A continent-wide framework for local and regional stratigraphies

Gijssel, K. van

Chapter 6

Synthesis: event correlation of the Middle Pleistocene terrestrial succession with the marine isotope stratigraphy

6.1 Scope of the marine isotope stratigraphy

In the previous chapters the multidisciplinary evidence from Northwest and Central Europe has been reviewed and grouped into unconformity-bounded lithogenetic units for natural geotectonic type regions. Palaeoclimatic and tectonic events at different spatial and temporal scale order, interpreted from regional markers and climate-indicators, are provisionally put into a continent-wide framework. Now the possibilities for the refinement of the low-resolution Middle Pleistocene terrestrial stratigraphy are sought by comparison and matching with the global marine isotope stratigraphy.

With the establishment of the marine isotope stratigraphy from the long continuous oceanic sequences and the polar ice cores, Quaternary stratigraphers have once more become aware of the incompleteness and heterogeneity of the local and regional land-based stratigraphies[1]. The fragmentary depositional records do not by far approximate to the long continuous and orbitally tuned record of climate history from the marine sequence. Local exceptions are some lake and mire sequences, that have yielded detailed pollen records, although hardly ever exceeding 100 ka. Of considerable chronostratigraphical potential, but not recording continuous deposition, are the wide-spread stacked loess-palaeosol sequences in Eurasia and China spanning many climatic cycles.

The isotope stratigraphy of alternating stages of relatively high and relatively low $^{18}O/^{16}O$-ratios is related to the former composition of sea water and indicative for the global ice volume stored on land (*cf.* Shackleton and Opdyke 1973). Therefore, the climatic variability shown in the marine isotope record, in the first instance, is a guide in further constraining the timing of the major glaciations in the northern hemisphere, their associated periglacial loess deserts and glacioeustatic sea-level fluctuations. Besides, the isotope record of the oceans (and ice cores) also serves as a global-scale climate proxy which can be used as a template for reconstructing Quaternary latitudinal climate zonations from non-glacial continental depositional sequences. Using the oceanic record as a relative time reference and stratigraphical tool for interregional correlation of palaeoclimatic events for Northwest and Central Europe should however be cautiously regarded.

Unfortunately, the oceanic record can only be indirectly correlated with the Middle Pleistocene terrestrial stratigraphy mainly because of the lack of chronological controls and marker horizons. Strictly speaking only comparison of interpreted palaeoclimatic event-stratigraphical units is feasible. To what extent these diverse local- and regional-scale terrestrial climatic signatures correspond to the MIS and their informal boundary levels, discussed in *section 2.4.3*, needs to be discussed. The evidence for repeated large-scale ice-sheet expansions, periglacial loess cycles and high sea-level stands support the assumptions made in *chapter 2* that large-scale climatic change, as can be indirectly observed in the marine isotope record, is a global phenomenon. Extreme palaeoclimatic events are reflected in both global and local records. Moreover, the close correspondence of local continuous lacustrine (pollen) records to the oceanic record shows the potential of the latter as a basis for a worldwide correlation of the Quaternary succession. This supports the use of the oceanic oxygen isotope record in the next sections as a reference frame to define an improved sequence of semi-synchronous geological and biological events for the Middle Pleistocene in response to zonal climate fluctuations on the European continent. Global matching is done at two scale levels:

- Matching of evidence of 4th scale order ‘climato-cyclic’ events of global significance that are interpreted from the wide-spread unconformity-bounded genetic sequences.
- Matching of palaeoclimatic evidence preserved in small-scale sequences and soil complexes in order to bridge the gaps between two subsequent global-scale events.

Considerations about this approach have been discussed in *section 2.5.3*.

6.2 Trend-matching of the land-based Middle Pleistocene framework with the marine isotope stratigraphy

6.2.1 Connecting the oceanic record with land-based events

The marine isotope stratigraphy reveals eight major cycles of global glaciation within the Brunhes Chron and two more in the upper part of the preceding Matuyama Chron, reflecting an increase in the intensity of glaciations from about 900 ka. The isotopic cycles of approximately the last 700 ka comprise an average 100 ka period frequency of which the durations range from 88 to 118 ka. Although amplitudes differ, the cycles generally end with a $\delta^{18}O$ maximum followed by a strong decrease to an isotopic minimum (= deglaciation/termination).

Pronounced $\delta^{18}O$ isotopic maxima during the last 700,000 years occurred in the final parts of MIS 2-4, 6, 12 and 16 (Shackleton 1987) suggesting that only during these four cold isotope stages have climatic conditions in Europe been sufficiently severe and sustained to permit the Fennoscandian ice-sheets to expand into the area south of the Baltic (Boulton *et al.* 1997). Moreover, these most intensive $\delta^{18}O$-peaks seem to coincide with the thickest units in the loess-palaeosol record, i.e. the cycles B, C, F and H in the Central European succession (Kukla 1975). On the other hand, there are the weakly expressed $\delta^{18}O$ maxima of MIS 8 and MIS 14 which may indicate periods of less extensive glaciation and loess accumulation. Marine transgressional phases in the North Sea and Baltic Sea margins, immediately following major glaciations, can be fixed to the warm isotope substage peaks succeeding a glacial stage $\delta^{18}O$-maximum[2]. An idealised correlation scheme based on these assumptions then corresponds to *Figure 6.1*.

