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Geoarchaeological and palaeontological research in the Maasvlakte 2 sand extraction zone and on the artificially created Maasvlakte 2 beach: a synthesis

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Part 2

Geoarchaeological and palaeontological research in the Maasvlakte 2 sand extraction zone and on the artificially created Maasvlakte 2 beach: a synthesis

**M. Kuitens, Th. van Kolfschoten, F. Busschers,
and D. De Loecker**

Colophon

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Summary

In order to facilitate a large-scale expansion of the port of Rotterdam, an extensive new area, called Maasvlakte 2, was created. Reclamation of the area involved the transportation of 240,000,000m³ of sediment from a sand extraction zone located ten kilometres off the coast of the Dutch province of Zuid-Holland, to the present location of Maasvlakte 2. Consequently, in both the land reclamation area and the sand extraction zone, drowned Palaeolithic and Mesolithic landscapes were disturbed. In order to collect as much data as possible and to record any archaeological remains encountered, a multidisciplinary geoarchaeological and palaeontological research project was carried out in the sand extraction zone and on the beach of the Maasvlakte 2 area.

The sand extraction zone was subjected to intensive geological field research. Dozens of boreholes were drilled and modern geophysical methods (e.g. seismic analysis, Side-Scan Sonar) were deployed. The geological structure of the sand extraction zone was mapped in detail and lithological analysis was performed on the core samples. Seven partially informal lithostratigraphic units were defined and characterised. These units, ranging in age from late-Early Pleistocene/Middle Pleistocene to recent, were broadly correlated with the stratigraphic framework known from the mainland. A detailed chronology and a comparison with lithostratigraphic units defined in other projects still await the publication of OSL dates obtained from the core samples; when the present report was being prepared these dates were not yet available. The cores yielded a rich malacological dataset and a limited amount of fossil vertebrates. In addition, the core samples were analysed for the presence of pollen, macrobotanical remains, dinoflagellates, diatoms, and fungal spores.

Targeted fishing trips were carried out in the sand extraction zone, using a beam trawler to look for molluscs, bone fragments, archaeological objects, and stones. This resulted in the identification and localisation of areas with a high concentration of archaeological and palaeontological finds. The collected material was identified and either taphonomically or typologically analysed. The fishing trips yielded a large amount of finds from different time periods. Almost all vertebrate remains derived from mammals that are typical of the mammoth steppe fauna association. Morphological characteristics of the material, such as a low degree of erosion, suggest that most of these finds were found *in situ*.

On the Maasvlakte 2 beach, where the sediment was deposited artificially, two types of field survey were deployed: collecting finds manually and collecting the finds mechanically using a so-called Mega Beach Cleaner. The purpose of these surveys was to search for archaeological material, gravel, and palaeontological remains at pre-selected and recorded locations on the beach. The different methods yielded a large quantity of material, including vertebrate skeletal remains, molluscs, wood, and gravel, as well as a few archaeological objects including flint flakes. After analysis of the finds it appeared that the species composition of the assemblage collected with the Mega Beach Cleaner broadly resembled that of the assemblage collected manually.

The source area of the transported sediments is broadly known. However, based on data presently available it is difficult to connect the finds from the beach and those collected during the fishing trips to specific lithostratigraphic units that have been defined in the extraction zone. The lithostratigraphic units reflect multiple episodes of intense sediment reworking during the various fluvial and marine depositional stages. Moreover, due to the material's depositional history, disturbance and subsequent methods of retrieval, uncontaminated associations are scarce. Once the OSL dates will become available, however, it will be possible to date the lithostratigraphic units in the sand extraction zone more precisely. Even so, establishing the real geological date of the finds from the beach and collected during the fishing trips will remain problematic due to the high degree of reworking of the superimposed fluvial sediments.

The geoarchaeological and palaeontological research project, financed by the Port of Rotterdam Authority, was successful and produced a large quantity of information. In the near future this will undoubtedly be followed by more, spectacular finds which, due to newly acquired knowledge, can then be placed within a better geological, stratigraphic, and environmental framework than before.

1 Introduction

1.1 Research context

The Pleistocene was characterised by pronounced changes in climate and associated sea level fluctuations. During this period the Palaeolithic landscapes were subjected to continuous changes, caused by alternations of ice ages (glacials) and warmer periods (interglacials). Sea-level fluctuations of over 100m, climate fluctuations and the effects of ice cover resulted in temporal changes in both the location of coastal zones and the behaviour and location of river systems. These changes in turn had an impact on the flora and fauna and, in the final phase of the Pleistocene, also necessitated constant economic and social re-adjustments by early hominins.

Because the southern North Sea shelf has a rather flat surface, the course of the palaeo-coastline was subjected to considerable changes during the Pleistocene glacial/interglacial cycles. During glacial periods the sea retreated more than 100m below its present level, leaving the entire area dry. The river Rhine (with its tributaries Meuse and proto-Scheldt) ran through the dry southern North Sea plain, where it converged with the river Thames. In the Early and Middle Pleistocene this North Sea Rhine flowed to the north, but when by the end of the Saalian the Strait of Dover was formed, the Rhine started flowing to the south through the Channel, where it merged with the rivers Somme, Solent, Seine, and a few smaller streams (Hijma et al. 2012).

During glacial periods the dry North Sea basin was mostly characterised by a landscape eminently suitable to large herds of herbivores such as woolly mammoth, woolly rhinoceros, horse, reindeer, giant deer, and bison. During interglacials the sea would return approximately to its current level, which again resulted in drastic changes in the North Sea Basins' palaeo-landscape (Peeters et al. 2009; Cohen et al. 2011; Hijma et al. 2012).

In the last few decades, thousands of Pleistocene and Holocene animal remains have been hauled up from the bottom of the North Sea, and the North Sea can indeed be regarded as one of the richest sites for Late Pleistocene fossil vertebrates in the world. Usually the fossils are found when fishermen accidentally catch them in their nets (See e.g. Mol 1991; van Kolfschoten and Laban 1995; Mol and de Vos 1995; Glimmerveen et al. 2004; Mol et al. 2007; Mol and Post 2010), or in the course of commercial dredging operations (see e.g. Peeters et al. 2009; Hublin et al. 2009; Tizzard et al. *subm. a and b*). Occasionally these finds include lithic, bone, and antler artefacts from the Early and Middle Palaeolithic and Early Mesolithic (see e.g. Louwe Kooijmans 1971; Verhart 1988; Glimmerveen et al. 2004 and 2006; De Loecker 2010; Pieters et al. 2010; Hijma et al. 2011; Momber et al. 2011; Tizzard et al. *subm. a and b*). Finds of fossil human remains from the bottom of the North Sea are exceedingly rare. Recently, for the first time ever, a skeletal part of a Neanderthal (*Homo neanderthalensis*) was found in Dutch North Sea waters. It concerned a skull fragment of a young male, presumably Late Pleistocene in age (Hublin et al. 2009).

The North Sea basin, however, has been inhabited by early hominins long before the Late Pleistocene. Recent excavations near Pakefield (Suffolk, United Kingdom) and Happisburg (Norfolk, United Kingdom) revealed that hominins already lived on the British mainland before 0.78 million years ago, i.e. in the Early Pleistocene (e.g. Parfitt et al. 2005, 2010). Undoubtedly, more evidence for different occupation phases during the Middle, Late, and possibly Early Pleistocene is still stored within the North Sea Basin sediments.

Because of its favourable palaeo-landscape (coastline) setting and the presence of game animals, the potential of the North Sea area for studies of early hominins in north-west Europe and their relation with the landscape (climate, fauna, and flora) is enormous. However, as informative as the artefacts and fossils can be regarding the drowned landscapes and their biota, essential data on the original stratigraphic find contexts is often lacking due to the method in which the material has been retrieved. Moreover, as

a result of natural erosion and sedimentation processes, most of the North Sea finds are no longer *in situ*. Studying the archaeological and palaeo-landscape data in context is nevertheless of great scientific importance (Hijma et al. 2011).

1.2 The Yangtze Harbour research project: background

Since 2009, the Port of Rotterdam Authority has been involved in a large-scale expansion of the port area through the construction of Maasvlakte 2.

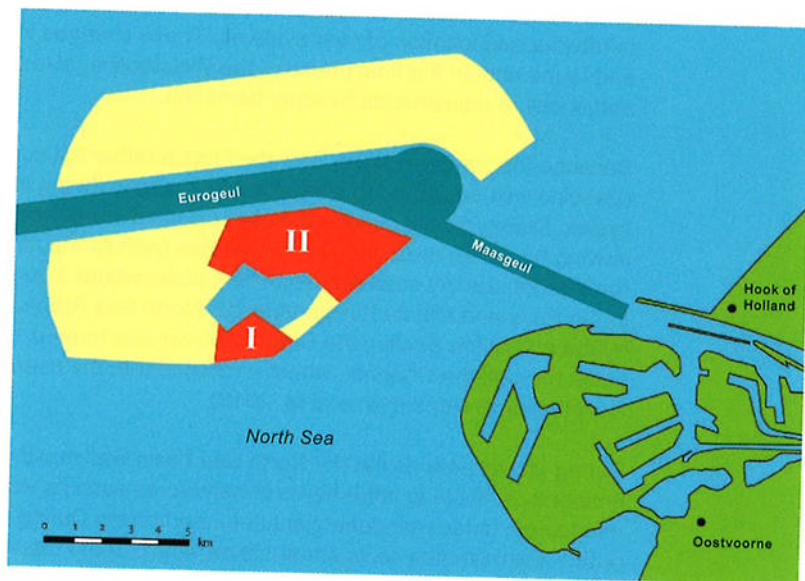


Figure 1. Location of the Maasvlakte 2 land reclamation project, Rotterdam, the Netherlands.

The reclamation of Maasvlakte 2 used sediments extracted and transported from two sand extraction pits (I and II) in an assigned sand extraction zone (in yellow) designated under the terms of the Soil Removal Permit (Du.: *Ogw*) issued by the Dutch water management agency RWS-DNZ, circa 10km west of the Dutch coastline. The average depth of Sand extraction pit I, exploited by contractor joint venture PUMA, is 30m - asl (10m of sand removed), while the average depth at Sand extraction pit II is 40m - asl (20m of sand removed). Image supplied by the Port of Rotterdam Authority.

To date, the construction of Maasvlakte 2 has required the extraction of circa 240,000,000m³ of sediment from a designated area in the North Sea, circa 10km off the coast of the Dutch province of Zuid-Holland (Fig. 1). The sediments were sucked up by trailing suction hopper dredgers, transported, and finally re-deposited at their destination by a process called *rainbowing* (Fig. 2), or by pipeline transport.

Earlier discoveries of archaeological artefacts and animal remains in the direct vicinity of the planning area (e.g. Eurogeul and Maasvlakte 1) had demonstrated that Palaeolithic and possibly also Mesolithic drowned landscapes both in the land reclamation zone and in the sand extraction zone were under threat as a result of construction-related activities (Manders et al. 2008; Peeters et al. 2009; Hijma et al. 2011).

A working group called "Working Group Archaeology Maasvlakte 2" (*Werkgroep Archeologie Maasvlakte 2*) was installed in order to minimise the negative impact of commercial exploitation and also to document the potential presence of archaeological and palaeontological remains in the affected parts of the sand extraction zone. Its members included representatives of Port of Rotterdam Authority, the Cultural Heritage Agency of the Netherlands, and the Rotterdam municipal archaeological service (BOOR). In accordance with terms stipulated in an agreement between the Cultural Heritage Agency and Port of Rotterdam Authority, which was in part based on current law regarding archaeological heritage management, Port of Rotterdam Authority set aside € 3,000,000,- for archaeological research and any associated palaeontological, geological,



Figure 2. Rainbowing of the extracted sediment to create new land. Photo: Th. van Kolfshoten.

and geophysical analysis. The research project was supervised by the above mentioned Working Group Archaeology Maasvlakte 2.

1.3 Research area

Activities carried out in the context of the construction of Maasvlakte 2 took place at sea, in the sand extraction zone (sediment extraction), and in the land reclamation area (rainbowing of sediment in preparation of new land as well as the beach). The Maasvlakte 2 project also involved dredging the existing Yangtze harbour to improve access to the newly built docks. The results of archaeological research prompted by these activities at Yangtze harbour will be reported elsewhere (e.g. Carmiggelt 2012; Weerts et al. 2012, 2013). The present report will focus exclusively on the goals, questions, and results of research carried out in the sand extraction area and at the Maasvlakte 2 beach.

1.4 Research goals

The main goals of the research project were: 1) Defining a stratigraphic framework; 2) Reconstructing the palaeo-landscapes; 3) Establishing the stratigraphic context of the archaeological and palaeontological material.

