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THE PLIO-PLEISTOCENE BOUNDARY IN THE NORTH SEA BASIN REVISION OF ITS POSITION IN THE MARINE BEDS

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ABSTRACT

A revision is given for the definition of the Plio-Pleistocene boundary in marine beds of the North Sea Basin. It has appeared that *Elphidium oregonense* Cushman & Grant (an arctic species at present living in the Bering Street) characterizes a narrow faunal zone, which falls into the lower part of the first glacial stage of the Pleistocene, the Praetiglian, as defined by means of pollen-analysis.

The *Elphidium oregonense*-zone is presently considered to mark the Plio-Pleistocene boundary. Beds hitherto assumed to belong to the Pleistocene i.e. Merksem beds, "Amstelian", are classified now within the Upper Pliocene.

1. INTRODUCTION

The position of the Plio-Pleistocene boundary in the marine beds of the North Sea Basin has been the subject of much discussion in the past twenty years. Originally, boundaries between the Lower-Pliocene, Upper-Pliocene and Lower-Pleistocene were based on changes in mollusc assemblages of shallow water environments. Consequently, the biostratigraphy based on foraminifers had to be adjusted to the existing stratigraphic subdivision of the Pliocene and Lower Pleistocene (van Voorthuysen, 1950). However, the discovery of the neritic facies of the Plio-Pleistocene in the Netherlands with only very sparse fine mollusc fragments and different foraminiferal faunas than previously known, presented problems with regard to the above mentioned stratigraphic subdivision.

Although in both, the shallow and deeper marine facies, a general impoverishment of the fauna was observed towards younger strata a correlation between the shallow and deeper marine deposits met with severe difficulties. In accordance with Glibert and de Heinzelin (1957) the "Merksemian" in the shallow facies area was considered by van Voorthuysen (1962) to represent the basal stage of the Pleistocene.

The strong increase of *Elphidiella hannai,* previously considered to be a criterion for the Plio-Pleistocene boundary (van Voorthuysen, 1950, 1957) occurs in the present concept within the Upper Pliocene. In the deeper facies area, the "Amstelian" of Dutch stratigraphers was also placed in the basal part of the Lower Pleistocene. In both areas the overlying marine Lower-Pleistocene strata are currently included in the "Icenian". However, it has become evident that the beds, originally called "Amstelian" by Harmer (1896), are synchronous with the Icenian beds in Dutch literature which are in turn correlative with the Icenian beds in East Anglia. Consequently it appears that Harmer's original "Amstelian" includes beds differing in age from and apparently younger than the beds which Dutch authors in a later stage generally included in the "Amstelian".

For two reasons new light has been shed on these problems. In the first place, pollen-analytical studies have shown that a clear definition of the Plio-Pleisto-

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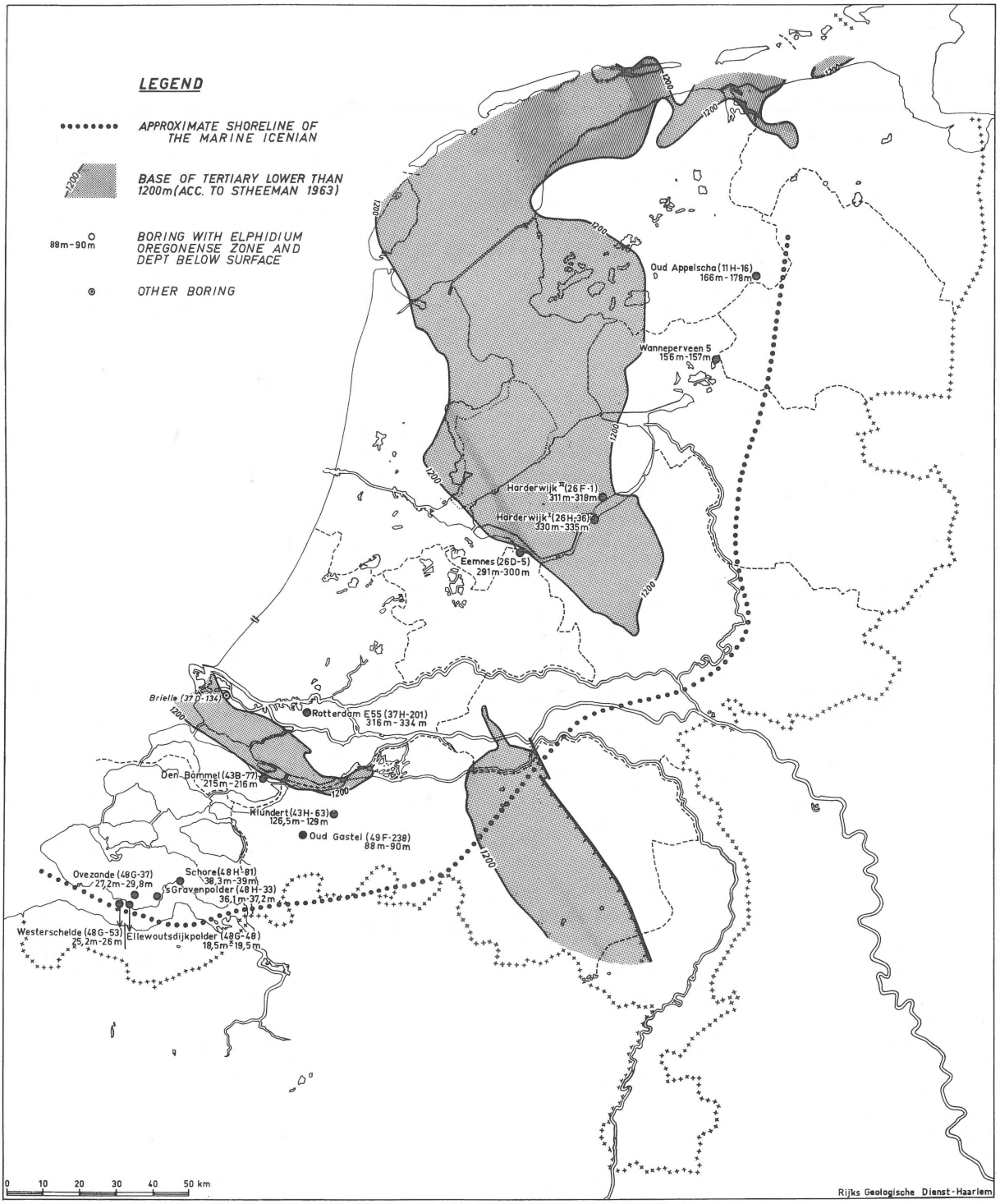

Fig. 1
Location map. Borings have been indicated with the file-number of the archive of Geological Survey.

