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A Pliocene pollen record from Moormerland (north-western Germany)

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ABSTRACT. A 95 m core from Moormerland, Leer District (Lower Saxony / Germany), was investigated by pollen analysis. The pollen record is focused on organic layers at 90–88 m, around 70 m, and 57–45 m. The pollen assemblage is a mixture of Pliocene and Pleistocene pollen types, with *Pinus* dominating, but *Taxodium*-type, *Nyssa*, *Liquidambar*, *Eucommia*, *Carya*, *Sciadopitys*, *Tsuga* and others also participating as Pliocene elements, as well as *Quercus*, *Ulmus*, *Taxus*, and others as Pleistocene elements. Wetlands and swamp forests under a warm climate are represented.

KEYWORDS: Late Pliocene (Reuverian), vegetation history, north-western Lower Saxony, stratigraphy, correlation

INTRODUCTION

Zagwijn (1957, 1959, 1960) did pioneer work by establishing an entire palynological subdivision of the Pliocene encompassing the Susterian stage, the Brunssumian stage and the Reuverian stage. According to his subdivision, the Brunssumian is characterised by high amounts of *Sequoia*-type, which dominate zones A and C. Zone B shows higher *Pinus* values. The subsequent Reuverian, which represents the top stage of the Pliocene, is also divided into three subzones. Zone A shows *Pinus* dominance and relatively frequent occurrences of *Sciadopitys* and *Sequoia*-type species. Zone B is characterised by higher percentages of *Alnus* and sometimes predominating *Taxodium*-type species, as well as *Nyssa*. The uppermost zone C is dominated by *Pinus*, accompanied by a decrease of Tertiary species and *Alnus* as well and an increase of Ericaceae to the top of the zone. Concerning the exact zonation in more detail, see Donders et al. (2007) and Kemna and Westerhoff (2007), including a critical discussion of this subdivision of the Pliocene, as well. According to Kemna and Westerhoff (2007), just the presence of *Symplocos*, *Tricolporites edmundi*, and *T. liblarensis* (*Edmundipollis* and *Tricolporopollenites liblarensis* after the nomenclature of Stuchlik et al. (2014)) has a diagnostic value as a indicator of deposits belonging to the first half of the Pliocene.

Regarding the Pliocene, there were additional palynological investigations (Fig. 1) in the region of north-western Germany (e.g. Chanda, 1962; Benda and Lüttig, 1968; Meyer, 1981; Mohr, 1986), Schleswig-Holstein (Menke, 1975; Proborukmi et al., 2017), as well as in the Lower Rhine Embayment of Germany (e.g. Brelie, 1959, 1981; Boenigk et al., 1974; Heumann and Litt, 2002) and the adjacent Netherlands (e.g. Westerhoff et al., 2020). However, these studies did not resemble the results by Zagwijn (1960) in detail. For instance, a study of Brelie (1981) revealed, that high amounts of