Preliminary studies revealed that layers in the sand extraction zone, containing remains from Palaeolithic and Mesolithic periods, and particularly the Middle and Late Palaeolithic and the Early Mesolithic, were at risk of being disturbed (Manders et al. 2008).

The publication (in Dutch) *Rapportage Archeologische Monumentenzorg 169 'Wetenschappelijk kader voor de archeologische monumentenzorg bij aanleg tweede Maasvlakte, Europoort-Rotterdam'* ('A scientific archaeological heritage management framework for the construction of the second Maasvlakte, Europoort-Rotterdam'; Manders et al. 2008, 22) formulates general targets for future research to be carried out in the context of the Maasvlakte 2 project regarding both the sand extraction area and the Yangtze harbour. A number of these targets also guided the research presented in this report:

- The project should expand our knowledge on the geological structure of, and the geological processes (erosion/sedimentation) in the area;
- The project should expand our knowledge on the research potential of the North Sea, and specifically the Meuse estuary, with regard to both prehistoric and

maritime archaeology;

- The project should generate knowledge on prehistoric exploitation of the coastal zone;
- The project should generate knowledge on the relation between hominin/human activity and the specific landscape context in which this activity took place;
- The project should expand the body of knowledge on the quality and condition of archaeological material present on the seafloor or in the underlying deposits;
- The project should serve as an exemplar for future large-scale underwater research;
- The newly generated information should be made widely accessible to the general public.

The same report (Manders et al. 2008, 22-4) also formulates a number of research questions. A selection of these questions, specifically those relating to geology, prehistoric archaeology, and methodology, will be addressed in the present publication. These questions are:

- What is the lithostratigraphic structure of the area, and what geogenetic information can be derived from it?
- What is the age of the observed stratigraphic layers?
- At which depths are the various chronostratigraphic units situated?
- If Late Pleistocene layers are indeed encountered in the sand extraction zone, do these contain Pleistocene faunal and other palaeo-ecological remains?
- What are the characteristics of the faunal assemblages (species, age, taphonomy etc.) and other palaeo-ecological materials?
- Do the faunal assemblages contain indications for human activity, and if so, what is the nature of these indications?
- If flint, stone, or organic artefacts are encountered, the following subsidiary questions will be relevant: what is the typochronological date of these artefacts, what are their typological features, and what can be stated about their past use?
- What can be stated about the possible depositional (behavioural) context of the artefacts?
- To what extent can the underwater inventory studies be improved?
- Are there points for improvement in the applied methodology, and if so, what are these points?

1.5 Implementation

The commissioning body for all subsidiary projects undertaken in the context of the Maasvlakte 2 project was Port of Rotterdam Authority. Given the multidisciplinary nature of the research project, specialists from various disciplines and institutions were involved in this extensive research campaign. The main institutions/organisations were: TNO Geological Survey of the Netherlands, Deltares, Naturalis *Biodiversity Center*, the Natural History Museum Rotterdam, and the Faculty of Archaeology of Leiden University. The project supervisor was the Cultural Heritage Agency of the Netherlands.

For the specialist geoarchaeological research conducted in the context of the preparation of Maasvlakte 2, an interdisciplinary approach was preferred, in which complementary geological, geophysical, biological, and archaeological analyses were merged into one integrated document. The results of the analyses have been presented in five separate reports, each issued by the institution/organisation involved (Table 1).

Nr.	Title	Institution/Organisation	Authors/Editors
1	<i>Het stratigrafische raamwerk voor de geologische opbouw van het zandwingebied Maasvlakte 2</i>	TNO Geological Survey of The Netherlands	F. Busschers; W. Westerhoff; S. van Heteren
2	<i>Geofysisch onderzoek zandwinput Maasvlakte 2</i>	Deltares	A. Wiersma; C. Mesdag
3	<i>Inventariserend onderzoek zandwinput Maasvlakte 2</i>	Naturalis Biodiversity Center	N. den Ouden; F. Wesselingh; A. Janse; F. Dieleman; O. van Tongeren
4	<i>Succesvol bot vangen</i>	Leiden University	M. Kuitems (ed.)
5	<i>Preliminary report on the lithic artefacts</i>	Leiden University	D. De Loecker

Table 1. List of reports presenting the results of subsidiary analyses performed in the context of geoarchaeological and palaeontological investigations in the sand extraction zone and beach Maasvlakte 2.

The first report focusses on the lithostratigraphic structure of the sand extraction zone (Busschers et al. 2013). The stratigraphic sequence has been reconstructed on the basis of the results of lithological, sediment, and (bio)stratigraphic analyses of 38 (virtually) intact cores taken with a powerful vibrocorer along two transects in the sand extraction zone. On the basis of macroscopic criteria, seven local, non-formalised lithostratigraphic units could be distinguished that indicated multiple episodes of intense sediment reworking in the course of the various fluvial and marine phases.

The second report presents the results of geophysical fieldwork conducted in the sand extraction zone (Wiersma and Mesdag 2013). Seismic analysis demonstrated the presence of two distinct seismostratigraphic levels in the sand extraction zone. The upper level was characterised by a fairly homogeneous sediment composition, while in the lower level indications for migrating channels prevailed. Side-Scan Sonar images provided information on find contexts and disturbance of the seafloor.

The third report discusses the finds that were collected during the mechanical and manual collecting surveys on the beach of Maasvlakte 2 (den Ouden et al. 2013). On the basis of the encountered bone, wood, and mollusc material, the faunal composition of the local sediments was established. The vertebrate assemblage was dominated by well-preserved skeletal material of species typical of a so-called mammoth steppe fauna. After analysis of the faunal material from a number of designated 'survey units', it appeared that none of these units yielded fauna that could be assigned unequivocally and exclusively to a specific lithostratigraphical unit.

The fourth report presents the results of specially organised fishing trips (Kuitems et al. 2013). With the aid of beam trawls dragged at both sides of a trawler, (fossil) bones, molluscs, stones, and recent material were hauled up. The objects' dates vary widely. Most of the mammalian skeletal elements are characteristic of a Pleistocene mammoth steppe fauna.

The fifth report (published in English) describes the flint material found in the perimeter zone and in the trawls (De Loecker 2013). A total of ten flint artefacts were retrieved: nine flakes and one core. The flint's morphological characteristics suggest that the artefacts vary in date and were originally embedded in different sediment types. The assemblage comprises different types of artefacts that show different procurement techniques.

The present synthesis summarises the main results presented separately in the five reports, and integrates them into a broader geoarchaeological and palaeo-landscape framework.

1.6 Administrative project data

Title: Geoarchaeological and palaeontological research in the Maasvlakte 2 sand extraction zone and on the artificially created Maasvlakte 2 beach: a synthesis

Archis Project registration number: 51754

Archis Find registration numbers: 432492
432494
437137
437142

Province: Sea/International waters (sand extraction zone), Zuid-Holland (Maasvlakte 2 beach)

Municipality: North Sea (sand extraction zone), Rotterdam (Maasvlakte 2 beach)

Locality: North Sea (sand extraction zone), Maasvlakte 2 (beach)

Toponym: Maasvlakte 2

Central coordinate sand extraction zone: 53000/450000

Central coordinate perimeter zone: 56500/444000

Complex type: XXX

Period: PALAEO-NTC

Present function locality: Water/Gully/Sandbank/Shelf

Commissioning body: Port of Rotterdam Authority Ltd
Projectorganisatie Maasvlakte 2

Responsible authority/supervision: Cultural Heritage Agency of the Netherlands

Implementation: TNO Geological Survey of the Netherlands
Naturalis Biodiversity Center
Faculty of Archaeology, Leiden University

Project supervisor: W. Borst, Port of Rotterdam Authority Ltd

Project starting date: 2009

Project closing date: 2013

Authors: M. Kuitems, Th. van Kolfschoten, F.S. Busschers, D. De Loecker.

2 Applied research and find retrieval methods

Archaeological research in general, and research of the Palaeolithic period in particular, tends to be multi- or interdisciplinary, with a range of specialists contributing to a chronological framework and reconstruction of the palaeo-landscape in which Palaeolithic hominins operated. The different specialists use a wide range of methods, which are standardly applied within their specific field. The present project, however, deployed a number of 'new' methods alongside the established ones. A number of factors, for example the depth of the finds, limited visibility at the bottom of the sea, and the fact that the seabed is subjected to ongoing transformations, made a traditional archaeological approach impossible (Manders et al. 2008). Innovative (geophysical) techniques had to be used to establish, among others, the geological context of the objects. Subsequent excavation of the archaeological/palaeontological finds, as is customary within archaeology, was also impossible. Therefore, fishing trips in the sand extraction area and campaigns to collect finds on the beach were organised. These 'new' methods will be discussed in the present chapter.

2.1 Geophysical research

During a six-day period in June 2011, geophysical research was conducted in the sand extraction zone, with the aid of two types of seismic recording devices and a Side-Scan Sonar (Wiersma and Mesdag 2013; Table 2). These field studies took place on board a fishing vessel, the BRA-7. The same vessel was also used for the palaeontological fishing trips.

Date	Side-Scan Sonar	X-Star	Boomer	Wave height* (cm)	Wave direction**
June 5, 2011	X			30	N
June 6, 2011	X	X		120	N
June 7, 2011	X	X		60	N
June 8, 2011		X	X	140	W
June 9, 2011	X			120	SW
June 10, 2011	X			60	W

Table 2. List of deployed equipment and wave conditions during the recording days. * Wave height refers to average wave height as recorded at the Europlatform between 8 am and 6 pm. ** Wave direction is an estimate based on the overall direction of waves in the 30-500 mHz spectrum observed at the Europlatform (see www.waterbase.nl). Table after Wiersma and Mesdag 2013, 9.

In order to trace different sediment layers and irregularities in the subsoil, seismic imaging was carried out with the aid of a so-called 'Boomer', which has a maximum range of circa 10m (Fig. 3), and a 'Chirp sub-bottom profiler' (X-Star) with a maximum range of a few metres below the seafloor. Both machines need to be suspended just below the sea surface, which was accomplished with the aid of the trawler's boom. The Boomer was equipped with floaters, while the Chirp was suspended from a cable and floated circa 1m below the sea surface.



Figure 3. Launching the Boomer from the trawler's starboard side. Photos: Wiersma and Mesdag 2013, 5.

The primary function of the Side-Scan Sonar was to look for objects that were partially emerging from the seafloor or that were visible on the slope of the pit. While being dragged just above the seafloor, a Side-Scan Sonar probe records a sideways view in an oblique angle that is more or less parallel to the seafloor. Any palaeontological objects thus observed by the Side-Scan Sonar were to be subsequently brought to the surface. A Side-Scan Sonar also provides information on sediment types and seafloor variations.

2.1.1 Seismic analysis

The quality of the seismic data generated by the Boomer was insufficient for the purpose of the project. The data demonstrated a poor signal-to-background noise ratio, probably as a result of surface wave action. On the day the Boomer was deployed, wave height measured circa 1.40m, causing much vertical movement in the Boomer and its floaters. Moreover, a Boomer is less accurate at shallow depths (a few metres beneath the surface) than at greater depths. Possibly this technique produces better results under calmer conditions (lower waves), or when a multichannel streamer is used.

Unlike the Boomer, the Chirp sub-bottom profiler, which floated circa 1m beneath the surface and in general produces more accurate results at shallow depths, revealed distinct irregularities in the various levels in the sand extraction area. At a depth of circa 27m beneath the surface, for example, a layer was observed with clearly defined internal structures suggestive of channel migration. Additionally, the interface between two layers was visible at a depth of circa 25m.