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cene boundary can be given in non-marine beds of the North Sea Basin area (Z a g w i j n, 1960).

Although based on changes in past vegetation, the boundary established in this way has a well defined palaeoclimatological meaning. On the basis of palaeoclimatic changes as traced by pollen-analysis time correlations are possible.

The first cold stage of the (Lower) Pleistocene defined by means of pollen-analysis is the Praetiglian. This stage follows the Reuverian of Upper-Pliocene age, which stage was likewise defined by means of pollen-analysis. In one case in the SW Netherlands (Z a g w i j n, 1959, 1960) it was possible to trace the pollen-analytical zonation into shallow marine deposits. Here, the Plio-Pleistocene boundary as defined by means of pollen-analysis was found within the equivalent of what appeared to be "Merksemian" beds (Z a g w i j n, 1960). Additional pollenanalytical data have since become available from the marine Plio-Pleistocene beds and will be discussed in this paper.

The second reason concerns the presence of the foraminiferal species *Elphidium oregonense* C u s h m a n & G r a n t in the Plio-Pleistocene marine beds of the Netherlands. This species was first observed in the Netherlands in the early 1950's (v a n V o o r t h u y s e n, 1952). Additional data have shown that the occurrence of this fossil is restricted to a narrow zone suggesting the simultaneous occurrence in the North Sea Basin during a relatively short time-interval. The narrow zone will be referred to in this paper as the *Elphidium oregonense*-zone. *Elphidium oregonense* was found for the first time in the Plio (?)-Pleistocene deposits at the Westcoast of North America (C u s h m a n and G r a n t, 1927). In recent sediments of the arctic region it occurs in the Bering Sea around Alaska (L o e b l i c h and T a p p a n, 1953; S a i d o v a, 1961; A n d e r s o n, 1963; T o d d and L o w, 1967).

According to Anderson this species is living under arctic conditions as has been proved by using the Rose Bengale staining method of W a l t o n (1952) on specimens collected from above mentioned region. The species was found living at depths ranging from 12 to 40 metres.

Furthermore, A n d e r s o n (1963) reported very complicated oceanographic conditions in the Bering Sea where three distinct watermasses are present with temperatures ranging from $-1.0°$ to $+9°C$ (centigrades) and salinities from less than 31.7 to 34‰.

Combining the palynological data and the information on the occurrence of fossil *Elphidium oregonense* in marine Plio-Pleistocene deposits of the Netherlands has resulted in a revision of the present views concerning the position of the Plio-Pleistocene boundary in this area, as will be discussed in the following pages.

2. THE FORAMINIFERAL DIAGRAMS

a. Presentation of data

The foraminiferal diagrams have been simplified in order not to confuse the foraminiferal picture, by plotting the sparse and rare species together in one group.

On the left side of the diagrams have been plotted: *Ammonia beccarii,* which points to more or less littoral depositional conditions; *Elphidiella hannai,* which is present in reasonable numbers in the Upper-Pliocene and generally occurs in very high percentages (up to 90%) of total population in the marine Icenian. This species has not been encountered to date in younger Pleistocene marine deposits. This apparent absence during younger Pleistocene time in the North Sea Basin cannot be explained particularly because this species is known to be living at present along the Californian coast; the most frequent species of *Elphidium* sp. div. is *Elphidium selseyense,* which is in fact a collective name for *Elphidium incertum, Elphidium clavatum* and *Elphidium selseyense;* between these three species there are so many transitional forms, that particularly in routinework it is hardly feasible to count them seperately.

On the right side of the diagrams the remaining species have been plotted. The borings have been indicated by topographic sheet and file number of the archive of the Geological Survey of The Netherlands.

