

26. Palynological and Geochronological Study of the Holsteinian/Hoxnian/Landos Interglacial

Mebus A. Geyh¹ and Helmut Müller²

¹Formerly Leibniz Research Institute of Geosciences, Box 510153, 30 631 Hannover, Germany

²Formerly Federal Institute of Geosciences and Resources, 30 631 Hannover, Germany

ABSTRACT

The discovery of a pollen assemblage in interglacial deposits comparable with that of the pollen assemblage zone (PAZ) MM 8 of the Holsteinian Interglacial at Munster Breloh allows us to distinguish coeval deposits from those of other pre-Eemian interglacials. Thus, there is palynological evidence for a reliable correlation of precisely investigated and numerically dated Holsteinian deposits with the Mazovian Interglacial (eastern Poland), the Hoxnian Interglacial (England and SW Ireland) as well as the Landos Interglacial in the Massif Central (France). Adapting the palynological correlation of the Praclaux Interglacial, Massif Central, with MIS 11, the Holsteinian/Hoxnian/Mazonian/Landos interglacial belongs to MIS 9.

²³⁰Th/U dates from fen peat layers of the Holsteinian reference site at Bossel in northern Germany and from two sites with Hoxnian deposits in England date these interglacial deposits to about 320 kyr BP corresponding to MIS 9. This correlation is supported by supplementary ²³⁰Th/U dates of fen peat from several both pre-Eemian and non-Holsteinian sites in Germany.

26.1 HOLSTEINIAN DEPOSITS AND THEIR CORRELATION WITH THE MIS TIMESCALE

Quaternary geologists identified three glaciations (Elsterian, Saalian and Weichselian) in the Quaternary of the lowlands of

northern Germany (Keilhack, 1896) and four in the northern Alps (Penck and Brückner, 1901/1909). The youngest glacial periods were correlated with each other. The interglacials in between were termed Holsteinian and Eemian, respectively. This simple concept was first truly questioned when Emiliani (1955) introduced stable isotope determinations into Quaternary marine geology. He discovered that variation of the oxygen isotope composition (given as $\delta^{18}\text{O}$ values) in planktonic foraminifera reflects global climatic changes between warm and cold periods. He termed them marine isotope stages (MIS) and related odd and even numbers to warm and cold periods, respectively. According to the number of isotopically identified cold periods in Antarctic ice cores, many more than four glaciations have occurred during the Quaternary, with eight cycles recognized during the last 740 kyr (EPICA Community Members, 2004).

The numerical timescale for the last 400 kyr was determined from the $\delta^{18}\text{O}$ record of the marine core V28-238 (Shackleton and Opdyke, 1973). By tuning this timescale with the modelled insolation cycles of the Sun, which are controlled by orbital forcing, the present SPECMAP numerical timescale was developed (Imbrie *et al.*, 1984). Its precision may be better than ± 5000 yr (Hays *et al.*, 1976).

Since the mid-1950s, one of the major tasks of Quaternary geologists has been to explain the discrepant number of terrestrial and marine glaciations and interglacials and to attempt a correlation of the

well-studied terrestrial periods with the corresponding marine isotope stages. The favourite way includes both the unequivocal palaeontological and sedimentological identification of the deposits as pertaining to a specific glacial or interglacial and their numerical dating. The pollen assemblages of the Schöningen and Dömnitz thermomeres (*sensu stricto* Lüttig, 1965) are examples which cannot be yet unequivocally identified as only parts of the whole Holsteinian pollen sequence are preserved. Attempts to use 'count-from-the-top strategy' of strata and to compare the results with the SPECMAP in most cases yield ambiguous results and do not solve the chronological problem in such cases. However, comprehensive lithological, sedimentological, geological and palynological studies in restricted regions may yield strong correlations. One of the best examples is the Quaternary geologic survey of Saxony, Saxony-Anhalt, South Brandenburg and Thuringia in eastern Germany by Eissmann (2002). He places the Holsteinian Interglacial in MIS 9. A second very good example is the comprehensive palynological survey in the Netherlands by Zagwijn (1989). He proposed an age of approximately 320 kyr for the Holsteinian Interglacial based on a comparison of the oxygen isotope curve of core V28-238 with the Quaternary climatic stratigraphy of the Netherlands.

The stratigraphic terms of the interglacials and interstadials used in this paper are compiled in Table 26.1.

26.2 PALYNOLOGICAL STUDIES

26.2.1 Unequivocal identification of the Holsteinian Interglacial

The first detailed palynological investigation of the Holsteinian deposits in Germany was done by Hallik (1960). Turner (1970) correlated them with the Hoxnian deposits in England. The Holsteinian pollen profiles in north Germany reflect a characteristic vegetation sequence (Hallik, 1960; Meyer, 1974; Müller, 1974; Müller and Höfle, 1994), with a late glacial period preceding the interglacial. Meyer (1974) and Müller (1974) elaborated the pollen sequence of the Holsteinian Interglacial in more detail and added a varve counted absolute time-scale. The most important discovery was, however, a short but noticeable vegetation decline about 6000 years after the beginning of the Holsteinian Interglacial. It became the palynological key element to identify the Holsteinian Interglacial across Europe (Geyh and Müller, 2005; Fig. 26.1).

At Munster Breloh and Bossel immediately after the spread of *Carpinus* and *Abies* in the upper part of the pollen assemblage zone MM VII (MM – Meyer 1974; Müller, 1974) at the transition of MM VII to MM VIII, thermophilous trees such as *Quercus*, *Carpinus*, *Abies* and *Corylus* decreased; *Taxus* completely disappeared. At the same time, Poaceae, *Betula* and *Pinus* spread to a larger extent. In the upper part of PAZ MM VIII thermophilous trees such as *Quercus*, *Alnus* and particularly *Corylus* increased again.

