

# DEINSEA



## The Kor & Bot collection revisited, with a biostratigraphic interpretation of the Early Pleistocene Oosterschelde Fauna (Oosterschelde Estuary, the Netherlands)

D.J. Scager<sup>1</sup>, H.-J. Ahrens<sup>2</sup>, F.E. Dieleman<sup>2</sup>, L.W. van den Hoek Ostende<sup>2</sup>, J. de Vos<sup>2</sup>  
& J.W.F. Reumer<sup>1,3</sup>

<sup>1</sup> Department of Geosciences, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, the Netherlands

<sup>2</sup> Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, the Netherlands

<sup>3</sup> Natural History Museum Rotterdam, Westzeedijk 345 (Museumpark), 3015 AA Rotterdam, the Netherlands

### ABSTRACT

For the first time in 30 years the Kor & Bot collection is surveyed and interpreted in its entirety (i.e. all known 2174 pieces) on the occasion of the 65<sup>th</sup> Kor & Bot expedition in 2015. The locality nomenclature within the Oosterschelde is restructured and clarified, the taxonomy and the anatomical information are corrected and complemented where necessary and 1631 fossils (excluding cetacean material) are measured to gain insight in their taphonomy. The collection contains five faunal groups: (1) Middle Miocene cetaceans, (2) Pliocene marine mammals, (3) Early Pleistocene (Middle Villafranchian) terrestrial mammals (forming the so-called Oosterschelde fauna), (4) Late Pleistocene terrestrial mammals and (5) Holocene terrestrial mammals, and derives for ~95% from three pits within the estuary. Moreover ~75% of cetacean material derives from only one of these three. The collection is diverse in taphonomical expression, but the majority of the material is small in size (mean length ~15 cm), fragmented and all material has been weathered and reworked. The Oosterschelde fauna (MN17, Villafranchian type) is a characteristic assemblage of Early Pleistocene terrestrial mammals and forms the larger part of the Kor & Bot collection. By means of West-European small and large mammal biozonation, correlated to local stratigraphy, its age is now considered 2.35-2.10 Ma.

**Keywords** MN17, MNR1, MNR2, Moriaanshoofd, Villafranchian

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**Author for correspondence**

Jelle W.F. Reumer:

j.w.f.reumer@uu.nl

**Editors of this paper**

Bram W. Langeveld

C.W. (Kees) Moeliker

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### INTRODUCTION

The Oosterschelde estuary forms part of the North Sea Basin and is located in the province of Zeeland, the Netherlands (Fig. 1). Over the past 65 years it has proven to be a locality rich in fos-

sil mammal material. Among the material dredged up from the estuary the Early Pleistocene (Middle Villafranchian; MN17) Oosterschelde fauna stands out for its faunal composition and richness (De Vos *et al.* 1998). The actual localities within the

estuary are pits with depths between 35 and 47.5 m below mean sea level within the more or less 20 m deep gullies along the south coast of Schouwen-Duiveland and the north coast of Walcheren. One day every year (since ~1950) a mussel cutter sets out to collect fossil material for scientific purposes (Heuff 2010); this is the so-called Kor & Bot expedition. This has resulted in 2174 bone fragments and molars of large mammals ranging in age from Middle Miocene up to recent. Since no study of the entire collection has been published since 1985 (Kortebout van der Sluijs 1985), and in honour of the 65<sup>th</sup> Kor & Bot expedition, a survey of this collection was undertaken as well as an (re-)interpretation of its content. Since the earliest years, the literature available almost solely focusses on the Early Pleistocene (Villafranchian, Gelasian, MN17) Oosterschelde fauna (Hooijer 1952, Kortebout van der Sluijs 1985, Drees 1986, 2005, Mol 1991, De Vos *et al.* 1995, 1998, Mol & De Vos 1995, Reumer *et al.* 1998, 2008, Kahlke 2001, Slupik *et al.* 2007, 2013; Mayhew *et al.* 2008, 2014), even though the collection also contains more and older cetacean material than would be apparent. In addition, since 1997 a quantity of small mammal material has been made available to allow for a better approximation of the age of this Oosterschelde fauna when combined with the large mammal fauna list in the context of West-European mammal biostratigraphy (Reumer *et al.* 2008). Here, for the first time in 30 years the Kor & Bot collection is surveyed and interpreted in its entirety (i.e. all known 2174 pieces) on the occasion of the 65<sup>th</sup> Kor & Bot expedition in 2015 (Scager 2015).

## MATERIAL AND METHODS

### Collection and conservation

The fossil material is trawled up by mussel cutters. These vessels are equipped with four dredging nets ('kor' in Dutch), two on both port and starboard, although only two of them are used during collection (one on each side). The nets have a width of 150 cm (this has not changed over time) and are equipped with a metal bar (the knife) on the lower side of their frontal opening that allows the nets to penetrate some centimetres into the sediment.

With the use of (GPS) coordinates the pits are located, after which the mussel cutter lowers two of its nets into the chosen pit. The pit is then circled in order to trawl as much surface as possible from both bottom and sides. After dropping the content of the net on deck, the fossil material is manually identified and removed before the residue is scooped and flushed overboard. As soon as they are emptied, both nets are lowered for the next haul. At the end of the day, after 30 hauls on average, the collected material is identified and taken to Naturalis Biodiversity Center (NBC, Leiden, the Netherlands) for conservation and storage. Apart from that a smaller amount of finds is stored at the Stadhuismuseum Zierikzee (103 specimens). In total, 2174 specimens are available.

To compensate for the loss of fine material, so-called 'Van Veen tubes' were introduced in 1997 as a trial (Reumer *et al.* 1998) and have been used ever since. With a diameter of 7.8 cm and a fine mesh (c. 0.5 mm) at the rear end, these metal tubes are attached to the knife of the dredging nets. The sediment obtained is sieved for fine material such as mollusc shells,