b. Explanation of the foraminiferal diagrams of four borings

1. Oud-Appelscha (11H-16) (fig. 1 and fig. 3). – The area where this boring has been carried out was a

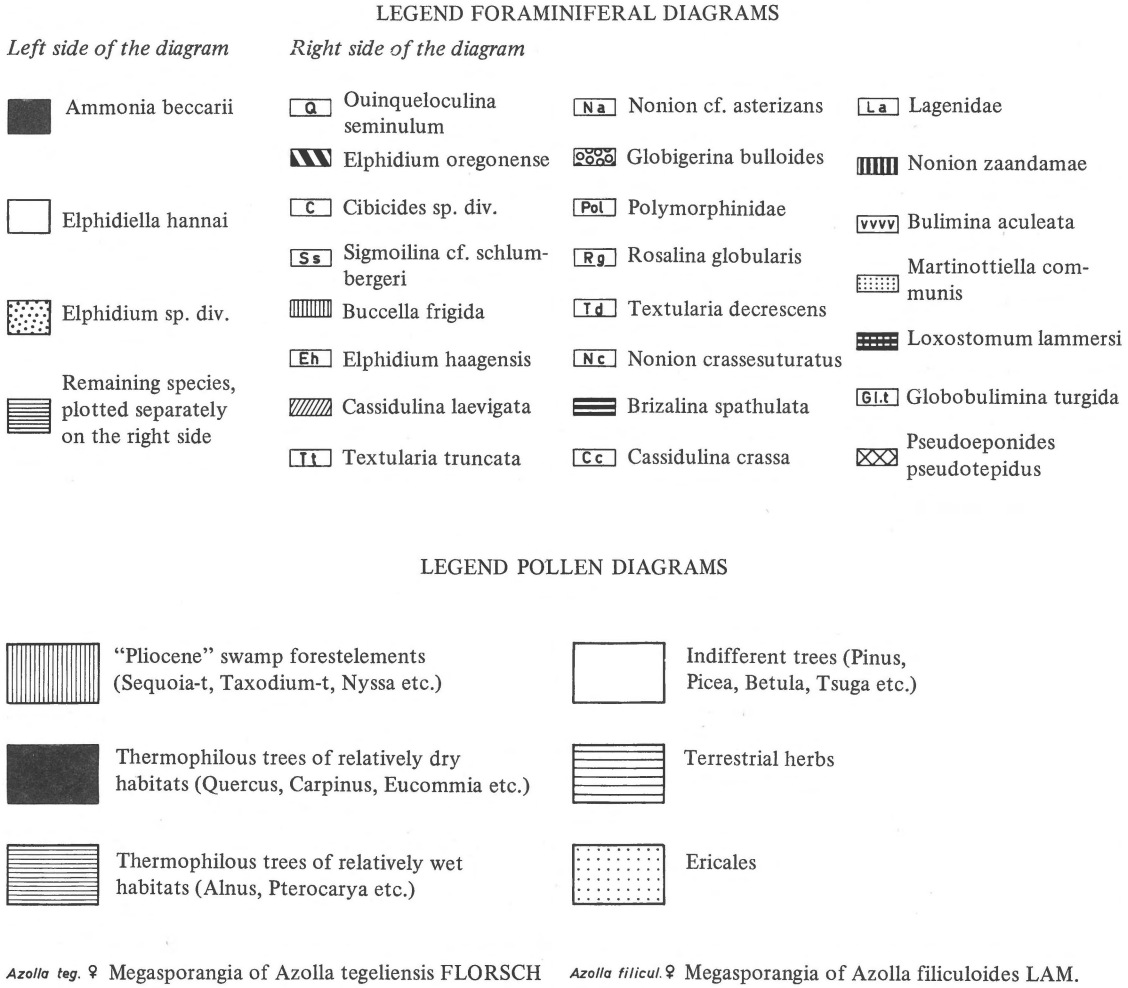

Fig. 2
Legend to the foraminiferal and pollen diagrams.

relatively stable part of the Netherlands during the Plio-Pleistocene; consequently the thickness of the littoral to innerneritic Lower-Upper(?) – Pliocene and marine Icenian is reduced. The Upper(?)-Pliocene is separated from the Lower Pliocene by an erosional bed of 25 cm. thick, consisting of calcareous sandy dark greenish grey claystone with shell-remains, shell-casts and *Ditrupa subulata,* the latter most probably derived from the underlying Lower-Pliocene. The Lower-Pliocene faunal picture points to a littoral to innerneritic depositional environment with a rather high percentage in total population of *Ammonia beccarii* together with *Cibicides spp., Textularia truncata,* various species of the Polymorphinidae *(Globulina, Polymorphina, Pseudopolymorphina* and *Pyrula), Rosalina globularis, Textularia decrescens; Elphidiella hannai* is absent; *Nonion crassesuturatus* occurs very sparsely and therefore has not been plotted separately on the diagram. The thickness of the Lower-Pliocene in this boring is 14 metres; however, as the base of the Lower Pliocene has not been reached at the total depth of 201 m. below surface, the actual thickness is not known.

From the beds of possibly Upper-Pliocene age one sample only was available from the interval 178-187 m. below surface. The fauna is distinctly different from that of the Lower-Pliocene; it contains about 65% of *Elphidiella hannai,* 18% *Elphidiums* (mostly bearing the collective name of *Elphidium*

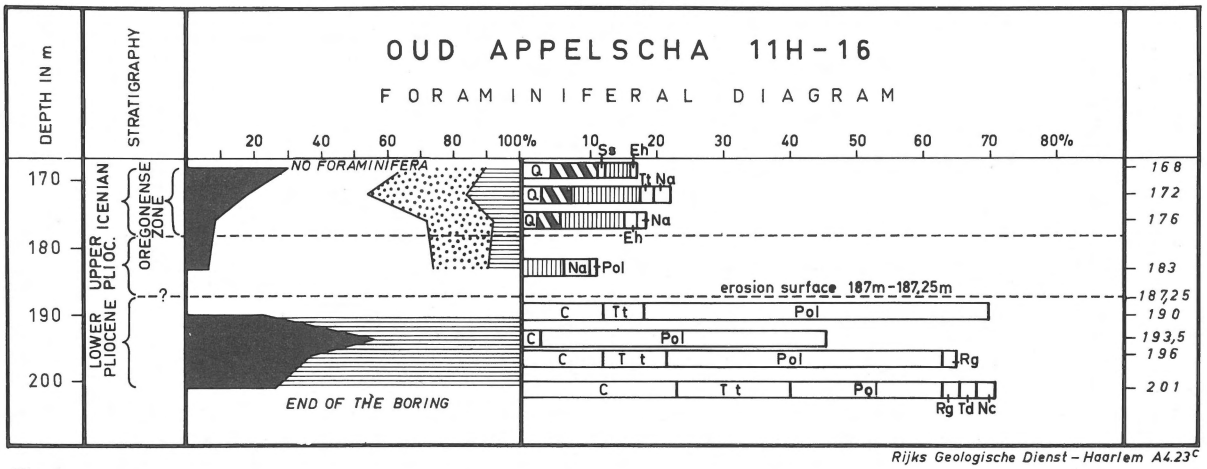

Fig. 3
Foraminiferal diagram of part of boring Oud Appelscha (11H-16). Location: fig. 1, legend: fig. 2.

selseyense), 8% *Ammonia beccarii* and about 10% of the sparser species plotted combined together on the right side of the diagram including *Buccella frigida, Nonion* cf. *asterizans* and also a few Polymorphinidae which are most probably derived from the underlying Lower-Pliocene. The beds of the *Elphidium oregonense* zone are considered to belong to the basal part of the Icenian; they range from 166-178 m. and are overlain by non-marine deposits.

2. Eemnes (26D-5) (fig. 1 and fig. 4). – This boring is located in a region where more downwarping since Plio-Pleistocene times has occurred than in the region of the boring Oud-Appelscha. This is indicated by the greater depth of the base of the Icenian at about 300 metres and the greater thickness of the "Icenian" attaining about 100 metres. The environmental conditions do not show much difference, when comparing the two diagrams. In the basal layer of the Icenian from 291-300 m. (the *Elphidium oregonense*-zone) there are more *Quinqueloculina seminulum* and less *Elphidium* spp. div., which points to a slightly deeper sea. In the basal-layers of both borings *Elphidium haagensis* occurs in low percentages together with *Sigmoilina* cf. *schlumbergeri* and *Buccella frigida.* However, the fauna in the boring Oud-Appelscha where among others some *Textularia truncata* and *Nonion* cf. *asterizans* are present, is composed of slightly more species.

