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Retrospective

Results of pollen analysis on the Pleistocene stratigraphy and the Pliocene-Pleistocene boundary in Schleswig-Holstein

Burchard Menke

Geologisches Landesamt Schleswig-Holstein, 2300 Kiel-Wik, Germany

Correspondence: Frank Preusser (frank.preusser@geologie.uni-freiburg.de)

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Abstract. Based on an overview of the current state of pollen analysis in Schleswig-Holstein the results and problems of Pleistocene stratigraphy are discussed. Late Pleistocene: new investigations regarding the Eemian, in combination with earlier investigations, allow an overview of past developments of vegetation and ecology. Investigations on deposits of the Early Weichselian question if the occurrence of the Roedebaek Interstadial can be confirmed in Schleswig-Holstein. Based on the profile "Keller I" and on additional investigations, the course of the development of the Early Weichselian is discussed. The stratigraphy of the Late Weichselian is exemplified on cover sands from Lieth. Middle Pleistocene: new investigations on marine sediments of the Holsteinian Warm Phase are available from Fahrenhorst. The regression of the Holsteinian Sea occurred surprisingly early. A younger cold stage was termed Mehlbeck Cold Stage, a younger warm stage Wacken Warm Stage. Together with the Holsteinian Warm Phase, these can be combined as the Muldsberg Series that is palynological characteristic. Early Pleistocene: the earliest Pleistocene ("Lieth Series") comprises at least five cold and warm periods. As of yet, it has not been possible to connect the Lieth Series to the Middle Pleistocene. The connexion with the Dutch Early Pleistocene (Tiglian, Waalianian) is discussed. Pliocene-Pleistocene boundary: the development of vegetation in the transition from the Pliocene to the Pleistocene (Lieth, Oldenswort) was more gradual than was expected on the base of former investigations, especially in the Netherlands. A new definition of the pollen floristic boundary between the Pliocene and the Pleistocene for northern Central Europe is discussed.

1 Introduction

Prior to a final conceptual classification of the Quaternary stratigraphic units, a critical inventory must be made. Even in Europe, which has been well investigated, this is far from complete. In addition, many sites require a revision. It is probably appropriate to concentrate the work on small and selected areas. Whereas Quaternary stratigraphy can, on a large-scale perspective, essentially only be based on climatic fluctuations, for small areas other more directly accessible criteria can also be used as a basis, for example, peculiarities in the vegetation development. Experience has shown that connecting isolated and distant pollen records is often not satisfactorily possible, because the vegetation development represents a complex process whose characteristic features usually have no more than regional validity. Therefore, the elaboration of a Quaternary stratigraphy as complete as possible must be attempted first for smaller areas. The following summarises the current state of Pleistocene stratigraphy in Schleswig-Holstein based on pollen analysis.

2 Late Pleistocene

In recent years, numerous new Eemian deposits have been discovered, especially during geotechnical investigations and within the framework of the geological survey of the state. The vegetation history of the Eemian period is now well known for Schleswig-Holstein. Questions concerning the landscape history, for example, the distribution of the Eemian water bodies and the Eemian drainage network, however, are still open.

The Saalian late glacial, which preceded the Eemian Interglacial, has been documented in several places. The earlier findings from Brokenlande (Menke and Ross, 1967) seem to be further confirmed: in terms of its vegetation history, the Saalian late glacial in Schleswig-Holstein was apparently only a short transitional phase during which climatic fluctuations have not yet been detected. This makes the Saalian late glacial fundamentally different from the Weichselian late glacial, despite strong floristic similarities.

The boundary between the Saalian late glacial and the Eemian Interglacial is, from the vegetation history perspective, best placed at the beginning of the final forestation. The pollen diagrams show in particular an increase in *Betula* pollen and the disappearance of heliophilous species of the ground vegetation and shrub layer. Of course, one cannot expect the onset of forestation to be a contemporaneous marker for all of Central Europe, but the transition from open vegetation to forest is an extremely striking change in landscape development, since forestation is associated with a comprehensive establishment of the substrate.

In the Eemian deposits, the oldest zones are generally only weakly represented. Often, there are gaps in the strata and other disturbances in these parts of the sequences. The main sedimentation generally began in the early mixed-oak forest phase, more precisely during the course of the oak-pine phase or at the beginning of the oak-hazel phase. This also confirms earlier findings (von der Brelie, 1955).

The vegetation character in the peak of the Eemian Interglacial was that of a deciduous forest in a summer-humid, oceanic area. So many events in forest history followed each other so closely that stable conditions were probably never reached.

The development of vegetation not only allows stratigraphic conclusions to be drawn, but is also of interest with regard to landscape history. Apart from the climatic development, the pollen diagrams clearly show the development of the trophic state of the soils. In the earlier half of the Eemian Interglacial, mainly the species that avoid highly acidic soils were widespread. In the course of the hornbeam-spruce phase, on the other hand, species spread increasingly that have their main distribution on more or less acidified soils. Towards the end of the hornbeam-spruce phase, the bogs mostly changed to a raised bog-like state. However, so far there is no evidence for the existence of extensive raised bogs. At the same time as this increasing oligotrophication of the soils, which has also been described from Denmark (Andersen, 1964, 1969), podsolation probably occurred (Dücker and Menke, 1970).

The spread of spruce has undoubtedly promoted the leaching of soils, but clear oligotrophication occurred even before the spruce spread, for example in a small lake near Mönkloh (West Holstein). There, the more or less eutrophic aquatic vegetation, which mainly consisted of water lilies, including *Brasenia*, was already replaced by oligotrophic *Isoetes* in the lime-yew phase (zone IVb in Fig. 1). At the same time, a dystrophic bog belt apparently formed (unpublished). At the end of the Eemian Interglacial, *Isoetes* was one of the dominant aquatic plants.

The Eemian lakes, however, do not show a uniform development of their trophic state. In the larger lakes, the sediments often have a pronounced lime content right up to the uppermost part of the deposits.

In Schleswig-Holstein, three groups of Eemian deposits can be distinguished:

1. Marine and perimarine deposits (Von der Brelie, 1954; Gripp, 1964). A comprehensive revision is sorely needed, especially with regard to the possible comparison to the coastal Holocene. In contrast to the transgression of the Holocene North Sea, the transgression of the Eemian Sea was apparently monocyclic.