However, there are ice-sheet developments other than the Fennoscandian/British ones to take into account for the northern hemisphere. Besides minor glaciations that have occurred in Iceland, Greenland and alpine regions such as the Himalayas, the Alps and the Cordillera, the largest part of the total ice volume during the glaciation cycles was the Laurentide ice-sheet on the North American continent. Stratigraphical and chronometric data, mainly K/

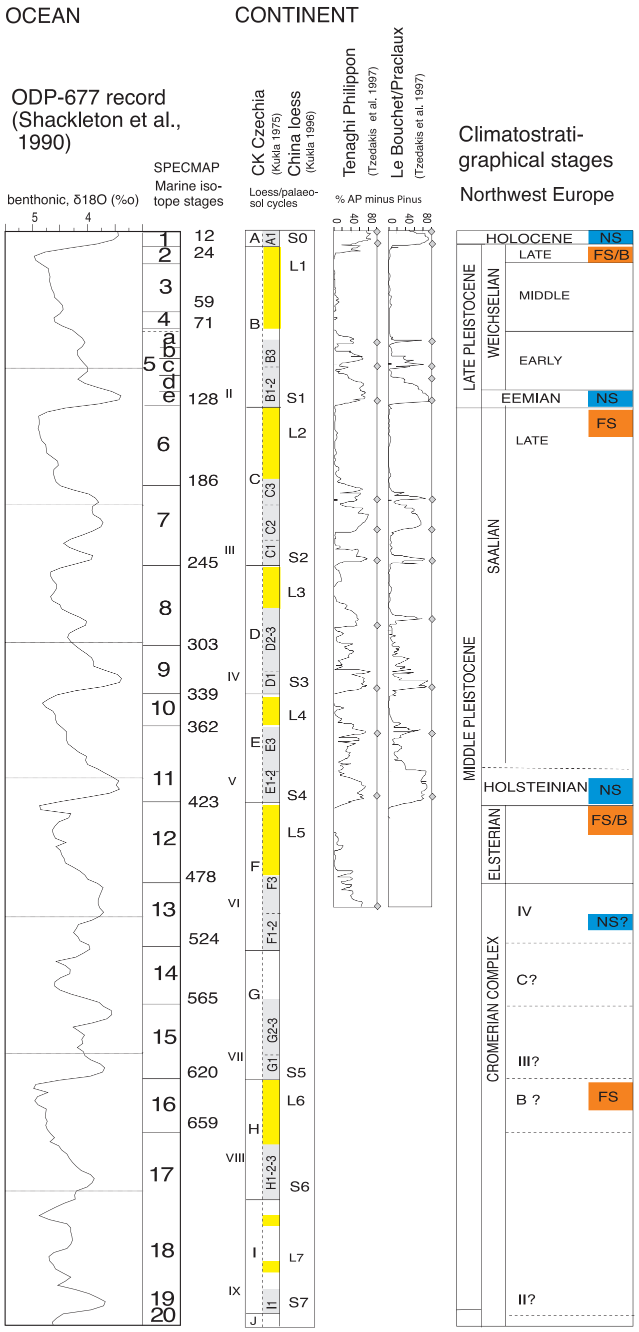


Figure 6.1: Idealised correlation diagram of the Central European terrestrial loess records (Kukla 1975) and Northwest European climatic 'stages' (including the Fennoscandian/British glaciations and North Sea marine transgressions) with the marine isotope record ODP-677 and the MIS. The loess record of China (Kukla 1987) and the local pollen records from Tenaghi Philippon and Lac du Bouchet (taken from Tzedakis *et al.* 1997) are given for comparison.

Ar and Ar/Ar dates from tephras intercalated in glacial sequences in the Cordilleran region, demonstrate that the late Quaternary glaciation events correspond rather well with the marine isotope record. However, this direct correlation should be considered tentatively (Fullerton & Richmond 1986) and is no proof for the expansion of the Laurentide glaciations. Independent radiometrical dates from a calcite vein at Devil's Hole, Arizona (Winograd *et al.* 1992) largely confirm these palaeoclimatic trends, although there are differences in phases and amplitudes compared to the marine isotope stages which have to be explained in more detail.

Marine isotope and regional glaciation maxima may not therefore always be exactly synchronous. Moreover, maximum glaciation limits of the different continental ice-sheets do not necessarily correspond to each other nor do they coincide with the most extreme $\delta^{18}O$ isotope maxima. Such properties may explain the remarkable discrepancies in the number and distribution of glacial sedimentary cycles recorded in the fragmentary Middle Pleistocene regional sequences of mid-latitude Europe. In spite of this indistinct relationship between the amplitudes of the isotope ratios and the regionally different glaciation limits, the trends in the oxygen isotope curves can at least be used as a basis for further confining the independent terrestrial chronostratigraphical evidence from the European non-glacial terrestrial record, such as regionally dated volcanic ash layers, secondary carbonates and biostratigraphical markers.

6.2.2 Connecting the terrestial record with marine isotope events

The correspondence of the terrestrial large-scale events to the marine isotope stratgraphy is closely related to the following questions:

- During which parts of the MIS-intervals were duration and intensity of cooling sufficient to produce ice-sheet expansions into the southern Baltic and further, into the southern North Sea basin and the Russian Plain, and how do these relate to the northern Alpine glaciations?
- To which periods of periglacial loess deposition in Central Europe and Asia do the glacial cycles correspond?
- To what extent does climatic and neotectonic evidence from (unconformities in) the fluvial terrace systems relate to the glacial cycles?