Table 26.1 Stratigraphic terms of the interglacials and interstadials used in this paper and correlation with the SPECMAP timescale

Germany	England	France	Thermomer	SPECMAP
Odderade			Interstadial	MIS 5a
Eemian			Interglacial	MIS 5e
Schöningen			Interglacial (?)	MIS 7 (?)
Holsteinian	Hoxnian	Landos	Interglacial	MIS 9
Gelkenbach		Jagonas	Interstadials	MIS 11
Rhumian		Praclaux	Interglacial	MIS 11

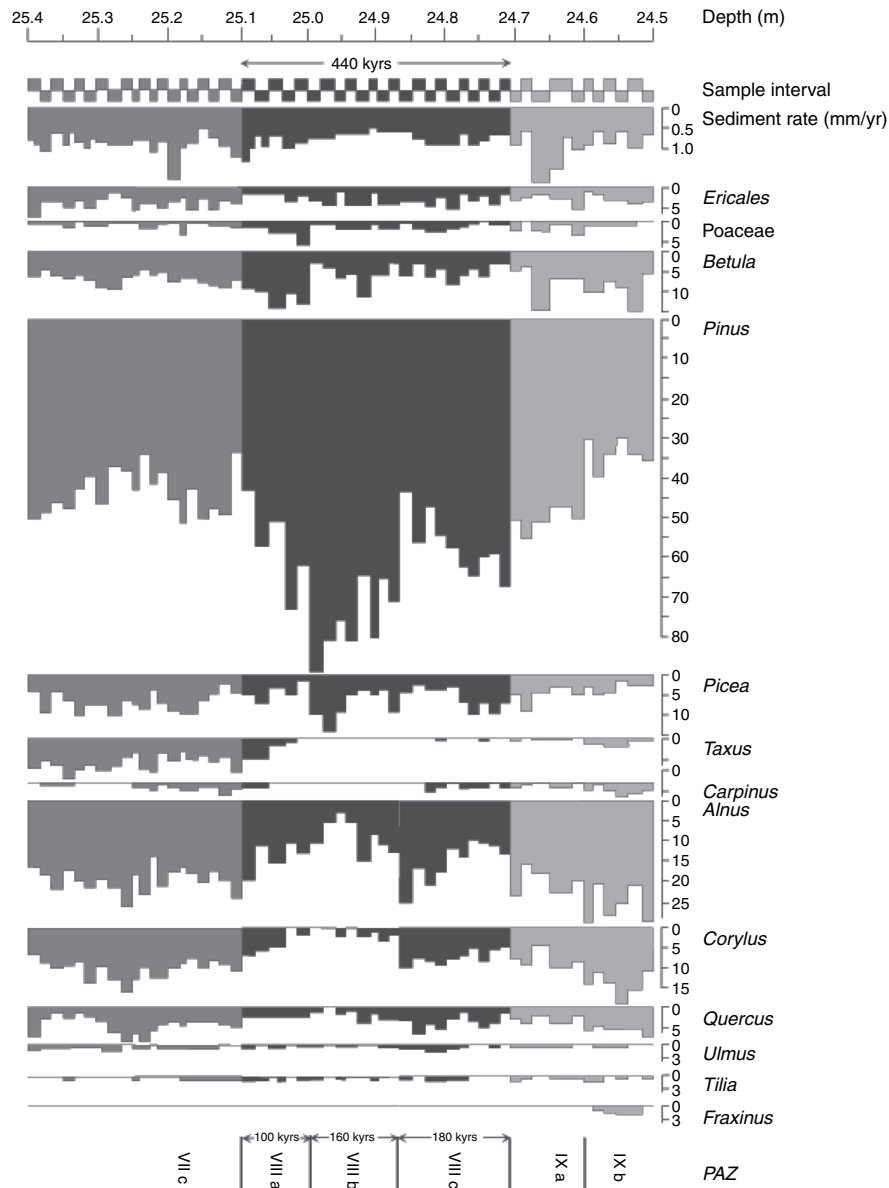


Fig. 26.1 Highly resolved pollen assemblage zone MM VII (dark grey), VIII (black) and IX (light grey) of the Holsteinian reference site at Munster-Breloh (Müller, 1974) as palynological key element of Holsteinian deposits.

Slightly later other thermophilous trees such as *Carpinus*, *Ulmus* and *Tilia* spread. *Taxus* returned at the beginning of MM IX and reached the former level long before the spread of *Abies*.

The time marks of the spread or disappearance of specific pollen in PAZ VIII were precisely determined by varve counting of the Munster Breloh profile (Müller, 1974; Geyh and Müller, 2005). Slight temporal deviations from this reference timescale

can be expected between the rim and the centre of a lake, between profiles situated at large distances (Poland, Germany, Ireland and France) and in deviating climatic conditions. This is why we did not give an absolute timescale in Fig. 26.1. The correlation of the pollen assemblage zones used in the mentioned regions is shown in Fig. 26.2. It has to be kept in mind that the temporal correlation may not be better than ± 100 years.