The *Elphidium oregonense*-zone, marking the base of the marine Icenian is at least 9 metres thick; the actual thickness is not known as, unfortunately, the Pliocene has not been reached at the total depth of 300 m.

3. E55 Rotterdam (37H-201) (fig. 1 and fig. 5). – This boring has been carried out by the Nederlandse Aardolie Maatschappij in 1955 during the E55-Exhibition in Rotterdam. As this boring is one of the very few which has been entirely cored, it has given much information, especially from the Tertiary and the Quaternary.

The *Elphidium oregonense*-zone has been determined to range from 316 to 334 m. and is consequently 18 metres thick. This well is situated in a deep Plio-Pleistocene basin with the base of the Lower-Pliocene at 406 m. The environmental conditions are those of a deeper sea, which is indicated by the virtual absence of the littoral form *Ammonia beccarii* and the presence of forms characteristic of deeper marine environments a.o.: *Cassidulina laevigata* (including a few *Cassidulina carinata*), *Brizalina spathulata* and the planktonic form *Globigerina bulloides.*

The diagram shows a gradual shallowing of the sea during the Upper-Pliocene and the Pleistocene. This is the normal picture for other places in the Netherlands too. From about 316 m. upward the fine grained sandy, micaceous and calcareous clays with only locally some small shell fragments (< 1 mm.) do not contain foraminifera. It is assumed that an estuarine-

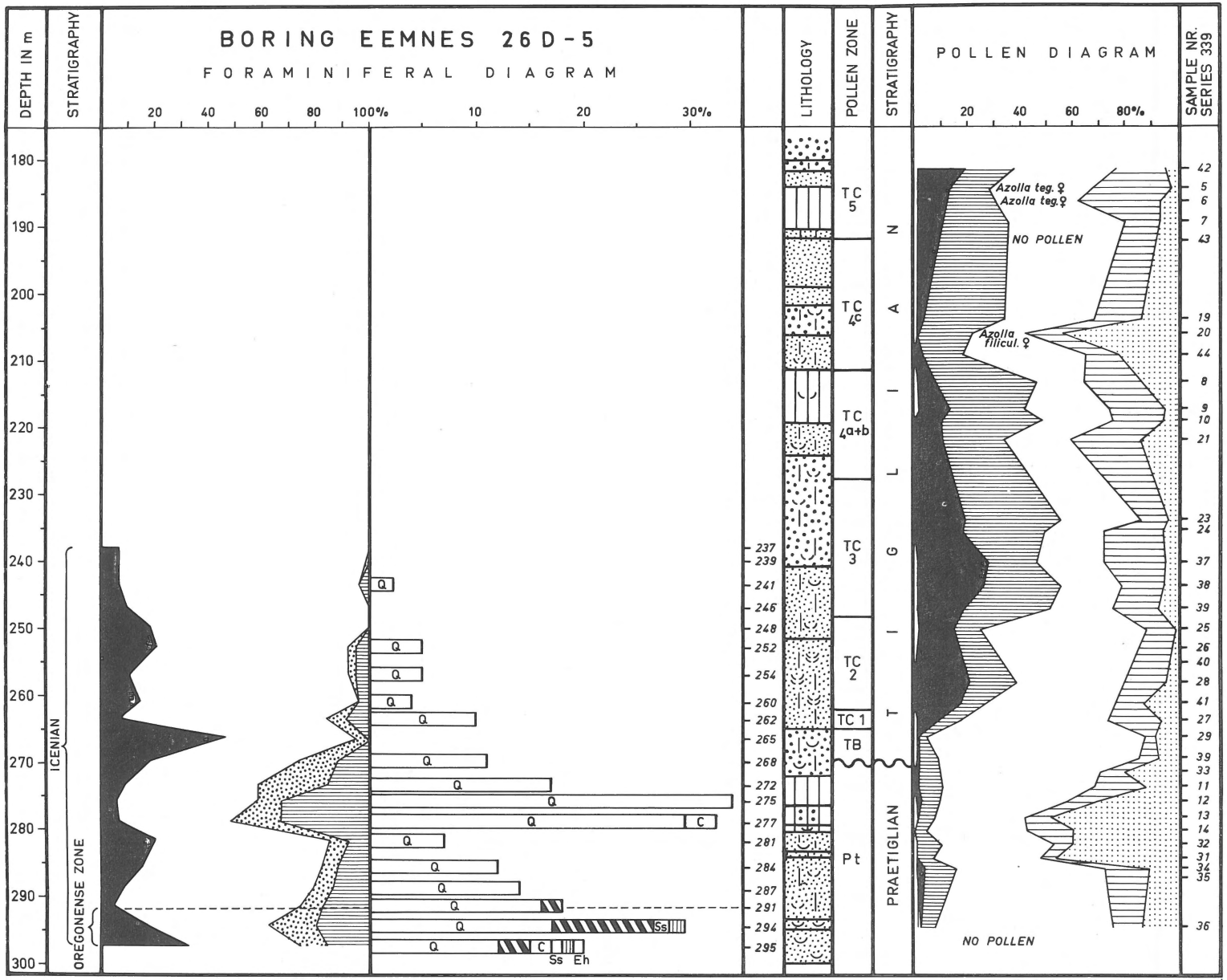

Fig. 4
Foraminiferal and pollen diagram of boring Eemnes (26D-5). Location: fig. 1, legend: fig. 2.