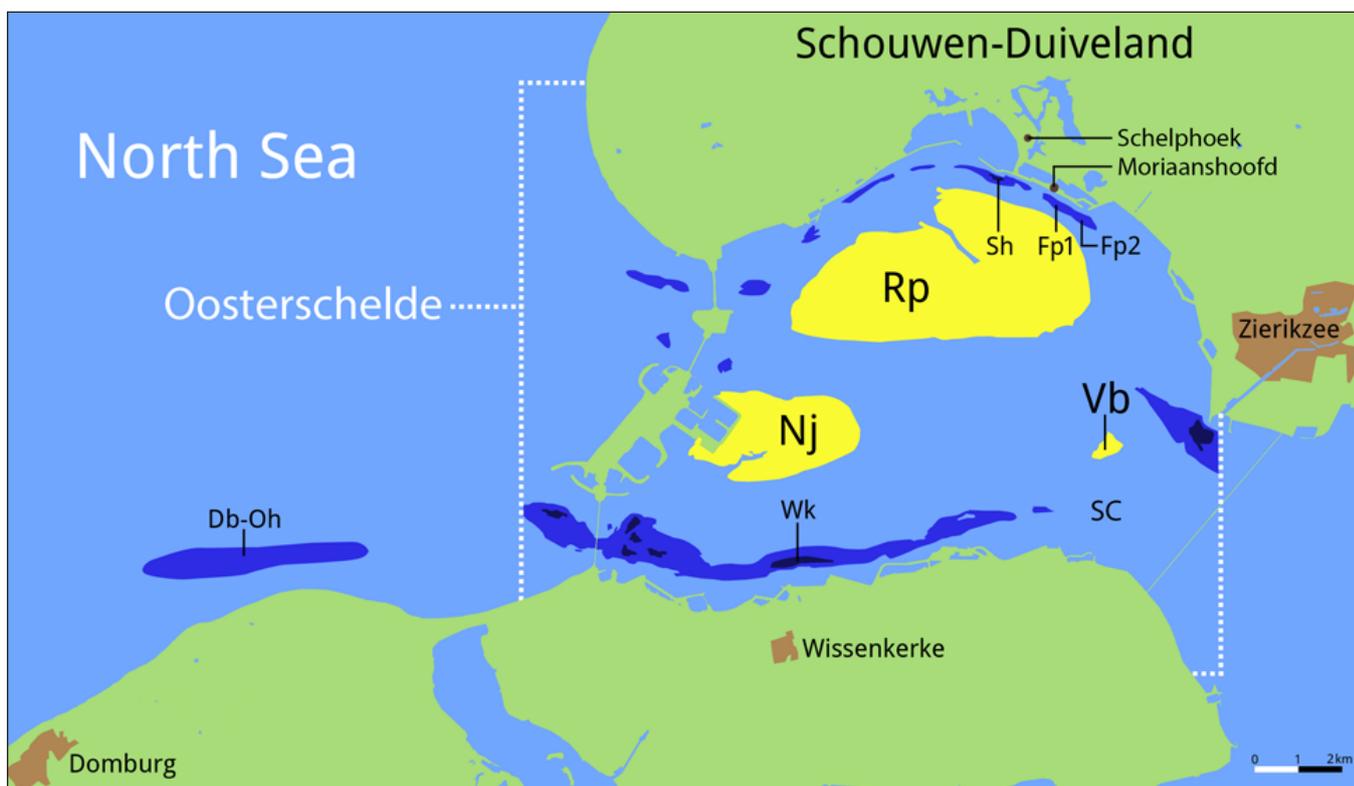


Figure 1 The Oosterschelde Estuary, with main localities ( $\geq 10$  finds per locality). Sand bars: **Rp** = Roggenplaat, **Nj** = Neeltje-Jansplaat, **Vb** = Vuilbaard. Localities: **Sh** = Schelphoek, **Fp1** = Flauwerspolder pit 1, **Fp2** = Flauwerspolder pit 2, **SC** = Schaar van Colijnsplaat, **Dp-Oh** = Domburg-Oosterhoofd. (L. Zuydgeest)

small mammal and bird skeletal elements and small mammal teeth. To wash the sediments, three sieves with decreasing mesh size are installed on deck. The small mammal material is kept at the NBC and the Natural History Museum Rotterdam (Rotterdam, The Netherlands) and is gradually investigated during the rest of the year.

Before storage the material is desalinated by immersion in a freshwater bath. Material collected in the earlier days, meant for display, has been cleaned and then coated with shellac (a substance made from the resin-like excretion of an Indian species of hemipteran insects). It is known to give fossils a somewhat brownish coloration and it protects against oxidation.

### Survey

While studying the Kor & Bot collection, several issues came forward that urged to be addressed. These issues can be roughly divided into the following categories: locality nomenclature, available information on anatomy and taxonomy, and taphonomic characteristics and interpretation of the material. The difficulties associated with *ex situ* collecting (i.e., the uncertain stratigraphical provenance of the material) have been described by De Vos *et al.* (1998), and will not be repeated here.

The available anatomical and taxonomical information about the fossils is variable. Here we distinguish the following information: (1) the nature of the skeletal element, (2) the nature of the specific fragment of bone or dentition, (3) whether it is sinistral or dextral, and (4) whether a fragment is from the distal or proximal parts of a bone. The available identification was corrected and complemented where possible by means of visual comparison of the fossils with material in the NBC collection or with published anatomical drawings (Owen 1866, Kingsley 1917, Heintz 1970, Romer 1970, Schmid 1972). The taxonomy was updated according to current standards (McKenna & Bell 1997, Wilson & Reeder 2005) in order to construct an up-to-date faunal list for the Oosterschelde localities.

Finally, to gain more insight in the taphonomy and the Oosterschelde as a fossil producing area, the material (excluding the Cetacea) was measured. Specimens were measured in three directions, perpendicular to one another. This was necessary since many specimens are little more than amorphous objects. The length (L) or line of greatest distance is measured between the two points farthest removed from one another. The width (W) is measured between another two points furthest away from and perpendicular to the line of largest distance. This is achieved with a Vernier calliper. Using the line of greatest distance as a rotation axis held parallel to the calliper's jaws the specimen is rotated between the jaws until the largest distance possible is reached. The thickness (T) is measured perpendicular to the width when still holding the line of greatest distance parallel to the calliper's jaws.

The different sizes are also expressed as ratios per specimen: L/W, L/T and W/T. The measurements were statistically described (IBM SPSS Statistics 22). The distribution of these sizes and ratios of the material over the collection should give some insight on the amount of erosion and fragmentation of the material and the underlying (physical) mechanism.

The distribution of the material was investigated to see

which pits yielded most material and whether there are any taxonomical differences. It was also investigated to what extent the amount of collection per pit influenced the distribution of the material. Finally, using the newly structured locality names, changes in depth and position of the pits were investigated.

Within the context of West-European large mammal biozonation (Palombo & Valli 2003), the fauna list of the collection was divided into faunal groups based on age and concurrence of species. For one such group, the Early Pleistocene Oosterschelde fauna, an attempt was made to narrow down a plausible age range by combining information gained from both large and small mammal material and knowledge about the local stratigraphy, such as the Moriaanshoofd borehole (Slupik *et al.* 2013).

## RESULTS

### Localities

Since multiple generations of scientists and curators have succeeded one another, and over time applied different toponyms, there are inconsistencies in the naming of the localities from which the material derives. In order to retrieve the exact locality from where the fossils were dredged, a list of registered locality names was composed, checked and validated. The list of (vernacular) toponyms was provided by NBC and the Stadhuismuseum Zierikzee. These names were checked with existing literature and a series of 34 hydrographic charts, spanning the past 65 years.

