

**THE ZUURLAND-2 BOREHOLE: SOME REMARKS ON THE RESULTS OF  
THE GEOLOGICAL AND PALAEOLOGICAL INVESTIGATIONS**

by

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This paper compares and evaluates the preliminary results obtained by the various disciplines on the stratigraphical and palaeontological interpretation of the Zuurland-2 borehole section (0 to -64 m) at Brielle, The Netherlands, as published in the present issue of this periodical.

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**SAMENVATTING**

De boring Zuurland-2: enkele opmerkingen over de resultaten van het geologisch en palaeontologisch onderzoek.

In dit artikel worden de resultaten van de diverse geologische en paleontologische onderzoeken aan de boring Zuurland-2 te Brielle, zoals die zijn vastgelegd in de voorafgaande publicaties in deze bundel, met elkaar vergeleken. Voor elk van de formaties (resp. Kedichem/Tegelen Formatie, Kedichem Formatie, Kreftenheye/Eem Formatie, Twente Formatie en Westland Formatie) worden het afzettingsmilieu van de sedimenten, de stratigrafische positie en het klimaat besproken.

## INTRODUCTION

The previous papers in this volume (Burger, 1988; Burger *et al.*, 1988; Gaemers, 1988; Hordijk, 1988; de Jong, 1988a, 1988b; Kuijper, 1988; Meijer, 1988; van Kolfshoten, 1988; Vervoort-Kerkhoff & van Kolfshoten, 1988) report on lithological, floral and faunal characteristics of the upper 64 metres of borehole Zuurland-2 at Brielle, The Netherlands. As the authors indicate, these results should not be considered to be the final word. They are progress reports on material from a partly finished borehole. Continuation of the drilling activities of Mr Hordijk will supply more material and, moreover, also the samples from the upper 64 m of the hole will be studied further and in more detail. Despite its incompleteness, this volume supplies useful information and new data, and it offers the possibility to get an insight into the work which is in progress. Here we compare and discuss the results presented in the previous papers.

### KEDICHEM/TEGELEN FORMATION (-54.15 m to -64.00 m)

#### Sedimentary environment

The lower part of the sequence is characterized by fine-grained clayey to very fine sandy sediments with in the top half metre moderately coarse sand. This indicates a dominance of quiet depositional conditions with an increase of energy towards the top.

Mammal fossils (van Kolfshoten, 1988) belong to terrestrial species indicative of rather continental climatic conditions. On the basis of the fish remains, Gaemers (1988) agrees that deposition occurred in a freshwater environment with a connection to the sea.

Palynological (de Jong, 1988b) and malacological data (Meijer, 1988), on the other hand, suggest deposition partly under marine influenced conditions. Kuijper (1988), who studied the plant macrofossils, observed only minor marine influences, at -63 m to -62 m and at -54 m.

It is attractive to ascribe the contradiction in the above conclusions about deposition in a marine or a freshwater environment, to the post mortem behaviour of the various fossil remains. Seeds, plant remains, fishes and mammals can float around when they are dead, and thus can be incorporated within marine (influenced) sediments. Thus deposition would have occurred near to the coast, with alternating influences of marine and fresh waters. In this respect, the iron concretions, found at about -59 m fit to such interpretation. Alternating reducing and oxidizing conditions favour the local enrichment of iron within sediments. Alternating redox potentials are especially favoured by a position within a coastal area with fluctuations of the groundwater level due to vertical tidal movements.

#### Stratigraphic position

depth in m	pollen	molluscs	mammals
62-54.15	Waalien or	Waalien or older	no data
64-62	Late Tiglien	Late Tiglien	Late Tiglien or Early Eburonian

Table 1. Comparison of the results of pollen, molluscs and mammals in the Kedichem/Tegelen Formation of the Zuurland-2 borehole at Brielle, The Netherlands.

On the basis of the pollen record, de Jong recognized one interglacial (substage of the Waalien Interglacial or of the Late Tiglien), whereas the mollusc remains allow the recognition of two malacological units, the lower one of Late Tiglien age and the other belonging to an interglacial of Waalian age or older. Mammal remains found in the interval of -62 m to -64 m are assigned to the Late Tiglien or Early Eburonian (compare Tab. 1). These results are not in conflict, but they do invite to look for additional age indicators.

#### Climate

The authors agree upon interglacial conditions during deposition of the studied part of the Kedichem/Tegelen Formation.

Some non-marine molluscs, indicative of a cold climate in the interval from -62 m to -50 m, that is in the upper 8 m of the Kedichem/Tegelen Formation and the lower 4 m of the overlying Kedichem Formation, might indicate the support of terrestrial material from a land surface dominated by a continental climate. Although continental climatic conditions seem to be in conflict with the interpretation of interglacial conditions, one should realize that most probably the English Channel was still closed in this period. Therefore, the Gulf Stream which nowadays heavily influences our climate, probably was a less dominant factor during deposition of the Kedichem/Tegelen Formation, thus allowing the occurrence of cool or even cold winters.