2. Deposits in formerly deeper lakes. The underlying sediment often consists of basin clay from the Saalian period (Menke and Ross, 1967). These Eemian lakes often survived the interglacial period without becoming completely silted up. They are so widespread that one can only imagine the Eemian landscape of Schleswig-Holstein as a lake district.

3. Limnic and semi-terrestrial deposits in small to very small hollow forms. The Eemian sequence usually begins with limnic deposits, but then the waters quickly silted up and peat formed. Deposits of this type are apparently abundant on the plateaus of Saalian age. An example is given by the Keller profile (Fig. 1).

The boundary between the Eemian Interglacial and the Weichselian Glaciation is placed conveniently at the begin-

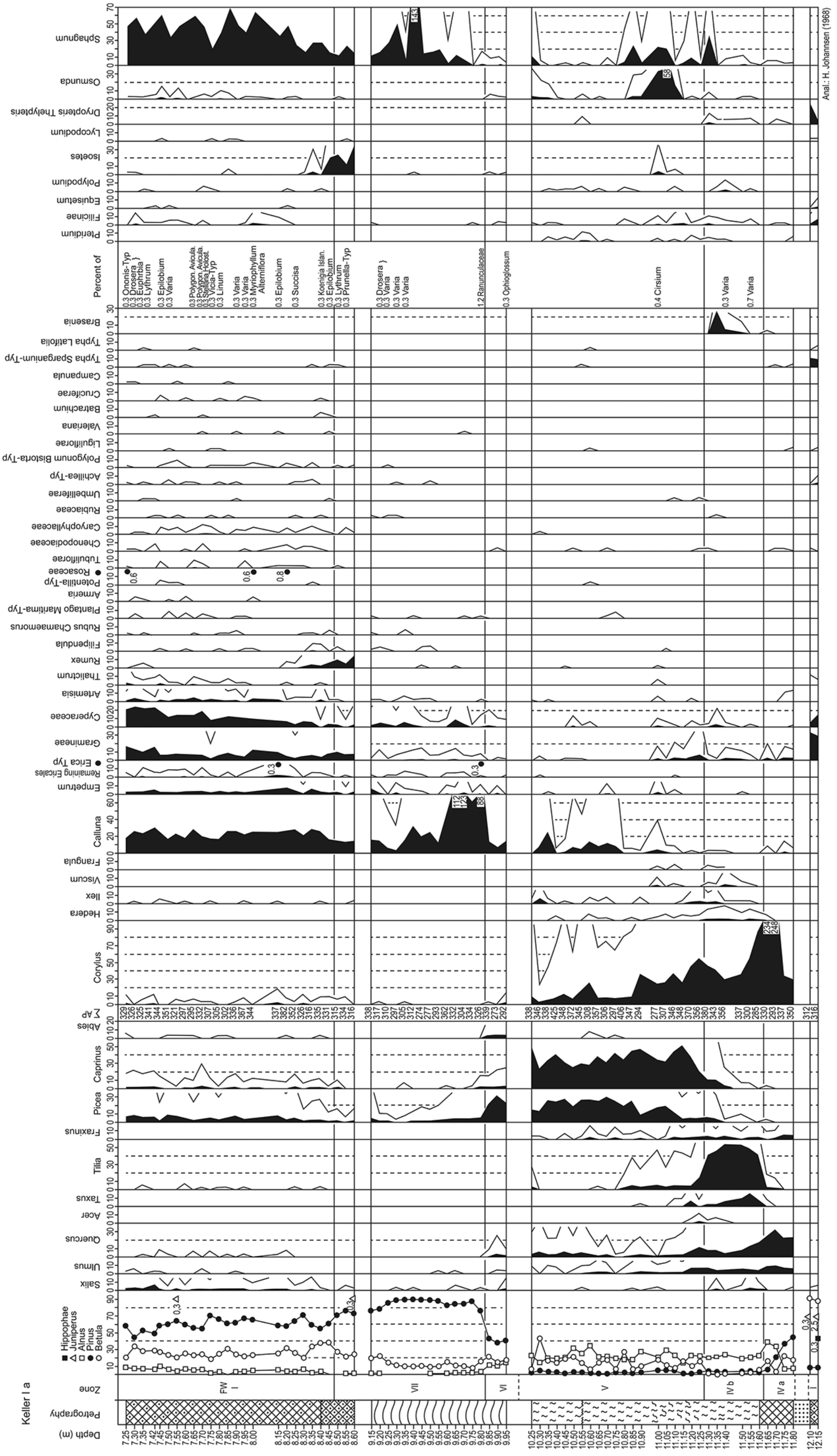

Figure 1. Pollen and spore diagram of profile "Keller 1" (Eemian and Early Weichselian).

ning of a deforestation of the mineral soils. In the pollen diagram, this is mainly reflected in an increase in the pollen content of light-demanding species of the ground vegetation, as long as they do not belong to the mire vegetation. *Artemisia* should be mentioned here in particular. In terms of landscape history, deforestation is also of great importance: under a forest cover, the land surface is largely conserved. With the onset of deforestation, however, the soil is mobilized to a considerable extent due to reworking by water and wind.

During the early Weichselian, several major climatic fluctuations can be detected. Pollen analyses of deposits where the early Weichselian is underlain by an Eemian sequence were published in Schleswig-Holstein from Odderade (Averdieck, 1967), Geesthacht and Loopstedt (Schütrumpf, 1967). More recent investigations are available from Keller (Figs. 1, 2), Bimöhlen and Mönkloh (unpublished). Further localities are also known. In neighbouring Lower Saxony, there is also a deposit at Oerel, which was studied by Selle (1965) and Schneekloth (1966).

In all cases, especially at the Keller site where larger layer gaps are very unlikely, the vegetation of the first, at least the first clear interstadial, has a distinct Brørup character. It comprises a very clear birch phase at the beginning and a subsequent long pine phase with spruce, larch and perhaps some alder. This interstadial ("Loopstedt Interstadial"; Dücker, 1967) must undoubtedly be connected with the Danish Brørup Interstadial (Andersen, 1961). A younger interstadial of very similar vegetation character has been proven in Odderade (Averdieck, 1967) and in Oerel (Selle, 1965; Schneekloth, 1966) (Odderade Interstadial, Averdieck, 1967; Nordhastedt Interstadial, Dücker, 1967).