The restructured locality nomenclature consists of multiple steps of increasing geographical detail: country, province, region, area, locality and locality specifics. Where country and province might speak for themselves, it is important to note that firstly the region denotes the part of the Oosterschelde estuary or Zeeland mainland in which the locality is located, secondly that the localities are named after the towns or cities that are closest to the locality on shore, or after the sediment bar ('plaat') along which they are located, and thirdly that the locality specifics denote the type of locality, i.e. whether it is a borehole, pit, or other.

The following locality names have been established for the main localities (Fig. 1); the names we wish to conserve are underlined:

#### De Hammen, Oosterschelde, Zeeland, the Netherlands

*Previously also known as* (note labelling is often in Dutch):

Noordkust van Schouwse Zuidoever  
Oosterschelde, tussen Roggenplaat en zuidkust Schouwen  
South beach, Schouwen, prov. Zeeland  
Zuidkust Schouwen Oosterschelde  
Oosterschelde bij Flauwers  
Oosterschelde Roggenplaat

De Hammen contains the following more specific localities:

#### Schelphoek pit, De Hammen, Oosterschelde

*Previously:*

Schelphoek, Oosterschelde, prov. Zeeland  
Schelphoek, Goeree, prov. S. Holland



Vos *et al.* 1995, Slupik *et al.* 2013). Moreover, according to a seventeenth-century nautical map (1666), the position of the pits was already established ~400 years ago. However, small changes in position of the gullies over time cannot be excluded.

As for the depth, only a few finds were actually registered with depth of collection. What can be deduced from the available information, is that the Oosterschelde pits have depths between 13 and 47.5 m below mean sea level (bsl). To be more specific: the Schaar van Colijnsplaat has depths noted between 13 and 20 m, Domburg-Oosterhoofd has depths between 22 and 32 m, Flauwerspolder pit 1 has noted depths between 13 and 40 m and Flauwerspolder pit 2 has depths between 37.5 and 47.5 m. The Flauwerspolder pit 1 measurements can be divided into lesser and greater depths of 16.5 m and 38 m. These lesser depths of ~16.5 m correspond with the observed average gully depth of ~20 m and denotes the bar called 'Schelpenrug' that separates pit 1 from pit 2. De Hammen has a noted depth of 35 m. However, what specific pits are meant is unclear. The depth of the pits has however decreased over the past 400 years, due to sedimentation. In 1666 the gullies had depths reaching to 60 m for De Hammen and to 54 m for Domburg-Oosterhoofd.

## Fauna

Apart from some pieces that were identified incorrectly, and 103 pieces that still had to be investigated and identified, nomenclatorial corrections mostly concerned the updating of several outdated genus names. Some pieces were registered as belonging to *Archidiskodon meridionalis* (NESTI, 1825), where this species is now considered to belong to the genus *Mammuthus* (Kortenbout van der Sluijs 1955), *Dicerorhinus etruscus* (FALCONER, 1868) is now considered to belong to the genus *Stephanorhinus* (Fortelius *et al.* 1993), the small Tiglian deer that is registered as *Cervus rhenanus* (DUBOIS, 1904) is considered to belong to the genus *Metacervoceros* (Alcalde & Van den Hoek Ostende 2015) and the fossil species of walrus currently known as *Ontocetus emmonsii* (LEIDY, 1859) was registered as either *Odobenus huxleyi* (LANKESTER, 1865), *Alachtherium* sp. or *Odobenus antverpiensis* (RUTTEN, 1907).

For the Cetaceans, all fossils ascribed to *Eurhinodelphis* sp. proved to be too inconclusive to warrant the presence of this genus. The fossils ascribed to *Choneziphius* cf. *planirostris* CUVIER, 1823 were identified to belong instead to *Ziphirostrum* cf. *marginatum* DU BUS, 1868 (pers. comm. K. Post and M. Bosselaers, March 2015).

Surprisingly, the *Hippopotamus* sp. tusk mentioned by Kortenbout van der Sluijs (1985) turned out to belong to *Ontocetus emmonsii*, thereby removing this species from the fauna list. Finally, the 'Van Veen' tubes have since their introduction yielded up to 18 different species of small mammal (4 Eulipotyphla and 14 Rodentia), three species of fish and some bird material. *Miomys newtoni*, mentioned in Reumer *et al.* (2005) is now placed in the genus *Borsodia* (Early Pleistocene ancestor of the extant Steppe Lemming *Lagurus*; Mayhew 2008). Two updated fauna lists, one for the Oosterschelde and one for Domburg, are given in Appendix 1.

## Taphonomy

The length, width and thickness frequency distributions show a very clearly left skewed normal distribution. The same goes for the size ratios L/W, L/T and W/T (Fig. 3). From these results it can be deduced that the material is characterized by an abundance of small specimens with low mean measurements of  $L = 14.8 \pm 7.9$ ,  $W = 9.2 \pm 5.0$  and  $T = 6.1 \pm 3.6$  cm, the average rough shape thus being elongated (nearly twice as long as wide and three times as long as thick) and slightly flat (1.6 times as wide as thick). Still there are some larger fossils present in the collection, the longest reaching a length of 105 cm. The surface texture is diverse, indicating different taphonomic circumstances.

## DISCUSSION

### Localities

The gullies within the Oosterschelde are formed by scouring due to tidal influences. The artificial reinforcements of the southern shore of Schouwen-Duiveland (Flauwerspolder and the Schelphoek harbour) and the northern shore of Walcheren, most likely determine the position of this scouring. They obstruct flow and cause eddies. Especially during outgoing tide (ebb), this will cause a turbulent flow to develop. Fortunately, these coastal reinforcements have been in the same place for as long as collection takes place. The indication of position, however, is not very precise on the charts used, so changes on the meter scale might still be expected.

The changes in depth could unfortunately not be more than approximated due to the limited detail on water depth of the hydrographic charts and the low amount of recorded depths for the material. Even so, using the nautical map from 1666 and the chart from 1951 it can be said that the overall depth of all the pits had decreased with ~10 m. For the period 1951-2012, the charts seem to indicate a depth decrease for De Hammen and Domburg-Oosterhoofd of another 7 m, but the depth of Wissenkerke seems unaltered or to even have increased by 2 m. During this period the Schelphoek harbour (1954-1955) and the flood barrier with its associated reinforcements of the 'Neeltje Jans' and 'Roggenplaat' sandbanks (1969-1983) were constructed. These were important events that might have caused the reduced depth of the pits, since they limit tidal influence in the estuary. Why then, on the other hand, the Wissenkerke pit seems unaltered, remains unexplained.