#### General

The above data and conclusions on age, climate, and sedimentary environment match each other fairly well. They suggest deposition during an interglacial period, with consequently a relatively high sea-level, related to a relatively small volume of polar icecaps. On the land the climate likely was more continental than it is today. Deposition of the fine-grained sediments must have occurred under quiet conditions, presumably the result of a protected location behind a coastal barrier or within a distributary system of a delta.

#### KEDICHEM FORMATION (-36.25 m to -54.15 m)

##### Sedimentary environment

On the basis of the lithological description three major units can be distinguished, each characterized by a sudden increase of the grain-size at the basis (at -54.15 m, -44.40 m, and -39.35 m) and a

gradual decrease in upward direction. The interval from -40.95 m to -39.35 m contains bimodally sorted sand and gravel.

With the exception of some non-marine molluscs, indicative of a cold climate in the lower 4 m of this formation (see discussion above), malacological data indicate deposition in a marine influenced environment. The number of marine species increases towards the upper part of this formation. These marine influences were not recognized in the other studies. The pollen spectra and the plant macrofossils lack clear indicators of marine conditions. The autochthonous fish remains belong to freshwater species and, moreover, the state of preservation of the terrestrial mammalian fossils does not indicate transport over a long distance.

depth in m	pollen	sediment. petrogr.	plants	molluscs	mammals
36.25	zone 3 Waalian C ?	Bavelian		Inter-glacial predating Cr IV	-37.00
37.50					
41.00	zone 2 cool (Waalian B, or Tiglian TC 6)		Early Pleistocene	Waalian	-43.75 Eburonian or Early Waalian -46.00
42.00					
43.00					
43.75					
46.00					
50.00				Interglacial Waalian or older	Eburonian or Early Waalian -56.00
56.00					

Table 2. Comparison of the results obtained by the various disciplines for the Kedichem Formation of the Zuurland-2 borehole at Brielle, The Netherlands.

Considering these features, deposition might have occurred in a shallow inshore environment, with tide-influenced channels. The iron concretions again indicate a fluctuating groundwater level with contribution of the Fe-ions possibly by marine waters.

#### Stratigraphic position

The pollen-analytical data permit a correlation with the Late Tiglian (TC 6). Pollen zone 3 (-36 to -37 m) represents an interglacial of the Early Pleistocene with a pre-Bavelian age. A Waalian C age would be possible. This conclusion is in contradiction with the Bavelian age for the interval -

36.25 to -41 m as suggested by the sediment-petrological data (Burger, 1988). The plant remains from below -42 m confirm an Early Pleistocene age for that part of the section.

Meijer divided the molluscs from the part of the section assigned to the Kedichem Formation, in five different units, ranging from a pre-Waalian age for the lower unit to an interglacial predating Interglacial IV of the "Cromerian Complex" for the upper one, and a Waalian age in the middle.

The deposits assigned to the Kedichem Formation yielded three different mammal faunas, which were assigned to a rather warm phase of the Eburonian glacial period and/or to an Early Waalian phase.

These results for the Kedichem Formation are summarized in Table 2.

#### Climate

The pollen spectra of pollen zone 2 indicate a quite cool interval which can be correlated with Waalian B. Mammal fauna 6 points to deposition under rather continental climatic conditions. The fish remains confirm such palaeoecological interpretation.

#### General

The relative abundance of coarse sediments in this part of the sequence points to rather strong water currents, which carried the smaller grains (fine sand, silt, clay) away to be deposited elsewhere. Such stronger water currents can be the result of a more direct influence of the tides as compared to the conditions that dominated the deposition of the underlying Kedichem/Tegelen Formation. However, considering the repeated mention of relatively cool climatic conditions during deposition of the Kedichem Formation, one also might think of a (slight) lowering of the sea level in relation to increase of the polar icecaps.

Such lower sea level would lead to an increase of the gradient of rivers in the coastal area and thus to an increase of current velocities and erosion capacity. Although this may be an subordinate factor, it should be noted that a cool climate moreover may have resulted in a coastal environment with a relatively poor vegetation, which in its turn may have led to an easy access of tidal currents with some erosive power.

#### KREFTENHEYE/EEM FORMATION (-23.80 to -36.25 m)

##### Sedimentary environment

The sedimentary succession is largely formed by coarse sands, moderately well sorted. The molluscs point to marine influences during deposition. The other disciplines do not recognize such marine influence.

##### Stratigraphic position

The lower boundary of this formation is marked by the volcanic mineral content as known from sediments of the Urk Formation and the Kreftenheye/Eem Formation in other places. Deposits belonging to the Urk Formation are unknown from this area. Therefore, Burger (1988) assigns these sediments to the Kreftenheye/Eem Formation.



