 2003) with a maximum thickness of about 2 meters. Information deduced from boreholes is presented in sections (Figs 3 and 4).

Material and methods

The Langenboom site is an artificial lake called 'De Kuilen' (Fig. 5), situated halfway between the villages of Langenboom and Mill (Fig. 2). It was initially formed due to the subaqueous excavation of Quaternary fluvial sands and gravels present between 0 and 5 - 9 m below the surface. After exhausting the gravels and sands in the 1980s, excavations were resumed in the mid 1990s concentrating on the underlying fossiliferous Neogene sands, down to a lake depth of about 20 meters. Sands are dredged using a stationary suction dredger, applying a water jet attached to the suction inlet that is propelled to loosen and undermine the sediments. Water with loose and collapsed material is pumped ashore through a floating pressure pipeline and dumped into large sand depots adjacent to the lake. This dredging method results in steep vertical walls with fresh outcrop under water that are well suited for inspection and sampling by scuba divers.

The main sampling site for this study is a vertical wall ranging in depth from 10 to 17 m below water surface, at

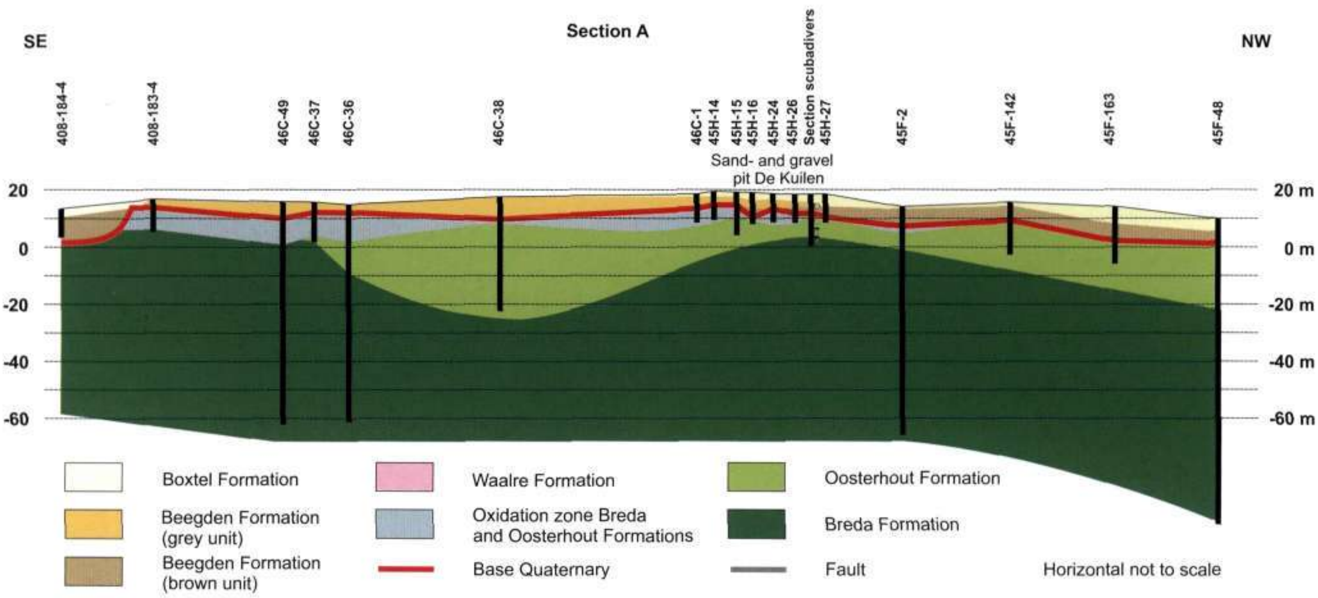

Fig. 3. Section A from southeast to northwest across the Langenboom locality. Note the 'De Kuilen' pit section with diver units A-D. Elevation in meters with respect to N.A.P.

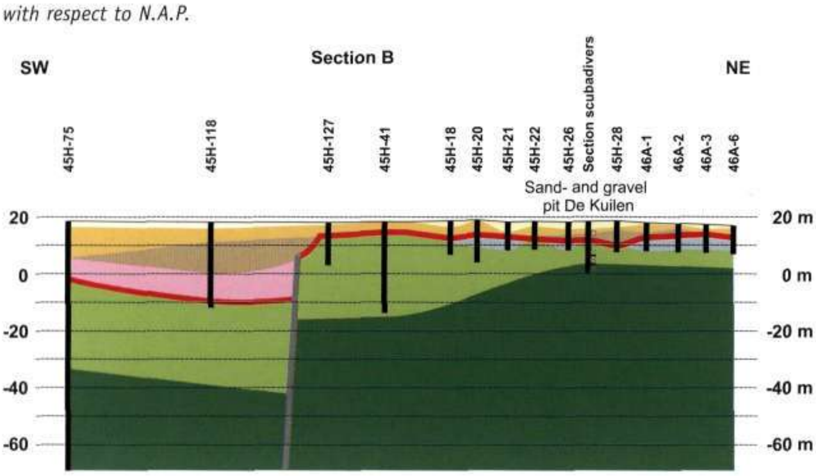

Fig. 4. Section B from southwest to northeast across the Langenboom locality. See Fig. 3 for legend.

Fig. 5. Aerial picture of the 'De Kuilen' lake, the Langenboom locality seen to north-east. The site of sampling, the dredge wall, is roughly where the suction dredger is located in the picture (fat arrow). The dump site is marked by a pointer.

WGS84 UTM coordinates 31U 0689709 5731071 (51°41'54.5"N; 5°44'42.8"E). The water surface is at about 17 m above N.A.P. The section was cleaned by removing possible precipitated sand from the wall surface, as well as incidental attached living zebra mussels (*Dreissena polymorpha*) on 16 August 2005. Samples were cut on 17 August 2005 from a rowing boat using closable plastic buckets that were lowered on lines to measured depths and were scooped with 3 - 6 litres of sediment by scuba divers. The sampling was started at the greatest depth, proceeding upward, preventing falling sands from contaminating underlying sampling depths. To prevent contamination of samples by swirling sands from diving activities, the succeeding sampling depths (being 1 meter apart vertically) were as well 3 metres apart horizontally. One extra sample was cut at 12.5 metres depth. The samples from 7 and 18 m below the surface were cut within a 60 m radius of the main sampling wall. No samples were taken at 8 and 9 m below the surface because that part of the section was not exposed in vertical walls and thus covered with precipitated sands. Samples are indicated throughout this paper by their sampling depth.