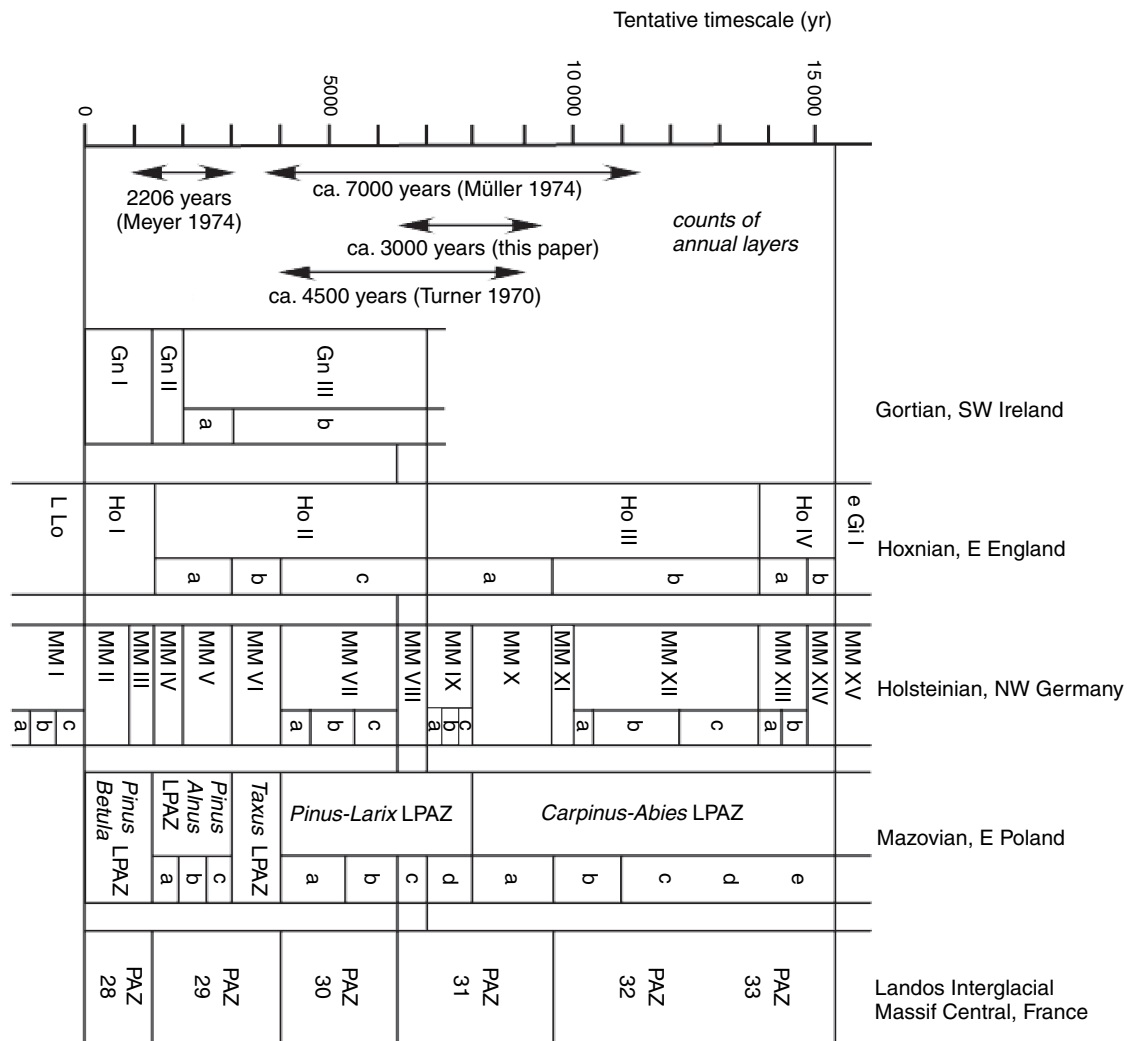


Fig. 26.2 Correlation of the pollen assemblage zones used in the following regions: Gortian in SW Ireland (Dowling and Coxon, 2004), Hoxnian in England (Turner, 1970), Marks Tey in Essex (Turner, 1970), Holsteinian in NW Germany (Meyer, 1974; Müller, 1974; Müller and Höfle, 1994), Mazovian in E Poland (Binka and Nitychoruk, 1995) and Landosian in the Velay area of the France Massif Central (Reille et al., 2000). The tentative time scale was elaborated by counts of varve-like annual layers (Turner, 1970; Meyer, 1974; Müller, 1974) and recent counts from diatomite cores between the beginnings of PAZ MM VIII and of PAZ MM XI, i.e. between the sudden decrease of *Taxus* and *Carpinus*.

Applying a high temporal resolution of several decades at the transition from MM VII to MM VIII, the Holsteinian Interglacial can be identified palynologically across Europe. Pre-supposition for such high temporal resolution is that (a) a sufficient large number of pollen grains per sample is counted, (b) the sampling intervals in the profile are very small, (c) the pollen grains are well preserved, (d) the local pollen input does not dominate over the regional one and (e) the sediments are stratigraphically undisturbed.

The following examples provide evidence that these particular palynological characteristics are a regional phenomenon:

1. In the pollen diagram of the Mazovian Interglacial in eastern Poland (Binka and Nitychoruk, 1995), approximately 900 km east of the Holsteinian-type section, this characteristic decline of thermophilous vegetation is found in spite of a dominant continental climate. After the disappearance of *Taxus*, *Quercetum mixtum* and

Alnus declined simultaneously with the increase of *Betula*, *Pinus* and Poaceae, but long before the distinct spread of *Abies*. Some *Carpinus* was present.