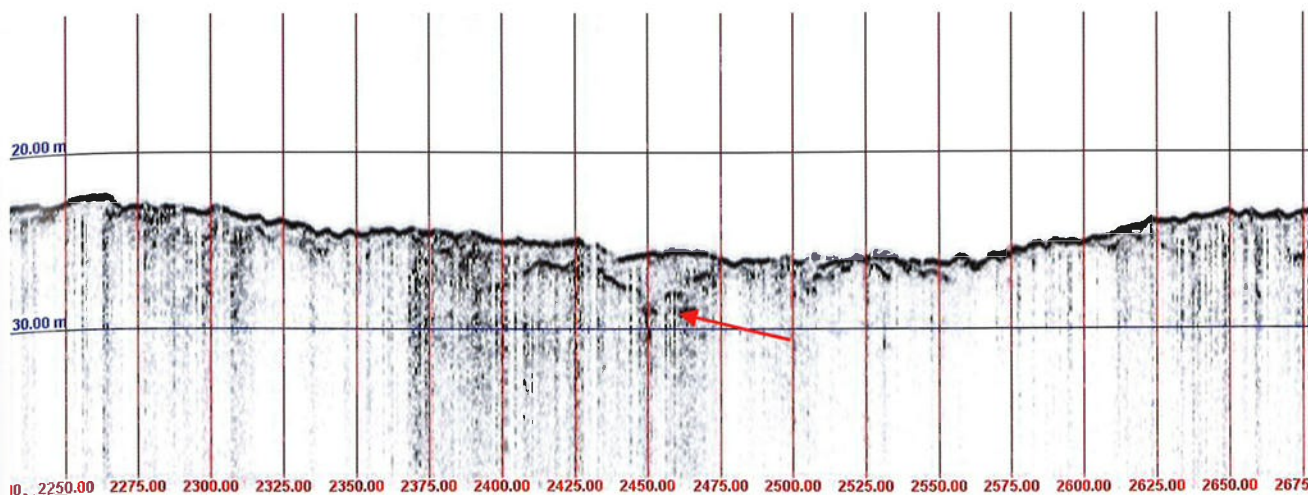


Figure 4. Part of a Chirp sub-bottom profiler seismic image taken parallel to the north-west slope. Length of the section circa 400m. Clearly visible (see arrow) is the irregular base of some former gullies cut several metres deep into the surrounding sediments. Figure: Wiersma and Mesdag 2013, 11.

This method allows a high-resolution investigation of layers that are situated at greater depths below the undisturbed seafloor (Fig. 4). As such, the advantages of deploying seismic analyses with the aid of a Chirp (occasionally in combination with a Boomer if conditions allow it) are considerable in studies of the geological context of palaeontological and archaeological finds from seafloor depressions.

2.1.2 Side-Scan Sonar

With the Side-Scan Sonar, larger objects that partially protrude from the slope of the pit or from the seafloor in the sand extraction zone could be identified (Fig. 5).

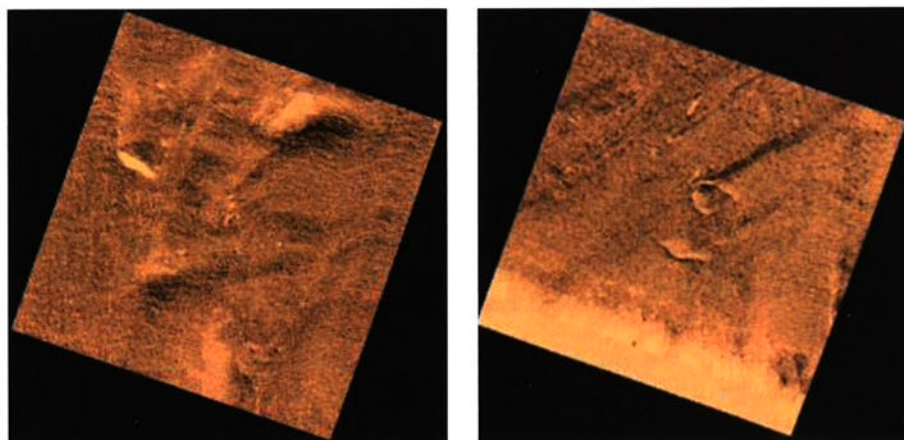


Figure 5. Examples of objects traced by the Side-Scan Sonar. Each square represents a 20x20m area on the sea bottom. Figure: Wiersma and Mesdag 2013, contact reports.

Object clusters could be easily mapped and tentatively linked to specific levels. It was not possible to establish the precise nature of these anomalies because a Side-Scan Sonar uses shade to render objects visible, rather than 'looking' at the density of the objects. Some of the anomalies that were subsequently hauled up turned out to be peat block clusters. This could indicate a transitional zone between two successive lithological (sub) units. On the basis of particle size variations of sandy deposits, however, transitions between layers could not be distinguished, as these particle variations, if present, were too subtle to be visualised with the Side-Scan Sonar. Some tentative gullies could be distinguished, but these were not recognised in the seismic data.

The Side-Scan Sonar had never been used before for this type of research. In general the quality of Side-Scan Sonar images varies. For optimal results the 'fish' (the probe) needs to be dragged just above the seafloor, but due to the geometry of the sand extraction pit, as well as the nature of the vessel's trajectory this was not always feasible. On occasion, when the probe was forced to follow a shallower course, its maximum resolution could usually not be achieved.

Despite the variable quality, the Side-Scan Sonar produced some interesting data on, for example, the structure of the seafloor and local conditions in and around the sand extraction pit. The images revealed that on the bottom of the pit, the top section of the sediments had been severely disturbed. However, large structures along its slope and a few accumulations of objects were clearly visible. Due to the level of detail with which, during this current research, Side-Scan measurements were taken (see above), it was impossible to identify the objects.

Moreover, it appeared that fishing for archaeological and palaeontological objects while recording with the Side-Scan Sonar, which had to be put overboard and positioned close to the trawls, was operationally unfeasible. Both the trawls and the sonar trailed some 80 to 100m behind a vessel that could not always maintain a straight course and also had to deal with local currents.

Despite its limitations, a high-frequency (900 kHz) Side-Scan Sonar is a valuable tool in palaeontological and archaeological field studies. The Side-Scan Sonar is able to locate larger objects, and accumulations of potentially interesting finds can be discovered by mapping larger areas. If this is followed up by multiple, short fishing trips that are focussed on these accumulations, the chance that some of the observed objects can be brought to the surface increases. In addition, data about the local conditions derived from the Side-Scan Sonar images may be linked to the finds, provided that the inaccuracies in find positioning are kept to a minimum. Fishing for objects observed on Side-Scan Sonar images, however, proved to be difficult. This was caused by a combination of inaccuracies: the local positioning of the Side-Scan Sonar from a line behind the ship produced a margin of error of several metres, and the positioning the vessel itself, including its trawls, produced an inaccuracy of 10 à 20m. These inaccuracies may be reduced to less than 1m by deploying a Side-Scan Sonar and trawls that are equipped with an accurate GPS system, a technology that is already available.

2.2 Fishing trips

Between 2009 and 2011, a chartered trawler set out fourteen times to conduct a geoarchaeological and palaeontological survey of the Maasvlakte 2 sand extraction zone. The seafloor was systematically dredged with bottom trawls (Fig. 6) and each haul was inspected for bone fragments and archaeological objects in order to locate and map find clusters and to collect material of geoarchaeological and palaeontological interest.

In the course of the various fishing trips an increasing amount of attention was paid to the accurate localisation of the surveyed transects and the documentation of the hauled-up material. The trawler's exact geographic position was determined, and at a later stage bathymetric data were added to the coordinates. Gradually, the selection of the survey transects became less and less random. The combined experience of earlier fishing trips and recent bathymetric images of the sand extraction zone led to the decision to make shorter transects within a more limited vertical range and to search part of the sand extraction zone systematically.

The fishing trips, which were conducted at different locations and depths in the sand extraction zone, yielded a large quantity of material from different time periods. In addition to large numbers of living fish and starfish, the catch consisted of lumps of peat, gravel, skeletal remains of vertebrates, molluscs, and artefacts (Fig. 7).



Figure 6. During each transect in the sand extraction zone, beam trawls were lowered on both sides of the vessel to collect archaeological and palaeontological objects from the seafloor. Photo: M. Kuitems.



Figure 7. The contents of the trawls after two hauls. On these chartered fishing trips, fish and other live animals were regarded as side catch; objects such as bones (left: mammoth shoulder blade) and archaeological objects (right: small beardman jug) formed the main catch. Photos: M. Kuitems.

2.3 Mechanical and manual artefact collection on the beach

Two methods were used to collect archaeological material, gravel, and palaeontological objects on the Maasvlakte 2 beach: 1) A systematic survey of the area on foot while manually collecting any encountered objects; 2) Mechanical collection using a beach cleaning vehicle, a so-called 'Mega Beach Cleaner' (MBC) with an attached screen of 1.5cm mesh size (den Ouden et al. 2013; Figure 8).

In order to survey a large area within a short period of time, it is possible to use an MBC. In the context of the Maasvlakte 2 project, tests were conducted to establish if collecting archaeological and palaeontological objects with an MBC is more efficient and if the resulting find assemblage differs from the assemblage collected simultaneously or at a later time by hand.

Two runs with the MBC were conducted. The first took place in February 2010 and the second in July 2010. Unfortunately, the yield of the first run (collected in eleven big bags) inexplicably vanished from Maasvlakte 2. Only the material that was simultaneously collected by hand in the designated survey areas was preserved.

The second run resulted in sixteen big bags of material, which a year later were sorted and searched for fossils with the aid of amateur palaeontologists and (young) visitors of the Naturalis Biodiversity Center (Fig. 9). Students of the Faculty of Archaeology of Leiden University sorted through some of the big bags looking for the presence of flint artefacts.



Figure 8. Mechanical survey, using a Mega Beach Cleaner, and manual survey both on the Maasvlakte 2 beach, to collect artefacts, bones, shells, and gravel. a. The beach cleaner in action; b. Manual collection in designated survey areas. Photos: D. De Loecker.



Figure 9. Children at NBC Naturalis looking for fossils in one of the big bags. Photo: den Ouden et al. 2013.

The two collections combined contained a large quantity of finds, consisting of vertebrate skeletal remains, wood, gravel, and molluscs. After the material had been studied, it became clear that the species composition of the MBC assemblage broadly resembles that of the manually collected assemblage (den Ouden et al. 2013, Appendices 3-9). Due to the large mesh size of the Mega Beach Cleaner's screen, the MBC big bags did not contain smaller remains of, among others, small molluscs and small mammals such as mice: taxa that were represented in the manually collected assemblage. Moreover, sorting the enormous amount of material collected by the MBC turned out to be very labour-intensive. In combination with the aforementioned absence of smaller remains, this could be a reason to prefer manual collection and to not use the MBC. However, in situations where an area can be surveyed only once (or only during a very short period of time), an MBC may still be useful, depending on the research question. What is preferable in a given situation: a large quantity of (rough) data from a large area, or more detailed information from a small(er) area.

3 The local and regional context

The subsurface of the north-east part of the sand extraction zone was mapped on the basis of the analysis of the 38 cores (Busschers et al. 2013, Appendix 1), data from the Side-Scan Sonar, and seismic investigations (Wiersma and Mesdag 2013). During the fishing trips it became clear that find densities were highest in that particular area of the sand extraction zone.

3.1 Disturbed deposits – traces of sand extraction

The geophysical analyses and coring surveys took place shortly after sand extraction activities in the north-eastern part of the extraction pit had been terminated. Both surveys showed that the top layer that covered the floor of the sand extraction pit had been disturbed considerably. This layer mainly consisted of fine sand and clay and had been deposited during or immediately after the sand extraction activities.

The Side-Scan Sonar images revealed the difference between the intact seafloor and the disturbed slope of the extraction pit (Fig. 10). The undisturbed seafloor displayed a regular pattern of WNW-ESE oriented sand waves. Where the slope of the extraction pit began, this regular wave pattern disappeared. The bottom of the pit clearly showed traces left by the suction hopper dredgers. Both the floor and slope of the extraction pit are characterised by (chaotic) lobe-like structures formed either by the dredge drag heads or accumulation due to slope processes.



Figure 10. Detail of the sonar images taken on Monday, June 6, 2011. Visible to the north is the intact seafloor (no bathymetric data available). The section on which bathymetric data are available (marked in shades of yellow and blue) shows the disturbance on the slopes of the extraction zone.

Figure: Wiersma and Mesdag 2013, 19.

3.2 Lithostratigraphic units

As stated in the report '*Het stratigrafische raamwerk voor de geologische opbouw van het zandwingebied Maasvlakte 2*' (Busschers et al. 2013), it is possible to place the encountered lithostratigraphic sequence in a (preliminary) broader geological context and to integrate the results with those of previous geological studies conducted in the vicinity of the sand extraction zone, on the basis of stratigraphic position and sediment characteristics.

During the analysis of the sediment cores, existing information on the subsurface composition of the Netherlands was used, which had been obtained during previous studies on cores taken in the central Netherlands, specifically in the present and past drainage basins of the rivers Rhine and Meuse (e.g. Busschers et al. 2007; Hijma et al. 2012). Lithological characteristics and composition of the sediments were used to define (local) lithostratigraphic units and to correlate those with units observed on the mainland. Lithological, sedimentological, and (bio)stratigraphical data on cores taken in or near the sand extraction zone (Busschers et al. 2013, Appendix 3: illustrations of all cores) allowed the definition of seven local lithostratigraphic units, coded MV2-1 to MV2-7 (Table 3). The age of each lithostratigraphic unit should, for now, be considered indicative. The OSL dates (which have not yet become available) might lead to more exact dates.