The situation is very similar in the Netherlands (Zagwijn, 1961), but there the participation of thermophilic species is somewhat greater due to its more south-westerly location. Different findings are reported from Denmark (Andersen, 1961). There, the Brørup Interstadial was preceded by an older Roedebaek Interstadial, which Andersen (1961) established on the basis of his view of temporarily lower foreign pollen influence and greater participation of aquatic plant. The stratigraphic value of the first feature is debatable. Regarding the stratigraphic value of water plants, Iversen (1964) stated: "The occurrence of water plants is so local that they cannot be used to define zone borders in the pollen diagrams." In addition, some of the water plants found in Denmark occur even in the present-day Arctic (Knapp, 1965). In Schleswig-Holstein, Averdieck (1967) speculated that the Roedebaek Interstadial is present at Odderade. Schneekloth (1966), however, suggested that this and the following phase could also be placed in the beginning of the Brørup Interstadial. In addition, these phases have only been found in one profile (Odderade 5) and they could not be reliably traced into the stratigraphic sequence of the Odderade sand pit (Dücker and Hummel, 1967).

If one compares the vegetation development in the individual occurrences, then in the author's opinion nothing would prevent a connection of the Dutch Ammersfoort Interstadial with the Brørup Interstadial and the Dutch Brørup Interstadial with the Odderade Interstadial. However, Wijmstra (1969) was able to prove two pronounced Weichselian early glacial interstadials in Macedonia, which were apparently preceded by a much weaker one. However, this has only been documented by two or three samples and in one diagram. Apart from the fact that one would expect at least one more diagram to prove this oldest interstadial, at least a third option of correlation should have been discussed in addition to the two discussed by Wijmstra (1969). Even in the well-known Weichselian early glacial, not all problems have been solved yet.

In the first Weichselian early glacial stadial, i.e. the phase between the Eemian and Brørup Interstadial, local water levels were generally high again. The Eemian peatlands were mostly covered by muds. Soil displacements reached a considerable extent. Apparently, this stadial in Schleswig-Holstein was still under a more or less oceanic climate. In the vegetation, dystraphic species played a major role. In the Brørup Interstadial, *Sphagnum* bogs mostly grew up again on top of organic-rich mud. Plant species of oceanic distribution have also been found in the Brørup Interstadial.

Up to now, a supposedly strong distribution of *Frangula* has been declared as characteristic. According to the new investigations, however, it is apparently not *Frangula*, but very probably an *Ericales* clade. The same pollen type occurs in the recent genera *Blaeria* and *Bruckenthalia* (*Blaeria type*, Fig. 2, cf. also Figs. 3, 4). This pollen seems to occur preferentially at the transition from a lowland bog to an *Ericales*-*Sphagnum* bog. It was found earlier in Middle Pleistocene deposits (Type 1615, Menke, 1968a) and more recently in early Pleistocene deposits ("*Rhamnaceae*-type", Menke, 1969b). Apparently, this pollen is widespread in the Pleistocene. It also occurs sporadically in Eemian deposits.

In the second stadial (Zone FW III, Fig. 2), organic-rich mud (gyttja) formation and soil reworking again prevailed. The presence of typical cold-temperate species (e.g., *Selaginella selaginoides*, *Helianthemum*, *Astragalus* type) seems to have been greater than in the first. According to Dücker (1967), frost contractions occurred for the first time in Schleswig-Holstein during this stadial. The following Odderade Interstadial has so far only been proven in organogenic facies in Schleswig-Holstein in Odderade (Averdieck, 1967). *Sphagnum* bogs also formed in this interstadial. The Eemian and Weichselian early glacial deposits are mostly covered by clayey solifluction material. Its thinness is surprising. Surface layers of 2 to 4 m thickness are common, much thicker surface layers are rare even in the lowlands.

Only little information is available from Schleswig-Holstein about the course of the Weichselian pleniglacial. It seems that there are hardly any deposits that are suitable for pollen analysis and radiocarbon dating. The radiocarbon dates from the Weichselian early glacial and peak glacial