2. In eastern England, West (1956) and Turner (1970) found evidence for a similar evolution of the vegetation in the late part of the Hoxnian assemblage zone Ho IIc. After an increase of thermophilous trees such as *Quercus*, *Taxus* and *Corylus*, *Taxus* and *Corylus* suddenly disappeared. At the same time Poaceae, *Betula* and *Pinus* spread. In the upper part of this PAZ Ho IIc thermophilous trees such as *Quercus* and particularly *Corylus* also increased. *Taxus* returned at the beginning of PAZ Ho IIIa and reached the former level long before the spread of *Abies*.
3. Even 1100 km W of the Holsteinian type region at the profile Gortian CB 2 in Cork Harbour, SW Ireland, the assemblage zone Gn IIIb (at 25 m depth) reflects a sudden drop of *Taxus*, a subsequent slight peak of *Betula* and *Picea* and a strong spread of *Pinus*. At about 24.5 m depth, *Taxus* regained a frequency as before its decline (Dowling and Coxon, 2001).
4. In spite of a low temporal resolution of about 200 years, the samples from the Landos Interglacial (32.60–32.56 m depth at PAZ 30) of the composite pollen diagram of the Massif Central in France (Reille *et al.*, 2000) reflect (a) the long-lasting decline of *Taxus*, (b) a short peak of Poaceae, (c) a limited spread of *Pinus* to low levels, (d) a fast decline of *Carpinus* and (e) an increase of *Corylus* and deciduous trees. In the upper part of the following PAZ 31 (32.32–32.00 m), *Taxus* returned. *Abies* spread strikingly in PAZ 32.

26.2.2 Evidence for a miscorrelation between the Holsteinian and Praclaux Interglacial

The most complete palynological record of the European Quaternary was elaborated by Reille *et al.* (2000) spanning the last 420 kyr.

The corresponding profiles are located about 1000 km SW of the Holsteinian-type section. Reille *et al.* (2000) elaborated pollen diagrams of three sites with a tephra layer as very reliable link. This tephra occurs in the sediments of the Amargiers Interstadial (the second interstadial above the Landos Interglacial) and has a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 275 ± 5 kyr.

The palynological miscorrelation of the Praclaux Interglacial preceding the Landos Interglacial in the French Massif Central (Reille *et al.*, 2000) with the Holsteinian Interglacial explains why many Quaternary geologists and palynologists link the Holsteinian Interglacial with MIS 11. The following reasons strongly suggest considering this correlation as a miscorrelation:

1. The main argument of Reille *et al.* (2000) in correlating the Holsteinian and the Praclaux interglacials is the presence of *Pterocarya* and *Fagus* pollen in the last two PAZ Ho IIIb and the older Ho IV of the Hoxnian Interglacial. However, the occurrence of a few *Pterocarya* and *Fagus* pollen grains does not allow a reliable correlation between any of these interglacials. Small quantities of these pollen grains were also found in both the Rhumian Interglacial (at Bilshausen and Kärlich; see Table 26.1) and at a slightly higher level in the Holsteinian Interglacial.
2. The Praclaux and the succeeding Landos interglacials (Table 26.1) are the oldest interglacials in the pollen sequence of the French Massif Central. Both contain a high amount of *Abies* pollen. This pollen already is present in the older part of the Praclaux Interglacial (MIS 11), which is similar to the Rhumian Interglacial (Table 26.1) in Germany (MIS 11 or older). But, *Abies* did not appear before the last third of the Landos/Holsteinian Interglacial (MIS 9). Hence, the temporal spread of *Abies* in the different interglacials supports a correlation of the Praclaux Interglacial with the Rhumian

Interglacial rather than with the Holsteinian Interglacial. Moreover, the Praclaux Interglacial does not have a low frequency of *Picea* in its upper part while the Landos Interglacial has.

3. The glacial period after the Rhumian interglacial was followed probably 10 000 years later by the two relatively short Gelkenbach interstadials (Chanda, 1962), which most probably are similar in age to the two Jagonas interstadials (Reille *et al.*, 2000) after the Praclaux Interglacial. *Betula* and *Pinus* appeared due to the climatic melioration besides some thermophilous trees such as *Carpinus*, *Ulmus* and *Quercus*.
4. According to Reille *et al.* (2000), the Praclaux Interglacial is palynologically younger than the Rhumian Interglacial (Table 26.1) at Kärlich, Germany (Bittmann and Müller, 1996). The latter contains a tephra layer which has a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 396 ± 20 kyr (van den Bogaard *et al.*, 1989).

For the correlation of the Praclaux Interglacial with MIS 11, the $^{40}\text{Ar}/^{39}\text{Ar}$ age of the Kärlich Interglacial was proclaimed as too young. Methodical or physical reasons are not given for this.

5. An important argument for our correlation of the Holsteinian/Hoxnian Interglacial with MIS 9 and the Rhumian/Praclaux Interglacial with MIS 11 is based on the different duration of the warm periods. Varves were counted from the Rhumian Interglacial at Bilshausen (Müller, 1992; Bittmann and Müller, 1996) and annual diatom layers from the Holsteinian Interglacial (Meyer 1974; Müller, 1974). The Rhumian Interglacial covered a period of about 25 000 years extended by a late glacial period of 8400 years. The Holsteinian Interglacial yielded only 15 000 to 16 000 varves preceded by the short Elsterian Late Glacial (Müller and Höfle, 1994). The different durations of these two interglacial periods support a correlation of the Rhumian and Holsteinian interglacials with MIS 11

and 9, respectively, rather than with MIS 13 and MIS 11, if compared with the time-scale of the Vostok ice core (Petit *et al.*, 1999) and that of Dome C (EPICA Community Members, 2004).