Lithological descriptions are based on visual inspection in the field, in addition to examination of sediment and sieve residues (0.2 mm mesh sieve) using a binocular microscope. Grainsize was judged with the aid of a sand ruler. All samples (except for 17 and 12.5 m) were selected for palynology and analysed with emphasis on organic walled dinoflagellate cysts (dinocysts). Samples 12.5 and 17 were not analysed since these samples showed no different lithology from the sample above it. Samples were processed at the Laboratory of Palaeobotany and Palynology at Utrecht University using standard techniques, involving HCL and HF digestion, no oxidation, 15 μm sieving, and preparation of at least two residue slides per sample. Dinocyst taxonomy is according to that cited in Williams et al. (2004). Key references concerning marine palynology of the Neogene and Early Pleistocene of the North Sea Basin e.g., Powell (1992), Head (1997; 1998; 1999), De Schepper et al. (2004), Louwye et al. (2004), Munsterman & Brinkhuis (2004), Meijer et al. (2006), and Kuhlmann et al. (2006) were consulted.

Fossil molluscs were obtained by washing circa 1 - 1.5 litre of sediment over a 2 mm sieve. Bivalve fragments with more than half the hinge and gastropod fragments with columella remains were counted. From these samples some plant fragments were obtained. Elasmobranch teeth and bony fish otoliths were obtained by washing an average of 2.2 litres of sediment over a 0.5 mm sieve, and sorting the residues. Duplicate sediment samples and all fossils obtained from these samples are filed in the paleontology collections of the National Museum of Natural History, Naturalis (Leiden, the Netherlands).

Identifications of additional *in-situ* finds were made (Table 4). These fossils did not result from our diving campaign, but were recovered during earlier dives. These fossils, when referenced with MAB numbers, are housed in the collections of the Oertijdmuseum 'De Groene Poort' (Boxtel, the Netherlands). Specimens in the private collections of Nico Taverne (Mill, the Netherlands) and Henry Peters (Sint Hubert, the Netherlands) are referenced with 'Coll. Taverne' and 'Coll. Peters' respectively. Stable isotope analyses on molluscs were performed using the methodology outlined in Vonhof et al. (2003). In this paper, we apply the timescale of the international stratigraphic commission and Gradstein et al., 2004.

Results

Lithological description

Four distinct lithostratigraphic units were identified in the Langenboom section, here identified bottom up as A through D (Fig. 6). These are based on lithological descriptions (Table 1), observations by scuba divers and borehole data.

Unit A (samples 16 - 18 m b.l.s.)

Unit A consists of homogeneous, compact, dark greenish brown, slightly silty, very fine-grained, well-sorted quartz sand with common fine-grained dark green glauconite and some small mica flakes. Unit A is largely decalcified. Aragonitic microfossils are lacking, however, calcitic microfossils like echinoid spines are still present. Macrofossils were not encountered by divers, but small fish remains like vertebrae and bones occur in the samples. The base of the unit probably extends below the bottom of the lake, but could not be observed below 18 m depth.

Unit B (samples 12 - 15 m b.l.s.)

The overlying unit B is a heterogeneous, 3 m thick, highly fossiliferous sand unit. It consists of dark greenish brown, slightly silty, fine-grained, well-sorted quartz sand with much fine-grained light green glauconite and abundant shell grit. Mica flakes are absent. A compact 10 - 30 cm thick basal shellbed is present at 15 m depth (Fig. 7), containing up to decimetre-sized pebbles and phosphoritic concretions, abundant thick bivalve shells (predominantly composed of *Arctica islandica*), phosphoritic shell moulds, many worn cetacean bones and elasmobranch teeth (*Cosmopolitodus hastalis* being most common). The basal shell bed is a distinctly protruding bed that is encountered on the same depth throughout the lake. Its base seems straight; the upper boundary is irregular. It is overlain by a two to three metres thick homogeneous, compact sand layer containing dispersed molluscs. Divers encountered *Xenophora* cf. *scaldensis*, *Scaphella lamberti*, *Callista chione*, *Mya truncata*, *Cyrtodaria angusta* and *Panopea faujasi*. About half of the bivalves are found paired, but oriented horizontally (suggesting some weak disturbance after death, possibly by

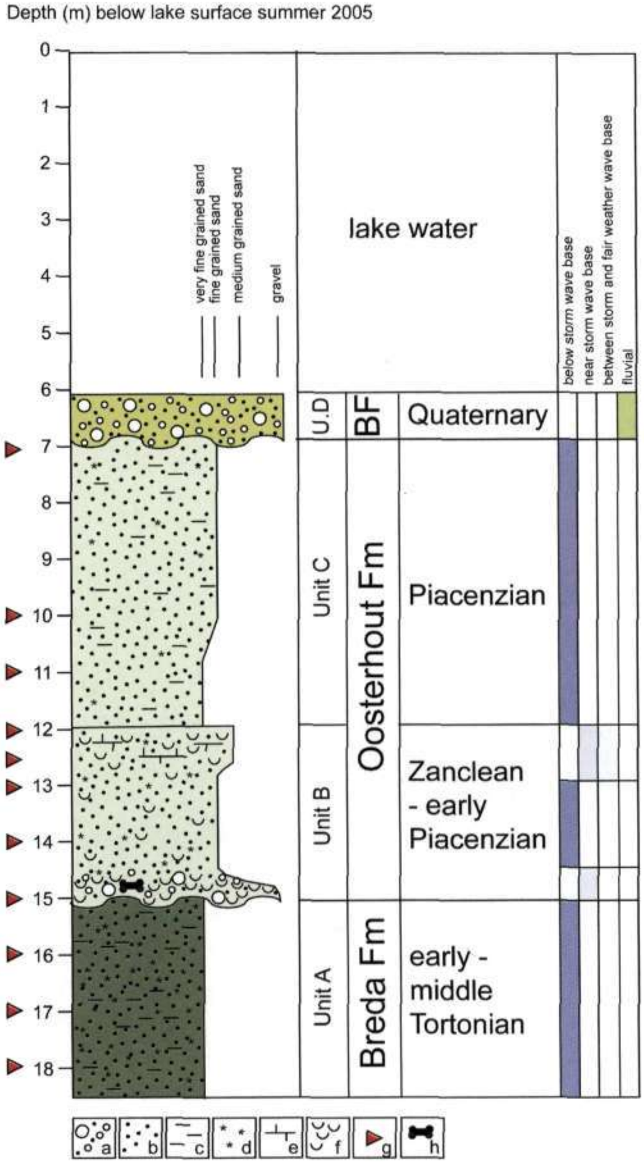

Fig. 6. Lithological column and stratigraphic interpretation of the Langenboom section based on samples and observations by scuba divers. Depth is in m below 17 August 2005 lake level. UD = unit D; BF = Beegden Formation; a = gravel; b = sand; c = silt; d = glauconite; e = carbonate cement; f = shells; g = sample location; h = bone.

bioturbation). At 12 m depth, a 30 - 60 cm thick, protruding, fossiliferous sandstone bank occurs in most places of the lake (Fig. 8). At places this layer is loosely packed, at other places it is very hard. Its lower boundary is poorly defined; the upper limit is sharp and straight. Irregularly, strongly cemented beds with tightly packed, very abundant *Ditrupa* cf. *arietina* tubes occur at the lower boundary of the 12 m layer.