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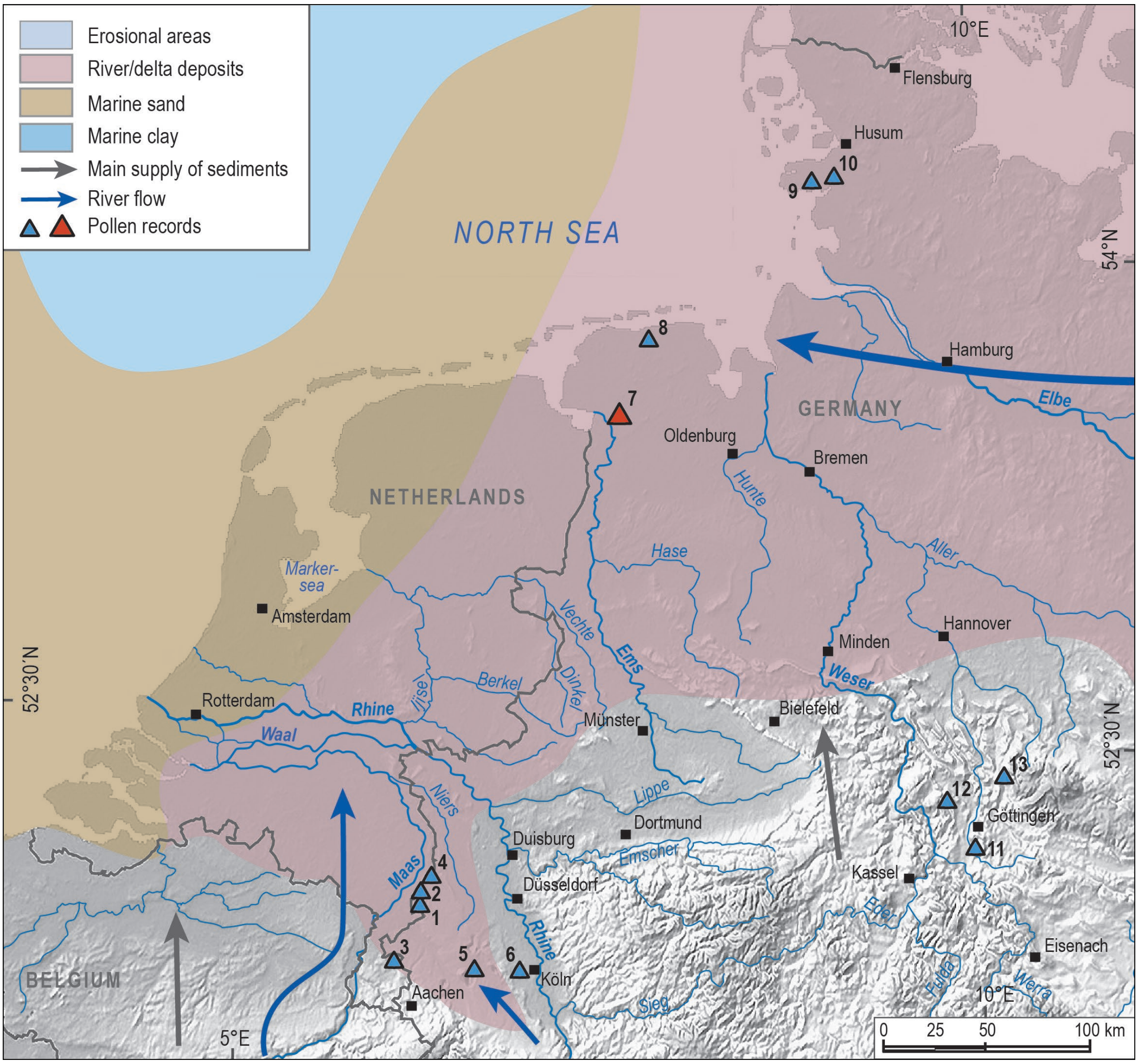

Figure 1. Map showing the Pliocene palaeogeography (modified from Gibbard and Lewin, 2016 and Dearing Crampton-Flood et al., 2020) and locations of pollen records of Pliocene age in north-western Germany, including the Dutch-German border region. **1**. Meinweg (Zagwijn, 1957, 1960); **2**. Brachterwald (Zagwijn, 1960); **3**. Bouwberg (Zagwijn, 1960); **4**. Maalbeek (Westerhoff et al., 2020); **5**. Hambach (Heumann and Litt, 2002); **6**. Frechen and Ville (Boenigk et al., 1974; Arias et al., 1984); **7**. Neermoor 006, Moormerland (this study); **8**. Wittmunder Forst (Meyer, 1981); **9**. Garding (Proborukmi et al., 2017); **10**. Oldenswort (Menke, 1975); **11**. Eichenberg (Chanda, 1962); **12**. Allershausen (Benda and Lüttig, 1968); **13**. Willershausen (Mohr, 1986). The location of the Moormerland borehole is highlighted in red

Seqouia pollen may also occur in the Reuver A horizon and are not restricted to Brunssuniam A and C only.

Here we report the palynological results from another pollen record of Pliocene age located in north-western Germany.