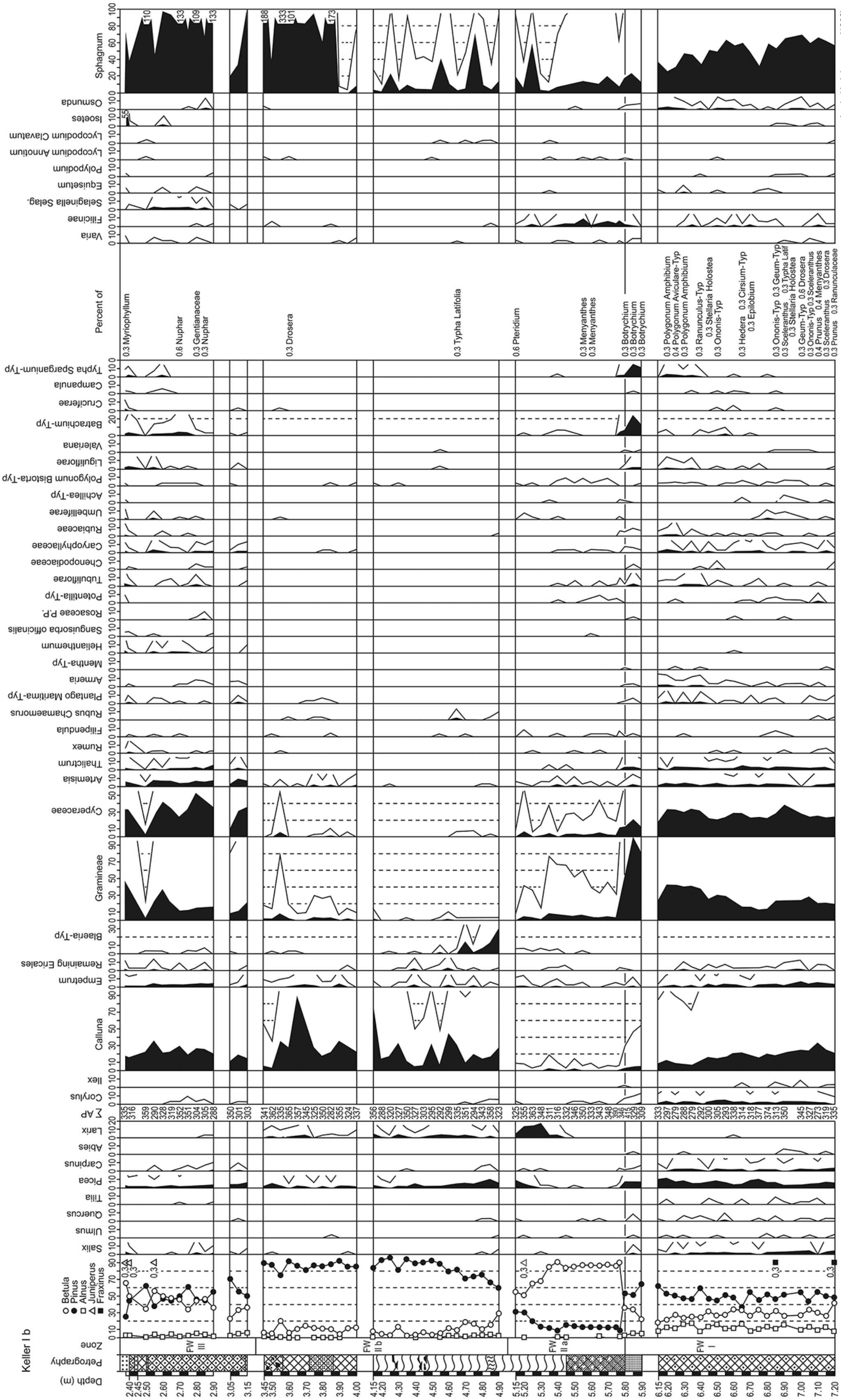

Figure 2. Pollen and spore diagram of profile "Keller 1" (Early Weichselian).

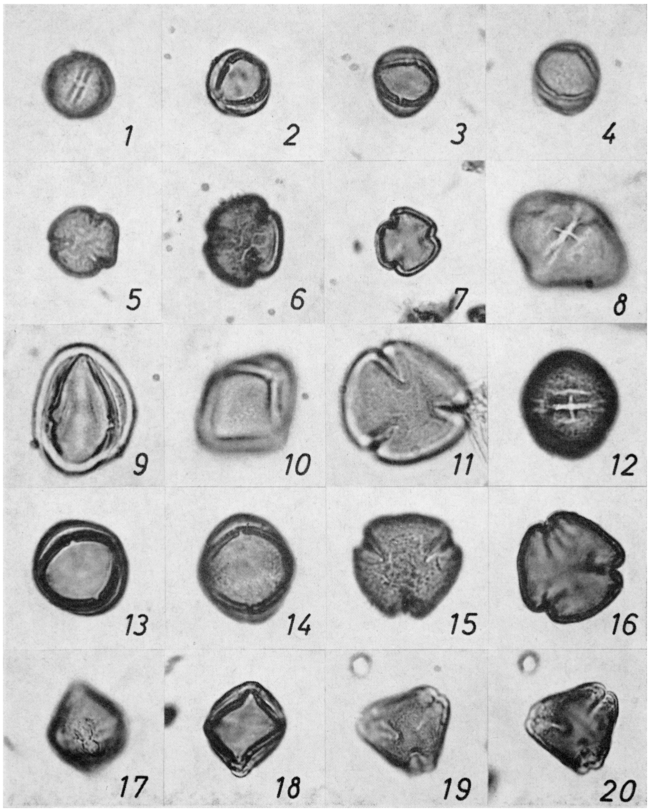

Figure 3. Fossil pollen grains (1000×). 1–7 *Blaeria*-type from the Early Pleistocene at Lieth; 8–11 *Blaeria*-type from the Wacken interglacial at Wacken; 12–16 *Blaeria*-type from the Brørup-Interstadial at Keller; 17–20 "*Clethra*-type" from the Early Pleistocene at Lieth.

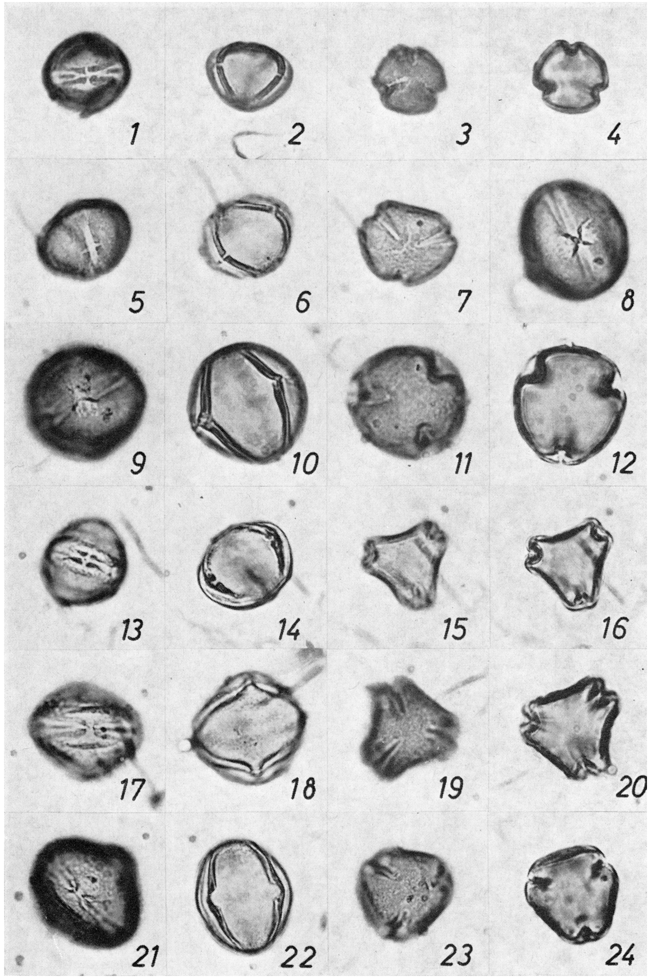

Figure 4. Modern pollen. 1–4 *Blaeria* sp.; 5–7 *Bruckenthalia* sp.; 8–12 *Enkianthus campestris*; 13–16 *Frangula alnus*; 17–20 *Cornus mas*; 21–24 *Cornus canadensis*.

conditions are still so unreliable that a stratigraphy based on them alone is fraught with great uncertainties. This is probably primarily due to the large and confusing sources of error in the material (Vogel and Zagwijn, 1967). It should also be remembered in this context that the dating of early Pleistocene wood from Lieth (Dücker and Menke, 1968; Menke, 1969a) is about 30 000 years (Lüttig et al., 1967).