Much of what is known about these points comes from the well-documented chronostratigraphy and climatic history of the Late Pleistocene. It is generally agreed that the Weichselian Fennoscandian, Devensian British and Würmian Alpine cycle B glaciations correspond to MIS 2-4, coinciding with the loess accumulation of cycle B (Kukla 1975) in the Central European extraglacial areas. Maximum glaciation limits were reached during MIS 2, a less extensive ice-sheet advance occurred during MIS 4, but did not spread outside Scandinavia. Radiocarbon dates estimate the age of the Weichselian glaciation maximum just south of the Baltic in MIS 2 at about 20 ka BP[3] (Boulton *et al.* 1985). Modelling suggests that ice-sheet advancing over lowland Northwest Europe during the Weichselian glaciation was restricted to the time period between 25 -18 ka (Van Weert *et al.* 1997). The durations of earlier ice-sheet cover peripheral to the Fennoscandian Shield probably never exceeded 20,000 years. Deposition of loess in periglacial deserts hold a wider time-range. Indicative for the duration in which deposition may take place, although not continuous, may be the period from MIS 4 through MIS 2 comprising some 60 ka. Because of their polygenetic character, fossil soils in first instance give overall time-ranges filling the gaps in between two successive MIS-fixed subaerial units in which they have formed. Since preservation potential is highest for the lowermost B(t)-horizon, representing the first post-sedimentary soil formation processes, these may therefore be equated to the warm marine isotope substage following the loess accumulation.

The Eemian sea-level maximum in the North Sea and the land-based Eemian Stage type forest vegetations broadly correspond to MIS 5 substage e (*cf.* Sánchez-Goñi *et al*. 1999). Stratigraphical relationships and glacio-isostatic interference in the North Sea basin confirms the dating of the transgressive marine sequences succeeding a major glaciation event, a phenomenon which is less clear in the marine terraces along the Channel or the Atlantic coast. Durations of transgressional phases covering the southern North Sea may be in the order of some thousands to 10 ka. Timing of the highest sea-levels however is regionally determined (Mörner 1980, Lambeck 1993).

The correspondence of the Saalian Fennoscandian glacial cycle C to MIS 6 is generally accepted nowadays. MIS 6 also most probably includes the youngest Alpine Rissian (III) glaciation and the Central European loess C accumulation. Some reservations have to be made for Eastern Europe where correlation of glacial sequences appears to be more complicated.

Serious chronostratigraphical problems arise further back in the Middle Pleistocene. This is illustrated in the correlation scheme of *Figure 3.2* compiled by Kukla (1977). In particular the age, or better time-range, of the Fennoscandian Middle Pleistocene glaciation events is not entirely resolved. Although the Elsterian glaciation has produced a distinct glacial sequence, its chronostratigraphical position has remained a matter of debate until recently. Since the first volcanic products of the East Eifel region, K/Ar- and Ar/Ar-dated at about 600 ka, underlie the Elsterian glacial sediments in the southern North Sea basin, this glaciation cannot be as old as MIS 16. Because Mollusca in the subsequent marine Holsteinian North Sea sequence are dated to older than 300-350 ka, i.e. equivalent or older than MIS 9, the Elsterian glaciation must be assigned either to MIS 12 or 10. Correspondence with the latter must be taken into account because of different stratigraphical interpretations and interregional correlations. Both options will be discussed. The Elsterian glaciation is assumed to be time equivalent with the oldest Alpine Rissian (I) glaciation.

Wide-spread glacial sequences predating the Elsterian glaciation are, outside Scandinavia, only found in eastern Europe. The southernmost glaciation limit is found in the Don river basin in the Russian Platform type area. Since its stratigraphical position is below the *Mimomys/Arvicola* boundary, which is contemporary in the Middle Rhine region with the first East Eifel volcanic activity at about 600 ka, and its deposits are normally magnetised, the Donian glaciation most likely corresponds to MIS 16. On other grounds, this may also be true for the northern Alpine Mindelian glaciation.

The lower boundary stratotype of the Middle Pleistocene at the Brunhes/Matuyama geomagnetic reversal approximates to the MIS 20/19 transition at termination IX. Since there are no clear 4th-order climatic signals prior to the Donian glaciation, no related event-stratigraphical boundary levels can be set for this period.

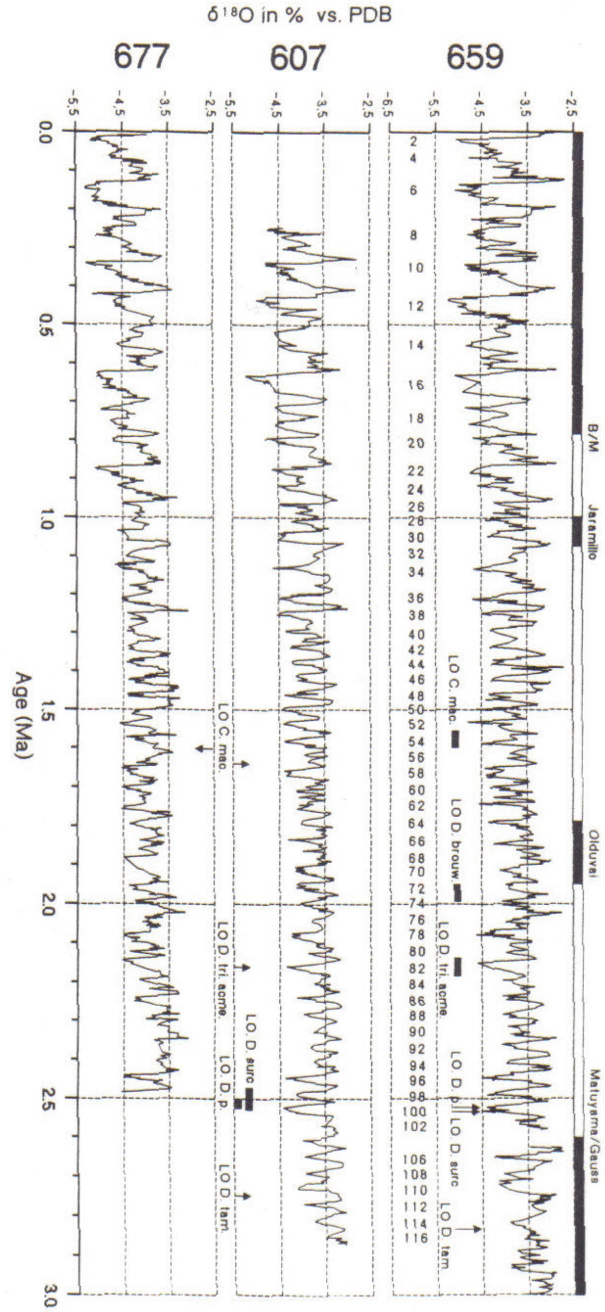


Figure 6.2: Correlated (benthic)□^{18}O core records from ocean sites ODP 607, ODP 677 and ODP 659 (taken from Tiedemann *et al.* 1994). Records are plotted using the site 677 timescale. Isotope stages are labelled. Age ranges for palaeomagnetical and biostratigraphical boundaries are plotted for comparison.