STUDY AREA

The surface of the area was shaped during the Drenthe stadial of the Saalian glaciation. The Quaternary base in the area is situated between 25 and 100 m below the surface (https://nibis.lbeg.de/cardomap3/). The Quaternary deposits overlay Pliocene sediments composed mainly of sand with some gravel, however, some intercalated clayey and silty layers also occur, as well as peat layers. The clayey and silty layers close to the Quaternary base belong to the so-called Tergast Clay (Kuster, 2005), representing an impermeable stratum (Josopait, 1984). However, recent investigations into core drilling in the Simonswolde – Tergast – Leer area have shown that the Tergast Clay is a sequence of clay-silt-fine sand alternation, which is often incomplete (Budde and Röhm, 2017).

During the Elsterian Glaciation, not only were subglacial gullies formed that cut deep into the Tertiary, but also glacitectonic stress on the Pliocene subsoil with upheavals and disruptions in the sedimentary structure down to −100 m sea level occurred. The sediment succession assigned to the Pliocene is up to 150 m thick in the wider region (Fritsch, 1984).

MATERIAL AND METHODS

SEDIMENT CORE SAMPLING

The studied sediment core "Neermoor 006" was drilled in Lower Saxony (north-western Germany, District Leer, Moormerland, 53°19′6.3588″N, 7°26′49.164″E), encompassing liner drill cores with a chamber length of 1 m. The complete core had a length of 95 m, composed mainly of sand with intercalations of peat and silty-clayey layers. The lithology is given in Table 1. In the depth intervals of 89.6–89.22 m, 88.78–88.25 m, and 70.0–69.53 m below the surface, the drill core is composed of compacted peat. Sandy silts occur between 55.9 and 55.8 m, 55.32 and 55.04 m, and also between 54.25 and 51.1 m. Another sandy silt layer is found from 49.65 to 49.10 m followed by a peat layer ~2 m thick and clayey silt between 47.20 and 45.46 m below the surface. In the overlying strata, only a few thin silty layers were deposited. Based on lithological observations, the Quaternary base represented by sand assigned to the Drenthe stadial is located at ~32.5 m below the surface.

POLLEN ANALYSIS

The peat and silt layers were subsampled for pollen analysis, resulting in a total of 98 samples. Pollen preparation included treatment with KOH, HF and acetolysis. Finally, the samples were sieved ultrasonically and stained in glycerol (Faegri and Iversen, 1989). The core was shared equally between the two first authors of this paper. Each sample was analysed to a sum of at least 600 arboreal pollen grains. The identification and nomenclature of pollen follow Beug (2004), and that of spores Menke (1976) and Moore and Webb (1978). The description of the local pollen assemblage zones follows Bastin (1979).

All charcoal particles >10 µm were registered. The pollen sum includes all terrestrial pollen except Cyperaceae and aquatics, as well as spores of mosses and pteridophytes. The pollen diagram includes 94 samples, as the uppermost four samples contained no palynomorphs. Additionally, the following literature was used for the identification of one embedded piece of wood: Kräusel (1949), Burgh (1973) and Vassio et al. (2008).

PALYNOLOGICAL RESULTS

In total, 98 pollen samples were analysed. The percentages of selected taxa are shown in Figure 2. Ten local pollen assemblage zones (LPAZs) could be described (Table 2).