26.3 $^{230}\text{Th}/\text{U}$ DATING OF HOXNIAN AND HOLSTEINIAN DEPOSITS

26.3.1 Numerical dates from the Hoxnian deposits

Most reliable and comparable numerical dates of Holsteinian and Hoxnian interglacials were obtained by means of the $^{230}\text{Th}/\text{U}$ method applied to fen peat. Rowe *et al.* (1997) analysed samples from the Tottenham Quarry, Nar Valley, NW Norfolk, UK, which is correlated palynologically with the Hoxnian Interglacial (Ventris, 1996). This latter peat is palynologically correlated with Ho I-Ho IIb (West, 1956; Turner, 1970; Ventris, 1985) corresponding to MM 1–MM 7 (Meyer, 1974; Müller, 1974) in the type region of the Holsteinian Interglacial in the lower Elbe area, north Germany. Therefore, the transgression of the Holsteinian Sea occurred at Tottenham at the same time as in the type area of the Holsteinian Interglacial near Bossel (Müller and Höfle, 1994) and Hamburg-Hummelsbüttel (Hallik, 1960). Rowe *et al.* (1997) obtained a mean $^{230}\text{Th}/\text{U}$ age of 317 ± 14 kyr corresponding to MIS 9. The reliability checks were positive.

Geyh and Müller (2005) dated Holsteinian fen peat deposits from the Bossel site. The boreholes GE 1/85 (29°13'E, 30°20'N; 5.6 m above sealevel) and GE 00/1 were drilled in 1985 and 2001, respectively, in Bossel about 30 km west of Hamburg. These cores contained two organic layers, one above and one below the sediments of the Holsteinian Sea (Fig. 26.3).

The first location became the reference site for the Holsteinian Interglacial in northern Germany as declared by the European Commission on Stratigraphy of the Quaternary (Jerz and Linke,

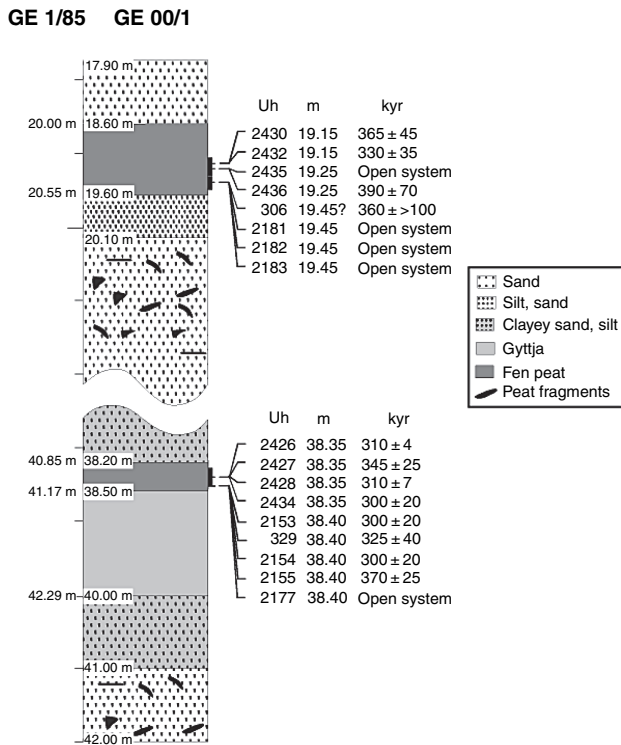


Fig. 26.3 Correlation of the Holsteinian Interglacial deposits in cores GE 1/85 and GE 00/1 from Bossel showing sampled layers and corresponding detritus-corrected $^{230}\text{Th}/\text{U}$ ages. Depth scales are given for each core.

1987). In the lower part of the cores, humic, sandy-clayey glacial lacustrine/marine sediments are present representing a cool phase at the beginning of the melting of the Elsterian ice corresponding to the onset of the marine Holsteinian Interglacial. These deposits are overlain by 1 m of clayey-to-sandy silt and about 1.5 m calcareous gyttja (PAZ MM I to MM V after Meyer, 1974 and Müller, 1974). Towards the top between 38.5 and 38.2 m (all depths refer to Core GE 00/1), fen peat (*Picea-Alnus-Pinus-Betula*) of PAZ MM VI is present. This peat is covered by approximately 16.2 m of compressed marine silty clay with plant remains mainly of a *Salicornia* facies. The uppermost part of the core contains more silty-to-sandy layers with fragments of marine shells.

At a depth of approximately 22 m, the sediment changes to humic silt and sand

containing organic fragments. A fen peat layer between 19.6 and 18.6 m belongs to the *Quercus-Abies-(Pinus)* (PAZ MM XIII) and the *Pinus-Alnus-Betula-Pterocarya* occurrence (PAZ MM XIV) of the late Holsteinian. The lower part of this layer is fen peat. Between 19.0 and 18.6 m sandy ombrogenic peat and reworked Holsteinian material are present.

Eight detritus-corrected $^{230}\text{Th}/\text{U}$ dates between 298 and 347 kyr ($< \pm 30$ kyr) were determined from the two peat layers (Fig. 26.3). The mean is 323 ± 4 kyr. The seven detritus-corrected $^{230}\text{Th}/\text{U}$ age between 293 and 369 kyr from the lower peat layer yielded a more reliable mean of 312 ± 3 kyr. The four corresponding dates of the upper peat layer yielded a mean of the detritus-corrected $^{230}\text{Th}/\text{U}$ ages of 327^{+130}_{-37} kyr. The reliability check was successful as the corresponding analytically controlled minimum $^{230}\text{Th}/\text{U}$ sample ages of >360 to >650 kyr (Geyh and Müller, 2005) exceed the calculated $^{230}\text{Th}/\text{U}$ ages.