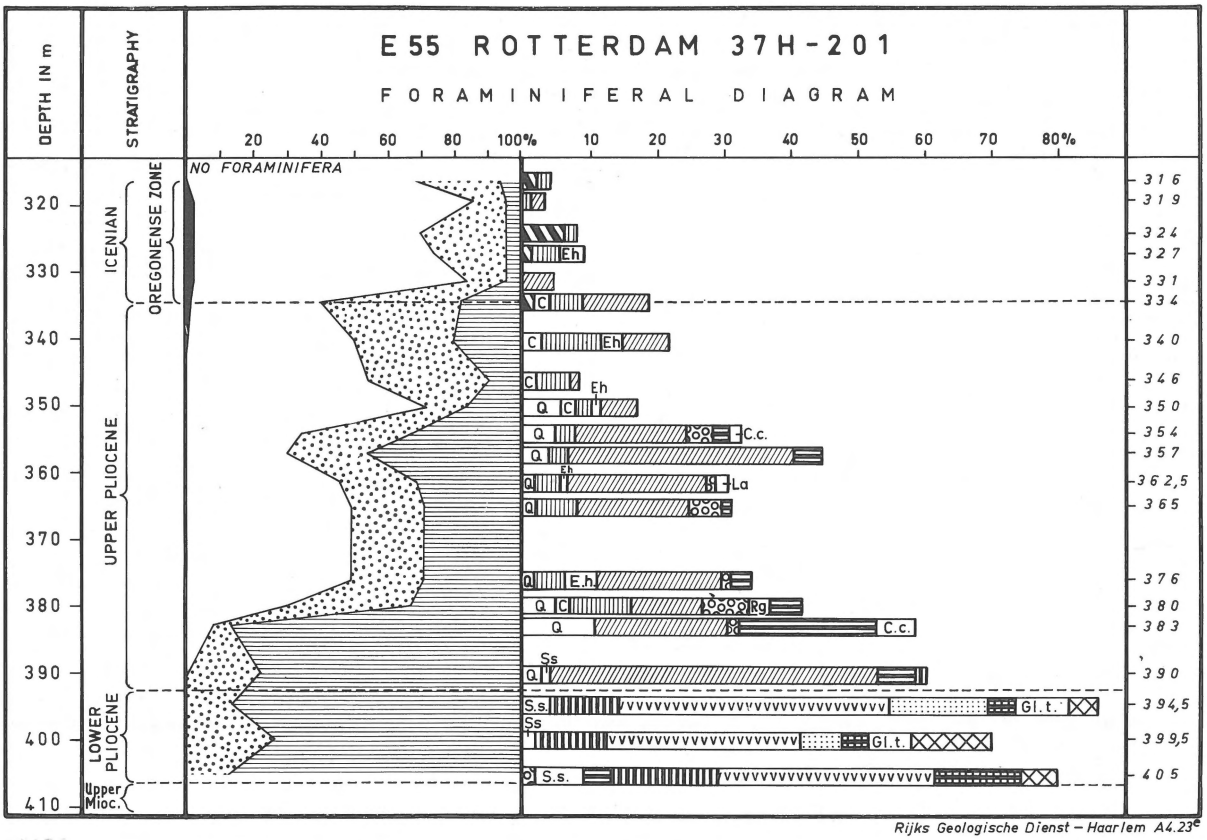

Fig. 5
Foraminiferal diagram of boring E55-Rotterdam (37H-201). Location: fig. 1, legend: fig. 2.

littoral environment was present in Icenian times (see also van Voorthuysen, 1960).

It is of interest to mention here briefly the results of the investigation on the Zaandam boring (van Voorthuysen, 1950), which is situated in a deeper part of the Tertiary basin than the E55-boring. The base of the Pliocene is at 684 m. in the Zaandam boring. The *Elphidium orogense*-zone was not found; however, it is possible that the zone is present above 382 m. where coring was started. At any rate, the previous assumption that from 394 to 586 m. marine Pleistocene (≠ Amstelian) is present has to be revised. Instead, the beds in the mentioned interval are presently considered to be of Upper-Pliocene age.

In the Zaandam boring the base of the Lower-Pliocene begins with a zone named the lower *cassidulinid* "province"; the fauna includes among others, *Globigerina bulloides*, a few *Nonion zaandamae* (see Loeblich and Tappan, 1953, p. 87) and *Pseudoeponides pseudotepidus*, *Elphidiella hannai* has not been found. Higher-up follows the zone named the *buliminid* "province", the fauna of which consists of many *Nonion zaandamae*, fair amounts of *Brizalina spathulata*, *Loxostomum lammersi* and *Pseudoeponides pseudotepidus;* these two "provinces" according to our present view, represent the Lower-Pliocene. Upwards follows a transition zone in which the appearance in low values of *Elphidiella hannai* is registered. We consider this zone as the upper part of the Lower Pliocene. The overlying zone named the upper *cassidulinid* "province" without *Nonion zaandamae* and only at the base some *Globigerina bulloides* is at present considered to be of Upper-Pliocene age. In the Upper-Pliocene the percentage of total population of *Elphidiella hannai* augments considerably. Where the numbers of *Elphidiella hannai* increase at the base of the Upper-Pliocene *Pseudoeponides pseudotepidus* has vanished.

In the E55-boring the Pliocene is only 80 metres thick and consequently the various different faunal "provinces" are more reduced in thickness or absent. It is assumed that the lower *cassidulinid* "province" is missing here. The *buliminid* "province" without *Elphidiella hannai,* but with *Loxostomum lammersi, Pseudoeponides pseudotepidus* and *Nonion zaandamae* is present and this part of the section is considered to be Lower-Pliocene in age. The Upper-Pliocene comprises the upper cassidulinid "province" and is overlain by the Pleistocene *Elphidium oregonense*-zone.

4. Klundert (43H-63) (fig. 1 and fig. 6). – The base of the Pliocene in this boring is situated at 271.50 m., but the diagram of fig. 6 shows only the upper part of the Upper-Pliocene, the *Elphidium oregonense*-zone and the remainder of the Icenian. The boring is in an area between little downwarping to the south and much downwarping to the north. The *Elphidium oregonense*-zone is represented by one sample from 126.50 to 129.00 m. only. The species is scarce in this sample.

