

23. Introduction: Climate, Vegetation and Mammalian Faunas in Europe during Middle Pleistocene Interglacials (MIS 7, 9, 11)

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The basic principles used in subdividing the Quaternary into chronostratigraphic units are the same as for other Phanerozoic chronostratigraphic units which require boundary definitions and designations of boundary stratotypes (Salvador, 1994). However, in contrast to the rest of the Phanerozoic, the division of Quaternary sequences on the basis of climatic changes documented in sediment records is fundamental and has a long tradition. Classifications based on climatostratigraphic units such as 'glacials' or 'interglacials' are reasonably well established in different countries or areas and are accepted as regional standards (Gibbard and van Kolfschoten, 2004; Litt *et al.*, 2005).

Regarding the lower and upper boundary of the Middle Pleistocene, the responsible stratigraphic commission suggests to use the palaeomagnetically defined Brunhes/Matuyama boundary (780 kyr, MIS 19) also as boundary between Lower and Middle Pleistocene (Richmond, 1996). There is a broad international consensus about this proposal (e.g. Pillans 2003). However, a formally defined boundary stratotype (GSSP) is still missing. The boundary between Middle and Upper Pleistocene is also not yet formally defined. Gibbard (2003) proposes to use the beginning of the last interglacial (around 130 kyr after U-series dating of calcite speleothems, see Spötl *et al.*, this volume) as Middle/Upper Pleistocene boundary. In addition, he suggests the newly processed cores from Amsterdam Terminal (parastratotype for the Eemian, see van Leeuwen *et al.*, 2000) as boundary stratotype (GSSP). This proposal is currently under examination by a working group of the stratigraphical commission.

Whereas the basal chronostratigraphic units (stages/ages) were not formally defined so far internationally, cold and warm intervals are used as chronostratigraphic units in terms of regional stages of Middle Pleistocene in northern and central Europe (e.g. Elsterian Stage, Holsteinian Stage, see Gibbard and van Kolfschoten, 2004; Litt *et al.*, 2005) (Fig. 23.1). The chronostratigraphic units include several complex stages (Cromerian, Saalian). Even in this case, the recognition of distinct criteria and of boundaries for the climatostratigraphic division is crucial. Numerous regional continental stratigraphic units and boundary stratotypes of the Quaternary were defined using palynostratigraphic criteria.

The climatostratigraphic terms interglacial and interstadial were first defined by Jessen and Milthers (1928) for periods with characteristic records of nonglacial climate, as indicated by palaeobotanical evidence for major vegetation changes. Following these suggestions, interglacials in central Europe have been identified unequivocally as temperate periods with a climate optimum at least as the present interglacial (Holocene) in the same region. Interstadials have been described as periods that were either too short or too cold to reach the climate level of interglacial type in the same region.

There is an increasing tendency of directly correlating terrestrial sequences with marine isotope records which is mainly based on curve matching. However, correlations must rely entirely on direct dating. Gibbard and West (2000) suspect that the extension of the use of isotope–stratigraphic subdivision and terminology of marine-core sequences (and