The lowermost pollen assemblage zone, LPAZ 1 (89.6–88.2 m, ten samples) is dominated by *Pinus sylvestris*-type pollen grains (up to 80%). Ericaceae attain values of around 20% and the *Vaccinium*-type pollen has proportions below 15%. Noteworthy are also the higher values of *Tsuga* and *Ilex* in the middle part of the pollen zone. Except for *Nyssa*, *Pterocarya* and *Tsuga*, so-called "Tertiary elements", like *Celtis*, *Eucommia*, *Liquidambar*, *Liriodendron*, *Sciadopitys* and *Sequoia*-type pollen grains are represented only at very low values. LPAZ 2 (88.2–70.1 m) is poor in pollen. The pollen content of LPAZ 3 (70.1–69.5 m, five samples) is characterised by the dominance of Cupressaceae (mainly *Taxodium*-type pollen grains) with values of ~60%. *Nyssa* is subdominant. At a depth of ~69.6 m below the surface, one embedded piece of wood could be identified as c.f. *Glyptostrobus*. According to Zagwijn (1960), the *Taxodium*-type pollen comprises, among others, the two genera *Glyptostrobus* and *Taxodium*, unfortunately. In contrast to the previous pollen zone, "Tertiary elements" are much more frequent and reach higher proportions than arboreal taxa typically occurring during the Quaternary. LPAZ 4 (69.5–57.0 m) shows no pollen as the sediment encompasses fine sand, like in LPAZ 2. In LPAZ 5 (56.9–53.75 m, twelve samples), high numbers of *Pinus sylvestris*-type pollen grains (up to 60%) occur again. *Quercus* and *Sciadopitys* are subdominant. The subsequent LPAZ 6 (53.7–51.1 m, 25 samples) also shows dominance of *Pinus sylvestris*-type pollen grains. Additionally, *Liquidambar* gains more importance compared to the previous pollen zone. The local presence of *Pinus* is evident from the frequent occurrence of stomata. Beside *Liquidambar*, other tertiary elements occur relatively frequently, such as *Carya*, Cupressaceae, and *Nyssa*. LPAZ 7 (51.0–49.7 m) is typified by the absence of pollen grains. LPAZ 8 (49.6–48.25 m, fourteen samples) is still dominated by *Pinus sylvestris*-type pollen grains and shows decreasing values of *Liquidambar* and Cupressaceae, whereas *Nyssa*, *Sciadopitys*, and *Quercus* have more or less the same values as in the previous pollen zone. LPAZ 9 (48.2–47.2 m, eleven samples) shows the dominance of *Taxodium*-type and the presence of *Pinus sylvestris*-type pollen grains at rather

Table 1. Lithology of the Moormerland profile

Depth (m)	Lithology	Remarks
1.10	core loss	–
2.55	sandy silt with gravel	till (Drenthe stage)
2.90	medium sand	glacifluvial (Drenthe stage)
4.00	fine sand	glacifluvial (Drenthe stage)
12.00	fine sand with some gravel	glacifluvial (Drenthe stage)
15.15	fine sand	glacifluvial (Drenthe stage)
18.30	silty fine sand	glacifluvial (Drenthe stage)
18.55	fine sand to medium sand with some gravel	glacifluvial (Drenthe stage)
19.60	fine sand to medium sand	glacifluvial (Drenthe stage)
21.35	medium sand	glacifluvial (Drenthe stage)
21.85	medium sand with some gravel	glacifluvial (Drenthe stage)
22.35	fine sand to medium sand	glacifluvial (Drenthe stage)
24.95	medium sand with some gravel	glacifluvial (Drenthe stage)
26.05	fine sand	glacifluvial (Drenthe stage)
26.35	medium sand	glacifluvial (Drenthe stage)
29.75	silty fine sand	glacifluvial (Drenthe stage)
30.25	fine sand	glacifluvial (Drenthe stage)
31.80	medium sand	glacifluvial (Drenthe stage)
31.90	silty fine sand	glacifluvial (Drenthe stage)
32.25	medium sand with some gravel	glacifluvial (Drenthe stage)
32.40	fine sand	glacifluvial (Drenthe stage)
32.70	silty fine sand	–
35.70	fine sand	–
37.15	medium sand	–
37.50	medium sand with some gravel	–
37.75	clayey silt	–
37.90	medium sand	–
38.55	clayey silt	–
38.95	fine sand	–
39.20	clayey silt	–
39.55	fine sand	–
39.80	medium sand to coarse sand with some gravel	–
39.95	fine sand	–
40.10	clayey silt	–
44.95	medium sand	–
45.15	clayey silt	wood remains
45.45	sand with some gravel	–
47.00	clayey silt	wood remains
47.20	silt	wood remains
49.10	peat	wood remains
49.75	silt	wood remains
51.10	silty fine sand	–
54.00	silt	wood remains
54.25	clayey silt	wood remains
54.40	fine sand	–
54.55	clayey silt	wood remains
55.05	fine sand	–
55.40	silt	wood remains
55.70	fine sand	–
56.20	silt	wood remains
56.65	fine sand	–
56.95	silt	wood remains
59.15	fine sand	–
60.10	medium sand	–
61.05	fine sand	–
61.50	medium sand with some gravel	–
61.60	peat	wood remains
63.90	fine sand to medium sand with some gravel	–
64.35	fine sand	–
69.45	medium sand	–
70.00	peat	piece of wood (c.f. *Glyptostrobus*)
81.10	fine sand	–
83.95	medium sand	–
87.00	silty fine sand	–
88.25	fine sand	–
88.90	peat	wood remains
89.20	fine sand	–
89.75	peat	wood remains
95.00	fine sand	–