In areas of Schleswig-Holstein not covered by ice during the Weichselian, the final part of the Weichselian cold stage periglacial series is again marked by cover sands over large areas. Dücker and Maarleveld (1958) were the first to find evidence of "older" cover sand in Schleswig-Holstein in Lieth (Elmshorn). Here, it is situated in parallel stratification over solifluction deposits, which terminate with a wind scour-bearing stone bed towards the cover sand. Dücker and Maarleveld (1958) placed the boundary between the "Older" and the "Younger" cover sand (in the sense of Van Der Hammen, 1951) in Lieth at a characteristic silty horizon, which is strongly humic in places (C in Fig. 5). This horizon lies below the typically formed soil of the Alleröd Interstadial, which is also widespread in Schleswig-Holstein and by which the "Younger" cover sand is divided in two parts. The Alleröd horizon is also peaty in places in Lieth (Fig. 5). It was analysed by Schütrumpf (Dücker and Maarleveld, 1958) and by the author (unpublished) with regard to pollen content. According to the pollen spectra, the lowest humic horizon is older than the Bölling Interstadial. It can probably be assigned to what used to be called the "Meiendorf Interval" (Menke, 1968b). Between this horizon and the Alleröd horizon, a third humic horizon is intercalated over a larger area in Lieth, in which – as in the Alleröd – birch pollen dominates. This horizon may belong to the Bölling Interstadial (Fig. 5), but it is hardly possible to date it with any certainty.

3 Middle Pleistocene

In West Holstein and around Hamburg, interglacial marine deposits have long been found in boreholes and as glacitectonized slabs in moraines from the Saalian period. Penck (1922) identified them as "Holsteinian Interglacial". Gripp

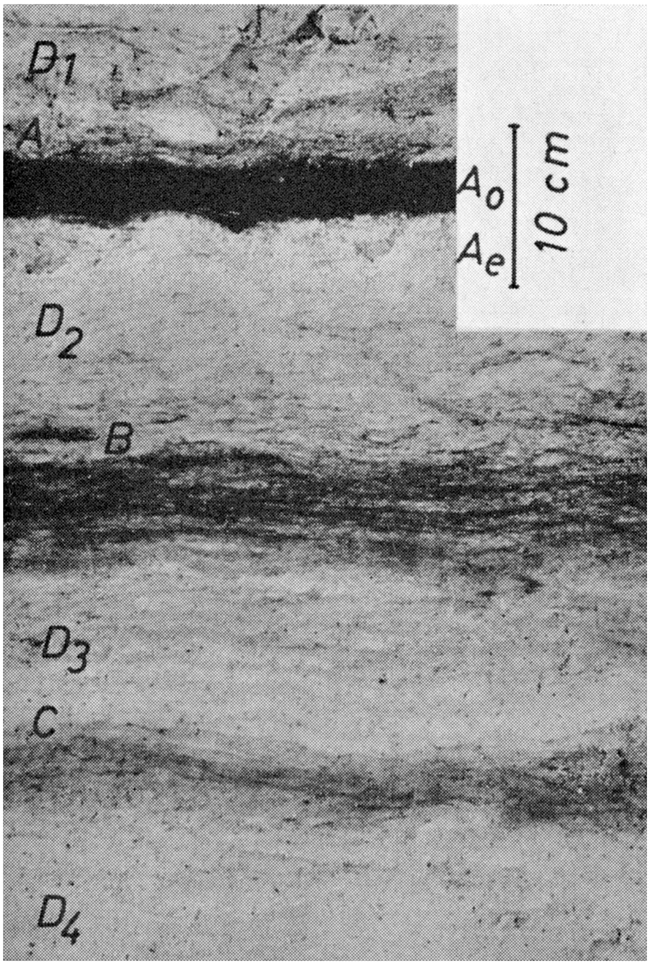

Figure 5. Stratigraphic succession of the Weichselian-Late Glacial cover sands at Lieth. A = Alleröd interstadial; B = Bölling interstadial (?); C = Meiendorf interval. D1, D2 = Younger cover sand; D3, D4 = Older cover sand.

(1952) called this warm phase period the "Stör" warm phase, while Dücker (1969) suggested the name "Muldsberg" warm phase. However, the name Holsteinian Interglacial has become established. Since Grahle (1936), the marine Holsteinian deposits have not been summarised, but individual investigations have been carried out. The first pollen analysis of the marine Holsteinian Interglacial in northwest Germany was carried out by Hallik (1960). Further studies are available from Denmark (Andersen, 1963) and West Holstein (Menke, 1968a). The microfauna has been studied by Lange (1962) and Woszidlo (1962). In terms of vegetation history, the Holsteinian Interglacial in north-western Europe had the same character everywhere, but was quite different from the Eemian Interglacial. Characteristic above all is a consistently strong coniferous presence, especially of pine and very early also of spruce, as well as an almost simultaneous spread of hornbeam and fir. With the exception of oak, the components of the so-called mixed oak forest were rather scarcely involved. However, distinctly thermophilic species were also present.

The marine Holstein deposits consist of grey, fossil-rich clay, silt and fine sand, with the sands forming the overlying strata. Underlying these sediments are often dark to reddish clays, often terminating against the Holsteinian clay with a distinct red clay. In contrast to the grey marine sediments, these clays are lacking a developed pollen flora and also have practically no faunal content. They have long been referred to as Elsterian basin clays, which is undoubtedly correct. The pollen-floristic boundary between the Elsterian late glacial and the Holsteinian Interglacial lies in Wacken (Menke, 1968a) in the lower metres of the grey marine clay, which also has an arctic-boreal fauna in its lower part. The marine intrusion here occurred at the very latest near the end of the Elsterian late glacial. This early marine intrusion is at first surprising when comparing the transgression of the Holocene North Sea (Menke, 1969b; Behre and Menke, 1969) and the Eemian Sea (Von der Brelie, 1951, 1954) in our area. In fact, these Holocene marine clays were deposited in deep channels (Gripp, 1964 and literature cited there).

The transgression did not occur so early everywhere (Hallik, 1960). In Fahrenhorst, in the Alster Valley, the marine deposition commences only during the early spruce-oak phase, which roughly corresponds to the early oak-mixed forest phase.

In the main, the grey marine clay generally belongs to the older half of the Holsteinian Interglacial, as already speculated by Grahle (1936). Towards the overlying strata, the deposits become sandier and the fauna takes on a more boreal-lusitanian character. Also, in Wacken and Muldsberg, the upper part of the marine deposits indicates a shallowing of the sea to mudflat-like conditions (Lange, 1962; Woszidlo, 1962). In Wacken, the marine clay is initially overlain by grey marine sands, which gradually change to "fibrous" sand. The formation of the "fibrous sand" probably extends into the hornbeam-fir phase, but most of the younger half of the interglacial is apparently missing here, as seems to be a common finding in general.