Local unit	Lithostratigraphy (Westerhoff et al. 2003)	General characteristics	Depositional conditions	Age (based on stratigraphic position)	Base of the unit	Potential corresponding geological units near sand extraction zone
MV2-1		Fine sand, clay	<i>Slumping</i> , in suspension	Recent	1m or less below surface slope and floor sand extraction zone	
MV2-2	Naaldwijk Formation	Fine and moderately coarse sand, clayey	(Freshwater) tidal	Holocene	28-30m - asl. Locally absent	
MV2-3	Kreftenheye Formation	Moderately coarse and coarse sand, shells, locally clay	Fluviatile, locally (freshwater) tidal	Middle Weichselian (MIS4-3), possibly in part younger. Locally Early Weichselian (MIS5d-a)	27.5-31m - asl	Units B2 and/or B3 (Busschers et al. 2007) Unit B4 or B5 (Hijma et al. 2012)
MV2-4	Kreftenheye Formation	Fine and moderately coarse sand, clayey, micaceous, shells	Fluviatile	Early Weichselian (MIS5d-a)	28-32m - asl	Unit B1 (Busschers et al. 2007)
MV2-5	Kreftenheye Formation	Moderately coarse and coarse sand, shells	Fluviatile	Early Weichselian (MIS5d-a)	30-33m - asl	Unit not encountered on mainland; not identified by Hijma et al. (2012)
MV2-6	Kreftenheye Formation	Coarse sand, gravelly, sterile	Fluviatile	Middle Pleistocene (Late Saalian, MIS6)	± 42m - asl	Unit S5 (Busschers et al. 2008; Hijma et al. 2012)
MV2-7	Urk Formation or Waalre Formation	Moderately coarse sand, wood remains	Fluviatile	Late-Early Pleistocene or Middle Pleistocene	Base of the unit not reached; depth >47m - asl	

Table 3. Defined local lithostratigraphic units. Table after Busschers et al. 2013.

The topmost lithostratigraphic unit, MV2-1, consists of the recently disturbed surface layer of the extraction zone, which covers the underlying sediments of Unit MV2-2. The combined malacological and palynological analysis suggest a Holocene date for Unit MV2-2.

Unit MV2-3 is characterised by the occurrence of reworked marine shells that form a basal layer of coarse material left behind after the finer particles had been washed out: a so-called lag deposit. Except for some clayey inclusions Unit MV2-3 is very similar, lithologically and sedimentologically, to Unit B2 and/or Unit B3 as defined by Busschers et al. (2007). In Unit B3 the fluviatile sediments consist of coarse to moderately coarse,

gravelly, calcareous sand. The brownish hue of Unit MV2-3 also resembles that of Unit B3 as described by Busschers et al. (2007). These similarities between Unit MV2-3 and Busschers' Unit B3 suggest that MV2-3 was probably deposited during the Middle Weichselian (Pleniglacial, MIS4 and/or Early MIS3). Until the OSL dates will become available, however, a correlation with more recent units (B4 or B5) as distinguished by Hijma et al. (2012) cannot be ruled out.

Unit MV2-4 is a conspicuous, micaceous layer. It includes a relatively thin lag deposit with shell material. The unit's lithological characteristics and its position beneath the prominent lag deposit of reworked marine shells of Unit MV2-3 render a correlation with Busschers' Unit B1 (Busschers et al. 2007) highly likely. Unit B1 includes 'cross-bedding' (i.e. sediment deposited at an oblique angle) and laminated sand deposited by the river Meuse in an estuarine environment. The correlation between Unit MV2-4 and Unit B1, which on the basis of (among other factors) OSL dates is ascribed to the Early Weichselian, is confirmed by stratigraphic observations on samples from Unit MV2-4.

Unit MV2-5 is probably also Early Weichselian in age. As is the case for Unit MV2-4, the presence of intensely worn shells of Eemian species in addition to – almost certainly – brackish-water and/or cold, marine elements shows that the deposition of Unit MV2-5 post-dated the warmer Eemian. Considering the age of the overlying unit, an Early Weichselian age is highly likely. Malacological data suggest that the cold fauna in Unit MV2-5 is still *in situ* or, at most, has only been minimally reworked. The fluvial, dynamic origins of the sediments themselves, however, seem to contradict this. No land-based equivalent to Unit MV2-5 has been identified so far (Busschers et al. 2007; Hijma et al. 2012).

A correlation between Unit MV2-6 and Unit S5 as defined by Busschers et al. (2008) and Hijma et al. (2012) is very likely, as indicated by Unit MV2-6's lithological characteristics and stratigraphic position. Unit S5 largely consists of gravelly, non-calcareous coarse quartz sand, that was probably deposited by a combined Rhine-Meuse system. Its correlation with Unit S5 implies that Unit MV2-6, too, was deposited during the Late Saalian (MIS6).

Unit MV2-7 is characterised by cross-bedding. It is the deepest unit in the extraction zone that was accessible by coring; its base was not reached but its depth exceeds 47m - asl. The date of Unit MV2-7 is yet unknown but Middle Pleistocene or late-Early Pleistocene are both plausible options (Busschers et al. 2013).

The distinct lithostratigraphic units were formed under different depositional conditions. Unit MV2-2 and a section of Unit MV2-3 have estuarine to freshwater-tidal features. Another section of Unit MV2-3 as well as the units MV2-4 to MV2-7 are fluvial in origin. The results of the sedimentological analysis indicate multiple episodes of intense reworking during several fluvial and marine phases (Busschers et al. 2013).

Seismic images (Chirp sub-bottom profiler) of the slope of the extraction pit locally provide additional information on the internal structure of a number of layers. The first level encountered from the seafloor down to a depth of circa 25m - asl is marked by a fairly homogeneous sediment composition. The underlying level (circa 30m - asl) revealed structures indicative of channel migration (Wiersma and Mesdag 2013), which in combination with observed lithological characteristics suggests, that these structures probably represent Pleistocene river channels. Geophysical data obtained on the core samples indicate that the reconstructed thickness of the superimposed layers is highly variable. The geological structure of the sand extraction zone is probably three-dimensionally complex, characterised by cross-cutting, erosive gullies of different dimensions.

4 Flora, fauna, and archaeology

4.1 Introduction

Botanical, zoological, and archaeological remains were retrieved during the fishing trips, the surveys on the beach, and analyses of the core samples. These remains were further analysed in order to reconstruct the depositional environment and to date the sediments. Both the age and the state of preservation of the plant and animal remains varied. Finds from respectively the cores, the Maasvlakte 2 beach and the floor and slopes of the sand extraction pit (obtained during the fishing trips) will be discussed, followed by general conclusions.

4.2 Material from the sediment cores

On the basis of lithological characteristics, sediment samples were taken from a number of cores (Busschers et al. 2013, Appendix 2) for the purpose of palynological, macrobotanical, malacological, and microvertebrate analysis. The analytic results served as an indirect age indication and refined the reconstruction of the depositional environment. The results of each find category are briefly presented here; more detailed information can be found in Busschers et al. 2013, Appendix 4.

4.2.1 Fauna

- Mammalian palaeontology; small mammals: Several lithostratigraphic units yielded remains of small mammals. Virtually all skeletal and dental elements were fragmentary, most of them highly fragmentary. The fragmentation probably pre-dates the elements' deposition, as a result of the frequently occurring consumption of small mammals by birds of prey, after which partially digested, regurgitated remains were deposited as pellets. The high degree of fragmentation made it virtually impossible to identify the skeletal elements. Mostly molar fragments from voles were encountered (Fig. 11), often a dominant taxon in Pleistocene mammalian faunal assemblages.

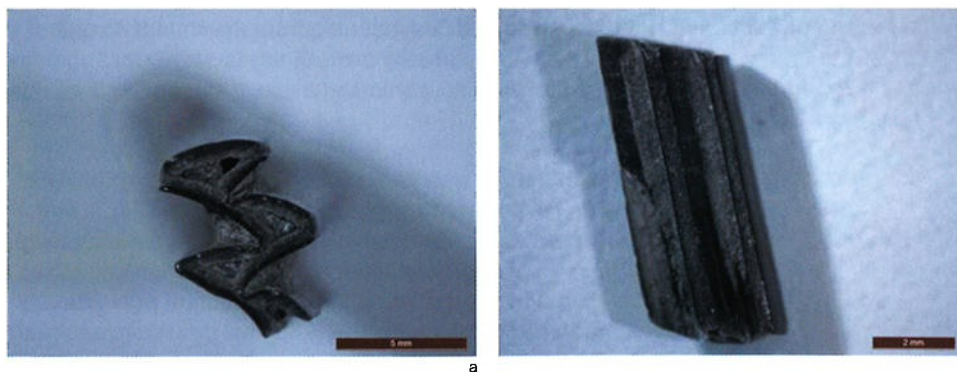


Figure 11. Molar fragment of the water vole (*Arvicola* sp.) from one of the sediment cores. a. Chewing surface of the molar; b. Side view of the same molar. Photos: A. Ramcharan.

- Ichthyology: The fish remains retrieved from the core samples, especially the more complete specimens, were easily identifiable. Several specimens showed rounding or other forms of wear. Most of the identified species, such as bream, roach, and tench, live in a freshwater environment, but some marine species were also encountered (e.g. cod, turbot, herring, and ray). Generally, herring and turbot only occur in marine environments, but they can sometimes be found in brackish water in particular during the juvenile phase. Cod and ray are typical for coastal environments.

- Malacology: The fossil mollusc assemblage was dominated by heavily worn, recrystallized, grey to greyish blue marine shells of Late Pleistocene species. A few species were indicative of the Eemian, and it is likely that most of the other heavily worn shells also have an Eemian age. This overall worn state suggests intense reworking, for example by water transport. Also representatives of two other fossil mollusc groups were frequently encountered: brackish-water species (occurring in variable numbers) and marine, middle-high boreal species. The state of preservation of the brackish-water species varied while the marine fossils tended to be well-preserved. Fresh-water molluscs and small land snails were present in variable but mostly small numbers. Finally, a very small number of heavily worn marine shells with an Early to Middle Pleistocene date were encountered. The shell material from the beach contain a (proto-)Scheldt component, which was also recognised in some of the lithological units in the cores. This component consists of heavily worn shells of Eocene species that occur in sediments with an outcrop near Ghent and Bruges. The fluvial sediments of the proto-Scheldt (in the Netherlands defined as the Koewacht Formation) indicate a river flowing straight north from Ghent and traceable up to the Oosterschelde area (Slupik et al. 2013). Further to the north the proto-Scheldt sediments have become embedded in those of the Rhine (Kreftenheye Formation) and can no longer be distinguished. This is also encountered in the sand extraction zone.

4.2.2 Flora

- Palynology: In addition to pollen analysis, botanical analysis also involved identification of any dinoflagellates, diatoms, fungal spores, and other (botanical) remains that might yield additional information on the depositional environment. Almost all samples contained enough palynomorphs to allow a general chronological and environmental assessment. In general, pollen and spores contribute to landscape and climate reconstructions, while diatoms and dinoflagellates are particularly helpful to distinguish fresh, brackish, and saltwater environments. Although strictly speaking foraminifers are not part of the flora, the pollen samples were also analysed for the presence of these eukaryote single-cell organisms, which – like dinoflagellates – provide information on water temperature, depth, and salinity.
- Macrobotany: All analysed layers in which identifiable macrobotanical fossils were encountered also contained water-plant remains. Most of the assemblages were indicative of a fluvial environment, which could not only be inferred from the identified species, but also from the rounded state of the material. Fragmentation was observed in virtually every analysed layer that contained plant macroremains. Many macroremains (particularly wood) had become rounded when transported by water.

4.2.3 Brief overview of biostratigraphic data per unit

- Malacological and palynological data in particular significantly contributed to a reconstruction of the depositional environment and to a chronology of the observed lithostratigraphic units. The next section presents a brief overview of the malacological and/or palynological data from each stratigraphic unit.

Unit MV2-1

- Malacology: This unit is characterised by a mixed shell fauna that is dominated by worn, recrystallized shells of marine species (including Eemian species) such as *Tornus subcarinatus* and the thick-lipped dog whelk (*Nassarius incrassatus*). In addition, the unit contained partially translucent, well-preserved shells of marine species (including fresh specimens) such as razor shell (*Phaxas pellucidus*) and *Angulus fabulus* as well as brackish, freshwater, and land species. The occasional presence of some much worn specimens of the Pliocene or Early Pleistocene *Dosina* cf. *casina* indicates a southern, fluvial influence of the proto-Scheldt. Oysters (*Ostrea edulis*) were fairly common. Unlike the lower units, MV2-1 also contained fresh, juvenile doublets of *Spisula* sp. and occasionally *Kurtiella bidentata*. Their occurrence is suggestive of very recent colonisation of the by sand extraction disturbed surface.