6.3 Global time-stratigraphical settings for the terrestrial Middle Pleistocene subseries

6.3.1 Marine isotope stage boundaries: scale and resolution

The ratio of the $^{18}O/^{16}O$-isotopes as preserved in the rests of fossil foraminifera in the deep-ocean sediments is dated by ^{14}C, U/Th and palaeomagnetic reversals, mostly by extrapolation. Since the mid-1970s its record has recurrently been calibrated with new palaeomagnetic data and has been statistically tuned with the astronomical time scale of the Earth's orbit (Hays *et al.* 1976, Johnson 1982; Imbrie *et al.* 1984; Martinson *et al.* 1987, Shackleton *et al.* 1990, Lourens *et al.* 1996). This has provided a relatively high resolution time scale. Imbrie *et al.* (SPECMAP group 1984) have generated a synthetic signal of global ice-sheet fluctuation for the last 0.75 Ma. Their isotope curve was constructed from many core sequences from the northern hemisphere and therefore is an average signal. Timing of the marine isotope stages, however, differs slightly between the different cores. Notwithstanding, the trends are confirmed from several single deep-sea core records by Martinson *et al.* (1987), and later Shackleton *et al.* (1990: using the Pacific ODP-677 lag) and Bassinot *et al.* (1994; using the Atlantic ODP-607 record off Morocco) among others. Since the SPECMAP record was calibrated to about 700 ka, the latter two cores (*Fig. 6.2*), extending through the whole Quaternary Period, are used here as reference profiles for the early Middle Pleistocene.

The stage boundaries, as defined by the SPECMAP group, are rather arbitrarily placed at the midpoints of the steep ($\delta^{18}O$ increases, i.e. at the terminations of the glacial-interglacial transitions (*cf.* Broecker and Van Donk 1970). Terminations are compromise dates which serve as worldwide averages for the age of the *deglaciations*. Deglaciations comprise relatively short intervals of exceptionally rapid $\delta^{18}O$-increases in the ocean waters, as a result of rapid melting of ice-sheets, starting from a 'full glacial' maximum into an 'interglacial' optimum (*cf.* Kukla and Cilek 1996). These rapid climate changes represent the least *time-transgressive units* in the marine isotope stratigraphy, although their time intervals range from 10 to 20 ka. Nevertheless, the fact that several time-transgressive boundaries of the relatively-dated mid-latitude terrestrial sequences lie within these deglaciation intervals can serve as a basis for extrapolation and correlation of interpreted events and isotope stages at a glacial-interglacial scale.
Because of their wide time-range, the MIS transitions only provide a rough indication of the timing of the terrestrial boundary levels. How accurate are the stage boundaries of the oceanic isotope record for use as arbitrary 'remote' boundary levels in the lack of terrestrial alternatives? The problem of using boundaries in the ocean-core isotope profiles is one of scale. It is very difficult to identify where boundaries should go when the scale of the isotope plots is so small. The detail is not always visible and time lags of up to thousand years must be considered because of bioturbation (Shackleton 1977). Moreover, the boundaries between the isotope stages are not drawn at fixed points in the marine sequences. They are graphic artefacts and do not represent real natural events. The variability of the timing of the isotope stages in different cores is the result of a combination of the graphic interpolation of the terminations and the impact of bioturbation. They together limit the chronostratigraphical resolution of ocean-bottom sediment. Therefore it is not possible to use the isotope sequences for 'golden-spike' boundary definition. Dates for the boundaries between the MIS transitions are thus in reality rather difficult to determine, extrapolation being the only reliable way of achieving a relatively reliable number.

6.3.2 Marine isotope stage boundaries and their terrestrial equivalents

Boundary stratotypes in the Middle Pleistocene terrestrial sequences are relative and lack adequate chronostratigraphical definitions (*chapter 2*). Chronological control to define (sub)stages is largely missing. The recommendation in the last edition of the ISG (Salvador *et al.* 1994), to fix corresponding physical marker units as intervals between designated boundary stratotypes, only applies to the Brunhes/Matuyama geomagnetic reversal as the lower boundary of the Middle Pleistocene. There are, however, no such other boundaries at or close to critical positions within the Middle Pleistocene sequences and palaeoclimatic events. The boundary levels in the marine isotope stratigraphy are a reasonable alternative, although they cannot form the basis for a classification or chronology of the land-based sequence. They are used as event-stratigraphical reference boundaries for comparing the spatial and temporal variability of their terrestrial equivalents. Kukla's 'marklines'[4] in the stacked loess sequences of Central Europe, the lower bounding unconformities of coastal marine sequences in the North Sea margins and the increasing tree pollen contents in pollen records from lake sequences, are, notwithstanding their diachronism, boundary levels of climate-driven events corresponding to different starting points within the global-scale deglaciation intervals.