Other numerical $^{230}\text{Th}/\text{U}$ dates support the $^{230}\text{Th}/\text{U}$ age of the Holsteinian deposits. Seven sites in Germany containing interglacial fen peat layers were palynologically classified as either older or younger than the Holsteinian Interglacial but older than the Eemian Interglacial. Twenty-eight $^{230}\text{Th}/\text{U}$ dates were determined and the 'isochron' approach was applied. All dates scatter apart from those of MIS 9. The dispersion histogram of these dates (Fig. 26.4; Geyh, 1980) plotted together with the $^{230}\text{Th}/\text{U}$ dates from the Holsteinian Interglacial form three distinct peaks. The $^{230}\text{Th}/\text{U}$ dates of those samples which are either older or younger than the Holsteinian Interglacial represent MIS 7 and MIS 11, the dates of the Bossel section represent MIS 9.

$^{230}\text{Th}/\text{U}$ dating of 'authigenic calcium carbonate with very low uranium and thorium concentrations that has been precipitated from the former lake water' was applied to the reference section of the Hoxnian at Marks Tey, UK (Rowe *et al.*, 1999).

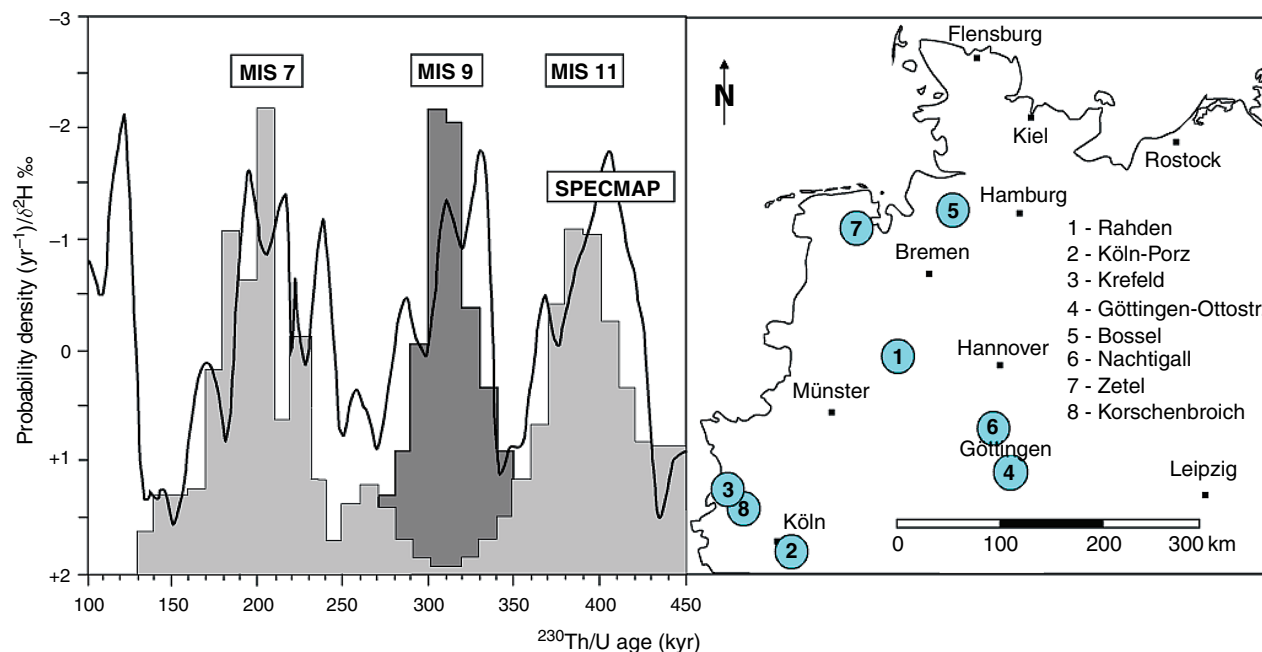


Fig. 26.4 left Dispersion histogram of the $^{230}\text{Th}/\text{U}$ isochron dates from (i) the Holsteinian section at Bossel (Geyh, 1980; dark grey) and from (ii) seven sites in Germany (map on right) palynologically assigned to non-Holsteinian and non-Eemian interglacials (light grey). The dispersion histogram supports the link between the Holsteinian Interglacial and MIS 9. The SPECMAP curve is also shown (Imbrie et al., 1984)

This material palynologically represents the whole interglacial (Rowe *et al.*, 1999). A probability interpretation ends up with the statement that the Hoxnian Interglacial 'indicates with 87% confidence that the Marks Tey sediments correlate with MIS 11 or some older stage'. But, the calculated analytically controlled minimum $^{230}\text{Th}/\text{U}$ sample ages (Geyh and Müller, 2005) range from >165 to >245 kyr only which are smaller than the published ages. Hence, the $^{230}\text{Th}/\text{U}$ ages from Marks Tey only allow the statement that the numerical age is older than MIS 7; they do not exclude, however, a chronological correlation of the Holsteinian Interglacial with MIS 9.