The differences in environmental conditions in the Klundert boring and E55-boring are evident in the diagrams of the two sections. The diagram of the E55-boring shows that the littoral species *Ammonia beccarii* is virtually absent in the Upper Pliocene and in the *Elphidium oregonense*-zone; instead, the fauna of the upper *cassidulinid* "province" of the Upper Pliocene age, points to middle neritic conditions (from 40 to 100 metres). In the Klundert well the Upper Pliocene strata and the beds of the *Elphidium oregonense*-zone show a littoral to innerneritic facies (highwatermark to 40 m.) with a low percentage of *Ammonia beccarii* and absence of *Cassidulina laevigata.* In this well the transition zone (between the buliminid "province" and the upper *cassidulinid* "province" of the Zaandam boring) and the upper *cassidulinid* "province" are present.

c. Other borings with Elphidium oregonense

Except for the four borings discussed in detail above, *Elphidium oregonense* has been found in 10 other borings in the Netherlands. The pertinent data

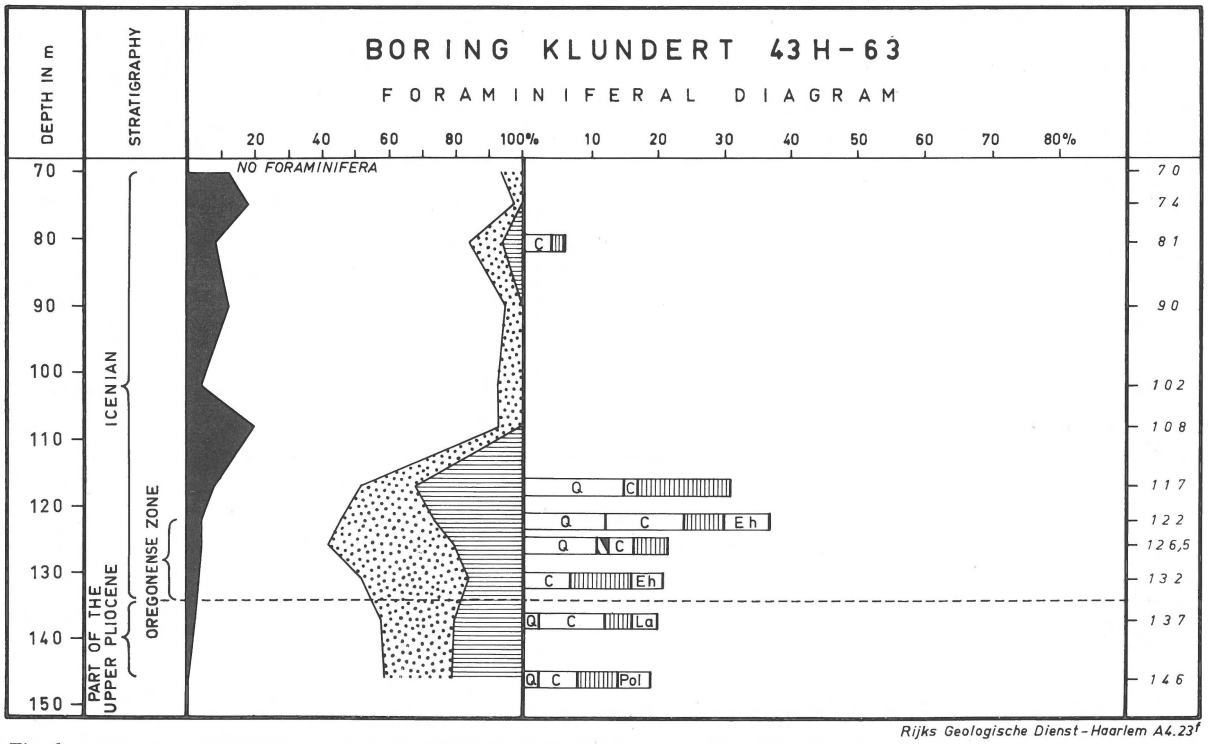

Fig. 6
Foraminiferal diagram of boring Klundert (43H-63). Location: fig. 1, legend: fig. 2.

can be found in fig. 1. In all places the *Elphidium oregonense*-zone is thin ranging from less than 1 metre in areas with little downwarping to 15 metres in the E55-Rotterdam boring, which is located in a basinal area. The stratigraphic position of the zone can be considered the same in these wells as in the examples discussed above.

Elphidium oregonense generally occurs in small numbers; the highest percentage does not exceed 10 percent.

3. THE POLLEN-ANALYTICAL DATA

a. Introduction

Pollenanalytical data are available from 5 borings out of a total of 14, in which the *Elphidium oregonense*-zone has been found in the Netherlands. These data will be discussed in this paragraph.

The pollen-diagrams have been plotted in the same way as described by Z a g w i j n (1963). In the main diagram, which is shown only, the following ecological groups are given from left to right:

1) trees not ranging further upward than the Pliocene (vertical hatching);
2) warmth-loving trees of relatively dry habitats (in black);
3) warmth-loving trees of relatively wet habitats (narrow horizontal hatching);
4) climatically indifferent and cool trees (in white);
5) herbs (wide horizontal hatching);
6) Ericales (stippled).

High values of 5 and 6 in combination with low ones of 2 and 3 indicate relatively cold (glacial) conditions. High values of 2 and 3, mostly associated with low ones of 4, 5 and 6 point to warm-temperate phases (interglacials), intermediate (cool) phases show high values of 4.

b. Eemnes (26d-5) (fig. 4)

Part of this pollen-diagram was published on an earlier occasion (Z a g w i j n, 1963). In that paper more details on the zonation of the Tiglian part of this boring will be found. It is recalled here only, that the finds of macrosporangia of *Azolla tegeliensis* at 180-184 metres permit the conclusion, that here part of the Tiglian Interglacial is present. Two warm temperate phases (pollenzone TC 2-3 and TC 5) respectively can be recognized. The upper limit of the marine "Icenian" is found in between these two zones. Below the Tiglian C a cool zone (270-265 m.) most probably represents the Tiglian B. The lowermost, warm-temperate part of the Tiglian, characterized by the presence of Fagus (Tiglian A, Z a g w i j n, 1963) has not been found in this boring.

Immediately below the cool zone TB, a strong rise in herbs and corresponding fall in thermophilous trees, indicates a phase of cold, subarctic conditions. This part of the diagram shows a close correspondence to diagrams of the Praetiglian glacial stage (Z a g w i j n, 1960) both in marine and non-marine environments. Unfortunately the boring did not reach deep enough to encounter definite Upper-Pliocene (Reuverian) beds. However, the fact that the amount of herbaceous pollen declines at the very base of the section, in addition to the find in the lowermost spectrum of a few percents of treepollen generally not ranging further upward than the Pliocene, suggests that Pliocene beds can be expected not far below total depth. In contrast to the next section to be discussed, the content of pollen reworked from older beds in this well was very low. This means that the presence of low percentages of "Pliocene" types in the basal spectra is not likely due to reworking, and that therefore the case for these beds being near to the Plio-Pleistocene boundary is reinforced.

c. Borings E55-Rotterdam (37H-201) and Brielle (37D-134) (fig. 7)

The upper part of the pollendiagram obtained from boring E55-Rotterdam has been published by Z a g w i j n (1963). At about 40 m. Waalian interglacial beds occur. From 150-80 metres the presence of beds belonging to the Tiglian C has been established. The two warm temperate zones TC 3 and TC 5 stand out clearly. In between the upper limit of the marine "Icenian" beds is situated, in a position very similar to that in boring Eemnes.