Unit C (samples 7 - 12 m b.l.s.)

This unit consists of homogeneous, less compact, greenish grey, slightly silty, fine-grained, well-sorted quartz sand with some fine-grained light and dark green glauconite, lacking carbonate

Table 1. Lithological description of the samples from the Langenboom section (compare Fig. 6).

7 m	Greenish grey, light grey mottled, slightly silty, very fine to fine-grained, well-sorted quartz sand with very fine to fine-grained light and dark green glauconite, lacking carbonate and mica. When exposed to air, the colour changes rapidly to light greyish brown. Some sediment concretions. Few small casts and moulds of bivalves and gastropods. Some brachiopod valve fragments (*Lingula*). Few limonitized foraminifers, otherwise no microfossils. Few elasmobranch teeth.
10 m	Greenish grey, light grey mottled, slightly silty, very fine to fine-grained, well-sorted quartz sand with very fine to fine-grained light and dark green glauconite, carbonate lacking; very few small mica flakes. When exposed to air, the colour of the sediment changes rapidly to light greyish brown. Some sediment concretions. Few small casts and moulds of bivalves and gastropods. Some brachiopod valve fragments (*Lingula*) and plant remains. No microfossils. A single elasmobranch tooth.
11 m	Dark greenish grey, slightly silty, very fine-grained, well-sorted quartz sand with fine-grained light and dark green glauconite, lacking carbonate; very few small mica flakes. When exposed to air, the colour changes rapidly to dark greyish brown. Some sediment concretions. Few small moulds and casts of bivalves and gastropods. Some brachiopod valve fragments (*Lingula*) and plant remains. No microfossils.
12 m	Dark greenish brown, slightly silty, fine to medium-grained, poorly sorted and strongly cemented sand. Common fine-grained light and dark green glauconite. Abundant rounded shell grit (diameter typically below 2 mm). Many worn mollusc shells (bivalves, few gastropods). Few annelid tubes (*Ditrupa*), echinoid remains, brachiopod valves (Lingula) and bryozoans. Few teleost bones and some otoliths.
12.5 m	Dark greenish brown, slightly silty, fine to medium-grained, poorly sorted, in part strongly cemented sand. Common fine-grained light and dark green glauconite, lacking mica. Abundant rounded shell grit. Many worn shells (bivalves, few gastropods) and common annelid tubes (*Ditrupa*) and barnacle shells (*Balanus*). Some echinoid remains, brachiopod valves (*Lingula*), bryozoans and foraminifers. Few teleost bones and comparatively common otoliths and usually worn elasmobranch teeth.
13 m	Dark greenish brown, slightly silty, very fine to fine-grained, well-sorted quartz sand with common fine-grained light green glauconite, shell grit. Some sediment concretions. Many well-preserved, but also some worn shells (bivalves, few gastropods) and annelid tubes (*Ditrupa*). Some echinoid remains, brachiopod valves (*Lingula*), bryozoans, foraminifers and ostracods. Few teleost bones and some otoliths, few elasmobranch teeth.
14 m	Dark greenish brown, slightly silty, very fine to fine-grained, well-sorted quartz sand with common fine-grained light green glauconite, shell grit, but lacking mica. Some sediment concretions. Many well-preserved, in part worn, mollusc shells (bivalves, few gastropods) and annelid tubes (*Ditrupa*). Some echinoid remains, brachiopod valves (*Lingula*), barnacle shells (*Balanus*), bryozoans, foraminifers and ostracodes. Few teleost bones and some otoliths, rather many in part worn elasmobranch teeth.
15 m	Dark greenish brown, slightly silty and very sandy, fine to coarse-grained, poorly sorted gravel. Centimetre- to decimetre-sized pebbles (a.o. quartzite, slate), phosphorite concretions, and common, strongly abraded cetacean bone fragments. Shell grit and very common fine-grained dark and light green glauconite but lacking mica. Abundant thick bivalve shells (*Pygocardia*, *Arctica* and *Glycymeris*), few gastropod and scaphopod shells (*Fissidentalium*). Some annelid tubes (*Ditrupa*), echinoid remains, brachiopod valves (*Lingula*), bryozoans, foraminifers, ostracodes and wood remains. Few teleost bones and some otoliths, common, largely worn elasmobranch teeth.
16 m	Dark greenish brown, slightly silty, very fine-grained, well-sorted quartz sand with much fine-grained dark green glauconite; carbonate lacking, mica rare. Some sediment concretions. Few small echinoid spines, some foraminifers and a single ostracod. Common phosphatic teleost remains (vertebrae, bones, scales, a single tooth), and a single elasmobranch tooth.
17 m	Dark greenish brown, slightly silty, very fine-grained, well-sorted quartz sand with much fine-grained dark green glauconite; aragonite lacking, mica rare. Some sediment concretions. Few small echinoid spines. Common phosphatic teleost remains (vertebrae, bones, scales).
18 m	Dark greenish brown, slightly silty, very fine-grained, well-sorted quartz sand with fine-grained dark green glauconite; aragonite lacking, mica rare. Some sediment concretions. Some small echinoid spines and foraminifers. Common phosphatic teleost remains (vertebrae, bones, scales).

and containing very little mica. Macrofossils were not observed by divers. Only few fossils were found in the samples; carbonate fossils are only present as moulds. Brachiopod valve fragments, moulds of small molluscs, elasmobranch teeth and plant remains are present in very low numbers. Observations by scuba divers indicate no visual change in lithology between 7 and 10 m.

Unit D (0 - 7 m b.l.s, no samples.)

The uppermost unit D consists mainly of light-coloured, brown, grey and yellow, coarse-grained sands with high concentrations of gravel en boulders. Most of the interval is poorly exposed, and the presence of additional lithologies can be expected as was discussed in the geological setting.

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Fig. 7. Underwater photograph of the base of unit B (15 m). Height of pictured surface measures roughly 30 cm. Typical of this layer is the presence of Dentalium *sp. (1). Further note specimens of* Astarte *sp. (2) and* Glossus humanus *(3).*

Macrofossil content and palaeoenvironmental implications

Unit A: (samples 16 - 18 m b.l.s.)

Only few macrofossils were sampled in unit A. Elasmobranch teeth are rare in this unit; only one tooth of the skate *Raja* was collected (Table 2). Some calcitic fossils like echinoderm spines are present in all samples. Few aragonitic molluscs found in a sample in unit A (Table 3) are considered to be contaminants from the overlying B-unit since other aragonite traces are absent in the samples.

Unit B: (samples 12 - 15 m b.l.s.)