Unit MV2-2

- Malacology: The mollusc associations showed a dominant presence of marine species that is typical for the Holocene. There were, however, also some Pleistocene and a few Eocene species present in the assemblage, such as *Omalaxis serratus*, which is indicative of a proto-Scheldt influence.
- Palynology: Pollen analysis of most of the lumps of clay and peat demonstrated a combination of typically Weichselian and Early Holocene plant species.

Unit MV2-3

- Malacology: This unit contains a distinctly mixed fauna with recrystallized and worn shells of marine species from the Late Pleistocene; fairly well preserved shells of cold to temperate marine species; fairly well preserved shells of brackish-water species; and a number of freshwater species including *Theodoxus fluviatilis* and one valve of *Unio pictorum*. Other identified species were indicative for the moderately warm Eemian; especially cockles (*Cerastoderma* sp.) were common. The intercalated laminated clay deposit and the associated (underlying) clayey sands presented a very different situation with regard to the mollusc fauna. Besides moderately to well-preserved marine molluscs (including Eemian type species) indicative of a temperate to warm climate, this intermediate unit also contained well-preserved, (most probably) non-eroded, or locally reworked remains of species that are indicative of a cold climate, including doublets of Boreal astarte (*Astarte borealis*), narrow-hinge astarte (*Astarte montagui*), *Altenaeum dawsoni*, and foolish mussel (*Mytilus trossulus*).
- Palynology: Pollen analysis results of samples from the clays pointed at relatively cool, boreal conditions.

Unit MV2-4

- Malacology: The state of preservation of the mollusc assemblage was variable. Mainly recrystallized and worn shells of marine species (including some Eemian type species) were encountered, such as the common mussel (*Mytilus edulis*), elliptical trough shell (*Spisula elliptica*), and carpet shell (*Venerupis senescens*). Also represented were a number of rather well-preserved shells of species that prefer moderately warm to moderately cold conditions, including narrow-hinge astarte (*Astarte montagui*), as well as shells of brackish water species, and well-preserved shells of freshwater species. The degree of erosion of the shells indicates sediment reworking. The presence of many worn shells of Eemian species in an assemblage with brackish and/or cold, marine elements (e.g. Baltic macoma, *Macoma balthica*) indicates that the deposition of Unit MV2-4 post-dates the Eemian. The presence of a worn specimen of the Eocene species *Haustator solanderi*, known from the Aalter Formation which outcrops in an area between Ghent and Bruges, suggests that part of the sediments originated in a proto-Scheldt environment. This also indicates sediment reworking.
- Palynology: Several small lumps of clay, loam, and peat were subjected to pollen analysis. The presence of (among others) boreal plant taxa such as *Pinus*, *Selaginella*, and *Artemisia* suggests that sedimentation took place during a late interglacial/early glacial period, in this case the Early Weichselian. The pollen spectrum of some of the lumps suggested an initial cohesive sedimentation during the Late Eemian, followed by reworking in the succeeding colder period.

Unit MV2-5

- Malacology: The mollusc assemblage in this unit was highly diverse, containing recrystallized and worn shells of marine species (including moderately warm, Eemian type species); fairly well to well-preserved remains of cold to temperate species such as *Macoma*, *Angulus tenuis*, *Abra nitida*; and reasonably preserved remains of brackish species (e.g. lagoon cockle, *Cerastoderma glaucum*). Also observed in Unit MV2-5 are a fair number of shells of land-based and freshwater species (e.g. a freshwater snail of the genus *Bythinia*). The mollusc assemblage suggests that the cold-climate fauna has not been reworked.

Unit MV2-6

- Malacology: This unit can be distinguished from the overlying sequence by the absence of marine shells, which indicates that its deposition pre-dates the Eemian. The identified material included some worn opercula (lids that cover the opening of a snail-shell) of a freshwater snail of the genus *Bythinia*.

Unit MV2-7

- Palynology: On the basis of pollen analysis, it can be concluded that this unit may have been deposited during the Early or Middle Pleistocene.

4.3 The Maasvlakte 2 beach

Five surveys were carried out (two mechanical surveys in combination with manual collection, three surveys with manual collection only) in a number of survey units at the Maasvlakte 2 beach. The purpose of these surveys was to collect material (fossils of small and large mammals, molluscs, fossil wood, gravel, and archaeological objects) and, with the aid of this material, to correlate the sediment sequence in the surveyed units to stratigraphic units defined in the sand extraction zone (den Ouden et al. 2013).

4.3.1 Fauna

Macrovertebrates: None of the survey units produced faunal material that could be assigned unequivocally and exclusively to a specific geological period (Fig. 12). Moreover, many of the survey units contained material that was to a greater or lesser extent fossilised, an indication of the (lithostratigraphically) mixed nature of the faunal assemblage in these units. Overall the material was well preserved. Rounding observed in a few skeletal elements suggested that past fluvial activity affected (at least part of) the material.



Figure 12. Metapodium of an Etruscan rhinoceros (*Stephanorhinus etruscus*), a species that inhabited the area from the Pliocene to the Early Pleistocene. The same survey unit also produced material from other periods, including a molar of a Late Pleistocene woolly mammoth. Photo: E. Kruidenier.

- Microvertebrates: In four survey units targeted searches were carried out for small-vertebrate remains. Most of the finds could not be identified at a species level, and the remains also lacked age indicators. Four (in)complete molars of voles were an exception. Two of them were identified as *Mimomys savini*; an Early to early-Middle Pleistocene ancestor of the modern water vole (Fig. 13). The two other vole molars (both listed in the report on palaeontological material from the beach: den Ouden et al. 2013) differed in the degree of rounding. Both molars are either coeval with, or more recent than the *Mimomys savini* specimens.



Figure 13. Chewing surface of an incomplete vole molar (*Mimomys savini*, M1 sin) found on the Maasvlakte 2 beach. Photo: F. Dieleman.

- Molluscs: The analysed shell material from all survey units was characterised by extensive blending of a number of different faunal associations. In most survey units the faunal assemblage largely consisted of fluvial reworked shells of Late Pleistocene marine species, but brackish and freshwater species were also encountered, as were a few terrestrial species.

4.3.2 Flora

- Wood: Interestingly, the wood remains in some survey units were well preserved and easily identifiable, whereas in other units the preservation of wood was poor to the point where the only distinction possible was that between deciduous and coniferous wood. Recent desiccation and solar exposure cannot be the primary causes for the poor state of the wood, as all survey units were exposed to the same recent weather conditions. On the basis of the variety in conservation, it was concluded that the wood originated from different layers and/or periods.

4.3.3 Archaeology

- Flint: The surveys conducted on the beach resulted in 68 flint objects (De Loecker 2013). The flint assemblage contained ten artefacts: nine flakes (including one retouched tool; Figure 14) and one core fragment.

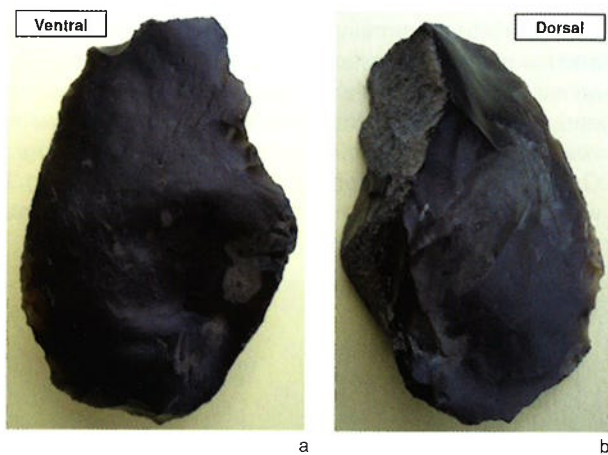


Figure 14. Retouched flint tool found on the Maasvlakte 2 beach (09-07-2010/Survey unit 2-II/018). a. Ventral face; b. Dorsal face. Maximum length: 55.6mm. Photo: D. De Loecker.

Thirteen finds were identified as 'incerto-facts', which means they should be considered as undefinable artefacts (De Loecker 2013, Appendix 3 and 4). After detailed inspection none of the remaining 45 finds proved to be an actual artefact. They have therefore been classified as so-called 'pseudo artefacts'; i.e. naturally shaped objects that merely resemble artefacts.

The state and quality of the artefacts suggest that the material probably derived from different sedimentological contexts, including a primary context (i.e. the objects have remained – virtually – stationary since deposition) and a secondary context (i.e. the artefacts were moved by fluvial action). The artefacts therefore form a mixed assemblage with different dates and from different locations, and by implication reflect a range of human activities during different periods in the past.

- Worked bone: One survey unit (2011-206) produced two fragments of deer antler (*Cervidae* indet.), one of which probably contains a cut mark. On the basis of colour and preservation it is presumed that both antler fragments have a Holocene age.

4.4 The fishing trips

A large amount of material, particularly skeletal elements of large mammals, was collected during fishing trips that were specially organised in the frame of this research project (Kuitens et al. 2013). The following section presents the results of the analysis of each material category.

4.4.1 Fauna

- Macrovertebrates: Several hauls resulted in hundreds of identifiable skeletal elements (bone, antler, and dental elements) from a wide range of species, mostly large land mammals such as woolly mammoth (*Mammuthus primigenius*), woolly rhinoceros (*Coelodonta antiquitatis*), reindeer (*Rangifer tarandus*), and giant deer (*Megaloceros giganteus*). Most of the skeletal material was well preserved and showed hardly any rounding. Some samples contained obvious traces of carnivore gnawing (Fig. 15).



Figure 15. Shin bone of a juvenile mammoth (Inv. Nr. NMR 9991-6937) showing various types of carnivore tooth marks: pits, (semi-)punctures, scores, and scooping. Photo: M. Knul.

- Molluscs: In total more than one thousand shell fragments were collected during the fishing trips. The fossil shell fauna was dominated by large shells of Eemian marine species (Fig. 16). The state of preservation varied greatly, from heavily worn (indicative of reworking) to exceptionally well preserved. The presence of well-preserved samples suggests the occurrence of locally reworked Eemian sediments. These were not observed in the cores. Freshwater and terrestrial molluscs were not encountered, and brackish-water species were rare.



Figure 16. Example of a well-preserved specimen, clearly showing the fine surface details and the intact top of the shell (umbo). *Acanthocardia tuberculata* (Linnaeus, 1758). Width 54mm (Fishing track 4-right 7-6, 2011). Photo: F. Wesselingh.

4.4.2 Flora

- Wood and peat: The trawls regularly brought up lumps of peat and pieces of wood. Several samples were taken from these lumps, which were not further analysed, but instead stored for future research.

4.4.3 Archaeology

- Bone modification: Two skeletal elements showed distinct traces of human activity. The first is a rib fragment of a Holocene bovid species (*Bos* sp.). Except for part of the distal end, the rib is virtually complete. V-shaped cut marks probably inflicted by a knife or other sharp (metal?) object are visible on both the inner (ventral) and outer (dorsal) side.

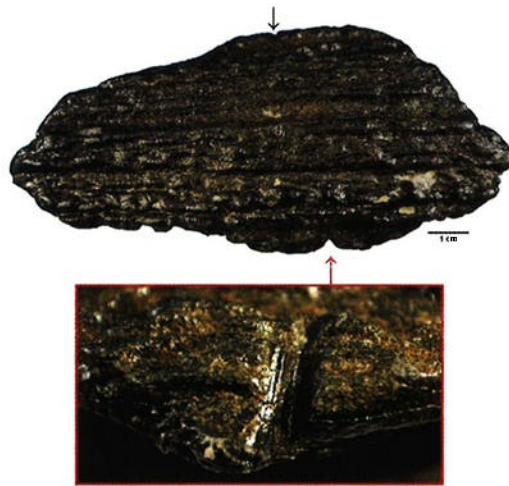


Figure 17. Fragment of red-deer antler (Inv. Nr.11-064Leiden059) showing cut marks on both sides. Photos: A. Ramcharan (top) and M. Kuitens (bottom).

The second item is a fragment of red-deer antler. It is a typical example of production waste; both sides of the piece show clear V-shaped cut marks, which were probably made with a flint tool (Fig. 17). Typologically the find cannot be assigned to a specific period. Bone and antler objects such as harpoon points, arrowheads, and adzes are often encountered in the area of the sand extraction zone and the beach of Maasvlakte 2. Often these archaeological objects are (Early) Mesolithic in date (see e.g. Louwe Kooijmans 1971; Verhart 1988; van Steijn 2012).