### Fauna

The fauna, most recently described by Kortenbout van der Sluijs (1985), can be revised and complemented. There are at least five temporally distinguishable groups of large mammals to be recognized in the Oosterschelde material:

- Middle Miocene marine mammals (Cetacea)
- Pliocene marine mammals (Cetacea)
- Middle Villafranchian terrestrial mammals (MN17; this is the so-called 'Oosterschelde fauna')
- Aurelian/Late Pleistocene terrestrial mammals (MNQ23 or younger)
- Holocene terrestrial mammals

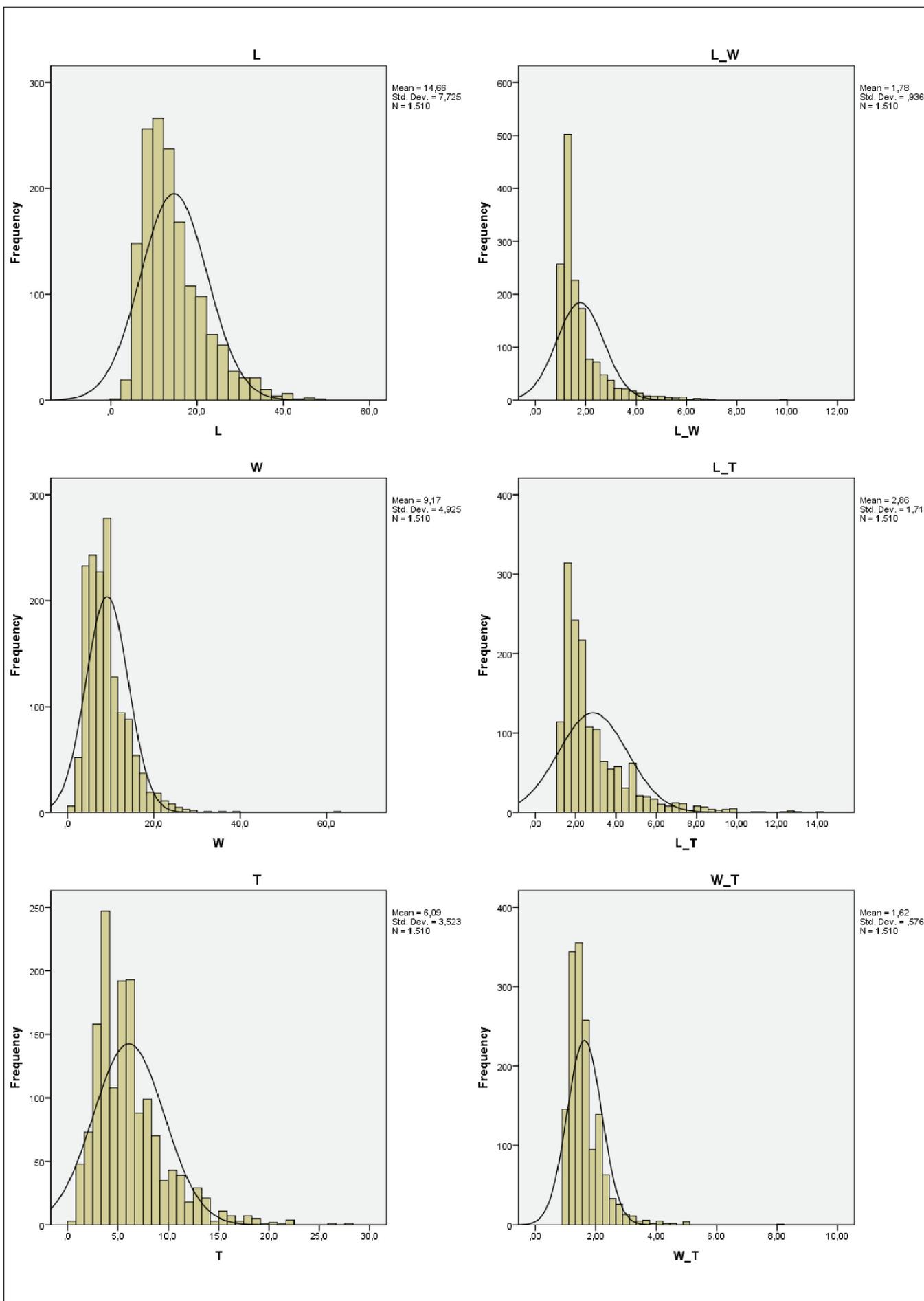


Figure 3 Distribution of material sizes (in cm) and size ratios of the measured material of known provenance. All plots show left skewed distribution.

A first notice on the faunal groups is that the previously recognized Eemian fauna (Kortenbout van der Sluijs 1985) was abandoned after the *Hippopotamus* sp. tooth was identified as being an *Ontocetus emmonsii* tusk. It is important to note that the term 'faunal group' is applied here, instead of simply 'fauna', since it is impossible to determine what material (if any at all) has been deposited *in situ* (Drees 2005). Taking into account the fragmented state and size range of the material, it is suspected that in fact all material has been reworked (redeposited) before having been collected *ex situ* (see Slupik *et al.* 2013 on the Flauwerspolder material).

The first cetacean fauna, and the oldest one found within the Oosterschelde, consists of several extinct whales like the beaked whale *Ziphirostrum* cf. *marginatum* and the baleen whales *Cetotherium* sp. and *Mesocetus* cf. *longirostris*. These are of roughly Middle Miocene age, and not found *in situ* in Early Pliocene sediments (pers. comm. K. Post and M. Bosse-laers, March 2015).

The Pliocene cetacean fauna, and constituting the majority of all cetacean material, is marked by large species of killer and sperm whale, some fossils of either beluga (*Delphinapterus* sp.) or narwhal (*Monodon* sp.) and baleen whales, orquals, dolphins and beaked whales.

The Middle Villafranchian group, also known as the Oosterschelde fauna, is placed within Neogene mammal stage MN17 (Early Pleistocene) based on the presence of *Anancus arvernensis*, *Mammuthus meridionalis*, *Hyaena perrieri*, *Canis* cf. *C. etruscus*, *Equus* sp. (a large species), cf. *Leptobos* sp., *Metacervoceros rhenanus*, *Eucladoceros ctenoides*, *Ontocetus emmonsii* and *Sus strozzi* (Palombo & Valli 2003).

The late Middle or Late Pleistocene group (MNQ23 or younger) is characterized by the presence of *Mammuthus primigenius*, *Coelodonta antiquitatis* and *Megaloceros giganteus*. It is further characterized by the presence of several extant species no longer found within Central Europe like *Rangifer tarandus* and *Odobenus rosmarus* and finally it shows the regional first occurrences of some species still present within Central Europe like *Cervus elaphus*, and *Sus scrofa*. *Panthera leo spelaea* also belongs with this group though it is not recorded precisely where within the Oosterschelde it was collected. A Middle Pleistocene fauna seems to be missing, although a single tibia fragment of *Trogotherium cuvieri* was recovered from the Oosterschelde. Its size would indicate a Middle Pleistocene age according to Mayhew *et al.* (2008) and also *Microtus oeconomus* and *M. agrestis*, both recovered from the Oosterschelde, are known from the Middle Pleistocene.