Molluscs: Unit B contains a diverse marine fauna dominated by bivalves (Table 3). The basal sample of unit B (15 m) is composed of a mixed fauna, with different preservation styles as well as some stratigraphic incompatible species (see age discussion below). In general, this 15 m shell bed is dominated by large bivalve species, such as *Glossus humanus, Arctica islandica* and *Pygocardia rustica* forma *tumida*. Scaphopods are a distinct group only found in this layer. Other common taxa in the basal shell bed include *Corbula gibba, Astarte incerta, A. obliquata, Turritella* cf. *incrassata* and *T. vanderfeeni*. Samples at 13 and 14 m yield in general a well-preserved fauna, dominated by *C. gibba*. Fragile species, such as *Yoldia semistriata, Abra* aff. *prismatica* and *A. alba* are common. Other common species include *Digitaria digitaria, Astarte*

Fig. 8. Subaqueous photograph of the top of unit B (12 m). Height of pictured surface measures roughly 20 cm. Note the high compaction of the material compared to the base of unit B. The top consists of in-situ broken shell fragments, among which are many Arctica islandica.

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Table 2. Distribution chart of elasmobranch teeth and teleost fish otoliths from the Langenboom section. Numbers between brackets refer to worn specimens.

			Elasmobranchii					Teleostei								
Unit	Sampling depth (m)	Sample size (l)	Hexanchidae indet.	*Cosmopolitodus hastalis*	*Cetorhinus* sp. (gill raker)	*Scyliorhinus canicula*	*Raja* spp.	*Gadiculus benedeni*	*Gadiculus verticalis*	*Trisopterus sculptus*	*Dicentrarchus labrax*	*Trachinus draco*	'genus Gobiidarum' *modestus*	*Pomatoschistius* sp.	'genus Gobiidarum' sp.	*Arnoglossus laterna*
C	7	3,0				1	1									
	10	3,0					1									
	11	4,4														
B	12	1,6			1				5			1				
	12,5	0,6					3 (8)	1	37	(1)		4	6	3	2	1
	13	1,6					2		7		1		4	1		
	14	3,8					10 (6)	1	16			1	3	3		
	15	2,5	(2)	(2)			6 (15)	10	1				1			
A	16	1,5					1									
	17	1,5														
	18	1,0														

incerta and *Ensis* cf. *hausmanni*. The common appearance of *D. digitaria*, whose upper depth range nowadays is 15 m below sea level (Marquet, 2005) and the presence of fragments of *Cuspidaria cuspidata*, whose modern upper depth range is quoted as 20 m below sea level, together with the presence of fragile *Abra* species, are indicative of depositional depths at or below 15 - 20 m. The extremely abundant occurrence of *Ditrupa* cf. *arietina* in the upper part of unit B resembles the mass occurrences of this species in the modern Mediterranean Sea (Grémare et al., 1998). There, dense populations (densities of thousands of individuals per square metre) occur in well-sorted fine sands and muddy sands in depths between twenty and thirty metres. Sample 12.5 m yields an admixture of species typical of samples 13 and 14 m, as well as some substrate dependent bivalve taxa (such as *Heteranomia squamula*). *Corbula gibba*, *Ensis* cf. *hausmanni*, *Astarte incerta*, *Digitaria digitaria* and *Cyclocardia scalaris* dominate the 12.5 m sample. Both fragile and well-preserved shells as well as strongly abraded shells and shell fragments occur in this sample. The 12 m sample contains few species that are generally worn. *Astarte incerta* is most common, but substrate-dependent species such as *Mytilus* cf. *antiquorum* also occur.

Concluding, the mollusc fauna is dominated by infaunal bivalves and gastropods, but epifaunal taxa occur in low numbers in the 15, 12.5 and 12 m samples. The shift in species composition, with common fragile infaunal bivalves in the 13 - 14 m interval suggests deepest depositional depths there.

Sharks and rays: Elasmobranch teeth are not rare in the samples from unit B (Table 2). The larger part (60%) of these teeth is worn, with larger elements like *Cosmopolitodus hastalis* concentrated in the shell bed at the base of this unit. Well-preserved teeth from this interval all belong to the skate *Raja*. In addition, a gill raker fragment of the basking shark *Cetorhinus* was found. The frequent occurrence of *Raja* throughout unit B may indicate a rather shallow sandy sea bottom with rich bottom vegetation, necessary for these fishes to attach the egg capsules.

Table 3. Distribution chart of mollusc species from the Langenboom section. # refers to fragmentary (uncountable) material.

Unit	Sampling depth (m)	*Nucula* cf. *trigonula*	*Nucula* sp.	*Yoldia semistriata*	*Glycymeris* sp.	*Mytilus* cf. *antiquorum*	*Aquipecten* cf. *opercularis*	*Palliolum gerardi*	*Ostrea edulis*	*Heteranomia squamula*	*Lucinoma borealis*	*Parvilucina scaldensis*	*Diplodonta rotundata*	*Felaniella astartea*	*Cyclocardia scalaris*	*Cyclocardia* spec.1	*Pteromeris corbis*	*Digitaria digitaria*	*Astarte incerta*	*Astarte obliquata* s.l.	*Astarte anus*	*Astarte corbuloides*	*Astarte trigonata*	*Astarte* cf. *galeotti*	*Astarte fusca* subspec.	*Astarte* sp. 1	*Astarte* sp. 2	*Astarte* sp. 3	*Astarte* sp. 4	*Astarte* s.l. sp.	*Parvicardium* cf. *scabrum*	*Laevicardium decorticatum*	*Spisula* sp.	*Spisula* cf. *triangulata*	*Spisula* cf. *albertanonorum*	*Cultellus cultellatus*	*Ensis* sp.	*Ensis hausmanni* s.l.	*Tellina benedeni*	*Tellina donacilla*
C	7																																							
	10			2																																				
	11																																							
B	12			1		#									4			4	17	1						3							1							1
	12.5		#	7			3	#		1		3			12		2	38	34	15				3			2		1			#	5	1				24	1	2
	13			11									1		3			15	23	9													1				#	15		
	14	1		11							1			#	1			15	14	6										2				3		1 ·	1	10		#
	15			4	1				1		3				2	2		1	22	10	2	5	5		6			2			1		2		1		1		1	
A	16																																							
	17																			1						1														
	18																																							