Traces observed on other skeletal elements were less obvious; they may also be the result of human activity, but for example gnawing by animals is also a possibility.

- Other finds: The fishing trips also produced many artefacts from later (post-1492 AD) periods, mostly (sub)recent. Examples are parts of airplanes (presumably WWII), part of a sea mine, and ships' anchors. Two finds were older: a few oak timbers of a small vessel and a virtually complete beardman jug. The shape of the timbers indicates that the vessel was clinker built, with hull planks attached to the timbers by wooden pegs. Scuppers were visible in the bottom section of the timbers. The clinker construction and the wooden pegs suggest a northern vessel. An initial suspicion that it might be part of a Viking ship proved incorrect: a radiocarbon date resulted in a calibrated age of 1670 – 1950 AD.



Figure 18. Small beardman jug, found on September 9, 2011.
Photo: A. Otte.

The small beardman jug is made of the grey-white stoneware typical of the pottery production centre at Frechen near Cologne (Friederich 1967). The jug depicts the head of a bearded man and a medallion with a stylised flower motif (Fig. 18). The fabric is covered in salt glaze, especially the upper half. The stylistic characteristics of the man's head and the medallion date the jug to the second or third quarter of the 17th century. Except for the partially broken neck the jug is almost complete. When found it was filled with sediment, which was sieved using a 1mm mesh-size screen. The contents, however, consisted exclusively of shell fragments. There were no remnants of the jug's original contents.

4.5 Integration of the data produced by the core analyses, the fishing trips and the field walking surveys

4.5.1 Vertebrates

The vertebrate assemblages from the perimeter zone and the fishing trips are dominated by (Late) Pleistocene land mammals that characterise a mammoth steppe fauna (Table 4). In general the skeletal remains were well preserved, showing little or no signs of weathering and rounding. This indicates that they had been exposed on the surface for only a short time and had not been transported in a fluvial environment over a long distance. Other skeletal elements besides those of a Late Pleistocene mammoth steppe fauna belonged to thermophile species (e.g. wild boar, red deer, beaver) or sea mammals (e.g. harp seal), and there were also younger components (e.g. a Holocene otter skull and specimens that were probably recent). The beach also yielded older fossils (e.g. species such as great white shark, mako shark, Etruscan rhinoceros, and the ancestor of the modern water vole, *Mimomys savini*), dating from the Early or Middle Pleistocene.

No Eemian indicator species were encountered in vertebrate assemblages from the fishing trips and the Maasvlakte 2 beach (den Ouden et al. 2013). An obvious explanation is the fact that the Eemian sediments in the sand extraction zone were deposited in a marine environment, where continental mammalian remains would be unexpected. Recently, however, some hippopotamus remains have been identified, which according to van Hooijdonk (van Hooijdonk 2013) are likely to be Eemian. An Early Pleistocene or early-Middle Pleistocene date, however, cannot be excluded.

Elephantidae	<i>Mammuthus primigenius</i>	Woolly mammoth	MV2-B+F
Rhinocerotidae	<i>Coelodonta antiquitatis</i>	Woolly rhinoceros	MV2-B+F
Rhinocerotidae	<i>Stephanorhinus etruscus</i>	Etruscan rhinoceros	MV2-B
Equidae	<i>Equus caballus</i> /sp.	Horse	MV2-B+F
Cervidae	<i>Alces alces</i>	Elk	MV2-B
Cervidae	<i>Cervus</i> (cf.) <i>elaphus</i>	Red deer	MV2-B+F
Cervidae	<i>Megaloceros giganteus</i>	Giant deer	MV2-B+F
Cervidae	<i>Rangifer tarandus</i>	Reindeer	MV2-B+F
Cervidae	Cervidae sp.	Deer sp.	F
Bovidae	<i>Bison priscus</i>	Steppe bison	MV2-B+F
Bovidae	<i>Bos primigenius</i>	Aurochs	MV2-B
Bovidae	<i>Bos</i> sp.	Bovid	F
Felidae	<i>Panthera leo spelaea</i>	Cave lion	MV2-B
Mustelidae	<i>Lutra lutra</i>	Otter	F
Ursidae	<i>Ursus</i> cf. <i>arctos</i>	Brown bear	F
Canidae	Canidae sp.	Dog or wolf	F
Hyenidae	<i>Crocuta crocuta spelaea</i>	Cave hyena	F
Suidae	<i>Sus scrofa</i>	Wild boar	MV2-B
Castoridae	<i>Castor fiber</i>	Beaver	MV2-B
Cricetidae	<i>Arvicola cantiana</i>	Vole	MV2-B
Cricetidae	<i>Arvicola</i> sp.	Vole	CO
Cricetidae	<i>Mimomys savini</i>	Vole	MV2-B
Cricetidae	<i>Microtus agrestis</i>	Common or field vole	CO
Cricetidae	<i>Microtus</i> sp.	Common or field vole	CO
Phocoenidae	<i>Phocoena phocoena</i>	Harbour porpoise	MV2-B
Phocidae	<i>Phoca</i> cf. <i>groenlandica</i>	Harp seal	F

Table 4. Mammalian species encountered at the beach (MV2-B), during the fishing trips (F), and/or in the cores (CO).

Few vertebrate remains were encountered in the core samples, which is not surprising taking into account the samples' small volume. No detailed assessment has yet been carried out of the relation between the finds collected from the beach and during the fishing trips, and the lithostratigraphic sequence in the sand extraction zone. It is possible, however, to speculate on the lithostratigraphic origins of some of the fossils on the basis of existing knowledge of the biostratigraphic distribution of identified species. For example, the oldest mammalian species that were encountered (Etruscan rhinoceros and *Mimomys savini*) are assumed to derive from Unit MV2-7, although there is a possibility that the remains in fact derive from older sediments but were incorporated into the Late Pleistocene fluviatile units as a result of fluviatile (erosive) processes. The Late Pleistocene mammalian remains that are indicative of a mammoth steppe fauna derive from one of the younger, higher Units MV2-2, MV2-3 or MV2-4.

4.5.2 Molluscs

The mollusc assemblages from Maasvlakte 2 beach and the cores were both dominated by marine species indicating a temperate climate and probably Late Pleistocene in age. The shells of these species were heavily weathered/worn and recrystallized: a phenomenon that indicates repeated reworking. Some of the taxa are indicative for the Eemian, while others, well-preserved shells of marine species as well as reasonably to well-preserved shells of brackish-water species, represent cooler periods. Holocene to recent, marine species were also found in fair numbers. In addition, a few Late Pleistocene land snails, Early/Middle Pleistocene river bivalves (clams), and (very rare) greatly worn shells of Early Pleistocene, Pliocene, and Eocene marine species were encountered (Tables 5 and 6). The latter category almost certainly arrived at the Maasvlakte sand extraction zone via a former proto-Scheldt channel.

<i>Diodora graeca</i>	n/a	MV2-B
<i>Gibbula magus</i>	Turban top shell	MV2-B
<i>Gibbula cinerea</i>	n/a	MV2-B
<i>Theodoxus fluviatilis</i>	n/a	MV2-B+CO
<i>Bithynia tentaculata</i> - opercula	n/a	MV2-B
<i>Bithynia tentaculata</i>	n/a	MV2-B
<i>Valvata piscinalis</i>	n/a	MV2-B+CO
<i>Littorina littorea</i>	Periwinkle	MV2-B+CO
<i>Littorina saxatilis</i>	Rough periwinkle	CO
<i>Lacuna vincta</i>	Northern lacuna	MV2-B
<i>Peringia ulvae</i>	Laver spire shell	MV2-B+CO
<i>Hydrobia acuta</i>	n/a	CO
<i>Ecrobia ventrosa</i>	Spire snail	MV2-B+CO
<i>Onoba semicostata</i>	n/a	MV2-B
<i>Alvania lactea</i>	n/a	MV2-B
<i>Rissoa parva</i>	n/a	MV2-B
<i>Tornus subcarinatus</i>	n/a	MV2-B+CO
<i>Turritella communis</i>	Auger shell	MV2-B+CO
<i>Haustator solanderi</i>	n/a	CO
<i>Cerithiopsis tubercularis</i>	n/a	MV2-B
<i>Epitonium clathrus</i>	n/a	MV2-B
<i>Balcis alba</i>	n/a	MV2-B
<i>Omalaxis serratus</i>	n/a	CO
<i>Euspira pulchella</i>	Common necklace shell	MV2-B+CO
<i>Euspira catena</i>	Large necklace shell	MV2-B+F+CO
<i>Euspira cf. catenoides</i>	n/a	CO
<i>Euspira sp. 1.</i>	n/a	MV2-B
<i>Buccinum undatum</i>	Common whelk	F
<i>Ocenebra erinaceum</i>	Sting winkle	MV2-B+CO
<i>Nucella lapillus</i>	Dog whelk	MV2-B
<i>Nassarius pygmaeus</i>	Small dog whelk	MV2-B
<i>Nassarius reticulatus</i> (sl.)	Netted dog whelk	MV2-B+F+CO
<i>Nassarius nitidus</i>	n/a	MV2-B+CO
<i>Nassarius incrassatus</i>	n/a	CO
<i>Nassarius spec. 1.</i>	n/a	MV2-B
<i>Oenopota turricula</i>	Turriculate lora	MV2-B+CO
<i>Haedropleura septangularis</i>	n/a	MV2-B
<i>Chrysallida sarsii</i>	n/a	CO
<i>Odostomia scalaris</i>	n/a	MV2-B
<i>Turbonilla crenata</i>	n/a	MV2-B
<i>Turbonilla lactea</i>	n/a	CO
<i>Philine aperta</i>	Sand slug	MV2-B
<i>Stagnicola palustris</i>	n/a	CO
<i>Radix ovata</i>	n/a	CO
<i>Radix auricularia</i>	Ear pond snail	CO
<i>Lymnaeidae</i>	n/a	CO
<i>Galba truncatula</i>	n/a	CO
<i>Planorbis planorbis</i>	Margined ramshorn	CO
<i>Gyraulus cf. rossmaessleri</i>	n/a	CO
<i>Ferrissia wautieri</i>	n/a	MV2-B
<i>Vallonia tenuilabris</i>	n/a	CO
<i>Vallonia sp.</i>	n/a	CO
<i>Vertigo genesii</i>	n/a	CO
<i>Pupilla muscorum</i>	n/a	CO
<i>Pupilla sp.</i>	n/a	CO
<i>Columella columella</i>	n/a	CO
<i>Oxyloma sp.</i>	n/a	CO
<i>Succinella oblonga</i>	n/a	CO
<i>Zonitidae</i> indet.	n/a	CO
<i>Trichia hispida</i>	n/a	CO
<i>Arianta arbustorum</i>	n/a	CO

Table 5. Mollusc species (Gastropoda) identified in shell assemblages collected on the Maasvlakte 2 beach (MV2-B), during the fishing trips (F), and/or from the cores (CO).