The Holocene group is characterized (as described by Kortenbout van der Sluijs 1985) by the anthropogenic domesticated fauna we still find here today, containing cattle (*Bos taurus*), sheep (*Ovis aries*), goat (*Capra hircus*), horse (*Equus caballus*), cat (*Felis catus*) and dog (*Canis familiaris*). The only wild Holocene aspect remains the roe deer (*Capreolus capreolus*). This Holocene group is probably connected to one of the historic flood events, killing humans and livestock, like the infamous North Sea Flood of 1953.

Finally, the Oosterschelde has yielded small mammal materi-

al. This group contains both Rodentia and Eulipotyphla dating from the first part of Early Pleistocene (*Mimomys praepliocenicus*, *Mimomys pliocenicus*, *Mimomys reidi*, *Mimomys tigliensis*, *Borsodia newtoni*, *Pitymimomys* sp., *Desmana thermalis*, *Galemys kormosi*, *Beremendia fissidens*, *Sorex praearaneus*) and perhaps Middle Pleistocene until recent times (*Apodemus* sp. *Microtus oeconomus*, *M. agrestis* and *Arvicola terrestris* ssp. A).

Mainly due to the fragmented character of the material, identification is not in all cases straightforward for the Kor & Bot collection. Some of the pitfalls are the differentiation between postcranial material of large Cervidae (*Eucladoceros ctenoides*) and Bovidae (cf. *Leptobos*) or to distinguish between *Sus strozzi* and its younger form *S. scrofa*, which are presumably in the same evolutionary lineage (Faure & Guérin 1984). The Cervidae are mainly represented by antler material (251 pieces) which is very basal in nature, making species recognition difficult. For the fragmented postcranial proboscidean material, identification is quite difficult due to relatively small differences between species. These last two aspects of the collection explain the high amount of unassigned material for Cervidae (344 pieces) and Proboscidea (249 pieces).

### Faunal distribution

The general trend of the faunas found in the Oosterschelde pits is that of mixed faunas. Every pit yields at least Early and Late Pleistocene material. The least visited pits yielded fossils from at least two out of five groups and the more regularly visited pits contain fossils from four out of five groups. There are, however, some notable differences. For instance, only Domburg-Oosterhoofd and Wissenkerke have registered representatives of the Middle Miocene cetacean fauna and Domburg-Oosterhoofd yields far more cetacean and pinniped material than the Flauwerspolder pits. This last difference is interesting since these pits yielded the majority of all material. It is especially remarkable due to differences in depth. Where the Flauwerspolder pits reach depths of 40 m to 47.5 m bsl, Domburg-Oosterhoofd only reaches 32 m bsl even though it yields Middle Miocene material which the Flauwerspolder pits do not.

The Westerschelde, the estuary to the south of the Oosterschelde, yields even more (and older) marine fossils and has a similar depth of ~45 m bsl (Post & Reumer 2016). Since the deeper stratigraphy dips in a NNE direction (Drees 1986), it should be expected that the Oosterschelde yields younger material than the Westerschelde. How the Middle Miocene cetacean fossils where recovered from around 30 m bsl (hydrographic chart 1961), could be explained by either one or a combination of two processes: vertically upward transportation of the material through Pleistocene reworking and/or spatial differences in erosion of older sediment. Vertically upward transportation might be deduced from the fact that Domburg-Oosterhoofd has decreased in depth from 54 m to 30 m bsl and the spatial differences in erosion can be deduced from the almost complete lack of a (Middle) Villafranchian fauna but presence of both old (Mio-Pliocene) cetacean material and of younger (Weichselian) terrestrial mammal material within the Westerschelde.

## The Oosterschelde fauna

In order to better define and constrain the age range for the Oosterschelde fauna, both large and small mammal European biozonations need be discussed. The West-European mammal zonation (Palombo & Valli 2003) will be used for the large mammals, in combination with the revised ages for the French reference localities of Chilhoc and Senèze (Nomade *et al.* 2014). For the small mammals, correlation has already been undertaken by means of correlating two local boreholes (Moriaanshoofd and Schelphoek) and UK type localities, in combination with the Eastern European MNR small mammal zonation (Tesakov 2004 cited in Mayhew *et al.* 2014, Mayhew 2015).

As mentioned in the introduction, the Oosterschelde fauna was described as an Early Pleistocene Villafranchian type fauna (MN17) with an age of around 1.9 Ma (De Vos *et al.* 1998). It had previously been placed within the warmer Tiglian complex 3 period (TC-3; Zagwijn 1975). It shows great resemblance with the MN17 type fauna of Chilhoc (Haute-Loire, France; Boeuf 1997, Mol & De Vos 1995). However, the Tiglian complex is disputed as temporal indicator (Drees 2005, Westerhoff 2009) and dating the Chilhoc fauna is not straightforward (pers. comm. D. Mol, December 2015). Most recent dating of the Chilhoc fauna yielded an age of  $2.36 \pm 0.04$  Ma (Nomade *et al.* 2014) and the age of the Oosterschelde fauna is therefore reconsidered as being older than 1.9 Ma for faunistic reasons (Slupik *et al.* 2013, Mayhew *et al.* 2014).

As for the larger mammals, the Oosterschelde fauna is clearly distinguishable from both the Pliocene cetacean fauna and the Late Pleistocene fauna. The Late Pleistocene fauna and the Early Pleistocene Oosterschelde faunas lack species with overlapping time spans within Western Europe. The separation of the two faunas can also be deduced from the erosional surface observed in the Moriaanshoofd borehole (Slupik *et al.* 2013), which is associated with an enrichment in fossil material of  $>2.2$  Ma. The erosional surface is associated with a 'Proto-Schelde' pebble lag deposit containing reworked fossil material (Slupik *et al.* 2013). However, it does not completely explain the very low amount of Middle Pleistocene sediments and fossils. This low amount can be explained in twofold: either by removal through several phases of erosion due to regression and a lack of sedimentation, or by the presumed presence of a glacial lake the size of the Netherlands, which existed around 450 ka (Gibbard *et al.* 1991, Gibbard 2007, Gupta *et al.* 2007). The breakthrough and megaflood events associated with this paleo-lake caused the onset of the separation of the UK from the European mainland, according to Gupta *et al.* (2007), and may have contributed to the removal of a substantial amount of Middle Pleistocene sediments.