Available local records and dates may provide a more precise age and may gain higher resolutions within the deglaciation intervals. The deglaciation phase of MIS 6, which began roughly from about 150 ka, to the warm climatic event of MIS 5 substage e is well documented and known in more detail from other types of records: a) $\delta^{18}O$-records from ice cores (GRIP-members 1993) and several oceanic cores, b) ice-rafted detritus accumulation rates from marine records in the Norwegian Sea (Baumann *et al.* 1995, Mangerud *et al.* 1996, and compared with glacier fluctuations in Western Scandinavia), c) foraminiferal analysis of shelf records from Denmark (Seidenkrantz 1993), d) pedostratigraphical records from France (Van Vliet-Lanoë 1995, Antoine 1997), pollen assemblages from marine cores off-Portugal (Sánchez-Goñi *et al.* 1999) and f) speleothems from Norway (Lauritzen 1991, 1995). This evidence reveals high order climatic fluctuations, of the Younger Dryas type, among which a short-termed climatic oscillation at about 130-135 ka just prior to the MIS 6-5e boundary level at 128 ka: the Zeifen-Kattegat oscillation (Seidenkrantz *et al.*1996). Whether this deglacial climatic fluctuation represents the Warthe re-advance phase is not clear as yet. Evidence for an independent Warthe glacial cycle is weak, however, since most evidence from non-glacial intermediate sequences has not revealed a marine transgressional maximum in the North Sea basin nor a full forest vegetation climax in lacustrine sequences overlying the regional Drenthe/Odra/Dniepr synthems (*section 4.3.1*).

Direct correlation of pollen evidence in deep sea-cores off the Iberian peninsula confirms an event-stratigraphical relationship with the $\delta^{18}O$-minima peak for MIS 11, the Holsteinian (Desprat *et al.* 2005), corresponding with a 32,000 year forest vegetation record. The time-range of forested periods is variable and geographically determined. Vegetation cycles, such as those in the lake sequences from Tenaghi Philippon and Lac du Bouchet, also reveal shorter climatic oscillations which may match marine isotope substages. They need, however, a MIS-fixed base for matching. In some cases time lags may be very short as is shown by varve counting in lacustrine records from Marks Tey (Turner 1970) and Bilshausen (Müller 1974).

6.3.3 Tentative substage boundary levels for the Middle Pleistocene in Northwest and Central Europe

The relatively well-dated last deglaciation phase (MIS 2/1) took place between about 18 and 6 ka BP. The age of termination I is dated at about 12.5 ka (Bard *et al.* 1992), but is time-transgressive between about 9 and 13 ka from different deep-sea cores. This date could logically be taken as the global Pleistocene-Holocene boundary level. Based on land evidence, the formal lower boundary of the Holocene for practical reasons is placed at 10 ^{14}C ka BP by the INQUA-Commission on Stratigraphy (Hageman 1969) in the absence of an internationally defined stratotype or GSSP. A boundary stratotype is now being defined in the NGRIP ice-core on Greenland (Walker *et al.* in press).

Just as the lower boundaries for the Holocene Series and for the Late Pleistocene Subseries, arbitrarily defined at 128 ka (termination II) within the deglaciation phase of MIS 6 to 5e between 135 and 122 ka (Gibbard 2003), at least two provisional Middle Pleistocene lower Subseries boundary levels valid for both the glaciated and non-glaciated areas in Northwest and Central Europe are placed here at relevant deglaciations further back in the marine isotope record:

- The lower boundary level of the late *Middle Pleistocene* corresponding to the deglaciation of MIS 12/11 substage c for which an average date of 423 ka (termination V) is interpolated (*section 6.3.3*),
- A lower boundary level within the *early Middle Pleistocene* corresponding to the deglaciation of MIS16/15 at about 620 ka (termination VII), subdividing this period into an part A followed by a part B that begins at the 620 ka point (*section 6.3.4*). The base of the early Middle Pleistocene coincides with that of the Middle Pleistocene, i.e. the B/M boundary, as is proposed by Richmond (1996).

Fixing the terrestrial boundary levels to these MIS transitions is of importance because they confine the timing of the most extensive Middle Pleistocene glaciations and of the loess/palaeosol cycles in Northwest and Central Europe, which represent the main building blocks of the regional stratigraphies within the continent-wide framework. The correlation scheme in *Figure 6.3* is based on these links between the oceanic and the terrestrial mid-latitude European Middle Pleistocene sequences and will be a guide in the next sections in discussing facts and arguments on the chronostratigraphical positions of the latter.

6.3.4 Evidence for the early / late Middle Pleistocene boundary level at the MIS 12/11 transition

In Northwest Europe this boundary level represents the chronostratigraphical boundary between the Elsterian Stage and the Holsteinian temperate Stage. Of crucial importance for their correspondence to the marine isotope stratigraphy is the timing of the coeval Fennoscandian and British cycle F glaciations and the subsequent Holsteinian marine sea-level maximum in the North Sea type region. Interregional correlation of these large-scale events with other regional stratigraphies, such as with the upstream Lower and Middle Rhine stratigraphy, the Central European terrace and loess stratigraphy, and with the reference pollen record of Lac du Bouchet in the Massif Central, relies on:

- The tephrochronology in the East Eifel region,
- The stratigraphical position of the tephras interbedded in the Middle Rhine subaerial and fluvial sequences,
- The heavy mineral composition of the subaerial and fluvial sequences in this area and downstream of the river Rhine,
- Various biostratigraphical markers in fluvial and lacustrine sequences and
- The relative time correspondence of the remarkable erosional breaks in several early Middle Pleistocene river terrace systems.