- Table 3 continued -

Unit	Sampling depth (m)	*Abra* aff. *prismatica*	*Abra* cf. *alba*	*Arctica islandica*	*Glossus humanus*	*Pygocardia* sp.	*Pygocardia rustica* forma *tumida*	*Pygocardia rustica* forma *solida*	*Dosinia lentiformis*	*Timoclea ovata*	*Venerupis rhomboides*	*Mya arenaria*	*Corbula gibba*	?*Lentidium complanatum*	*Cyrtodaria angusta*	*Hiatella arctica*	*Cuspidaria cuspidata*	*Thracia* sp.	Bivalvia indet.	*Calliostoma* sp.	*Turitella* cf. *incrassata*	*Turitella vanderfeeni*	*Epitonium frondiculum*	*Natica* sp.	*Aporrhais scaldensis*	*Galeodea bicatenata*	*Ficus conditus*	*Xenophora* sp.	?*Buccinum undatum*	*Amyclina labiosa*	*Ringicula buccinea*	*Pyramidella laeviuscula*	*Scaphander lignarus*	*Cylichna cylindracea*	*Dentalium* 'floratum'	*Dentalium sexangulum*	*Dentalium* sp.	**Total**
C	7																			1																		**1**
	10																			#																		**2**
	11																																					**0**
B	12						1			1			8	#	1			#																				**43**
	12.5	5	3	2						3	1	1	109	1	6	3	#			1	2		2	1	#								2	#				**296**
	13	10	7	2									51		2	4	#		#		5					#		#					1	1				**161**
	14	13	1	#	1	#			1	1	2		115		3				#			2		3				1				1	1	1				**212**
	15	2		14	2		4	1			1		42		2			1	1		9	11		1			#		1	1	1				2	1	2	**171**
A	16																																					**0**
	17																																					**2**
	18																																					**0**

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Bony fish otoliths: Otoliths were recovered from unit B only (Table 2). The 15 m sample is dominated by *Gadiculus benedeni* over *G. verticalis*. In the higher samples (12-14 m), *G. verticalis* is dominant over *G. benedeni*. Other common species include *Pomatoschistius* sp., *Arnoglossus laterna* and 'genus Gobiidarum' *modestus* (following the recommendation of Nolf, 1982, pp 98-99, otoliths of Tertiary Gobiidae are best described in open nomenclature).

Additional fossils from unit B are described in Table 4. These fossils were found by scuba divers in the years preceding this study, and do not result from the sampling campaign. These fossils are subjected to a distinct sampling bias of divers collecting generally larger fossils and focussing on the highly fossiliferous base of unit B.

Unit C (samples 7 - 11 m b.l.s.)

From the 10 m sample a small twig was recovered of a tree that could be identified as the pine *Sciadopitys verticillata* forma *fossilis* (RGM 234 632). Additionally, some unidentified angiosperm seeds were recovered from that sample. *Sciadopitys* is indicative of a warm temperate climate lacking very cold winters. It occurred in nutrient-poor lignite-forming swamps that occurred in the Niederrhein area to the east of Langenboom during the Pliocene.

Only rare manganese-oxide moulds of molluscs were found in the C unit, including a fragment of the gastropod *Calliostoma* and a paired mould of *Yoldia semistriata*. The presence of a paired specimen of *Yoldia* in unit C is characteristic for normal marine depositional settings below the fair-weather wave base. Few elasmobranch teeth were found in unit C, comprising one tooth of the catshark *Scyliorhinus canicula* and two teeth of the skate *Raja*.

Age

For the age determinations we rely mainly on dinocysts (Table 5). In general, the samples are moderately rich in reasonably to well-preserved and diversified marine dinocysts. The relative abundance (as compared to other palynomorph groups), and diversity of dinocysts both become less towards the top of the succession. A relatively large portion of the palynofacies is made up out of large fragments of plant remains and other palynodebris, in all slides. Reworking of older palynomorphs is limited, with a maximum of 5% of specimens in sample 16, the top of unit A. The reworked component of the dinocyst flora is dominated by Eocene and Oligocene specimens (see Table 5: PR symbols). Additional age indications from other fossil groups are discussed as well.

Unit A (samples 16 - 18 m)

An early-middle Tortonian age (SNSM12 Biozone *sensu* Munsterman & Brinkhuis, 2004) is assigned to unit A based on the FOD (= First Occurrence Datum) of *Achomosphaera andalousiensis*, the LOD (= Last Occurrence Datum) of

Table 4. Record of known in-situ found fossils from the Langenboom site. These fossils were recovered in the years preceding the sampling campaign. There is a distinct sampling bias in these fossils because divers focused on the highly fossiliferous base of unit B. MAB = Collection Oertijdmuseum, Boxtel.

Sharks and Rays	230 Recovered shark and ray teeth (Coll. Peters) from the base of unit B (15 m) are almost invariably black and worn. Only two well-preserved bluish teeth with sharp cutting edges are present. Larger teeth are dominated by *Cosmopolitodus hastalis* (n = 156) while *C. escheri* (n=19), *Lamna* sp. (n = 17) and *Notorynchus cepedianus* (n = 14) are also common. Other elasmobranch remains comprise teeth of *Squatina* sp., *Carcharias* spp., *Cetorhinus maximus*, *Carcharinus priscus* and dermal denticles (bucklers) of *Raja clavata*.
Birds	Three fragments of bird bones were recovered from the base of unit B at 15 m (Coll. Peters). These are brown or black in colour, and can be attributed to at least two species of auks (Alcidae), one of which, a humeral diaphysis, is identified as *Alca antiqua*.
Terrestrial mammals	A molar of the deer *Cervus rhenanus* was found in Unit B at a depth of 14 m (De Vos & Wijnker, 2006).
Marine mammals	Over 200 fossil bones and teeth (all Coll. Peters unless indicated otherwise) were recovered from the 15 m layer. About 85% were identified as baleen whales (Mysticeti) of which the far majority belongs to the Cetotheriidae, a polyphyletic basket of archaic mysticetes. Judging from size, at least 2-3 taxa are present. One bulla belongs to the family Balaenopteridae. Among toothed whales (Odontoceti) teeth of sperm whales (Physeteridae) are most common. All are attributed to rather archaic forms carrying enamel cups on the teeth. Beaked whales (Ziphiidae) are present, the best-preserved element being a black, heavily mineralized rostrum of *Mesoplodon longirostris* (MAB 04231). This specimen is worn and presumably reworked. A single element of a porpoise (Phocoenidae) was identified. Pinnipedia are scarce and all pertain to true seals (Phocidae). At least two unidentified taxa are present. Walruses (Odobenidae) are represented by few elements of *Alachterium cretsii*. Bones of marine mammals from the base of unit B are uniformly black in color and generally well preserved. The fossils are always found disarticulated. A single vertebra of an unidentifiable baleen whale (Mysticeti) was found in the top of unit B, at 12 m (Coll. Taverne). The vertebra is, contrary to material found in the base of unit B light brown in color, perfectly preserved and is at some points covered by cemented molluscs.

Table 5. Dinocysts from the Langenboom section. A = abundant, C = common, P = present, R= reworked. Samples at 12.5 and 17 m have not been analysed.