Table 2. Description of pollen zones

No.	Zone name	Description	Upper limit (event)	Upper limit [m]	Studied sediment
10	*Liquidambar-Nyssa-* Ericaceae	Predominance *Pinus*, Subdominance Ericaceae, *Nyssa*, *Liquidambar*	end of pollen-bearing samples	45.45	clayey silt and silt
9	*Taxodium*	Predominance *Taxodium*	*Taxodium* <25%	47.15	peat
8	*Nyssa-Sciadopitys-Quercus*	Predominance *Pinus*, Subdominance *Sciadopitys-Quercus-Nyssa*	*Taxodium* >30%	48.25	silt and peat
7	without pollen		onset of pollen-bearing samples	49.7	silty fine sand
6	*Liquidambar*	Predominance *Pinus*, Subdominance *Liquidambar*	end of pollen-bearing samples	51	silt
5	*Sciadopitys-Quercus*	Predominance *Pinus*, Subdominance *Sciadopitys-Quercus*	*Liquidambar* >5%	53.75	clayey silt, silt and fine sand
4	without pollen		onset of pollen-bearing samples	57	fine to medium sand
3	Cupressaceae-*Taxodium-Nyssa*	Codominance Cupressaceae-*Taxodium-Nyssa*	end of pollen-bearing samples	69.5	peat
2	without pollen		onset of pollen-bearing samples	70.1	fine and medium sand
1	*Tsuga-Pinus*	Predominance *Pinus*, Subdominance *Tsuga-Sequoia-Sciadopitys*	end of pollen-bearing samples	88.2	peat

low values. Compared to the preceding pollen zone, other tertiary elements are less important. Amongst them *Nyssa* is the next frequent taxon. LPAZ 10 (47.1–45.5 m, seventeen samples) is dominated by *Pinus sylvestris*-type pollen grains followed by *Nyssa* and *Liquidambar*. Furthermore, Ericaceae, including *Vaccinium*-type pollen grains, occur frequently.

Samples of potentially pollen-bearing sediments at around 39.1, 38.45, 38.1, and 32.5 m depth below the surface are poor in pollen or contain no pollen at all. These sediments underwent glacitectonic stress, resulting in upheavals. Potentially, this section had a position near the former surface, where it was exposed to weathering processes that led to pollen destruction.

DISCUSSION

AGE RANGE OF THE POLLEN RECORD

From a lithological point of view, the investigated pollen profile must be of younger Pliocene age as it is situated in the area of the so-called "Tergast Ton" (Tergast Clay) (Kuster, 2005) and, as mentioned above, the Pliocene-Pleistocene boundary is located at a depth of ~32.5 m below the surface. Based on comparisons with the known pollen records of north-western Germany and adjacent areas, which are shown in Figure 1, the record presented here is a time equivalent of the Reuverian. For instance, the Garding pollen record (Proborukmi et al., 2017) shows pollen assemblages with striking similarities characterised, for instance, by alternating dominance of *Pinus sylvestris*-type and *Taxodium*-type pollen grains like in our pollen record. Due to the low values of *Sequoia*-type pollen, however, our record cannot be of Brunssumian age. Furthermore, *Edmundipollis* and *Tricolporopollenites liblarensis* are totally missing in our profile, and *Symplocos* was identified only in two samples (single findings) at a depth of ~55 m below the surface. Another study shows that *Symplocos* was not found in the pollen assemblages which were assigned to the Reuverian (Winter, 2015).