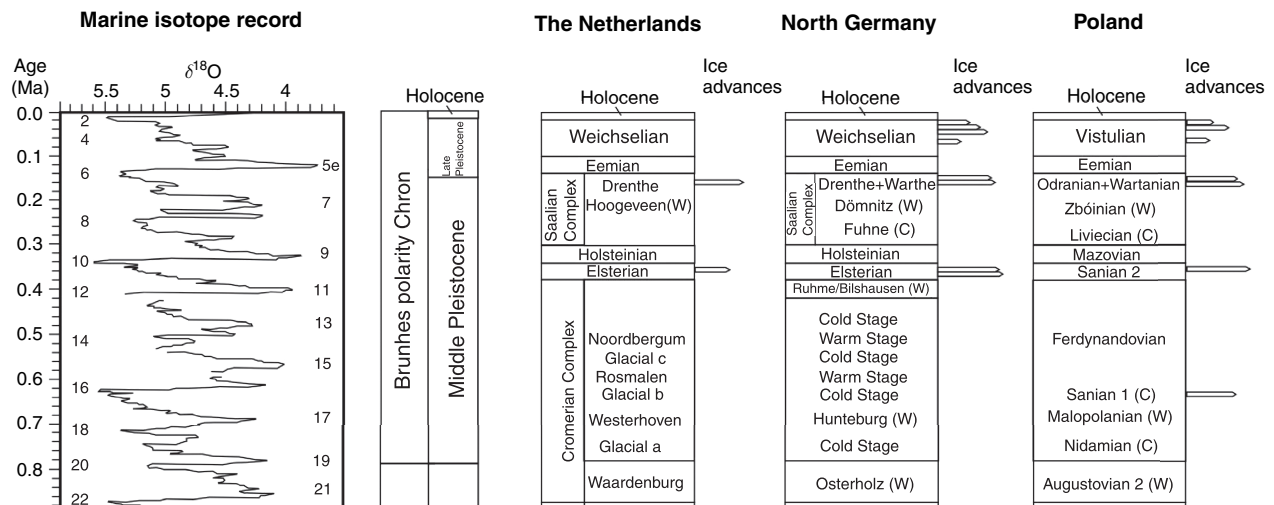


Fig. 23.1 Chronostratigraphical correlation table of the Middle and Upper Pleistocene in north-central Europe (compiled after Zagwijn, 1989; Gibbard and van Kolfschoten, 2004; Lindner et al., 2004; Litt et al., 2005). (C) – cold stage, (W) – warm stage.

ice-core sequences) on land might lead to a new stratigraphic Esperanto. Regional terrestrial stratigraphy, marine stratigraphy and ice-core stratigraphy are each a key to different parts of the climate system. For understanding the regional variability, it is essential to develop local and independent stratigraphies and chronologies.

With respect to the terrestrial record, favourable geological conditions in southern Europe have in some cases led to the relatively undisturbed accumulation of thick Quaternary sedimentary sequences. Such sequences provide an opportunity to develop complete records of terrestrial events over multiple glacial–interglacial cycles. The linking of the longest pollen sequences from southern Europe (Tenagi Phillipon in Greece, Velle di Castiglione in Italy and Bouchet/Praclaux in France) has led to the emergence of a coherent stratigraphical framework of changes in vegetation for the last 450 kyr and has allowed tentative comparisons with the marine isotopic record (Tzedakis *et al.*, 1997, 2001). This showed that the many stages and substages into which the marine isotopic sequence is divided into are also appropriate for viewing the continental record, although the marine and

terrestrial boundaries may not be precisely synchronous. The last five marine isotopic interglacials were investigated in Iberian margin deep-sea cores. The direct comparison between terrestrial pollen, benthic/planktic foraminifera and isotopes from the same cores shows that temperature changes are not in phase with ice volume variations (Desprat, this volume). Pronounced offsets between marine isotopic warm stage boundaries and forested intervals, as previously described by Sánchez Goñi *et al.* (2002) for MIS 5, are also documented for older interglacial stages (see Roucoux *et al.*, this volume).

Caused by biogeographical reasons, it is difficult to correlate interglacials from south European long sequences with warm stages from north-central Europe based on palynology alone. The way forward should be to date fixed events as accurately as possible based on new approaches in absolute dating methods. Based on these tie points, the astronomical cyclicity can provide a finer-scale chronology. A good geochronological frame can resolve long-standing disagreements such as whether the Holsteinian relates to MIS 9 or 11. Questions of the nature and duration of the Saalian, and

precisely how many warm events occur within the Saalian cannot be resolved by 'counting-backwards' methods (Gibbard and West, 2000).

The north-central European area known to have been affected by both the Elsterian and the Saalian glaciations provides good opportunity to establish a regional chronostratigraphy of the Middle Pleistocene based on stratigraphic superposition: the relationship of the Cromerian Complex to the Elsterian glaciation and the Holsteinian Interglacial to the Saalian Complex. In other parts of Europe from which interglacial pollen sequences are known, relationships to particular glaciations are sometimes difficult to elucidate. Therefore, the following brief overview about the Middle Pleistocene in north-central Europe should demonstrate the importance of interglacial sequences as stratotypes in relation to glacial deposits.