26.3.2 Other dating attempts of Holsteinian deposits

Miller and Mangerud (1985) applied amino-racemization analysis to Holsteinian mollusc shells collected on various European coasts between northern France and

Norway and concluded that the Holsteinian Interglacial may belong to MIS 7 or less probably to MIS 9. ESR dating yielded ambiguous numerical results. Holsteinian mollusc shells collected from a Holsteinian profile near Hamburg yielded dates between 195 and 220 kyr (Linke *et al.*, 1985), supporting a correlation with MIS 7. Sarnthein *et al.* (1986) published ESR dates >370 kyr from the same site and correlated the Holsteinian Interglacial with MIS 11. The reason for the discrepancy of the ESR dates of the same site was the use of different evaluation protocols. ESR dates of 319 ± 38 kyr of two teeth, collected from the base of Stratum C at Hoxne, first placed the corresponding deposits in MIS 9 (Grün *et al.*, 1988; Schwarcz and Grün, 1993). These ESR dates were later revised and model-corrected to fit correlation with MIS 11 (Grün and Schwarcz, 2000). In view of the large number of uncertain parameters used for ESR dating by Grün and Schwarcz (2000), we feel that the correlation of the Hoxnian could well be re-revised back to MIS 9.

Misleading correlations are obtained with the 'count-from-the-top strategy' though referring to numerical dates of base or top layers. Examples are found by Urban (1995). She correlates the Holsteinian Interglacial with MIS 11 without palynological evidence and only based on two $^{230}\text{Th}/\text{U}$ dates of peat of the Schöningen Interglacial (Table 26.1).

26.4 CONCLUSION

Both the Holsteinian and the Hoxnian interglacials are correlated with MIS 9 based on $^{230}\text{Th}/\text{U}$ dates from the stratigraphic reference site of the Holsteinian Interglacial at Bossel in Germany and from the Tottenham Quarry and Marks Tey sites of the Hoxnian Interglacial in England, respectively. This correlation is further supported by numerous $^{230}\text{Th}/\text{U}$ dates from fen peat of non-Holsteinian and non-Eemian interglacial sites in Germany. There is palynological evidence from high-resolution pollen diagrams in Poland, Germany, E England and SW Ireland that the Holsteinian Interglacial as well as the Hoxnian and Landos interglacials are correlated with MIS 9, and the Praclaux Interglacial with MIS 11.

ACKNOWLEDGEMENTS

We thank Mrs. Gudrun Drewes, Sabine Mogwitz and Dipl.-Phys. Deniz Oezen for the analyses and measurements of the Bossel samples and the field campaigns. T. Litt, Bonn, contributed references. P. J. Rowe and D. H. Keen read the paper critically and made many valuable suggestions which substantially improved the manuscript. Our sincere thanks to Henry Toms, geologist and English translator, for his thorough and critical reading of our paper, corrections.

REFERENCES

- Binka, K., Nitychoruk, J., 1995. Mazovian (Holsteinian) lake sediments at Woskrzenice near Biala Podlaska. *Geological Quarterly* 39, 109–120.
- Bittmann, F., Müller, H., 1996. The Kärlich Interglacial site and its correlation with the Bilshausen sequence. In: Turner, C. (Ed.), *The Early Middle Pleistocene in Europe*. Balkema, Rotterdam, pp. 187–193.
- Chanda, S., 1962. Untersuchungen zur pliozänen und pleistozänen Floren- und Vegetationsgeschichte im Leinetal und im südwestlichen Harzvorland (Untereichsfeld). *Geologisches Jahrbuch* 79, 783–844.
- Dowling, L.A., Coxon, P., 2001. Current understanding of Pleistocene temperate stages in Ireland. *Quaternary Science Reviews* 20, 1631–1642.
- Eißmann, L., 2002. Quaternary geology of eastern Germany (Saxony, Saxon-Anhalt, South Brandenburg, Thüringia), type area of the Elsterian and Saalian stages in Europe. *Quaternary Science Reviews* 21, 1275–1346.
- Emiliani, C., 1955. Pleistocene temperatures. *Journal of Geology* 63, 538–573.
- EPICA Community Members, 2004. Eight glacial cycles from an Antarctic ice core. *Nature* 429, 623–628.
- Geyh, M.A., 1980. Holocene sealevel history: case study of the statistical evaluation of ^{14}C dates. *Radiocarbon* 22, 695–704.
- Geyh, M.A., Müller, H., 2005. Numerical $^{230}\text{Th}/\text{U}$ dating and a palynological review of the Holsteinian/Hoxnian Interglacial. *Quaternary Science Reviews* 24, 1861–1872.
- Grün, R., Schwarcz, H.P., 2000. Revised open system U-series/ESR age calculations for teeth from Stratum C at the Hoxnian Interglacial type locality, England. *Quaternary Science Reviews (Quaternary Geochronology)* 19, 1151–1154.
- Grün, R., Schwarcz, P., Chadam, J., 1988. ESR dating of tooth enamel: coupled correction for U-uptake and U-series disequilibrium. *Nuclear Tracks and Radiation Measurements* 14, 237–241.
- Hallik, R., 1960. Die Vegetationsentwicklung der Holstein-Warmzeit in Nordwestdeutschland und die Altersstellung der Kieselgurlager der südlichen Lüneburger Heide. *Zeitschrift der deutschen geologischen Gesellschaft* 122 (2), 326–333.
- Hays, J.D., Imbrie, J., Shackleton, N.J., 1976. Variations in the earth's orbit: pacemaker of the ice ages. *Science* 194, 1121–1132.
- Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., Shackleton, N.J., 1984. The orbital theory of Pleistocene climate: Support from a revised chronology