The species that are ascribed to the Oosterschelde fauna fit within the MN17 biozone (Palombo & Valli 2003). This is supported by the evolutionary stages of both *Anancus arvernensis* and *Mammuthus meridionalis* (Mol *et al.* 1999). Their combined stages are also found at the French MN17 type locality of Chilhoc (De Vos *et al.* 1998). The MNQ18 type locality of Senèze contains *Mammuthus meridionalis* and *Canis etruscus*, but lacks *Anancus arvernensis*. The identification of a mandibular fragment from the Oosterschelde as *Canis* cf. *C. etruscus* in

Reumer & Piskoulis (2017) seems to indicate placement near the transition from MN17 to MNQ18 when also *Anancus arvernensis* disappears from the fossil record. Nomade *et al.* (2014) provide revised ages by means of Ar40/Ar39 isotope dating for the biozonation scheme used by Palombo & Valli (2003) in which type localities are used as tie points between the zones themselves. The Oosterschelde fauna fits best within the MN17b zone which is, in this scheme, placed in between type localities Chilhoc ( $2.36 \pm 0.04$  Ma) and Senèze ( $2.21 - 2.09 \pm 0.02$  Ma) (Nomade *et al.* 2014; see also Table 1). As mentioned before, the exact dating of the Chilhoc fauna is complicated. The sediments from which the Chilhoc fossils derive are overlain by pyroclastic debris. It is not fully understood what the effects of this pyroclastic flow have been on these sedimentary deposits and many different ages have consequently been suggested over time (e.g., Boeuf 1997). The exact dating of the Senèze deposits is far more reliable and indicates a time-window of 2.2 - 2.1 Ma, indicating that indeed the Oosterschelde fauna material is older than 1.9 Ma as already mentioned by Slupik *et al.* (2013) and Mayhew *et al.* (2014). Hooijer (1981) noted, however, that one of the rhinocerotoid molars in the collection could belong to either the older *Stephanorhinus jeanvireti* or the more fitting *Stephanorhinus etruscus*. If it should turn out to belong to *S. jeanvireti*, or if there would be additional material belonging to this species deriving from the Oosterschelde, it would hold some implications for the age of the Oosterschelde fauna. Until an answer is provided it will be considered to belong to *Stephanorhinus* cf. *etruscus*, as De Vos *et al.* (1998) concluded.

## Small mammals

The small mammal assemblage of the Oosterschelde demands a different approach. For the Flauwerspolder pits, the small mammal material can be compared to the small mammal assemblage of the Moriaanshoofd borehole, which is located ~100 m from the pits in a northerly direction. The Moriaanshoofd borehole small mammal assemblages have been ascribed to two different MNR zones, which are correlated to dated localities within the UK (Mayhew *et al.* 2014). An age range for the small mammals was obtained through this correlation. The deeper part of the Moriaanshoofd borehole (55-56 m) has been ascribed to the latter half of the MNR2 small mammal zone and the river lag deposit small mammal material (34-36 m) derives from the MNR1 zone. Within the UK the second half of the MNR2 zone is correlated to the upper part of the Norwich crag deposits (2.35-2.25 Ma) and the MNR1 zone is correlated to the Weybourne crag deposits (2.25-2.1 Ma, Mayhew *et al.* 2014). The correlation of material to these zones was established, firstly, by comparison and identification of different phases within the *Mimomys pliocaenicus* lineage (Dieleman 2013). Secondly, it was re-established by both the presence of *Mimomys tigliensis* (typical for the latter half of MNR2 and MNR1) and the absence of *Macoma balthica* (Mollusca) in the sediments underlying the river lag deposits (Maassluis Formation *sensu* Slupik *et al.* 2013). The remains of *Macoma balthica* could still be of any age up until the present, but for the English crags *M. balthica* has been found only in association with *Mimomys pliocaenicus* (MNR1) and never with the more primitive *Mimomys praepliciocaenicus*

(MNR2). The same type of material and a similar combination of species has been dredged up from the Oosterschelde and it provides a clear link between the Flauwerspolder pits and the Moriaanshoofd borehole.

### Age

In conclusion, comparison of the age constraints found for both the large and small mammal assemblages indicates an age range of roughly 2.35 - 2.10 Ma (Table 1) for the Oosterschelde fauna. The age constraints provided for Chilhac approach those of the upper part of the Norwich Crag Formation and the constraints for Senèze are very similar to those of the Wroxham Crag Formation (former Weybourne Crag Formation). Even though the dating of the Chilhac fauna is a complicated issue, the age constraints for Senèze are more certain and the inferred ages of the small mammal assemblage support the proposed range. This confirms that the Oosterschelde fauna should be considered older than 1.9 Ma. The similarity in small mammal material between the Oosterschelde and Moriaanshoofd borehole, and their respective distance, are the criteria upon which the age ranges are here coupled.

### Taphonomy

The first, and most important, taphonomic observation is that all specimens show signs of weathering, even the small mammal dentition elements, although this is not always visible without magnification. This leads to the conclusion that all material has been reworked at some point in time. This is confirmed by the frequency distributions of the size and size ratios of the specimens, which indicate an overall abundance of small pieces with low size ratios.

The second observation is that the specimens are very diverse in taphonomic and diagenetic expression, i.e. coloration, surface texture and detail, completeness and types of traces on the surface. The processes, to which these different characters could be coupled, are (Fig. 4):

- Mechanical weathering (cracking [Fig. 4A], fragmentation and abrasion)
- Chemical weathering (dissolution and oxidation [Fig. 4B])
- Biological weathering
  - Animal attack (gnaw marks, most possibly of hyenas [Fig. 4C])
  - Bacterial/fungal attack (bone tissue deterioration [Fig. 4D])
  - Damage due to collection (fragmentation [Fig. 4E] and scratching)
- Fossilisation (several expressions [Figs. 4F, 4G])

The large scale mechanism, driving these processes, is most likely the cyclic sea-level variation associated with the rapid temperature changes during the Pleistocene. Transgressions would have allowed for the accretion of sediments and consequently the burial of organic remains. These would already have had a myriad of different textures, caused by different organisms as well as chemical/mechanical weathering. Some might have been buried on the floodplains or in lakes while others might have been transported and then be buried in river channels or in sandbars.

During regressions large quantities of sediment would have been transported offshore, leaving behind the heavier and larger remains to be buried again during the next transgression. Some of the fossils were redeposited rapidly while others could have been transported large distances, whilst being abraded and rounded off further. During the following transgression the process would repeat itself, enriching the sediments even further with fossils.