HAMPERED CORRELATION WITH OTHER RECORDS

As stated by Kemna and Westerhoff (2007), the chronostratigraphic subdivision of Central and North-western Europe was not correctly executed. Therefore, the correlation of the pollen profiles published by Zagwijn (1960) with other pollen records is hampered. Another factor, making the correlation very difficult, is the fact that the pollen content is often facies-related, resulting in a very strong local signal, which overprints the regional vegetation development. For example, high values of *Alnus*, *Nyssa*, *Sequoia* and *Taxodium* can be referred to a backswamp area (e.g. Kemna and Westerhoff, 2007). Furthermore, differences in the composition of the pollen assemblages were

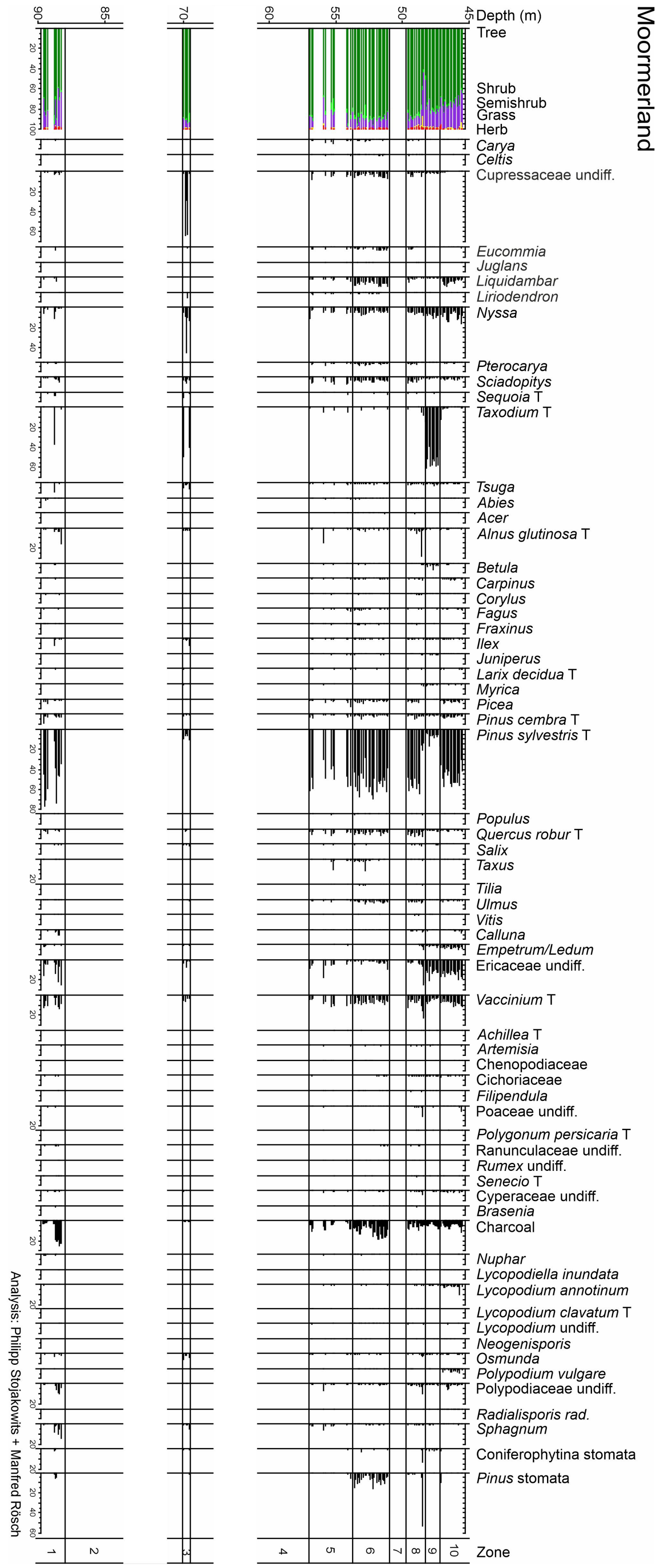

Figure 2. Pollen diagram of drill core Neermoor 006, Moormerland

often driven by oscillating groundwater levels, and many pollen records are not continuous or cover only a snapshot of the Pliocene vegetation history as they were deposited in developing oxbow lakes.