23.1 CROMERIAN COMPLEX STAGE

This stage comprises several interglacials and is therefore believed to cover a much longer time span than the Cromerian Interglacial Stage (*sensu stricto*) as defined in East Anglia (West, 1980). The Cromerian Complex Stage of the Netherlands is defined by the recognition of at least four warm temperate and three cold substages (Zagwijn, 1985) indicating the climatic complexity of this time interval. As described previously, the Early–Middle Pleistocene boundary should be linked to the Brunhes–Matuyama palaeomagnetic boundary which has been recognized as falling within the end of Interglacial I (Waardenburg) of the Cromerian Complex or a bit later (780 kyr, MIS 19; see Turner, 1996). The upper boundary of the Cromerian Complex is widely agreed in north-central Europe. It is placed where major climate cooling heralds the onset of the Elsterian Glacial Stage. In northern Germany, the warm stages of the lower Middle Pleistocene

were palynostratigraphically defined based on a long continental record at Gorleben (Müller, 1986, 1992). The Gorleben sequence encompasses five warm phases in a stratigraphic superposition above the Bavelian Stage and below the Elsterian Stage. The oldest one is the mainly reversely magnetized Osterholz Interglacial (= Waardenburg). The youngest one is the Rhume (or Bilshausen) Interglacial, immediately preceding the Elsterian ice advance. It is the best-studied Cromerian interglacial in northern Germany. The duration of this interglacial is estimated as about 27 000 years, based on varve counts of Müller (1992). The pollen sequence shows several oscillations and two distinct forest declines, which may indicate fast climate deteriorations. At least the younger decline follows a tephra layer derived from the Eifel volcanic field. The pollen sequence as recorded for the Bilshausen Interglacial correlates well with the corresponding part of the Kärlich Interglacial in the Middle Rhine area (Bittmann and Müller, 1996) which represents the early *Arvicola cantianus* fauna (see von Koenigswald, this volume). The age of the so-called Brockentuff – a tephra layer related to the Kärlich Interglacial – is about 400 kyr based on $^{40}\text{Ar}/^{39}\text{Ar}$ laser method (van den Boogard *et al.*, 1998), which would correspond to MIS 11 (and to the Praclaux Interglacial in the Massif Central, southern France).

23.2 ELSTERIAN STAGE

The term Elsterian named after the river Elster in central Germany first appeared on the geological maps (1:25 000) of the 'Königlich Preußische Geologische Landesanstalt' (i.e. Keilhack, 1911).

It is the oldest glaciation represented by widespread till sheets throughout north-central Europe (Eissmann *et al.*, 1995; Ehlers *et al.*, 2004). Two glacial cycles can be

identified in northern Germany during the Elsterian Stage. However, no intra-Elsterian interglacial has been identified. During both ice advances of the Elsterian Stage, major erosional structures were formed (subglacial channels and basins). In the erosional zones, lakes were formed which persisted into the Holsteinian Stage.

23.3 HOLSTEINIAN STAGE

The term Holsteinian originates from Geikie (1894), who described interglacial marine sediments as Holsteinian beds. Hallik (1960) first defined Holsteinian sediments palynostratigraphically and correlated them with continental limnic interglacial records. Type sections of the Holsteinian are Hamburg-Dockenhuden (marine deposits) and Bossel, west of Hamburg (lacustrine deposits) (see Jerz and Linke, 1987). The vegetation succession of the Holsteinian warm period was later described by several authors who assigned regionally differing pollen assemblage zones (Erd, 1973 for eastern Germany; Müller, 1974 for north-western Germany; Krupinski, 2000 for Poland, where this interglacial stage is named Mazovian). The INQUA Subcommittee on European Quaternary Stratigraphy defined the lower boundary of the Holsteinian as the transition from subarctic (still late Elsterian) to boreal conditions, and the upper boundary as the transition from boreal to subarctic (Saalian) conditions (Jerz and Linke, 1987). The duration of the Holsteinian is estimated as about 15–16 000 years, based on varve counts of Müller (1974) at Munster-Brelow, a milestone in the geochronological study of the Holsteinian stage in northern Germany. New Th/U datings based on peat deposits from the type section Bossel indicate an age of about 310–330 kyr BP (Geyh and Müller, 2005; and this volume). The consequence would be that the Holsteinian Interglacial in the type region as well as the Hoxnian Interglacial in England and the Landos Interglacial in the

Massif Central, France (Reille *et al.*, 2000), are correlated with MIS 9.

The interglacial vegetation development reconstructed by palynological data is very similar throughout north-central Europe and begins with a pine-birch forest. The immigration of thermophilous trees including alder, oak, elm, lime, ash, yew and hazel occurred more or less simultaneously. The early expansion of spruce is remarkable. Hornbeam and fir immigrated during the course of the interglacial. Particularly characteristic of numerous Holsteinian sites in north-central Europe is the appearance of *Pterocarya* and *Azolla filiculoides*. Our knowledge of the Holsteinian vegetation history is mainly based on pollen records obtained from interglacial lake sediments in glacial basins which were already formed during the Elsterian. In this respect, the discovery of a new Holsteinian sequence at Döttingen in the Western Eifel volcanic field (Diehl and Sirocko, this volume) is a real progress, because it is situated outside the glacially affected region. Nevertheless, the palynological features are similar to those of the classical Holsteinian sites in north Germany. The biostratigraphical correlation and synchronization is obvious.