Unfortunately pollen-preservation in the underlying stretch from 300-150 metres proved to be not very good. However, from the section below 300 metres it was possible to obtain a diagram, though with some difficulty. In the same area, boring Brielle

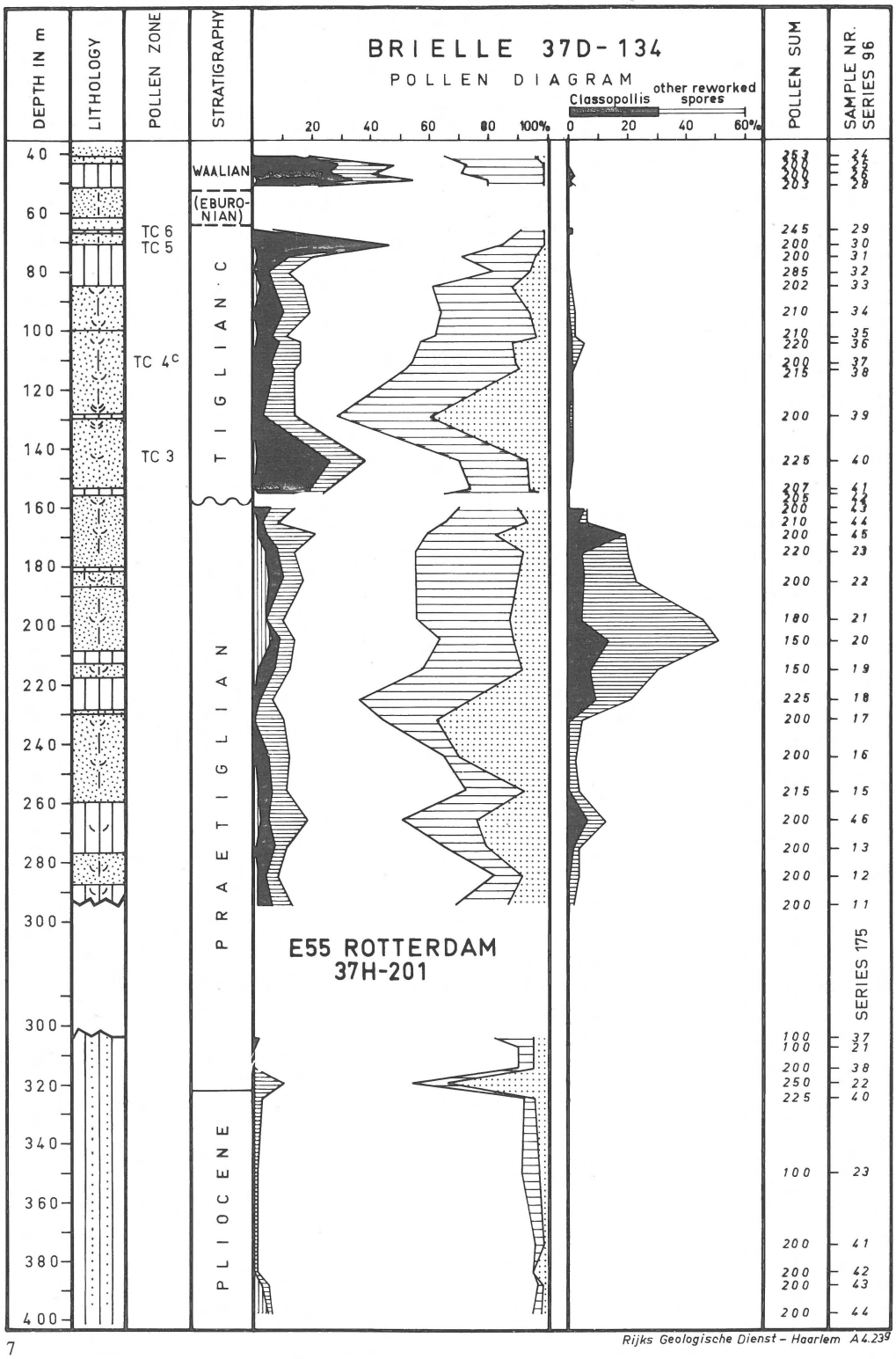

Fig. 7
Combined pollen diagram of borings Brielle (37D-134) and E55 Rotterdam (37H-201). Location: fig. 1, legend: fig. 2.

(37D-134) yielded a diagram, which in its upper part is identical to that of E55-Rotterdam, showing the presence of the Waalian as well as the various zones of the Tiglian C in nearly the same range of depth. Consequently, it may be assumed that there is no tectonic disturbance between the two sites. As moreover, the stretch below the Tiglian C i.e. below 158 m. in boring Brielle has yielded a pollen-diagram which shows a clear picture this diagram is shown here, down to 300 metres, in combination with the part of 400-300 metres of boring E55-Rotterdam.