A comparison of our pollen record with LPAZ 3 and 4 of the Garding pollen sequence (Proborukmi et al., 2017) reveals some striking similarities, particularly regarding the already mentioned alternating higher frequencies of *Pinus sylvestris*-type and *Taxodium*-type pollen grains. Additionally, higher amounts of Ericaceae were also found there compared to the two preceding LPAZ 1 and 2 of the Garding record, which were assigned to the Brunssumian. Nevertheless, the closest site, Wittmunder Forst (distance around 40 km north-east), studied by Meyer (1981), shows no striking similarities, which underlines the difficulty in correlating terrestrial pollen records caused by different facies-related pollen assemblages. The strong influence by facies was recognised rather early (e.g. Brelie, 1959; Menke, 1975).

MODERN ANALOGUE AND DERIVED VEGETATION ZONATION

A comparison of the pollen assemblages found in the Moormerland drill core with pollen diagrams from the Great Dismal Swamp (e.g. Whitehead, 1972), located in eastern USA, shows striking similarities, so that this swamp can be considered a modern analogue. The temperature is averaging ~15.5°C, and the annual precipitation is ~1250 mm (Willard et al., 2023). Today, the Dismal Swamp is characterised by wetland forests with a so-called red maple-gum (*Acer rubrum* / *Nyssa sylvatica*) forest as the dominant forest type (Willard et al., 2023). The next frequent forest type is dominated by pine, mainly composed of *Pinus serotina*. The dominance of these two forest types is a result of the colonial ditching and logging. Due to the human impact in the area, the so-called Cypress-Tupelo (*Taxodium distichum* / *Nyssa biflora*) swamp forests still occur just in poorly drained patches of the Swamp (Willard et al., 2023). Areas in the Dismal Swamp, where forests were destroyed by cutting or fire, are often occupied by dense shrub vegetation composed of many different shrub species. Amongst them, *Ilex* and *Vaccinium* also occur (Whitehead, 1972). Having a look at the Moormerland pollen record, it is clear that higher frequencies of Ericaceae and *Vaccinium* are present in conjunction with high charcoal values. Consequently, the fire regime during the younger Pliocene likely faciliated the expansion of Ericaceae shrub stands.

A DIFFERENTIATION OF VEGETATION TYPES AT MOORMERLAND

Generally, *Abies*, *Juniperus*, *Picea*, *Pinus*, *Sciadopitys*, *Taxus* and *Tsuga* are regarded as upland conifers during the late Pliocene, whereas *Alnus*, Cupressaceae, *Fraxinus*, *Myrica*, *Nyssa*, *Salix*, *Sequoia*-type, and *Taxodium*-type pollen belong to the group of wetland trees (e.g. Westerhoff et al., 2020). All other deciduous trees are regarded as upland Angiosperm trees. However, it is likely that some *Pinus* species also grew in wetland areas at least in the drier parts. This should apply to some other tree genera as well, like *Sciadopitys*. Concerning the Miocene brown coal mires, Teichmüller (1958) proposed a pattern of how the mire zonation potentially appeared (Fig. 3). The driest parts of the mire were composed of a forested *Sequoia* fen. Other characteristic tree genera are *Sciadopitys* and *Pinus*. Wetter sites with a higher groundwater table were occupied by the so-called Myricaceae-Cyrillaceae fen, consisting mainly of shrub stands. Other shrub taxa like *Juniperus* and *Symplocos*, as well as Magnoliaceae occurred there as well. Sites with a high water table throughout the whole year were characteristic of the *Nyssa*-*Taxodium*