### CONCLUSIONS

This survey and interpretation of the Kor & Bot collection ultimately shifts the predominant view of the material as only a Villafranchian-type terrestrial fauna from the Oosterschelde estuary, towards a broader collection containing five sepa-

Table 1 Comparison of inferred age ranges for the Oosterschelde fauna and the Moriaanshoofd borehole small mammal assemblages including key species.

locality	biozone	approx. age (Ma)	reference	key taxa
Chilhac	MN17a/b transition	2.36 ± 0.04	Nomade <i>et al.</i> 2014	<i>Anancus arvernensis</i> <i>Mammuthus meridionalis</i>
Senèze	MN17b/MNQ18	2.21 / 2.09 ± 0.02	Nomade <i>et al.</i> 2014	<i>Mammuthus meridionalis</i> <i>Canis</i> cf. <i>C. etruscus</i>
early Norwich crags	MNR2 (older part)	2.45 – 2.35	Mayhew 2015	<i>Mimomys praepliocaenicus</i>
late Norwich crags	MNR2 (younger part)	2.35 – 2.25	Mayhew 2015	<i>Mimomys praepliocaenicus</i> <i>Mimomys tigliensis</i>
Weybourne crags	MNR1	2.25 – 2.1	Mayhew 2015	<i>Mimomys pliocaenicus</i> <i>Mimomys tigliensis</i>

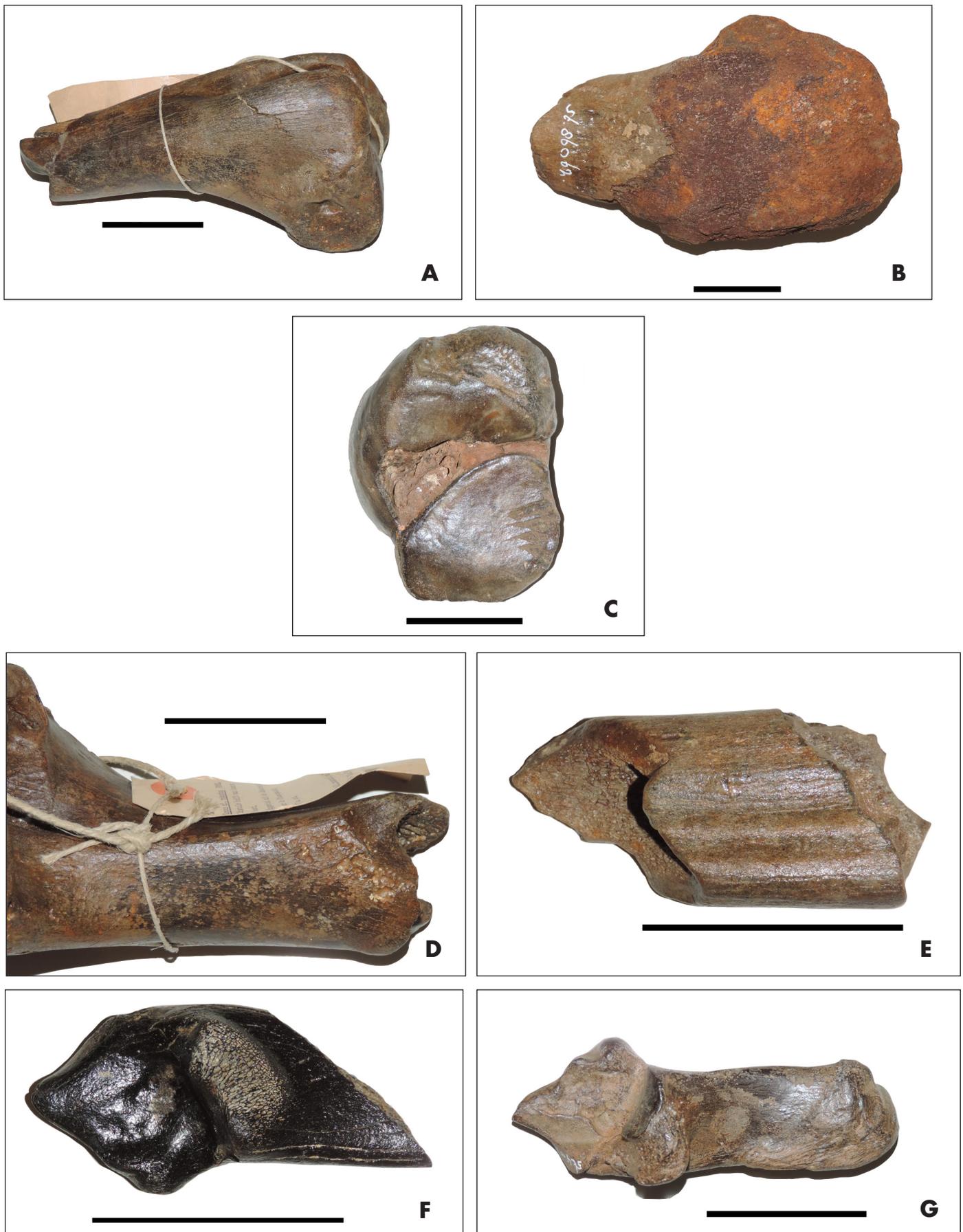


Figure 4 Examples of expression of different taphonomic processes: **A** surface cracking due to drying of bone before fossilization (RGM 152542), **B** oxidation of hematite (RGM 86062), **C** animal attack, gnaw marks, possibly by a hyaena (RGM 140440), **D** bacterial attack before fossilization (RGM 152542), **E** collection damage (RGM 119502), **F** fragmented and abraded fossil calcaneus with black coloration and **G** virtually unaltered fossil calcaneus with brownish coloration. All scale bars are 5 cm long; RGM refers to the collection of Naturalis Biodiversity Center, Leiden. (A. Molenkamp)

rate faunal groups of greatly diverging age and diversity of taphonomic expression. Moreover it contains more cetacean material than would appear from the existing literature. Also, the suggestion that the Villafranchian-type fauna is older than 1.9 Ma has been reaffirmed. According to our current study, the Kor & Bot collection contains at least five different faunal groups, ranging from Middle Miocene up till recent times: (1) Middle Miocene cetaceans, (2) Pliocene marine mammals, (3) Middle Villafranchian (MN17) terrestrial mammals, (4) Late Pleistocene MNQ23 or younger) terrestrial mammals and (5) Holocene terrestrial mammals. The Flauwerspolder pits have also yielded four species of Eulipotyphla and fourteen species of rodents, ranging in age from Late Pliocene up until recent. The locality names have been restructured and clarified, and the material derives for ~95% from two pits, within the Oosterschelde; Flauwerspolder pit 1 and Flauwerspolder pit 2 and one pit just outside the Oosterschelde in the North Sea: Domburg-Oosterhoofd. The iconic early Pleistocene Oosterschelde fauna (MN17 Villafranchian type) has been assigned an age range of 2.35 - 2.10 Ma based on the comparison of West-European large and small mammal biozonations in combination with local stratigraphy, obtained from the Moriaanshoofd borehole. All material, from all pits, has been reworked, as can be concluded from its fragmented and eroded state and average length of ~1.5 cm, and the taphonomic expression indicates diverse conditions and durations of burial.

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**Appendix 1** Fauna lists for the Oosterschelde and Domburg.**Oosterschelde**

## Mammalia

## Eulipotyphla

## Talpidae

*Galemys kormosi* SCHREUDER, 1940*Desmana* sp.*Desmana thermalis* KORMOS, 1930

## Soricidae

*Beremendia fissidens* PETENYI, 1864*Sorex praeearaneus* KORMOS, 1930

## Rodentia

## Cricetidae

*Mimomys pliocaenicus* (FORSYTH MAJOR, 1889)*Mimomys praepliocaenicus* RABEDER, 1981*Mimomys reidi* HINTON, 1910*Mimomys tigliensis* TESAKOV, 1998*Pitymimomys* sp.*Borsodia newtoni* (FORSYTH MAJOR, 1902)*Microtus* sp.*Microtus oeconomus* PALLAS, 1776*Microtus agrestis* LINNAEUS, 1761*Arvicola terrestris* LINNAEUS, 1758*Lemmus* sp.