- of the marine $\delta^{18}\text{O}$ record. In: Berger, A.L., Imbrie, I., Hays, J., Kukla, G. (Eds.), *Milankovitch and Climate*. Reidel, Dordrecht, pp. 269–305.
- Jerz, H., Linke, G., 1987. Arbeitsergebnisse der Subkommission für Europäische Quartärstratigraphie. Typusregion des Holstein-Interglazials (Berichte der SEQS 8). *Eiszeitalter und Gegenwart* 37, 145–148.
- Keilhack, K., 1896. Die Geikiessche Gliederung der nordeuropäischen Glacialablagerungen. *Jahrbuch der Königlich Preußischen Geologischen Landesanstalten für 1895*, 111–124.
- Linke, G., Katzenberger, O., Grün, R., 1985. Description and ESR dating of Holsteinian interglaciation. *Quaternary Science Reviews* 4, 319–331.
- Lüttig, G., 1965. Interglacial and interstadial periods. *Journal of Geology* 73, 579–591.
- Meyer, K.-J., 1974. Pollenanalytische Untersuchungen und Jahresschichtzählungen an der holsteinzeitlichen Kieselgur von Hetendorf. *Geologisches Jahrbuch A* 21, 87–105.
- Miller, G.H., Mangerud, J., 1985. Aminostratigraphy of European marine interglacial deposits. *Quaternary Science Reviews* 4, 215–278.
- Müller, H., 1974. Pollenanalytische Untersuchungen und Jahresschichtenzählungen an der holsteinzeitlichen Kieselgur von Munster-Breloh. *Geologisches Jahrbuch A* 21, 107–140.
- Müller, H., 1992. Climatic changes during and at the end of the interglacials of the Cromerian Complex. In: Kukla, G.J., Went, E. (Eds.), *Start of the Glacial*. Nato ASI Series 13, Springer, Berlin, Heidelberg, pp. 55–69.
- Müller, H., Höfle, H.-Ch. 1994. Das Holstein-Interglazialvorkommen bei Bossel westlich von Stade und Wanhöden nördlich Bremerhaven. *Geologisches Jahrbuch A* 134, 71–116.
- Penck, A., Brückner, E., 1901/1909. *Die Alpen im Eiszeitalter*, Band I–III; Leipzig.
- Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.M., Basile, I., Bender, M., Chappellaz, J., Davis, J., Delaygue, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V., Lorius, C., Pépin, L., Ritz, C., Saltzman, E., Stievenard, M., 1999. Climate and atmospheric history of the past 420,000 years from the Vostok Ice Core, Antarctica. *Nature* 399, 429–436.
- Reille, M., de Beaulieu, J.L., Svoboda, H., Andrieu-Ponel, V., Goedry, C., 2000. Pollen analytical biostratigraphy of the last five climatic cycles from a long continental sequence from the Velay Region (Massif Central, France). *Journal of Quaternary Science* 15, 665–685.
- Rowe, P.J., Richards, D.A., Atkinson, T.C., Bottrell, S.H., Cliff, R.A., 1997. Geochemistry and radiometric dating of a Middle Pleistocene peat. *Geochimica et Cosmochimica Acta* 61, 4201–4211.
- Rowe, P.J., Atkinson, T.C., Turner, C., 1999. U-series dating of Hoxnian interglacial deposits at Marks Tey, Essex, England. *Journal of Quaternary Science* 14, 693–702.
- Sarnthein, M., Stremme, H.E., Mangini, A., 1986. The Holsteinian Interglaciation: time-stratigraphic position and correlation to stable isotope stratigraphy of deep-sea sediments. *Quaternary Research* 26, 283–298.
- Schwarcz, H.P., Grün, R., 1993. ESR dating of the lower industry. In: Singer, R., Gladfelder, B.G., Wymer, J.J. (Eds.), *The Lower Paleolithic Site at Hoxne, England*. University of Chicago Press, Chicago, pp. 203–205.
- Shackleton, N.J., Opdyke, N.D., 1973. Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28–238: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Quaternary Research* 3, 39–55.
- Turner, C., 1970. The Middle Pleistocene deposits at Marks Tey, Essex. *Philosophical Transactions of the Royal Society of London, Series B* 257, 373–440.
- Urban, B., 1995. Palynological evidence of younger Middle Pleistocene interglacials (Holsteinian, Reinsdorf and Schöningen) in the Schöningen open cast lignite mine (eastern Lower Saxony, Germany). *Mededelingen Rijks Geologische Dienst* 52, 175–185.
- van den Bogaard, C., van den Bogaard, P., Schmincke, H.-U., 1989. Quartärgeologisch-tephrostratigraphische Neuaufnahme und Interpretation des Pleistozänprofils Kärlich. *Eiszeitalter und Gegenwart* 39, 62–89.
- Ventris, P.A., 1985. Pleistocene environmental history of the Nar Valley, Norfolk. Ph.D. thesis, University of Cambridge.
- Ventris, P., 1996. Hoxnian interglacial freshwater and marine deposits in northwest Norfolk, England and their implications for sea level reconstruction. *Quaternary Science Reviews* 15, 437–450.
- West, R.G., 1956. The Quaternary deposits of Hoxne, Suffolk. *Philosophical Transactions of the Royal Society of London, Series B* 239, 265–356.
- Zagwijn, W.H., 1989. The Netherlands during the Tertiary and the Quaternary: a case history of coastal lowland evolution. *Geologie en Mijnbouw* 68, 107–120.