The best dates to estimate the lower boundary level for this division with are between 370-450 ka, coming from K/Ar- and Ar/Ar-dates of pyroxene-rich tephras attributed to the Rieden phase of volcanic activity in the East Eifel region. These markers are represented in the Middle Rhine Kärlich H sequence, at Miesenheim I and in and above the Middle Rhine mMT gravel terrace sequence at Ariendorf. Their intercalated tephra beds have been dated at around 450 ka and are associated with cold-climate conditions equated to MIS 12. The palaeosol complexes on top of these cold period units are overlain by tephras dated to between 370 ka (Kärlich *Brockentuff*) and 420 ka (Ariendorf *Selbergit tuff*), which can therefore be attributed to MIS 11. The predominance of pyroxenes in the heavy-mineral assemblages in the upper part of Middle Rhine Kärlich G sequence and in the mMT terrace gravels indicate that the pyroclastic deposition was already taking place during MIS 13 and continued into MIS 12 and MIS 11.
The dates for the East Eifel Rieden eruption phases in the Middle Rhine fluvial and subaerial sequences, together with the MIS trend matching, are used to determine the timing of the subsequent erosion, northward fluvial transport and incorporation of the derived volcanic minerals in the alluvial sediments of the Anglo-Dutch/ North Sea sub-basin. Since high augite contents first occur in the heavy-mineral spectra of the North Sea Noordbergum marine intercalation (= Cromerian IV Substage *cf.* Zagwijn) this early Middle Pleistocene sea-level highstand can be assigned at the earliest to MIS 13. Based on the stratigraphical position of the Elsterian glaciation in this type region, intermediate of augite-rich fluvial synthems of the Anglo-Dutch North Sea Urk sequence group, it can be concluded that MIS 12 is the best option for its correspondence to the oceanic isotope record. The maximum extent of the Elsterian glacial advance then took place prior to the release of the augite-containing *Selbergit tuff* in the East Eifel region and subsequent fluvial transport by the river Rhine to the north.

Based on similar interregional correlations with the Dutch stratigraphy, but using early radiometric dates on the release of the augite-bearing *Selbergit tuff* at around 400 ka, Zagwijn (1986, 1992) attributed the marine North Sea Noordbergum intercalation to MIS 11 and the subsequent glacial advances of the Elsterian glaciation to MIS 10. In this option the early/late Middle Pleistocene boundary level would be assigned to the deglaciation of MIS 10/9 (termination IV at 339 ka). This differs from by about 100,000 years with the present proposal[5], assuming that deposition of augite-rich alluvial sediments in the Anglo-Dutch North Sea subbasin may already have taken place during a 100 ka cycle earlier, that is from MIS 13.
Additional evidence for equating the lower late Middle Pleistocene boundary level with MIS12/11 comes from biostratigraphical evidence of marine and lacustrine deposits assigned to the Holsteinian Stage s.s. and their supposed correlation with the Praclaux forest vegetation optimum in the Massif Central Lac du Bouchet maar lake record. The late-temperate phase of many 'Holsteinian' pollen spectra contain the last appearance datum (LAD) of *Pterocarya* pollen which is tentatively used as a biostratigraphical marker in the reference pollen record of the Lac du Bouchet that coincides with MIS 11 (De Beaulieu and Reille 1995). Since these pollen records represent the first forest climax of interglacial type following the Elsterian/Anglian glaciation maximum and accompanied by high sea-level stands in the North Sea area, they most likely correspond to substage c of MIS 11. Furthermore, lower and middle section fine-grained fluvial channel deposits of several European rivers contain *Pterocarya* pollen and the characteristically Holsteinian mollusc *Viviparus diluvianus*. Among others, the so-called '*Krefeld clay beds*' in the Lower Rhine Embayment type region which lie conformably on top of the MTIIIa- or '*Rinnenschotter*' cold period aggradation, equivalent to the Middle Rhine mMT sequence and attributed to MIS 12.
The absence of *Pterocarya* in the forest pollen assemblage of the Middle Rhine Kärlich Seeufer lake sequence, dated to the first warm climate event following the deposition of the *Brockentuff* at 396 ± 20 ka, points to correspondence with MIS 9 and confirms the timing of the Elsterian-Holsteinian boundary level at the MIS 12/11 transition. This conclusion is supported by most dates on carbonates and fossils from Holsteinian Stage deposits (*section*