Unit	Sampling depth (m)	*Achomosphaera andalousiensis suttonensis*	*Filisphaera microornata*	*Lingulodinium machaerophorum*	*Melitasphaeridium choanophorum*	*Operculodinium centrocarpum*	*Spiniferites mirabilis*	*Spiniferites* spp.	*Tectatodinium pellitum*	*Achomosphaera andalousiensis*	*Barssidinium pliocenium*	*Bitectatodinium tepikiense*	*Heteraulacacysta* spp.	*Selenopemphix quanta*	*Trinovantedinium* spp.	*Amiculosphaera umbracula*	*Nematosphaeropsis* aff. *downiei*	*Operculodinium eirikianum*	*Ataxiodinium choane*	*Barssidinium graminosum*	*Impagidinium* spp.	*Operculodinium* sp. 1 (Louwye et al., 2004)
C	7	R	P	C	P	R	R	C	P													
	10	P		R	P	C		C		P	P	P	P	P	P							
	11	R	R	C		C	R	P						R		P	P	P				
B	12		R	A		A	R	C		R			R									
	13	P		A	P	R	P	R		R	C		P	P					P	R	P	P
	14			P	P	P	P		P	P	C								P			
	15			R	R	P		A		P	R	P		P		R				P		
A	16			C	P	P		C		R	C	P			R							
	18			P		P				P	P											

Unit	Sampling depth (m)	*Operculodinium tegillatum*	*Selenopemphix armageddonensis*	*Selenopemphix brevispinosum*	*Trinovantedinium ferugnomatum*	*Invertocysta lacrymosa*	*Hystrichokolpoma rigaudiae*	*Operculodinium* spp.	*Reticulatosphaera actinocoronata*	*Selenopemphix dionaeacysta*	*Cristadinium* spp.	*Enneadocysta* spp.	*Habibacysta tectata*	*Headinium miocenicum*	*Hystrichokolpoma* spp.	*Kalyptea stegasta*	*Labyrintodinium truncatum*	*Palaeocystodinium golzowense*	*Paralecaniella* spp.	*Wetzeliella* spp.	*Cordosphaeridium minimum*	*Dapsilidinium* spp.	*Hystrichosphaeropsis obscura*
C	7																			PR			
	10																						
	11																						
B	12																						
	13	P	P	R	P																		
	14		P	P		P																	
	15	P		R		P	R	P	C	P													
A	16			R					C	P	P	PR	R	R	P	PR	C	C	C	PR			
	18			P					R	P				R			C	P	R		P	P	P

Palaeocystodinium golzowense (that is common in sample 16), the LOD of the common *Labyrinthodinium truncatum* and the LOD of *Hystrichosphaeropsis obscura* in sample 18. Unit A can be correlated with the Deurne Sands of the Late Miocene Diest Formation in the Antwerp area (Louwye, 2002).

Unit B (samples 12 - 15 m)

Based on the common occurrence as well as the LOD of *Reticulatosphaera actinocoronata* in sample 15 m, that sample is assigned an early Zanclean age. The species has a last common occurrence within Subchron C3n2r (~ 4.7 Ma) in the western North Atlantic, DSDP Site 603C (Head, M.J., unpublished data), respectively in the northern North Atlantic, DSDP Site 611 within Subchron C3n1r (~ 4.4 Ma; Baldauf et al., 1987). Louwye et al. (2004) show the LOD of *R. actinocoronata* in the Kattendijk Formation of the Antwerp region (age estimates of this and other Pliocene formations given in Table 6). Dinocysts with a LOD in the Miocene are absent in the sample, and are also absent as reworked specimens. The mollusc fauna of the 15 m sample is dominated in numbers of species and abundance by taxa of Zanclean-Piacenzian age. Several species only known from the Zanclean Kattendijk Formation and the Coralline Crag Formation of eastern England (Table 6) occur in the 15 m sample, including *Pygocardia rustica* forma *tumida* and forma *solida* and *Turritella vanderfeeni*. Furthermore, reworked Late Miocene mollusc taxa, such as *Fissidentalium* sp. and *Astarte anus* occur in low numbers in sample 15 m. These latter taxa are very often strongly worn.

Table 6. Age estimates (in Ma) of Pliocene formations in the southern North Sea Basin from literature data. [1] Head & Norris, 2003; [2] De Schepper, 2006. BSU = 'Basal Shelly Unit'.

Formation/Member	Age estimate (Ma)
Red Crag Formation	< 2.74[1]
Lillo Formation	
Kruisschans Member	3.21 - 2.76 (?2.76 - 2.55)[1]
Oorderen Member (including BSU)	3.21 - 2.76[1]
Luchtbal Member	3.8 - 3.21[1]
Coralline Crag Formation	4.4 - 3.8[2]
Kattendijk Formation	4.86 - 4.37/4.00[1]

Based on the LOD of *Selenopemphix armageddonensis*, the FOD of *Achomosphaera andalousiensis suttonensis* and the LOD of *Operculodinium tegillatum*, interval 13 - 14 m is interpreted to be of a middle-late Zanclean age. *Reticulatosphaera actinocoronata* is absent in samples from this interval, suggesting an age younger than early Zanclean. Louwye et al. (2004) suggest that the LOD of *S. armageddonensis* occurs in the Kattendijk Formation (at the Verrebroek Dock near Antwerp, Belgium). However, a hiatus, comprising the Luchtbal Member (De Schepper, 2006: 3.21-3.8 Ma), is recorded above the Kattendijk Formation in the Deurganck and Verrebroek Dock outcrops near Antwerp (Louwye et al., 2004). In the overlying 'Basal Shelly Unit' of the Oorderen Member, *S. armageddonensis* is absent. Together, this information also suggests an age younger than early Zanclean for this interval at Langenboom. Moreover, the FOD of *A. andalousiensis suttonensis* is evidenced from the 'Basal Shelly Unit' in Belgium (Louwye et al., 2004), matching our record from Langenboom. Also, the LOD of *O. tegillatum*, discussed in Louwye et al. (2004), has an age of ~3.5 Ma (near the Zanclean-Piacenzian boundary). This while occurrences younger than ~3.9 Ma possibly represent reworking according to unpublished studies of M.J. Head (pers. comm., 2006).

The mollusc fauna of the 13 - 14 m interval is dominated by Zanclean and Piacenzian mollusc taxa. In the Langenboom samples only *Cyclocardia scalaris* is present but *C. chamaeformis* is lacking. Within the Antwerp Pliocene succession the former species occurs in the Zanclean Kattendijk Formation, and both co-occur in the overlying Piacenzian Lillo Formation as well as in the Late Zanclean Coralline Crag Formation of East Anglia. Furthermore, the presence of *Turritella vanderfeeni* and *Pyramidella laeviuscula* in sample 14 m, both so far only recorded from the Kattendijk Formation and the Coralline Crag Formation (Marquet, 1998; Wood, 1848), support a Zanclean age.