In the Fahrenhorst borehole, the marine Holsteinian deposits are apparently present in situ. Here they are directly overlain by a freshwater peat (with the intercalation of a thin, almost pollen-free, rich clay). This peat – like the upper part of the marine sediments – belongs to the older part of the Holsteinian hornbeam-fir phase, i.e., the optimum of the interglacial. The early regression of the sea is thus clearly proven here. Hansen (1965) interpreted the early regression of the Holsteinian Sea as being due to an isostatic uplift of the land.

In Wacken, the "fibrous" sands are covered by light-coloured sand, in the upper part of which coarser layers and pronounced drop-shaped structures were found, described by Dücker (1969). At least these parts are to be regarded as cold period deposits. We have been looking for signs of a cold phase in this sand since 1963. In fact, an extensive autochthonous peat and mud deposit lies on the sand, which was formed under freshwater conditions and again belongs to a warm phase. The vegetation development does not show a continuation of the marine Holsteinian series, but rather the deposits begin in an early phase of this warm phase. Pollen of thermophilic species are initially completely absent, but then gradually spread (Menke, 1968a). In the period between the Holsteinian Interglacial and this younger Wacken Interglacial, conditions must have prevailed that at least corresponded to the proximity of the subarctic forest boundary. Dücker (1969) called this cold period the "Mehlbeck cold phase". It undoubtedly corresponds to the "Fuhne cold phase" according to Cepek (1965) and Erd (1965); the Wacken Interglacial corresponds to the "Dömnitz Interglacial".

The whole series was formed together with the Holsteinian clay in the Drenthe period. There are many disturbances in the bedding, but the sequence of stratification within individual blocks are well preserved.

The peat of the Wacken Interglacial is overlain by fine-grained sand, which carries considerable scree layers of redeposited Tertiary lignite; occasionally ice wedges are also found.

We are still poorly informed about the pre-Elsterian Pleistocene in Central Europe. How the deposits of Westerhoven (Zagwijn and Zonneveld, 1956), Bilshausen (Müller, 1965) and Elze (Grüger, 1967) can be related stratigraphically to each other and to the Danish Harreskov Interglacial (Andersen, 1965) is still unclear. In addition, the occurrence in the Elm prompted Geodeke et al. (1966) to postulate an "Elbe cold phase".

In this context, the Fahrenhorst borehole must be mentioned again. The marine Holsteinian clay is underlain by about 40 m of thick basin clay of the Elsterian period. This is followed by clays and sands about 12 m thick with numerous clasts of redeposited Tertiary lignite. This is followed by fine and medium sands about 54 m thick, which can also be considered to be of Elsterian age. This is underlain by about 22 m of thick silt and fine sand, which is finely stratified and contains numerous mollusc shells. The pollen analysis showed that it is clearly a Quaternary warm-phase-deposit. However, a connection with another deposit from north-western Europe is not yet possible with any degree of certainty. It must still be verified whether these depositional conditions are genuine. Below, there are 20 m of poorly sorted material, again with a considerable content of redeposited Miocene materials; it is probably a local glacial deposit. Below this follow 14 m of sand, further underlain by 5 m of glacial drift. This sequence lies 250 m below the surface directly on Miocene mica-rich clay ("Glimmerton").

Grube (1968) suspected that Schleswig-Holstein experienced several pre-Elsterian glaciations. But the silts, which Grube regarded as interglacial or interstadial deposits and thus as stratigraphic markers, proved by pollen analysis to be unmistakably redeposited Tertiary deposits. This attempt at classification is therefore untenable. The stratigraphic sequence had only a very low thickness and was located in an extremely localised glacial deposit in Lieth (Elmshorn). Incidentally, it did not lie above the Early Pleistocene, as one might assume according to Grube's report.

4 Early Pleistocene

The most comprehensive series from the earliest Pleistocene in Central Europe was uncovered in Lieth near Elmshorn (Lüttig et al., 1967; Dücker and Menke, 1968; Grube, 1968; Menke, 1969b). Further pollen-analytical investigations will be reported in detail later. The deposits of Lieth lie above the Elmshorn salt dome, the top of which is of Permian age. Ernst (1931) already described kaolin sands from hollows and trench-like intrusions (Illies, 1949) in the surface of the Zechstein, which he placed into the Pliocene. These sands have been studied on many occasions. Weyl (1949) already mentioned a lignite layer from the kaolin sand found by Illies. In 1960, such a lignite layer at the old Bremsberg (Meinert'sche Kalkgrube) was investigated by Averdieck. Contrary to the opinion at the time, he determined the age of the lignite to be Pleistocene. However, the findings remained unpublished (Archive of the Geological Survey of Schleswig-Holstein). The initiative for a new investigation came from two small lignite layers that were excavated during the construction of the new Bremsberg (around 1966). A pollen analysis has now clearly revealed that the lignite layers were from the earliest Pleistocene. A total of five thicker lignite layers and two further lignite layers of lesser thickness are known to exist today, which are separated from each other by sands and silts. The lignite layers were all formed during warm phases, whereas the silty to organic-silt muds and apparently most of the sand layers were formed during cold phases.

Generally speaking, this "Lieth Series" (Menke, 1969b) contains the typical pollen assemblage of the Dutch Lower Rhine Tiglien-Waalian series with a number of Tertiary relicts, such as *Alnus cf. viridis*, *cf. Ostrya*, *Pterocarya*, *Eucommia*, among others. However, there are also differences that were mentioned earlier (Menke, 1969b).

The "*Rhamnaceae* type" can be renamed "*Blaeria*-type" (Fig. 6). The "trilete spore type"" could meanwhile very probably be determined as *Selaginella sibirica*. Rarely, Neogenisporis also occurs. The pollen called "*Cletbra*-type" is shown in Fig. 3. It could not yet be determined with certainty (probably it is not *Cletbra*). The "*Celtis*" type is identical with "*Coriaria*" in Zagwijn (1963). Zagwijn (personal communication) believes that it is probably *Celtis*.

The absence of *Tsuga* and *Carya* in Lieth (apart from isolated pollen grains) is particularly striking. Lieth was probably already north of the distribution limit of these species at that time. But perhaps local conditions also played a role.

Figure 6. Typical formation of costae in **(a)** *Cornus* (*C. mas*-type), **(b)** *Rhamnaceae*, **(c)** *Blaeria* and *Bruckenthalia*.