The diagram from the beds below the Tiglian C and ranging from 158 to 300 m. in boring Brielle is characterized by high values of herbaceous pollen as well as by pine domination among the tree-pollen, pollen of thermophilous trees being rather scarce. Moreover, most of the latter is probably reworked, as is shown by the diagram part 158-220 m., in which besides pollen of thermophilous trees, those of trees normally confined to Pliocene and older beds are present, in addition to very high values of certainly reworked pollen of Mesozoic age (*Classopollis* and others). The pollen-diagram evidently indicates a stage of cold climatic conditions which according to its stratigraphic position represents the Praetiglian. The base of this cold stage is found in boring E55 at 320 m. Below it a *Pinus*-zone is found which can be considered to represent the uppermost Pliocene, its pollen-diagram strongly resembling that of the Reuverian C (Z a g w i j n, 1960). Further down an increase of pollen-types characteristic of Pliocene beds can be observed, although pollen-preservation is very bad. It is, however, also possible that the strong domination of *Pinus* and the absence of typical pliocene types in the stretch 325-380 m. is due to the deeper marine facies of these deposits. At any rate, the increase of herbaceous pollen upward in this boring as well as in boring Brielle cannot be explained by selective pollen dispersal and therefore can be considered to represent the pollen-analytical Plio-Pleistocene boundary.

d. Den Bommel (43B-77) (fig. 8)

From the lowermost part of this boring, 192-222 m., a pollen-diagram has been obtained which is very similar to that of the Praetiglian in boring Brielle. It is especially of particular interest to notice the strong increase of Lower-Tertiary and Mesozoic palynomorphs reworked in the diagram of Den Bommel which correlates with a similar feature in the diagram of boring Brielle. The *Elphidium oregonense*-zone was found at 216-217 metres.

e. Klundert (43H-63)

Unfortunately this boring has been drilled with a straight flush equipment and a drilling mud containing pollen was used in this process. An attempt has been made to obtain a pollendiagram from the part containing the *Elphidium oregonense*-zone, but it appeared that part of the spectra evidently contained

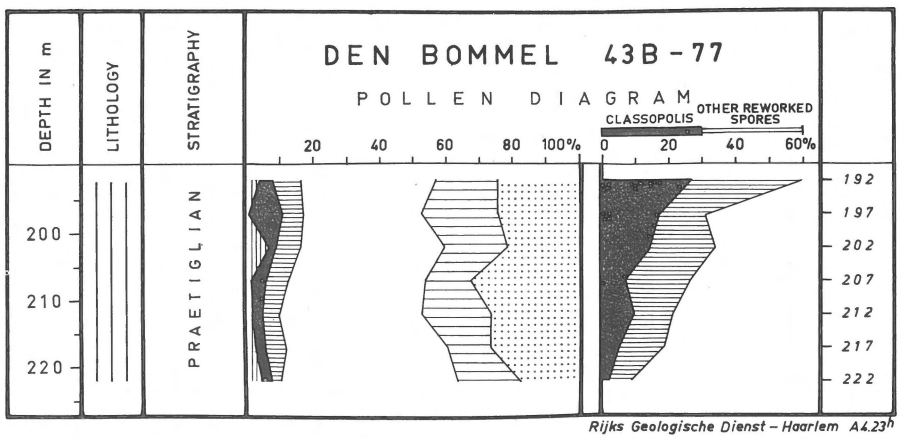

Fig. 8
Pollen-diagram of part of boring Den Bommel (43B-77) containing the *Elphidium oregonense*-zone at 216-217 m. Location: fig. 1, legend: fig. 2.

pollen derived from the drilling mud. Therefore no conclusions could be drawn.

f. Harderwijk (26H-36)

Below Tiglian C, which could be recognized well by means of pollen-analysis (211-302 m.) a few spectra of cool and cold character have been obtained (308-330 m.) which indicate the presence of the Praetiglian. The *Elphidium oregonense*-zone was found at 330-335 m.

g. Oud-Appelscha (11H-16)

Overlying the marine Plio-Pleistocene beds, continental deposits are present in this boring. They yielded pollen-spectra of interglacial character from 102-152 m., which belong to the Tiglian. Downward, however, at 157 m., high values of herbaceous pollen (45%), together with 27% *Pinus*, 8% *Betula*, 6% *Picea*, 4% *Alnus* and only 5% of thermophilous treepollen indicate the presence of beds formed under cold climate conditions, namely in the Praetiglian. The *Elphidium oregonense*-zone was found in the underlying marine beds.

4. CONCLUSIONS

1. Comparison of the data concerning the occurrence of the *Elphidium oregonense*-zone in 5 wells from which also pollendiagrams exist, indicates that this zone is found in the lower part of the first cold stage of the Pleistocene, the Praetiglian Glacial Stage. In one case E55-Rotterdam the lowermost occurrence of *Elphidium oregonense* is slightly below the pollen-analytical Plio-Pleistocene boundary, though its clear expansion is exactly where in the pollen-diagram the herbaceous pollen content increases strongly, indicating the opening of forests as a response to increasing cold. Moreover this boring is situated in a basin where rapid sedimentation and subsidence prevailed and here the *Elphidium oregonense*-zone has a greater thickness than in any of the other borings discussed.
   The expectation that this narrow zone is time-correlative in the area investigated has been confirmed by pollen-analytical data. Unfortunately, however, in one place only (E55-Rotterdam) the boring was deep enough to yield a pollen-diagram reaching well into Pliocene beds. In the future further research has to be conducted in order to obtain more pollen-diagrams from borings containing a well-developed *Elphidium oregonense*-zone and penetrating far down into Pliocene strata.
   It may be concluded at present, that at the Plio-Pleistocene boundary in the Netherlands the first occurrence of the arctic marine species *Elphidium oregonense* is in accordance with the onset of subarctic climatic conditions as revealed by pollen-analysis.
2. *Elphidium oregonense* has been found in littoral and innerneritic faunal assemblages, which is in accordance with the present depth range of the species.
3. The thickness of the Quaternary, especially in the marine facies, is owing to the new definition of its lower boundary considerably less than assumed todate (P a n n e k o e k, 1956, K e i z e r and L e t s c h, 1963). In the NW part of the country it does not exceed 400 metres, instead of 600 metres as hitherto assumed.
4. Untill now not a single specimen of *Elphidium oregonense* has been found either in the Crags of East Anglia (Great Britain) or in the area of Antwerp (Belgium). It may possibly be assumed that no marine beds of the Praetiglian are present in these two areas, which are situated at the edge of the North Sea Basin. Moreover, marine Lower-Pleistocene beds have not been found todate in Belgium; in East Anglia a stratigraphic hiatus may be present between the Coralline and Red Crags (Pliocene) and the Icenian Crags (Pleistocene). This assumption is supported by a written communication of Dr. C.W. Haskins, micro-paleontologist of Robertson Research Cy to the first author, in which he informed that *Elphidium oregonense* has been found only in wells located in the central part of the North Sea, where its presence is assumed to be indicative of the basal Pleistocene.

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