The dinocyst association of sample 12 m consists of stratigraphically long-ranging, undiagnostic taxa only, and based on superposition the age is established as undifferentiated middle Zanclean to (early) Piacenzian. The mollusc fauna of samples 12.5 and 12 m shares numerous species with the latest Zanclean-Piacenzian Luchtbal and Oorderen Members of the Antwerp region and the late Zanclean Coralline Crag Formation of East Anglia, but lacks a number of indicative species of the late Piacenzian Kruisschans Member and Red Crag Formation. The presence of two Pacific immigrant species, *Mytilus antiquorum* and *Mya arenaria*, associated with an immigration event dated at ~3.1 - 4.1 Ma (Marinkovich & Gladenkov, 2001; Gladenkov et al., 2002) indicate a late Zanclean – early Piacenzian maximum age. Earlier fauna exchange existed between Pacific and Atlantic Oceans, leading to the predominant dispersal of Atlantic taxa into the Pacific, but the introduction of *Mytilus* and *Mya* into the northern Atlantic has been documented in the Tjoernes successions of northern Iceland as part of the Pliocene event. The total mollusc evidence thus points to a latest Zanclean to middle Piacenzian age for interval 12 - 12.5 m. The only exception is the presence of *Pygocardia rustica* forma *tumida*, thus far only described from the lower part of the Kattendijk Formation. Its presence in the 12.5 m sample possibly concerns a reworked specimen.

The dominance of *Gadiculus benedeni* over *G. verticalis* in the 15 m sample seems to be comparable with the Kattendijk Formation and Luchtbal Sand Member of the Lillo Formation (Zanclean) of the Antwerp area (Nolf, 1978). In the higher samples (12 - 14 m), *G. verticalis* is dominant over *G. benedeni*. In the Pliocene of the Antwerp region *G. verticalis* is known throughout the section, albeit in small numbers from the Kattendijk Formation and Luchtbal Sand Member (Nolf, 1978). *Pomatoschistius* sp., 'Genus Gobiidarum' *modestus* and *Arnoglossus laterna* are known throughout the Pliocene of the Antwerp region, with their maximum abundance in the Luchtbal Sand Member. The recovered otoliths do not permit a more detailed stratigraphic interpretation. A single worn specimen of *Trisopterus sculptus*, typical of the northeastern Atlantic Miocene, from 12.5 m, is probably reworked, because the species is completely unknown from the Pliocene.

Unit C (samples 7 - 11 m)

Based on the LODs of *Achomosphaera andalousiensis suttonensis*, *Melitasphaeridium choanophorum* and *Barssidinium pliocenicum*, the age of unit C is interpreted as (early) Piacenzian. According to Head (1998) the LODs of *A. andalousiensis suttonensis* and *M. choanophorum* are in the early Piacenzian (~3.4 - 3.6 Ma). Louwye et al. (2004) recorded *A. andalousiensis suttonensis* in the Oorderen Sands Member. The first occurrence of this taxon is in the aforementioned 'Basal Shelly Unit'. Louwye et al. (2004) show that the last occurrence of *M. choanophorum* is associated with the Kruisschans Member in Belgium. Kuhlmann et al. (2006) show that the LOD of *Barssidinium* spp. falls within the Piacenzian (circa 2.6 Ma).

The presence of a mould of a pair of *Yoldia semistriata* in sample 10 m indicates that the deposits are older than the late Piacenzian Kruisschans Member of the Antwerp region, where the species is replaced by *Y. heeringi*, and confirms the Piacenzian age of the upper Oosterhout Formation sequence in Langenboom. The presence of the pine *Sciadopitys verticillata* forma *fossilis* in sample 10 m points to a Pliocene or early Pleistocene age.

Sea surface temperatures (SST)

The presence of the dinocysts *Barssidinium*, *Achomosphaera andalousiensis*, *Melitasphaeridium choanophorum*, *Tectatodinium pellitum* and common *Spiniferites* spp. indicate a temperate to subtropical sea surface temperature. (Sub)polar taxa, like *Habibacysta tectata*, *Filisphaera microornata*, *Headinium miocenicum* and *Bitectatodinium tepikiense* are only rarely recorded. Delta ^{18}O ratios of six shells from the B-unit ranged between +1.6 and +2.5 per mil. Applying a paleotemperature equation for aragonite (Kim & O'Neill 1997), a 4.5 - 8.3° C sea surface temperature was reconstructed based on these $\delta^{18}O$ values. These conflicting results are discussed below.

Discussion

Stratigraphic synthesis

Four lithological units are present in the Langenboom section of which the lower three are marine and of Neogene age (Fig. 6). Unit A consists of homogenous decalcified fine-grained glauconitic sands and is attributed to the Breda Formation (Doppert et al., 1975; Westerhoff, 2003). The unit was deposited in normal marine settings below storm wave base during the early to middle Tortonian (~8.7 - 11.0 Ma).

Unit B is characterized by grey sands with variable (but relatively low) amounts of glauconite and abundant carbonate fossils. It is attributed to the Oosterhout Formation for which the abundant presence of marine shells and relatively low content of glauconite are indicative (Doppert et al., 1975; Ebbing & De Lang, 2003). Unit B appears to comprise a single depositional sequence, with a basal transgressive shell bed at 15 m that contains many reworked Early Pliocene and some Miocene fossils (with a very heterogeneous preservation). The shell bed grades into fine-medium-grained sands with dispersed

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molluscs that lived in and on sandy bottoms at or slightly below 15 - 20 metres water depth, and that in turn grades into a more coarse-grained sandstone with abundant abraded bioclastic grit and increasing numbers of substrate dependent species at 12.5 - 12.0 m indicative of shallowing above storm and possibly fair-weather wave base. The upper part of the sequence is indurated. The fossils point to an early Zanclean age for the base (with considerable addition of naturally reworked Late Miocene taxa), a middle-late Zanclean age for the middle part of the sequence (13 - 14 m) and a late Zanclean to early Piacenzian age for the top of unit B.

Unit C consists of homogeneous, fine, decalcified sands in which few fossils are present. The recovered molluscs, shark and ray teeth indicate normal marine depositional settings below the fair-weather wave base. The presence of plant debris indicates proximity of terrestrial sources. The fossil data point to an early-middle Piacenzian age. The C-unit is also attributed to the Oosterhout Formation based on criteria discussed in Doppert et al., 1975 and Ebbing & De Lang, 2003.

Unit D consists of fluvial sands, gravels and boulders of presumed Quaternary age. These deposits are tentatively assigned to the Beegden Formation, which includes all Quaternary Meuse deposits (Westerhoff & Weerts, 2003a). However, the presence of Waalre Formation deposits (Westerhoff & Weerts, 2003b) cannot with certainty be excluded. Directly below the surface, covering the Langenboom section, a thin deposit of the Boxtel formation was possibly present (Figs 3, 4). It comprises mainly fine sands of local and aeolian origin.