<i>Anadara</i> indet.	n/a	MV2-B
<i>Arcopsis lactea</i>	n/a	MV2-B
<i>Mytilus edulis</i> sl.	Common mussel	MV2-B+F+CO
<i>Modiolus modiolus</i>	Horse mussel	MV2-B
<i>Ostrea edulis</i>	Common oyster	MV2-B+F+CO
<i>Anomia ephippium</i>	Saddle oyster	MV2-B+F+CO
<i>Aequipecten opercularis</i>	Queen scallop	MV2-B
<i>Mimachlamys varia</i>	Variegated scallop	MV2-B+F+CO
<i>Flexopecten flexuosus</i>	n/a	MV2-B
<i>Lucinella divaricata</i>	n/a	MV2-B+CO
? <i>Scacchia</i> indet	n/a	MV2-B
<i>Pseudopythina macandrewi</i>	n/a	MV2-B
<i>Montacuta ferruginosa</i>	n/a	MV2-B
<i>Kurtiella bidentata</i>	n/a	MV2-B+CO
<i>Astarte borealis</i>	Boreal astarte	MV2-B+F
<i>Astarte</i> (cf.) <i>montagui</i>	Narrow-hinge astarte	MV2-B+F+CO
<i>Goodallia</i>	n/a	CO
<i>Venericor planicosta</i>	n/a	MV2-B
<i>Cerastoderma glaucum</i>	Lagoon cockle	MV2-B+F+CO
<i>Cerastoderma edule</i>	Edible cockle	MV2-B+F+CO
<i>Cerastoderma edule</i> f <i>major</i>	Cockle	MV2-B+F+CO
<i>Cerastoderma</i> spp.	Cockle	CO
<i>Laevicardium oblongum crassum</i>	Norway cockle	MV2-B+F
<i>Laevicardium oblongum castanea</i>	n/a	MV2-B+F+CO
<i>Acanthocardia tuberculata</i>	Rough cockle	MV2-B+F
<i>Acanthocardia echinata</i>	Prickly cockle	MV2-B+F
<i>Macra stultorum</i>	Rayed trough shell	MV2-B+F
<i>Macra stultorum cinerea</i>	Rayed trough shell	CO
<i>Macra stultorum plistonae</i>	Rayed trough shell	MV2-B+F+CO
<i>Macra glauca</i>	n/a	MV2-B+F
<i>Spisula elliptica</i>	Elliptic trough shell	MV2-B+F+CO
<i>Spisula solida</i>	Thick trough shell	MV2-B+F+CO
<i>Spisula subtruncata</i>	Cut trough shell	MV2-B+CO
<i>Lutraria lutraria</i> sl.	Otter shell	MV2-B+F
<i>Lutraria magna</i>	n/a	MV2-B+F
<i>Solen marginatus</i>	Grooved razor shell	MV2-B+CO
<i>Phaxas pellucidus</i>	Razor shell	MV2-B+CO
<i>Ensis magnus</i>	Sword razor	MV2-B+CO
<i>Ensis ensis</i>	Sword razor	MV2-B+CO
<i>Ensis americanus</i>	Atlantic jack-knife clam	MV2-B
<i>Ensis minor</i>	Minor jack-knife clam	MV2-B
<i>Ensis phaxoides</i>	Sword razor	MV2-B
<i>Ensis siliqua</i>	Pod razor shell	MV2-B
<i>Ensis directus</i>	Atlantic jack-knife clam	MV2-B
<i>Ensis</i> indet.	n/a	CO
<i>Tellina tenuis</i>	Thin tellin	CO
<i>Donax vittatus</i>	Banded wedge-shell	MV2-B
<i>Gari fervensis</i>	Faroe sunset shell	MV2-B+CO
<i>Gari depressa</i>	Large sunset shell	MV2-B
<i>Angulus tenuis</i>	n/a	CO
<i>Angulus fabulus</i>	Bean-like tellin	MV2-B+CO
<i>Angulus pygmaeus</i>	n/a	MV2-B+CO
<i>Macoma balthica</i>	Baltic macoma	MV2-B+F+CO
<i>Macoma obliqua</i>	n/a	MV2-B
<i>Macoma</i> cf. <i>praetenuis</i>	n/a	CO
<i>Gastrana fragilis</i>	n/a	CO
<i>Abra alba</i>	White furrow shell	MV2-B+CO
<i>Abra prismatica</i>	n/a	MV2-B
<i>Abra nitida</i>	n/a	CO
<i>Scrobicularia plana</i>	Peppery furrow shell	MV2-B+CO
<i>Arctica islandica</i>	Iceland cyprina	F+CO
<i>Corbicula</i> (cf.) <i>fluminalis</i>	n/a	MV2-B

<i>Pisidium amnicum</i>	Greater European peaclam	CO
<i>Pisidium henslowanum</i>	Henslow's pea mussel	CO
<i>Pisidium supinum</i>	n/a	CO
<i>Pisidium cf. moitessierianum</i>	Pygmy pea mussel	CO
<i>Pisidium</i> sp.	n/a	CO
<i>Sphaerium corneum</i>	Horny orb mussel	CO
<i>Unio tumidus</i>	n/a	CO
<i>Unio cf. pictorum</i>	n/a	MV2-B
<i>Dosinia exoleta</i>	Rayed artemis	MV2-B+F
<i>Dosinia lupinus</i>	Smooth artemis	MV2-B+F+CO
<i>Dosina cf. casina</i>	n/a	CO
<i>Chamelea striatula</i>	Striped venus	MV2-B+CO
<i>Venerupis senescens</i>	n/a	MV2-B+F+CO
<i>Venerupis senegalensis</i>	Pullet carpet shell	MV2-B
<i>Venerupis corrugata</i>	Corrugated venus	MV2-B
<i>Mya arenaria</i>	Softshell clam	MV2-B
<i>Mya truncata</i>	Truncate softshell clam	MV2-B+F
<i>Varicorbula gibba</i>	Basket shell	MV2-B+CO
<i>Panopea glycymeris</i>	n/a	MV2-B
<i>Saxicavella jeffreysi</i>	n/a	MV2-B
<i>Barnea candida</i>	White piddock	MV2-B+CO
<i>Zirfaea crispata</i>	Great piddock	MV2-B+F+CO
<i>Pholas dactylus</i>	Common piddock	MV2-B+F
<i>Yoldia</i> indet.	n/a	CO
<i>Limopsis</i> indet.	n/a	CO
<i>Hiatella arctica</i>	Wrinkled rockborer	CO
<i>Thracia cf. pubescens</i>	n/a	CO

Table 6. Mollusc species (Bivalvia) identified in shell assemblages collected on the Maasvlakte 2 beach (MV2-B), during the fishing trips (F), and/or from the cores (CO).

While reworked Eemian material was retrieved in fairly large quantities from the cores and collected on the Maasvlakte 2 beach, definite evidence for *in situ* Eemian faunal assemblages is still lacking. Compared to the assemblages identified during the aforementioned parallel studies, several groups are highly underrepresented or completely absent in the material produced by the fishing trips. In the fishing-trip assemblage the shell fauna is dominated by typical Eemian species; a large part of the material consists of exceptionally well-preserved, large marine shells and therefore appears to derive from *in situ* Eemian sediments or from intact lumps of cohesive Eemian sediment that during erosional processes were incorporated into younger sedimentary units.

4.5.3 The source of the remains

The mammalian and other macro remains collected during the fishing trips and on the beach probably derive from the base of lithostratigraphic units MV2-3 and MV2-4. The land-based equivalents of sediments found in Unit MV2-3 are known to have been deposited during an erosion phase of the Rhine-Meuse system (Weichselian Early Pleniglacial, MIS 4). This event involved a pronounced lateral scouring of the sediments of the Eemian and Early Weichselian coastal system (MIS 5). Any mammalian remains once present on old surfaces, or molluscs and other macro remains embedded in these near-coastal sediments, will therefore have been eroded into the river channels, concentrating particularly at the base of the channel deposits. The occurrence of a high degree of, for example, Early Pleistocene components indicates that also Early Pleistocene sediments (Waalre and/or Stramproy Formation) were eroded, and/or that these components were already present in a reworked position in Eemian or early Glacial sediments. At the moment we cannot exclude the possibility that earlier reworking had taken place also, and that part of the macro remains retrieved during the fishing trips and the surveys originated from the base of Unit MV2-4.

5 Correlating the finds from the Maasvlakte 2 beach and those collected during the fishing trips with the lithostratigraphic units in the sand extraction zone

In order to establish the age of the different finds and to determine which specific flora and faunal associations characterise a specific period, it is crucial to connect the finds from the extraction zone collected during the fishing trips and from the Maasvlakte 2 beach with the lithostratigraphic sequence in the sand extraction zone.

5.1 Survey units

Identifying the specific lithostratigraphic units from which finds (categories) from a specific survey unit at the beach were retrieved, requires detailed information on the origins of the imported sediment. The GPS coordinates of the corner points of the survey units were recorded, so the exact locations of these units are known. Furthermore, the contractor (PUMA) had made available a list of all locations where the suction hopper dredgers extracted the sand and where they deposited it ('the dumping units'). The same contractor had defined dumping units (circa 25 x 50m) for the entire Maasvlakte 2 area, and these data made it possible to reconstruct, for the most part, the origins of the sediments in each survey unit. Reconstructing the original location of the surface finds from the beach depended on information as to which suction hopper dredger was the last to dump sand there, and where it had extracted the sediment from. However, as the report on the finds from the beach shows (den Ouden et al. 2013), the origin of the sediment exposed in the individual survey units could not be established with certainty.

5.2 Fishing trips

Also the fishing trips did not yield any finds that could univocally be ascribed to a specific lithostratigraphic unit. Especially objects of a greater diameter than the hopper dredger's suction pipe occasionally slid down to a (much) greater depth than their original position in the sediment matrix, resulting in an artificial, mixed lag deposit of larger fossils. In addition, due to their length and encountered variations in depth, the longer transits covered several lithological units. These two factors contributed to the stratigraphically mixed character of the fishing assemblages.

Due to the mixed character of the assemblages it is difficult to establish a reliable correlation between, on the one hand, finds from the beach and – especially – the fishing trips, and, on the other, the lithostratigraphic units defined on the basis of geological/stratigraphic research.

Only by taking into account information from other studies (e.g. data on the stratigraphic range or ecological preferences and restrictions of certain species) some finds could be assigned to a specific lithological unit. However, also the lithostratigraphic units themselves showed signs of repeated, severe reworking during the fluvial and/or marine depositional phases. It is likely that none of the assemblages are pristine and free from mixing, due to the depositional and (post-disturbance) retrieval history of the material. This makes it very difficult to assign archaeological finds to a precise stratigraphic unit and to reconstruct their ecological and environmental context.

6 Conclusions and discussion

6.1 Answering the research questions

The *Rapportage Archeologische Monumentenzorg* 169 (Manders et al. 2008) formulated the general research questions; growing insight has since led to a refinement and to supplementary, more detailed questions. The following section discusses the partially revised research questions and attempts to supply brief answers based on the results of the associated reports.

What is the lithostratigraphic composition of the disturbed area, and what geogenetic information can be derived from it?

Macroscopic analyses of the contents of cores drilled in the north-eastern section of the sand extraction zone allowed the definition of seven local stratigraphic units, MV2-1 to MV2-7. The upper unit (MV2-1) was formed during or immediately following the sand extraction process. Unit MV2-2 has a saltwater, brackish or freshwater-tidal character and is part of the Naaldwijk Formation. The upper section of Unit MV2-3 has a (freshwater) tidal nature while the lower section of the same unit is fluvial in origin, as are Units MV2-4 to MV2-7. Units MV2-3 to MV2-6 are part of the Kreftenheye Formation; Unit MV2-7 probably belongs to either the Urk Formation or the Waalre Formation.

What is the date of the distinct stratigraphic units?

Unit MV2-1 is very recent in age, its formation coinciding with the sand extraction process. Unit MV2-2 is Holocene in age; Unit MV2-3 was probably formed during the Middle Weichselian but a more recent age cannot be excluded. A clayey lens within this unit probably dates from the Early Weichselian. Presumably also Early Weichselian in date are Units MV2-4 and MV2-5; Unit MV2-5 has not been encountered on the mainland. The sediments of Unit MV2-6 were formed in the Late Saalian. The formation date of Unit MV2-7 is yet unknown, but environmental data as well as pollen analysis results suggest a Middle or Early Pleistocene date.

The dates mentioned above are all preliminary estimates. They will be verified and, when necessary, modified once the OSL dates become available.

At which depths are the various (litho)stratigraphic units situated?

Unit MV2-1 consists of sediment deposited on the slopes and the bottom of the sand extraction pit. The sediments on the slopes are up to 1m thick while those on the bottom, at a depth of 41 to 43m - asl, are circa 0.5m thick. The base of Unit MV2-2 is mostly situated at a depth of 27 to 29m - asl, but occasionally slightly deeper. Locally the unit is completely absent. The base of Unit MV2-3 is situated at a depth of 27.5 to 31m - asl, that of Unit MV2-4 is mostly situated at a depth of 28 to 32m - asl, and the base of Unit MV2-5 was encountered at a depth of 30 to 33m - asl. The depth of the base of Unit MV2-6 is circa 42m - asl. Unit MV2-7 was the deepest unit encountered in the sand extraction pit; its base was never reached but exceeds 47m - asl.

To what extent does the bottom of the sand extraction pit differ from the surrounding, undisturbed seafloor?

The bottom and slopes of the sand extraction pit are composed of chaotic, lobe-like structures caused by the suction hopper dredger or by slope processes. The slope's gradient ranges from 1:7 to 1:10 and stabilised after the completion of the extraction process. The slope is uneven, being in part composed of small steps (places where sand was extracted parallel to the slope) and gullies (where the direction of the extraction process was perpendicular). The surface of the undisturbed seafloor, on the other hand, forms a regular pattern of WNW-ESE oriented sand waves.

Do the Late Pleistocene layers contain Pleistocene faunal remains and/or any other palaeo-ecological remains?