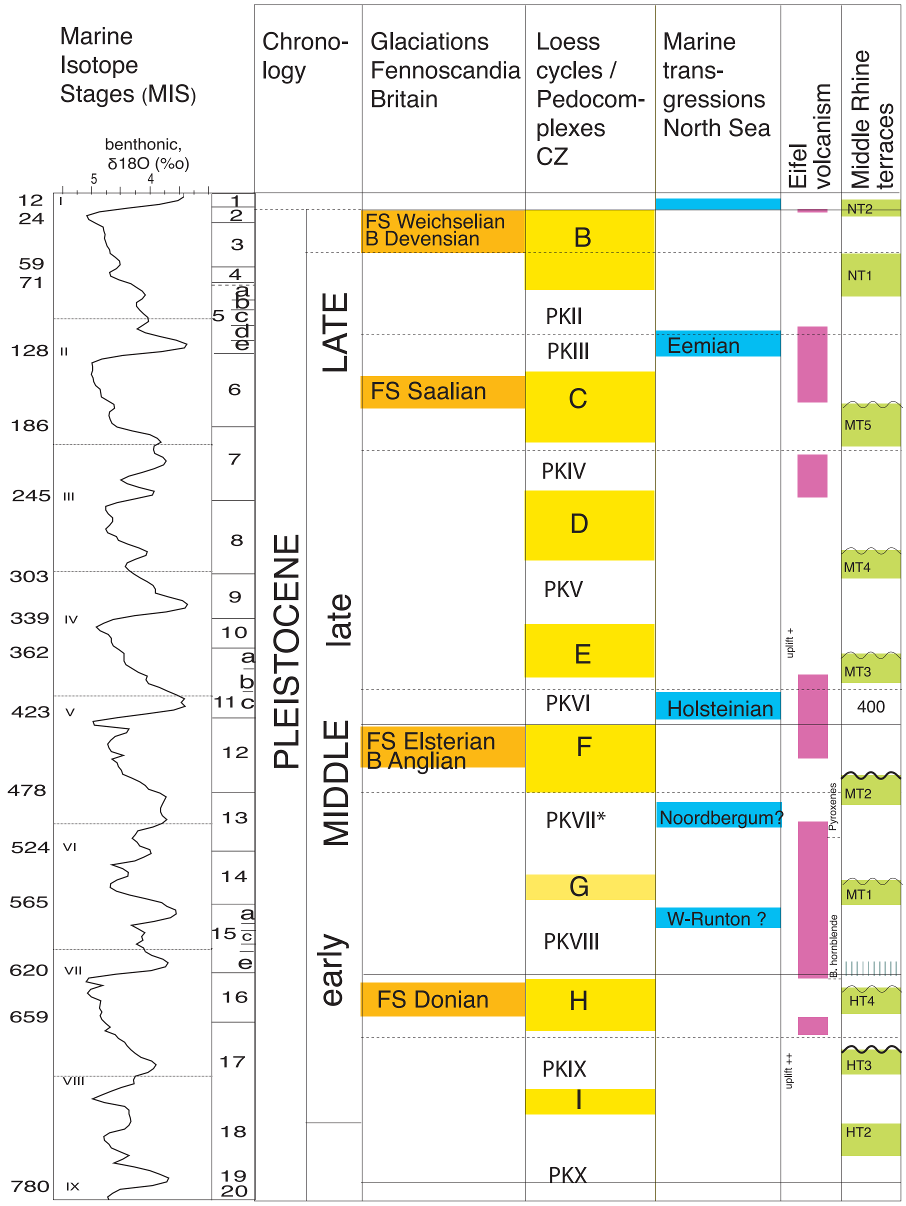
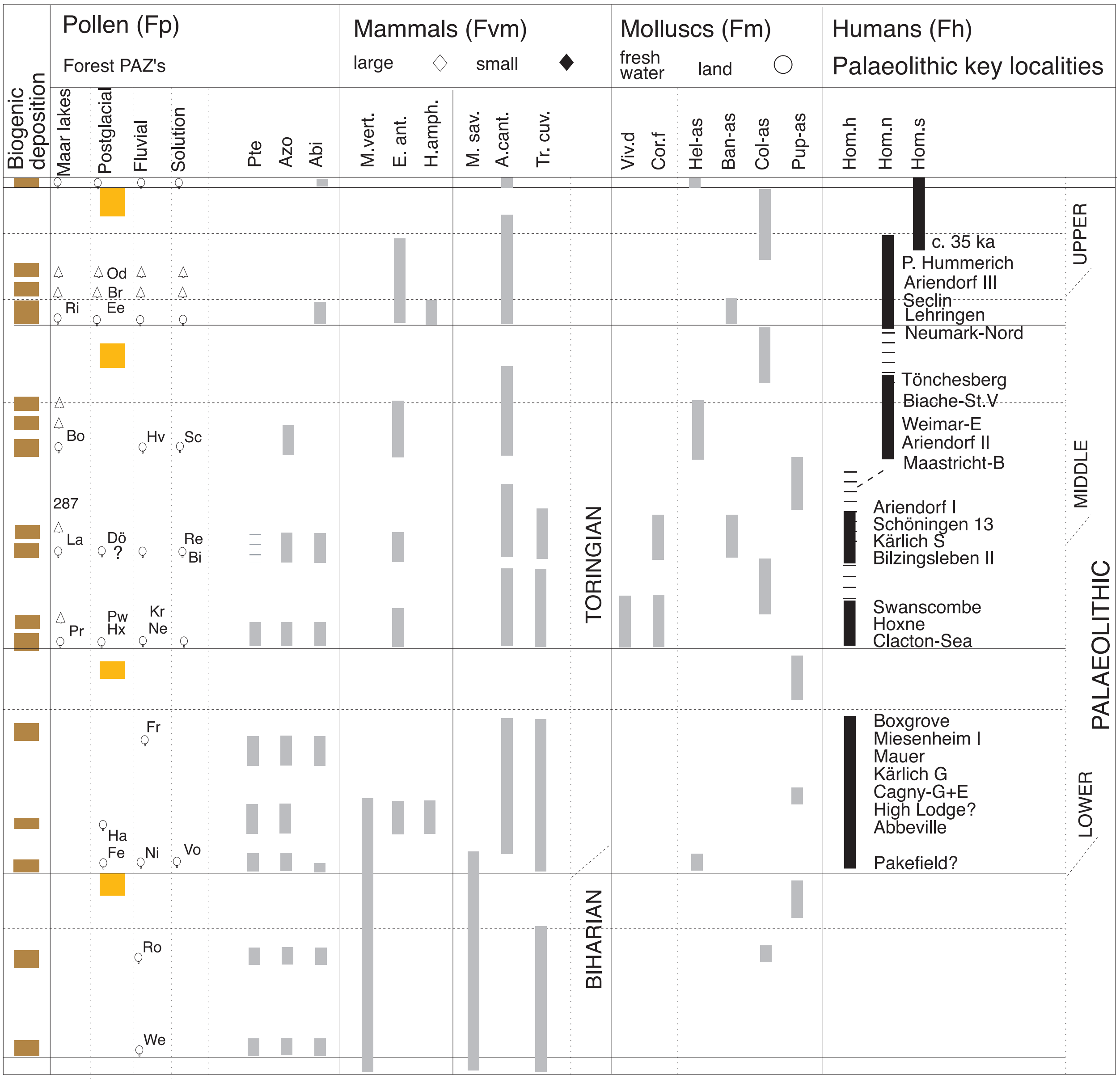


Figure 6.3 Correlation of the terrestrial event-stratigraphical subdivision of the Middle (and Late) Pleistocene for Northwest and Central Europe with the marine isotope stratigraphy, on a linear time scale.