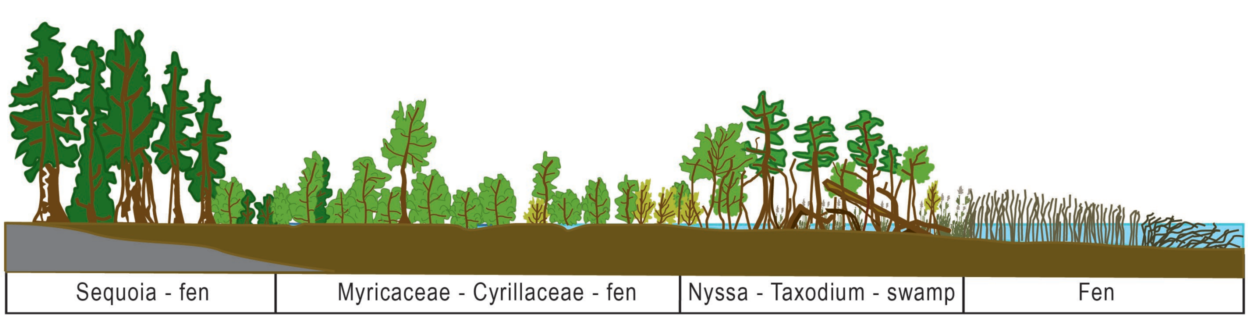

Figure 3. Mire zonation of Miocene brown coal formations in the Lower Rhine embayment (after Teichmüller, 1958; modified)

swamp forest. Besides *Nyssa* and *Taxodium*, *Glyptostrobus* was also common.

According to more recent studies, many more tree taxa were growing in the mires at different sites than originally thought. For instance, the presence of *Abies*, *Pinus*, *Picea*, *Sciadopitys*, and *Liquidambar* is witnessed by wood findings (Burgh, 1973), as well as upland Angiosperm trees such as *Tilia*. Furthermore, according to Brelie and Wolf (1981), observations of the coal petrography in conjunction with the pollen assemblages show clearly that *Sequoia* was also present in wetter parts of the mires and not only at drier sites. This also applies to brown coals, which were formed during the Pliocene. Additionally, Brelie and Wolf (1981) stated that *Sciadopitys* was growing in the driest parts of the mires during the Pliocene, too.

Based on this ragtag of different tree genera, which could have potentially grown in the mire, a detailed vegetation zonation cannot be reconstructed as Teichmüller (1958) did for the Miocene brown coal formations. Having a look at the Pliocene lake record of Willershausen (Mohr, 1986), totally different pollen assemblages were detected compared to the ones revealed from the peats and coals of Pliocene age originating from the lower Rhine area and adjacent Lower Saxony. Even though the Willershausen pollen record also belongs to the Reuverian, no pollen peaks driven by facies (changes) occur, and the pollen curves are more smoothed. Generally, trees regarded as upland deciduous trees, such as *Carya* and *Fagus*, gain higher percentage values in this pollen profile. The same applies to the Eichenberg pollen record (Chanda, 1962), which is also of limnic origin.

SUMMARY AND CONCLUSION

A 95 m thick drill core, consisting of sand with intercalated fines, was studied by pollen analysis. The studied lithological sequence, which focused on organic layers at 90–88 m, ~70 m, and 57–45 m, covers chronologically parts of the Reuverian sensu Zagwijn (1960). The identified pollen assemblages reflect mainly the former forest swamp vegetation. The alternating higher proportions of *Pinus sylvestris*-type and *Taxodium*-type pollen grains are referable facies-related changes. Fire also played a role as a modifying factor leading to a facilitated expansion of shrub stands rich in Ericaceae, subsequent to fire events. To overcome the stratigraphical issue of these Pliocene pollen contents is strongly influenced by facies (over-representation of local trees), and to a minor extent by the local fire regime, a long continuous lake record is needed to establish a solid biostratigraphy with a regional signal and not truncated by facies-related changes. This would allow long-distance correlation from coastal areas in the northern German lowlands and adjacent areas to sites located in the inland.

ADDITIONAL INFORMATION

CONFLICT OF INTEREST. The authors have declared that no competing interests exist.

ETHICAL STATEMENT. No ethical statement was reported.

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