An unsolved problem is the direct link between palynologically defined Holsteinian sites and mammalian faunas. From none of the typical north-central European Holsteinian deposits have mammalian remains been described so far. Middle Pleistocene interglacial faunas younger than the Elsterian were mainly found in sites with uncertain stratigraphical position (see von Koenigswald, this volume).

The first half of the Holsteinian is characterized by temperatures somewhat lower than today. In the second half, the reconstructed mean temperatures are higher than today, in particular the July temperature (Kühl and Litt, this volume). In addition, the Holsteinian seems to be less stable than the present interglacial (Holocene) or the last interglacial (Eemian) with some intra-interglacial coolings. The magnitude of the

main cooling in the mid-Holsteinian is reconstructed as approximately 5°C for January temperature. No great change is reconstructed for July temperature during this episode.

23.4 SAALIAN COMPLEX STAGE

Based on the definition of the Subcommittee on European Quaternary Stratigraphy (Litt and Turner, 1993), the Saalian Complex Stage encompasses the period from the end of the Holstein Interglacial Stage (boundary between boreal and subarctic phase of the subsequent Fuhne cold phase) to the beginning of the Eemian Interglacial Stage (beginning of the birch zone). After these specifications, the Saalian proves to be a complex unit including several cold and warm fluctuations, whereas the latter may even reach the character of an interglacial.

The Lower Saalian Complex Stage, i.e. the period between the end of the Holsteinian Stage and the first Saalian ice advance, is characterized by extensive valley-widening and intense accumulation of fluvial gravels. In the exposures (lignite open pits) of the type region in central Germany, a generally continuous, 5–20 m thick coarse sand and gravel terrace is observed (Eissmann *et al.*, 1995). This important stratigraphic marker horizon separates the Elsterian and Saalian glacial sequences. In many profiles, several successive generations of ice wedge casts are found. Silty intercalations are often disturbed by cryoturbation. However, this terrace complex reflects changing climatic conditions during the lower Saalian substage. There is some evidence in north-central Europe of at least one pronounced warm event (Dömnitz warm Stage in north-eastern Germany after Erd, 1965 and as a synonym Wacken warm Stage in north-western Germany after Menke, 1968), possibly even of two warm periods after Urban (1995, this volume). However, these warm phases

(Reinsdorf, Schöningen) are documented as incomplete pollen sequences. In no case are they separated by glacial sediments and stratigraphically they are situated before the first Saalian ice advance. At least for the Schöningen Interglacial (Urban, 1995), which probably correlates with the Wacken/Dömnitz warm Stage, $^{230}\text{Th}/^{234}\text{U}$ dates are available, suggesting a correlation with MIS 7 (see Urban, this volume), whereas the Fuhne cold Stage just after the Hostenian, which is only documented with periglacial deposits, could be equivalent to MIS 8.

Comparable temperate conditions in between a periglacial climate both before and afterwards have been documented in the Netherlands (Zagwijn, 1985; Vandenberghe, 1995). This temperate interval (Hoogeveen) also preceded the advance of the Saalian land ice. Similar to Wacken and Dömnitz, it is described rather as an interstadial with interglacial character than a full interglacial based on the absence of *Abies* and thermophilous genera such as *Hedera* and *Buxus* which do occur in the underlying Holsteinian beds.

The equivalent of MIS 7 in the continental European scale is well developed in southern European long sequences from the Massif Central, France (Reille *et al.*, 2000). This stage is characterized by three warm phases interrupted by stadials. It is interesting to note that none of these warm intervals in the Massif Central (named as Bouchet interstadials 1–3) reach the climatic level of a full-developed interglacial (such as in MIS 5e or 9 and 11).

Several ice advances are known to have occurred in north-central Europe during the Upper Saalian. In northern Germany, the subdivision into two major ice advances has been used since Woldstedt (1954). The older Saalian ice advance (the so-called Drenthe) marks the maximum extent of the Saalian ice sheet. The younger Saalian ice advance is named Warthe. It must be stressed that between the maximum of the Saalian glaciation (i.e. the Drenthe phase) and the Eemian

no true interglacial intervened. With a high probability, both Drenthe and Warthe are correlated with MIS 6.

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