Reworking

Reworking of fossils is observed in two different layers. The base of unit B (15 m) shows much reworking and contains mollusc taxa indicative of Miocene age: *Fissidentalium* sp. and *Astarte anus*. The presence of both the walrus *Alachterium cretsii* and the beaked whale *Mesoplodon longirostris* (Table 4) corroborates this observation. Reworking in the 12.5 m sample was also shown, but to a far smaller extent: the mollusc *Pygocardia rustica* forma *tumida* is presumably reworked from Early Pliocene deposits and the teleost fish *Trisopterus sculptus* is most probably Miocene.

Sea surface temperatures (SST)

Sea surface temperature estimates based on $\delta^{18}O$ ratios indicate very low temperatures of 4.5 - 8.3° C. This contradicts temperature estimates based on dinocysts from our samples as well as previous estimates for the southern North Sea Basin during the Early Pliocene, that show higher than modern values (Johnson et al., 2000; Kuhlmann et al., 2006). Johnson et al. (2000), comparing growth increment lengths and stable isotope values of both modern and Zanclean *Aequipecten opercularis*, concluded that cryptic diagenesis caused these aberrant isotope estimates. It is therefore likely that the Langenboom shells, despite their often (superficial) good preservation also may have undergone such diagenesis. The presence of many stenohaline mollusc species rules any substantial deprivation of salinity by influx of fresh water out.

Inconsistent ex-situ finds

Our observations point to unit B (Oosterhout Formation) as the most likely source for the carbonate fossils such as molluscs and otoliths, commonly collected by collectors in Langenboom. However, some mollusc taxa have been collected *ex-situ* at Langenboom that are generally seen as late Piacenzian to Gelasian indicators. These include *Tridonta elliptica*, *'Laevicardium' parkinsoni*, *Cerastoderma hoistei*, *Lentidium complanatum* and *Hinia propinqua* (Spaink, 1975). *Lentidium complanatum* is common in the Kruisschans Member (latest Piacenzian-earliest Gelasian) of the Antwerp area, but other *Lentidium* species occurred in the North Sea Basin during the Miocene, allowing for the possibility that its absence in deposits of Zanclean-Piacenzian age is due to rarity. The high form of *C. hoistei* with its distinctly triangular rib profile matches with cardiids seen in the Zanclean Coralline Crag Formation of East Anglia. Thus three mollusc species suggest that other sources than the B-unit may have been present in the Langenboom area: *T. elliptica*, *'L.' parkinsoni* and *H. propinqua*. Whether it concerns local carbonate bearing strata in unit C, locally exposed marine fossiliferous units overlying the C-unit or species of which the known stratigraphic range should be extended is uncertain.

De Vos and Wijnker (2006) citing Gliozzi et al. (1997) previously indicated that the wild boar *Sus strozzii* reported by Ahrens (2004) is a taxon that has not been reported prior to 2.2 Ma. However, according to Faure (2004), *S. strozzii* is known from the Lower Villafranchian (= Piacenzian) onwards and hence does not conflict with the age estimates of the Oosterhout Formation interval in the Langenboom section. We can however not exclude a possible origin of this tooth from the overlying unit D.

Derivation of other fossils

The Langenboom locality has yielded impressive numbers of fossils. Currently, 191 species of molluscs (Burger, 2006) have been reported as well as 35 species of birds (Meijer, 2004; Wijnker, 2005), and several species of terrestrial mammals (Ahrens, 2004; De Vos & Wijnker, 2006). Preliminary identifications further indicate the presence of at least 9 crustaceans (René Fraaye, pers. comm.), 30 plus species of sharks and rays (Taco Bor, unpublished data), more than 30 teleost taxa (otoliths) (Kristiaan Hoedemakers, unpublished data), over 20 species of whales and dolphins, a walrus, four seals (Klaas Post, unpublished data). All these fossils have been collected *ex-situ*.

The presence of molluscs cemented to an *ex-situ* found tooth of the mastodont *Anancus arvernensis* and a bear radius of *Ursus* cf. *etruscus* (Ahrens, 2004) can be held indicative for their derivation from carbonate bearing unit B. We assume the fossils derive from the top of the unit that consists mainly of cemented shell grit. As such, these mammals can be associated with the *in-situ* molar of the deer *Cervus rhenanus* from the middle part of unit B (De Vos & Wijnker, 2006).

Shark teeth collected by divers from the basal shell bed of unit B are almost invariably worn and have a black colour. However, over half the teeth collected *ex-situ* are well preserved, and bluish instead of black. Therefore, considerable numbers of shark teeth derive from other sources than the basal layer of unit B.

The base of unit B produces large amounts of fossil marine mammals, bones that are invariably black in colour, whereas many found *ex-situ* are brown. The stratigraphic origin of the latter is uncertain. A vertebra of a mysticete in the 12 m layer is brown in colour, indicating the 12 m layer is a possible source. The absence of true dolphins (Delphinidae) among the fossils retrieved from the base of unit B is remarkable compared to their regular occurrence in the *ex-situ* material. Most *ex-situ* found periotica belong to this family that did not become dominant until the Piacenzian. The possibility that divers do not recognize periotica of Delphinidae in the base of unit B is regarded unlikely seen in the light of the many often small, fossils present in their collections. The presence of cemented carbonate fossils to some *ex-situ* found periotica of Delphinidae points to the top of unit B as source of at least part of these fossils. The presence of the walrus *Alachtherium cretsii* in the base of unit B pushes the first occurrence of the species into the Zanclean, like was previously reported for the deer *Cervus rhenanus* (De Vos & Wijnker, 2006).

Conclusions

The Langenboom section comprises an early-middle Tortonian interval of the Breda Formation, two Zanclean-early Piacenzian sequences of the Oosterhout Formation and is topped by Quaternary fluvial gravels, presumably of the Beegden Formation.

The succession of the Breda-Oosterhout Formation may roughly be associated with that in the Antwerp-Campine area (northern Belgium). The deposition of the marine Diest Formation in that setting ended by lowering of the sea level, resulting in a distinct disconformity (latest Tortonian-Messinian) between the Diest Formation and the superjacent lower Pliocene Kattendijk Formation (Louwye et al., 2007). The shallow marine environment shoaled and a regressive phase started, which also strongly affected the Langenboom area, notably on the Peel Block High. The lithological change in Langenboom at 15 m, indicates the presence of an erosional or regressive phase between the Breda and Oosterhout formations. This phase recorded during the latest Miocene at the border of the southern North Sea coevals the global cooling and increasing ice volume (e.g. Hodell & Kennett, 1986; Adams et al., 1977).

Almost all carbonate fossils we found in sands mined from the lake are from the lower Oosterhout Formation sequence that also comprises older (Miocene) reworked fossils in its base and top. The mollusc fossil fauna from the suppleted terrains contains low amounts of taxa that are usually associated with latest Piacenzian to Gelasian ages. Such deposits were not found in the studied section.

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