Yes, they do. Units MV2-3 to MV2-5 are presumably Late Pleistocene in age. Core samples from these units contain palaeo-ecological remains (pollen, dinoflagellates, diatoms, foraminifera, fungal spores, seeds, fruits, molluscs, and mammalian skeletal elements) which supplied information on the age and depositional environment of the sediment in the units.

What are the characteristics of the faunal assemblages?

The surveys in the sand extraction pit and on the beach resulted in a large number of faunal remains (e.g. large and small mammals, fish, and molluscs) dating from the Early Pleistocene to the Holocene. Late Pleistocene molluscs and large mammals dominate. Many of the (Late) Pleistocene fossils belonged to typical so-called mammoth steppe associations with species such as woolly mammoth, woolly rhinoceros, horse, giant deer, and steppe bison. In addition to these continental species, other identified remains came from Late Pleistocene marine mammals. Overall, the skeletal remains were well preserved with few signs of weathering and little or no rounding. Such taphonomic characteristics indicate that the skeletal material did not lie on the surface for long, nor was it transported over large distances.

The mollusc assemblages from the Maasvlakte 2 beach and the cores were dominated by marine species indicative of a temperate climate and probably with a Late Pleistocene age. The shells were heavily worn and recrystallized, which suggests repeated reworking of the assemblage. A significant number of the encountered species are known from the Eemian Interglacial.

In the assemblages collected during the fishing trips several categories are greatly underrepresented or completely absent, due in part to the hauling methods that were used. Among the shell fauna, large shells of Eemian marine species dominated. Many of them were very well preserved and may derive from *in situ* Eemian sediments or from eroded, large lumps of such sediments. In addition, the mollusc assemblages from several samples included Late Pleistocene, temperate-brackish and temperate to cool species, variable numbers of Holocene (to recent), marine species, and (very) low numbers of Early Pleistocene species – besides freshwater and terrestrial species and 'worn' shells of even older species.

Do the faunal assemblages contain indications for human activity, and if so, what is the nature of these indications?

The fishing trips resulted in the discovery of two skeletal elements that showed obvious signs of human activity. One concerns a virtually complete rib of a Holocene bovid; only part of the distal end is missing. Characteristic V-shaped cut marks are visible on the inner as well as the outer surface. The second specimen is a fragment of a red-deer antler. It is a typical example of production waste, as both ends show distinct, V-shaped cut marks from a flint tool. Such traces are the result of attempts to break the antler; probably something went wrong after which the fragment was discarded. The specimen cannot be assigned to a specific archaeological period on the basis of its typology.

A number of skeletal elements from the beach and the extraction zone showed less distinct traces, which may or may not be related to human activity. None of the molluscs hauled up during the fishing trips contained traces of anthropogenic modification.

What is the typochronological date of the flint/stone artefacts, what are their typological characteristics, and what can be stated about their past use?

The survey units on the Maasvlakte 2 beach yielded a total of ten flint artefacts: eight complete or fragmentary flakes, one core fragment and one flake that was used as a tool. The latter concerns a rather thick flake and was identified as an *éclat débordant* type artefact. It shows retouch on the lateral face and the proximal face was retouched into a convex end scraper. As such it represents a backed blade with a naturally shaped back (*sensu* Bordes 1961). It may be Palaeolithic in age.

What can be stated about the possible depositional context of the artefacts?

The varying condition of the flint artefacts, such as rounded (i.e. fluvial transportation) versus sharp edges (i.e. virtually no transportation), and patina versus no patina (indicating differential weathering and different types of weathering) demonstrate that the finds were originally imbedded in different sediment types.

6.2 Maasvlakte 2 in a broader context

Geographically, the sand extraction zone is situated in a region that is particularly rich in Quaternary finds. For decades fishermen have hauled up material from the bottom of the North Sea. Tens of thousands of specimens ended up in collections of museums and amateur collectors, and studies of these so-called side catches have resulted in a wealth of information, especially on Pleistocene mammalian faunal assemblages in north-west Europe (e.g. Mol et al. 2008; Mol and Post 2010). The finds also included dozens of Palaeolithic/Mesolithic artefacts. The stratigraphic date of the material ranges from the Late Pliocene/Early Pleistocene (e.g. finds from the southern part of the North Sea and from the Oosterschelde and Westerschelde; e.g. van Kolfschoten and Laban 1995; Heuff 2010) to Late Pleistocene/Early Holocene (for example the so-called Brown Ridge and Dogger Bank in the North Sea; e.g. Louwe Kooijmans 1971; Glimmerveen et al. 2006). Fossils and artefacts are also being collected on both sides of the North Sea along the British and Dutch coasts. Along the British coast (particularly in East Anglia), Early and Middle Pleistocene sediments surface at, among other places, Pakefield (Parfitt et al. 2005) and Happisburgh (Parfitt et al. 2010). These Palaeolithic sites provide the opportunity to collect *in situ* material. Along the Dutch coast amateur collectors regularly pick up material in areas where sand is being brought up to strengthen coastal defences.

Exceptionally rich fossil vertebrate assemblages are also known from three sites near the sand extraction area: the Eurogeul, Maasvlakte 1, and the Zuurland boreholes near Brielle (respectively Mol et al. 2006; Vervoort-Kerkhoff and van Kolfschoten 1988; van Kolfschoten and Vervoort-Kerkhoff 2013; van Kolfschoten 1988). Over the past few decades the vertebrate fossils from these three sites have been extensively studied, providing an opportunity to compare and correlate the assemblages with one another and with the assemblages from the sand extraction area Maasvlakte 2. Other find categories are less numerous and/or have been studied in less detail.

Eurogeul

In order to facilitate access to the Rotterdam harbour area for ships with an increasingly greater depth, the so-called Eurogeul (a major deep-water route) and adjoining areas were dredged, a process that involved removing sediments that had been deposited in the Late Pleistocene and Holocene. Many finds were collected in zones where the extracted sediment was dumped, and in addition fishermen brought to shore many fossil vertebrate remains. The Eurogeul area produced spectacular finds, such as the fragmentary skull of a mammoth calf (van der Plicht et al. 2012). In many respects the Eurogeul fauna resembles that of Maasvlakte 2, which is hardly surprising in view of the proximity of the two locations. A remarkable and as yet unexplained difference between the two areas, however, is a greater diversity of fossil sea mammal species at Eurogeul in comparison to the assemblage from the Maasvlakte 2 sand extraction area.

Maasvlakte 1

In many respects the lithostratigraphic origins of the sediments used in the construction of Maasvlakte 1 are similar to those of the Maasvlakte 2 sediments. Through time, thousands of fossil vertebrate remains have been found on the beaches of Maasvlakte 1. Many different species are represented, with fossils dating from the Early Pleistocene, the Early-Middle Pleistocene transition, the Late Pleistocene, and the Holocene (van Kolfschoten and Vervoort 2013). The material from Maasvlakte 1 includes worked bone, which often concerns Holocene artefacts such as beautifully crafted harpoon points, or pieces of red-deer antler with clear cut marks indicative of anthropogenic modification (Verhart 1988). So far, a smaller number of vertebrate species have been identified in the assemblage from the Maasvlakte 2 compared to the Maasvlakte 1 assemblage, but nonetheless the two assemblages broadly resemble each other.

Zuurland (Brielle)

Over a dozen sediment cores taken in the polder Zuurland (Brielle) yielded an enormous collection of small-mammal fossils (van Kolfschoten 1988). The cores reached a maximum depth of over 100m and contained large mammalian assemblages

Fauna	Species	Period/characteristics	Presence
Unit 1	<i>Microtus oeconomus</i> , <i>Microtus</i> gr. <i>arvalis</i> , and <i>Arvicola terrestris</i>	- Final section Late Pleistocene to Holocene	In the upper levels (ca. 14-26m)
Unit 2	<i>Arvicola</i> sp., <i>Microtus</i> gr. <i>arvalis</i> , <i>Dicrostonyx</i> sp., <i>Lemmus</i> sp., <i>Mimomys savini</i> , <i>Clethrionomys</i> cf. <i>acrorhiza</i> , <i>Microtus gregaloides</i> , <i>Mimomys</i> gr. <i>reidi-pusillus</i> , <i>Allophaiomys</i> sp.	- Combined presence of Late Pleistocene, early-Middle Pleistocene and Early Pleistocene species - Much disturbance	27-37m, clustering between 28 and 32m
Unit 3	<i>Mimomys savini</i> , <i>Mimomys</i> gr. <i>reidi-pusillus</i> , <i>Allophaiomys deucalion</i> , <i>Ungaromys dehmi</i> , <i>Lemmus kowalskii</i> , <i>Clethrionomys kretzoi</i> , <i>Craseomys</i> aff. <i>major</i> , and <i>Mimomys pliocaenicus</i> .	- Early Pleistocene - <i>Allophaiomys deucalion</i> is the dominant species (ca. 1.8-2 MA)	39-54m, clustering between 42 and 44m
Unit 4	<i>Lemmus kowalskii</i> , <i>Clethrionomys kretzoi</i> , <i>Ungaromys dehmi</i> , <i>Borsodia newtoni</i> , <i>Mimomys pliocaenicus</i> , <i>Mimomys tigliensis</i> , <i>Mimomys pitymyoides</i> , <i>Mimomys hordijki</i> , <i>Mimomys reidi</i>	- <i>Allophaiomys</i> no longer present - Tegelen fauna (Early Pleistocene) - Most diverse assemblage of all Zuurland cores	61-65m
Unit 5	<i>Clethrionomys kretzoi</i> , <i>Mimomys tigliensis</i> , <i>Mimomys reidi</i> , <i>Mimomys</i> cf. <i>praepliocaenicus</i>	- Still Quaternary fauna (Early Pleistocene), but more primitive than Tegelen fauna	91-101m

Table 7. The five fauna units recognised in the Zuurland cores, defined on the basis of the presence/absence of specific vole species. Table after van Kolschoten and Tesakov 2010.

which formed the basis for a biostratigraphic framework (Table 7) that may serve as a regional reference point, with the provision that the stratigraphic depths at Zuurland cannot be extrapolated automatically to the sand extraction area due to the more southern position of the boreholes.

The definition of the fauna units is based on the presence or absence of specific vole species. The presence of vole remains of the genus *Arvicola* in cores taken in the Maasvlakte 2 sand extraction zone suggests that it may be possible to correlate the faunal assemblages from these core samples with those from Units 1 and 2 at Zuurland. The genus *Arvicola* is absent from the three lowermost Zuurland fauna units (Units 3-5).

The fauna from Zuurland Unit 2 forms a mixed assemblage in which species from different stratigraphic units occur side by side. Early Pleistocene and early-Middle Pleistocene species identified in the assemblages from the Maasvlakte 2 sand extraction area and the beach probably derive from the same stratigraphic level as the species in Zuurland Unit 2. Hence, it can be concluded that the informal (litho) stratigraphic units MV2-1 to MV2-7 are a local refinement of the biostratigraphic unit Zuurland Unit 2.

6.3 To be continued ...

The geoarchaeological and palaeontological research of the sand extraction area and the Maasvlakte 2 beach generated many data. However, OSL dates of the sediment samples from the cores are not yet available. Processing and analysing these dates within the time frame assigned to the project proved to be impossible. It is expected that the OSL results, when available, will result in a greater accuracy of the geological dates established for the defined lithostratigraphical units.

The analysis results for the gravel from the cores have been incorporated into Appendix 4 of the report *Het stratigrafische raamwerk voor de geologische opbouw van het zandwingebied Maasvlakte 2* (Busschers et al. 2013). Due to delays in the process neither these results, nor those of the analysis of the gravel collected on the beach and during the fishing trips have been included in the present report. Once available, these results may clarify the correlation between the sediments exposed on the beach and the lithostratigraphic units in the sand extraction area.

The present synthesis summarises specialist studies carried out in the Maasvlakte 2 beach and sand extraction zone. Of course, more discoveries can be expected and the research will continue. A large group of collectors regularly scan the Maasvlakte 2 beach for finds, and it is probably only a matter of time before species so far identified only at Maasvlakte 1 will also be found at Maasvlakte 2. Already the small-mammal assemblage has recently been much expanded so that several species can now be added to the fauna retrieved at Maasvlakte 2 (Dieleman, pers. comm. October 2013). New recent discoveries include a number of hyena coprolites (see e.g. Mijts 2013).

The lively interest among the general public in archaeological and palaeontological finds, as well as the stimulating role of the *Futureland* Visitor Centre as facilitator in this process, may well lead to many more unexpected discoveries in the near future. One such exciting discovery would certainly be the identification of fossil Neanderthal remains. The geological studies conducted in the sand extraction area allowed the construction of an improved geological framework for the finds, which increased their scientific value, while the innovative methods applied in the course of this research will benefit future large-scale projects.

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