The high percentage of augite at the base indicates a maximum age of Interglacial IV of the "Cromerian Complex". The mollusc fauna in the above lying interval indicates an Eemian age. Pollen and molluscs allow a further refinement of this stratigraphic subdivision.

Considering the malacological data, the pollen from the upper part of this formation must have been derived from older formations (de Jong, 1988b). The fish fossils confirm reworking from older deposits. Although the mammal fossils from the lower 10 m of this formation do not show clear signs of reworking, the conclusions of van Kolfschoten (1988) on the stratigraphic position do not agree with the interpretations of the other authors. This implies that a derivation from older formations has to be considered.

The fauna (4) found at -25.70 m indicates a post-Hoogeveen interstadial age for that particular part of the section.

#### Climate

Botanical data (Kuijper, 1988) indicate cool climatic conditions during deposition of the part of the section between -28 and -33 m. Palynological, malacological and other data, however, do not support this.

#### General

Results indicate relatively strong water currents, which in the hinterland led to some erosion of older sediments. Although the rather good sorting of the sediment can be indicative of marine (tidal) sorting processes, this characteristic may also be inherited from eroded older deposits.

### TWENTE FORMATION (-22.30 to -23.80 m)

#### Sedimentary environment

The deposits assigned to this poorly developed formation consist of moderately coarse, well-sorted sand. They are suggested to be of periglacial origin (Burger, 1988). Pollen, molluscs, plant and fish remains are lacking.

#### Stratigraphic position and climate

The Twente Formation dates from the Weichselian. The mammalian fossils from a depth of -22.70 m may indicate glacial conditions during deposition. This confirms a Weichselian age.

The absence of pollen, plants, molluscs and fish remains fit to the conclusion of deposition in a terrestrial environment during glacial times, when the sea-level was relatively low, due to storage of water in polar ice caps.

### WESTLAND FORMATION (0.00 to -22.30 m)

The pollen spectra from the lower part of this section (-20 m to -22.30 m) reflect the nearby presence of temperate forests of Holocene (Atlantic) age. A Holocene age for these deposits is confirmed by the results of the other disciplines.

The lower part of this interval consists of marine clastic deposits (mainly fine well-sorted sands), the upper part of clay and peat layers, indicating that at this site sedimentation has kept pace with, or even slightly exceeded the rise of sea level. The marine influence is indicated by palynological, botanical as well as malacological data. Also the fish remains are strongly dominated by marine and brackish water species.

#### GENERAL REMARKS

The results presented in the various papers of this volume on the Zuurland-2 borehole demonstrate the complexity of multidisciplinary research on sedimentary successions, the formation of which was influenced by a series of quite different features, such as the nature of source areas supplying the sediment, the climate on land influencing the supply of terrestrial fossils to terrestrial and marine deposits, the climate influencing the tidal and wave regime within the sea, ecological marine conditions, etc.

The sedimentary sequence at Zuurland typically reflects sedimentation in the interregnum of the land and the sea. On the globe such areas, typified by mixed marine/continental conditions, occupy, at any one moment, only a minor part of the total surface. In fossil sediments, however, such transitional sediments are much more abundant. The reason for this is well illustrated by the Zuurland sequence and the processes that led to its development. On the land, transport of sediments is, especially for the coarser part, confined to channels, resulting in a relatively strong water flow. Especially during glacial periods when the sea level drops due to the accumulation of ice upon polar icecaps, the base level is lowered, leading to an increase of flow velocity of river waters and consequent erosion.

River water flowing out into the sea arrives in a large body of standing water which retards the flow velocity and the capacity to transport sediment. This can result in a large scale dumping of sediments, if the tides and waves in the sea are small enough and do not lead to a large scale reworking. At present, tides and waves strongly attack the Dutch coast. For an important part this is related to the influence of man artificially strengthening and straightening coastlines in order to protect the land and its inhabitants. Under natural conditions, however, marine invasions can lead to the creation of protected inshore areas with some influence of the tide and an alternating presence of fresh and salt waters (all parts of Holland that are presently below sea level). Examples of such environments can be found, e.g. in the southern part of The Netherlands in the "Drowned land of Saeftinghe", the "Slufter" on the island of Texel, and especially the "Biesbosch" as it was before the large artificial construction works in the SW Netherlands were started. In the latter area a free connection with the sea existed, tides could enter and leave freely, and from East to West the full range of fresh to fully marine waters could be observed.

An aspect, which as yet cannot be fully evaluated, is, that the tides as they are experienced at present along the Dutch coast, have not been of constant amplitude during the geological history. Calculations and models which are made nowadays do not yet allow accurate predictions backward in time to establish the tidal regime in different intervals of periods as long ago as the Early Pleistocene. Oceanographic studies, however, indicate that tidal amplitudes and tidal currents have changed in the past. Similarly, the various combinations of the environmental conditions which dominated, influenced or contributed to the development of the sedimentary succession of borehole Zuurland-2 are different from those observed along our coast at present.

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