## Muridae

*Micromys* sp.*Apodemus* sp.

## Castoridae

*Castor fiber* LINNAEUS, 1758*Trogontherium cuvieri* FISCHER VON WALDHEIM, 1809

## Proboscidea

## Elephantidae

*Mammuthus meridionalis* (NESTI, 1825)*Anancus arvernensis* (CROIZET & JOBERT, 1828)*Mammuthus primigenius* (BLUMENBACH, 1799)

## Artiodactyla

## Bovidae

*Bos taurus* LINNAEUS, 1758*Bos* sp.cf. *Leptobos**Bison priscus* BOJANUS, 1827*Bison* sp.*Ovis aries* LINNAEUS, 1758*Capra hircus* LINNAEUS, 1758

## Cervidae

*Eucladoceros ctenoides* (NESTI, 1841)*Megaloceros giganteus* (BLUMENBACH, 1799)*Cervus elaphus* LINNAEUS, 1758*Rangifer tarandus* (LINNAEUS, 1758)*Alces* sp.*Capreolus capreolus* (LINNAEUS, 1758)*Metacervoceros rhenanus* (DUBOIS, 1904)

## Suidae

*Sus scrofa* LINNAEUS, 1758

- Sus strozzii* FORSYTH MAJOR, 1881
- Perissodactyla
- Equidae
- Equus robustus* POMEL, 1853
- Equus* sp.
- Equus caballus* LINNAEUS, 1758
- Rhinocerotidae
- Coelodonta antiquitatis* (BLUMENBACH, 1799)
- Stephanorhinus etruscus* (FALCONER, 1859)
- Stephanorhinus* cf. *C. S. etruscus* (FALCONER, 1859)
- Stephanorhinus* sp.
- Carnivora
- Hyaenidae
- Crocuta crocuta spelaea* (GOLDFUSS, 1823)
- Hyaena perrieri* (KRETZOI, 1938)
- Felidae
- Felis catus* LINNAEUS, 1758
- Homotherium* sp.
- Panthera leo spelaea* (GOLDFUSS, 1810)
- Canidae
- Canis* cf. *C. etruscus* FABRINI, 1877
- Canis familiaris* LINNAEUS, 1758
- Ursidae
- Ursus* sp.
- Odobenidae
- Ontocetus emmonsii* (LEIDY, 1859)
- Odobenus* sp.
- Phocidae
- Phocanella minor* VAN BENEDEN, 1876
- Cetacea
- Physeteridae
- Physeter* sp.
- Scaldicetus caretii* DU BUS, 1867
- Delphinidae
- Orcinus* sp.
- Monodontidae
- Delphinapterus leucas* (PALLAS, 1776)
- Delphinapterus* sp.
- Balaenidae
- Balaena* sp.
- Balaenula balaenopsis* VAN BENEDEN, 1872
- Balaenopteridae
- Balaenoptera borealina* VAN BENEDEN, 1882
- Balaenoptera musculus* LINNAEUS, 1758
- Primates
- Hominidae
- Homo sapiens* LINNAEUS, 1758
- Reptilia
- Testudines
- Emididae
- Emys* sp.
- Aves
- Anseriformes
- Anatidae
- gen. et sp. indet.
- Galliformes

- Phasianidae  
gen. et sp. indet.
- Pisces
- Eutrichiuridae  
*Trichiurides delheidi* LERICHE, 1908
- Gadidae  
*Melanogrammus aeglefinus* LINNAEUS, 1758
- Acipenseridae  
*Acipenser sturio* LINNAEUS, 1758

## Domburg

### Mammalia

- Proboscidea
- Elephantidae  
*Mammuthus meridionalis* (NESTI, 1825)  
*Anancus arvernensis* (CROIZET & JOBERT, 1828)  
*Mammuthus primigenius* (BLUMENBACH, 1799)
- Artiodactyla
- Bovidae  
*Bos taurus* LINNAEUS, 1758  
cf. *Leptobos*  
*Bison priscus* BOJANUS, 1827  
*Ovis aries* LINNAEUS, 1758  
*Capra hircus* LINNAEUS, 1758
- Cervidae  
*Eucladoceros ctenoides* (NESTI, 1841)  
*Megaloceros giganteus* (BLUMENBACH, 1799)  
*Rangifer tarandus* (LINNAEUS, 1758)  
*Alces* sp.  
*Metacervoceros rhenanus* (DUBOIS, 1904)
- Suidae  
*Sus scrofa* LINNAEUS, 1758
- Perissodactyla
- Equidae  
*Equus robustus* POMEL, 1853  
*Equus* sp.
- Rhinocerotidae  
*Coelodonta antiquitatis* (BLUMENBACH, 1799)  
*Stephanorhinus* sp.
- Carnivora
- Hyaenidae  
*Crocuta crocuta spelaea* (GOLDFUSS, 1823)
- Odobenidae  
*Ontocetus emmonsii* (LEIDY, 1859)  
*Odobenus* sp.
- Phocidae  
*Phocanella minor* VAN BENEDEN, 1876
- Cetacea
- Physeteridae  
*Physeter* sp.  
*Physeter macrocephalus* LINNAEUS, 1758  
*Scaldicetus caretii* DU BUS, 1867
- Delphinidae  
*Orcinus* sp.  
*Globicephala melaena* (TRAILL, 1809)  
*Grampus* sp.

*Tursiops* sp.

Ziphiidae

*Ziphirostrum* cf. *marginatum* DU BUS, 1868

Monodontidae

*Delphinapterus leucas* (PALLAS, 1776)

*Delphinapterus* sp.

Balaenidae

*Balaena* sp.

*Balaena primigenius* VAN BENEDEEN, 1872

*Balaenotus isignis* VAN BENEDEEN, 1872

Balaenopteridae

*Balaenoptera borealina* VAN BENEDEEN, 1882

*Balaenoptera musculus* LINNAEUS, 1758

*Protororqualus cuvieri* (FISCHER VON WALDHEIM, 1829)

Cetotheriidae

*Cetotherium* sp.

*Plesiocetus* sp.

*Mesocetus* cf. *longirostris* VAN BENEDEEN, 1880 [nomen dubium]

Pithanodelphininae

*Pithanodelphis cornutus* DU BUS, 1872

Pisces

Gadidae

*Melanogrammus aeglefinus* LINNAEUS, 1758

Acipenseridae

*Acipenser sturio* LINNAEUS, 1758



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