In contrast to the Netherlands, *Selaginella selaginoides* and *Selaginella helvetica* in Lieth strictly follow the cold periods.

In the closed Lieth basin, which was boggy during warm phases, redistribution and long-distance transport of pollen grains can hardly be expected, at least in the warm phase deposits. Oligotrophic conditions prevailed throughout, which were scarcely alleviated by the cold phase soil rearrangements. The Zechstein limestone cannot have had practically any influence on the vegetation at that time.

With regard to the hydrography, the local water level in the hollow form was low in the interglacial and in the interstadials. Accordingly, paludification, which was more or less of raised-bog character. In the cold phases and in the cooler episodes, the local water level was at least temporarily high, and mineral and organic-rich mud areas were formed or there was a stronger input of sand. *Isoetes* played a major role in the vegetation of these waters.

The cold phase vegetation in the Lieth series is characteristically different from the vegetation of the Middle and Late Pleistocene cold phases. The basiphilic heliophytes, such as *Helianthemum*, which are characteristic of the younger cold phases, are almost completely absent in Lieth. A high participation of *Ericales* pollen and *Myrica* justify to envisage that the vegetation of the cold phases was essentially subarctic heaths under an oceanic climate. Only the oldest cold phases (Ekholt cold phase) of this series is an exception. It was apparently the most pronounced cold phase of this series. But even this period is not comparable with the Middle and Late Pleistocene glaciations. The cold phases of the Lieth series are similar to the first Weichselian stadials in ecological terms and in the extent of soil displacement.

Thus, the cold and warm phases of the earliest Pleistocene deviate considerably from the common cold-warm cycles of the Middle and Late Pleistocene and are also interesting from a palaeobotanical point of view. Particularly noteworthy is a silting sequence at the beginning of the Uetersen warm phase: *Isoetes*, *Pilularia* and *Alismataceae* played a role in the water body, followed by an *Equisetum* bog, which was replaced by a *Sphagnum* bog with *Menyanthes* and *Scheuchzeria*. Later, the bog turned to heath with a stage in which pollen of the *Andromeda* type is strongly represented. The final stage was a *Sphagnum* bog with *Calluna*, *cf. Empetrum* and other *Ericales* with *Vaccinium*-type pollen. This is a sequence that could be found in a similar fashion in an oligotrophic lake in north-western Europe.

The stratigraphy of this series, however, gives us some problems to solve. When trying to connect the Lieth series with the Dutch findings, it is best to start with the Tornesch warm phase (Fig. 7). If the connection with the Waalian (Menke, 1969b) is correct, the older warm phases of the Lieth series must correspond to the Tiglian. However, the Ellerhoop warm phase (Ellerhoop interstadial in Menke, 1969b) and the Nordende warm phase are separated by a real cold phase in the sense of Zagwijn (1957, 1960), the Krückau cold phase. This would mean that the Tiglian would have to consist of two separate warm phases. Conjectures of this kind have been made in the Netherlands before (Van der Vlerk and Florschütz, 1950, 1953). Zagwijn (1963), on the other hand, assumed only one warm phase, which, however, was subdivided by at least one cool phase (Tiglian B). It has neither been clearly proved nor disproved that this phase was a real cold phase from the Netherlands. While the Nordende warm phase can easily be connected with Tiglian A (it was also somewhat richer in Tertiary relics than the other warm phases), connecting the Ellerhoop warm phase with Tiglian C presents greater difficulties (Menke, 1969b). The open questions can only be solved by connecting the Lieth series to the Pliocene.

It is not yet known how thick the graben filling is in total, because the deepest borehole drilled so far had to be abandoned at a depth of 100 m below ground level. The Permian was not reached. The stratigraphic sequences in the boreholes can be easily connected with the stratigraphic sequence in the present outcrop. The correspondences often go right down to the details. In the deepest borehole, the deposits of the Ekholt cold phase are found at a depth of about 47 m. Then, up to about 92 m, medium to fine-grained sands follow, in colourful alternating stratification with silty and clayey layers. It seems that these are underwater deposits in the area close to the shore. Details of the drillings will be reported later.

If the connection with the Dutch Early Pleistocene is correct, the deposits of the Ekholt cold phase should be followed by deposits of the Upper Pliocene. Around 58 m, the specimens indicate a clearly thermophilic flora, in which Tertiary relicts, such as *Eucommia* and *Pterocarya*, were considerably less represented than in the North End warm phase. The pollen flora again indicates a more or less boresic vegetation in the range between 65 and 88 m. However, there is no

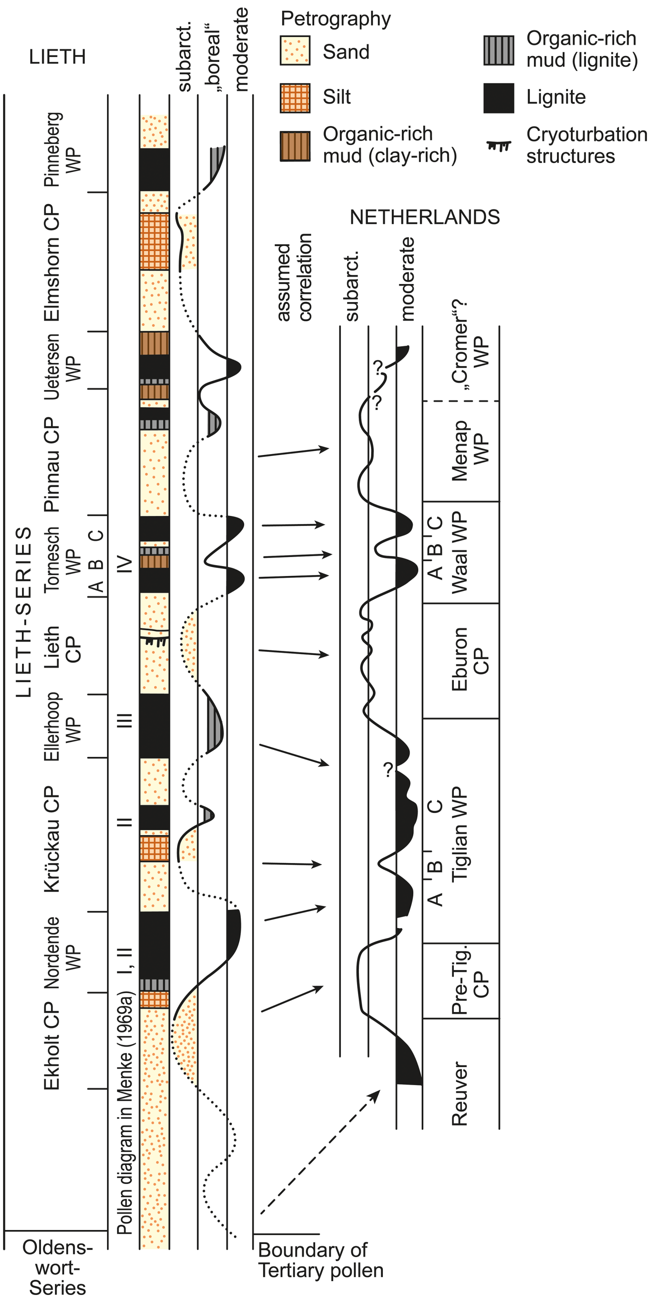

Figure 7. Stratigraphy of the Early Pleistocene sequence at Lieth and presumed correlation to the Early Pleistocene of the Netherlands.

evidence of a true cold phase. Below 88 m, the pollen flora is again richer in thermophilic species, among which typical Tertiary elements such as *Sequoia*-type pollen, *Nyssa*, *Tsuga*, etc. are now represented to a lesser extent. At least these deposits obviously belong to the Pliocene. Thus, the Ekholt warm phase is probably the first true warm phase of the Pleistocene. The connection of the Lieth series with the Dutch Early Pleistocene (Fig. 7) thus seems to be substantially supported.

If the Tornesch warm phase corresponds to the Waalian, the Pinnau cold phase must probably be connected with the Dutch Menap cold phase. But this does not mean that the Early Pleistocene series in Lieth is complete; it contains at least two more warm phases, the Uetersen and the Pinneberg warm phase. However, since the connection to the Middle Pleistocene has not yet been established, it remains open how many cold and warm phases are still to be expected in the Lieth series. Clearly, the Early Pleistocene stratigraphy is incomplete.

The special advantage in Lieth is that all the deposits of this series lie on top of each other at one location. The strata dip steeply in a northerly direction in the outcrop, and one might at first think of overthrusts, so that in reality there would be fewer than five seams. In fact, however, the vegetation development in the individual lignite layers shows so many differences that cannot be explained by the local situation that the possibility of duplications caused by bedding disturbances can be practically ruled out. To explain this in detail would go beyond the scope of this report.

5 Pliocene and Pliocene-Pleistocene boundary

The Pliocene-Pleistocene boundary has been recorded in a further borehole. In Oldenswort/Eiderstedt, Wintershall AG drilled an oil well northwest of the Oldenswort salt dome in 1969, approximately in the trough axis of the Tertiary Basin. Wintershall AG kindly provided us with the samples for processing and allowed us to publish them, for which I would also like to express my sincere thanks. A detailed report is in preparation.

According to the pollen analysis, a clearly Pliocene series was crossed over a drilled section of about 800 m. According to Wintershall AG, the strata probably dip shallowly, which makes this the thickest Pliocene in Schleswig-Holstein to date.

In the range between about 550 and 990 m, pollen of *Alnus* and *Quercus* dominate, while *Sequoia*-type pollen is only minimally present. This is probably the Susterian (Zagwijn, 1960). In the range between about 500 and 200 m, the pollen of *Pinus* and the *Sequoia* type reaches high proportions in several places. This section can be assigned to the Brunssumian and the Reuverian (Zagwijn, 1960). Further details of the Pliocene pollen flora cannot be reported here. In the range between 190 and 160 m typical Tertiary elements, such as *Sequoia* relatives, *Sciadopytis*, *Nyssa* and others, disappear. Subsequently *Tsuga* also disappears. The specimens in the range between 140 and 100 m correspond very well to the specimens of the Lieth series below the Ekholt cold phase. It is very likely that both boreholes overlap stratigraphically. According to the material available so far, the vegetation development in Oldenswort during the transition from the Pliocene to the Pleistocene was similarly smooth and subject to the same variations as in Lieth.

According to the previous pollen-floristic definition (Zagwijn, 1960), the Pleistocene would have to begin with the first appearance of subarctic vegetation in north-western Central Europe. This would be the beginning of the Ekholt cold phase. With this definition, however, one accepts that the pollen species spectra take on the typical character of the Early Pleistocene much earlier, so that the boundary between the Pliocene and the Pleistocene can become uncertain, particularly if incomplete series are present. But since the Pliocene-Pleistocene boundary is at the same time a boundary between high stratigraphic units, such an uncertain boundary delineation must remain unsatisfactory. It is therefore proposed to place the Pliocene-Pleistocene boundary – based on a pollen-floristic definition – lower in north-western Central Europe, namely at the disappearance of typical Tertiary elements that do not return during the Quaternary. In pollen-floristic terms, this would be the upper rational boundary of the autochthonous pollen of the *Sequoia* type, *Sciadopytis* and *Nyssa*. However, when drawing this boundary, the Pleistocene does not begin with the first appearance of subarctic conditions, but with a relatively temperate phase, that, judging by the large sediment thicknesses in Lieth and Oldenswort, possibly covers a longer period of time.

Connecting the Pliocene-Pleistocene boundary (defined for Schleswig-Holstein in terms of pollen flora) with the Pliocene-Pleistocene boundary (defined palaeontologically as the basis of the marine Calabrium in Italy) is not possible, at least for the time being. On the one hand, there are no corresponding marine deposits known from our area so far, on the other, it is not certain whether criteria valid for Italy can be transferred to Schleswig-Holstein without further consideration. If one follows the decision of the Geological Congress London 1948, strictly speaking the Pliocene-Pleistocene boundary for Schleswig-Holstein may not be defined in the manner that has been done here. However, such a renouncement on the grounds of a conflicting resolution remains unsatisfactory if, on the basis of other criteria, a sufficiently unambiguous and practically usable, at least regionally valid boundary demarcation is possible. One possible solution would be not to speak of the Pliocene-Pleistocene boundary in the present case, but of the boundary between the pollen-floristically defined (Pliocene) Oldenswort series and the equally defined (Early Pleistocene) Lieth series. Whether this would not unnecessarily complicate matters, however, remains to be seen.

A comparison with vertebrate palaeontology is also not possible, as there have been no vertebrate finds from the Lieth and Oldenswort areas in question so far.

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