3.4.3). Similarly, Ehlers, Gibbard & Rose (1991) for Europe attributed MIS 11 as the most probable correlative of the Holsteinian Stage, as most workers from Britain and the European continent do today.

Indirect correlation of the strong basal unconformities of the pyroxene-dominated mMT- and '*Rinnenschotter*' synthems in the Middle Rhine and Lower Rhine Embayment type regions and of the subaerial Kärlich H I synthem, dated between 450 and 500 ka, with similar erosional phenomena documented in other Central European terrace (and loess) sequences, may provide a link between the chronostratigraphical position of the Elsterian glaciation and fluvial response to tectonic movements in the extraglacial stratigraphies (*section 4.4.3*). The exceptionally deep incision phase in the Rhineland type regions is also found in, and may be correlative with, a) the middle sections of the Elbe drainage basin, where the so-called '*Frühelsterterrasse*' (EET) sequence is immediately overlain by the Elsterian glacial sequence, and b) the terrace stratigraphy of parts of the Danube drainage basin. The latter concern the erosional breaks separating the northern Alpine Foreland alluvial Younger *Deckenschotter* supersynthem from the *Hochterrassen* supersynthem and the eastern Alpine Foreland Červený Kopec 3 fluvial terrace sequence from the CK2 terrace sequence. The initial age of these dissimilar downcutting and aggradation phases is intermediate between the Central European pedocomplex PKVII and the thick Central European loess unit F which are correlated to MIS 13 and MIS 12, respectively. Since



the erosional breaks are provisionally linked with fluvial response to (glacio-)isotatic rearrangements by Kukla and Çilek (1996), they may support their conclusion that the extensive Elsterian/Anglian/Alpine oldest Rissian (I) glaciations were responsible for these fluvial anomalies in the extraglacial areas and for the extreme changes in erosion base levels in the North Sea basin. Subsequent infilling of the incised valleys and the subglacial channel system, e.g. the Peelo Formation in the Netherlands, probably took place during the ice-sheet maximum close to the end of MIS 12.

To conclude: the assignment of the early/late Middle Pleistocene boundary level at the MIS 12/11 transition in the marine isotope stratigraphy (*Fig. 6.3*) would solve the chronostratigraphical problems concerning the north European glacial models in the correlation scheme (*Fig. 3.2*) and establish a link between the glacial and extraglacial terrace and loess stratigraphies. This lower boundary would then represent:

- The transition of the glacial deposits and unconformities associated with the Fennoscandian, British and Alpine glacial cycle F (Elsterian, Sanian 2, Okian, Anglian and the oldest Rissian) to the Holsteinian (Hoxnian, Mazovian and Likhvinian) non-glacial sequences of marine, lacustrine and fluvial origin in the glaciated type areas, including the transition to forest vegetation in these,
- The transition of the subaerial synthems equivalent to the Central European loess cycle F to the formation of soil complexes correlative with PKVI,
- The transition to the (coeval) fluvial sequences following the erosional unconformity of Central European cycle F in the terrace systems of the extraglacial type areas.

6.3.5 Evidence for the MIS 16/15 boundary level within the early Middle Pleistocene

Terrestrial evidence for an event-stratigraphical boundary level within the lower Middle Pleistocene succession coinciding with the MIS 16/15 transition (midpoint at 620 ka: termination VII) is only well-documented in eastern Europe. There the boundary level represents:

- The transition of the glacial sequences correlative to the Fennoscandian cycle H (Donian, Sanian I, Narevian, Servackian) glaciation event to the Russian Plain Muchkap and Polish Plain Ferdynandov non-glacial sequences of lacustrine and fluvial origin,
- The transition of the Russian Plain Borisoglebsk loess cycle to the formation of soil complexes correlative with the Russian Plain Vorona soil complex.

The latter transition is contemporary with that of the Central European loess cycle H to the soil complexes PKVIII and PKVII in Central Europe. PKVII contains rubified Bt-horizons ('*Braunlehm*') of forest soils among others, which are associated with intense warm and humid climate conditions probably during MIS 13. They are also found in several other type regions, among which the northern Alpine Foreland ('*Riesenboden*'). Here the Alpine Mindelian glaciation predates these pronounced soils of Bt-type and therefore most probably can be equated with the Donian glaciation.

Distinguishing criteria of the subsequent Russian Plain Muchkap/ Polish Plain Ferdynandov lake sequences concern:

- The presence of the *Mimomys-Arvicola* boundary,
- A characteristic bi-optimal warm stage type floral succession.

Although evidence of wide-spread cold climate events prior to the Elsterian glaciation is scanty in Northwest and Central Europe (*section 4.3.1*), extrapolation of this biostratigraphical evidence and interpreted palaeoclimatic and -environmental features also seem to justify a subdivision of the early Middle Pleistocene in these type areas. Their correlation with regional event-stratigraphical markers and independent dates show that:

- The *Mimomys-Arvicola* boundary in the Kärlich section occurs between the deposition of loess synthem F and the first depositional cycle of Kärlich subaerial sequence G. It, however, post-dates the Bt-type soil complex developed in loess unit F which is equivalent to MIS 15 (substage e),
- The West Runton marine synthem in East Anglia indicates a transgression in the North Sea basin which may correspond to MIS 13 or MIS 15 (substage a) and post-dating the Donian glaciation. Unfortunately, stratigraphical control is lacking and there is no equivalent in the North Sea basin. The estuarine deposits are overlying the warm-stage sequence of the West Runton Freshwater Bed (West 1996), containing *Mimomys savini*, and comparing well with the pre-Elsterian Voigtstedt warm-stage fluvial lake sequence in Germany based on mammal fauna,
- The *Mimomys-Arvicola* boundary roughly coincides with the first subaerial and fluvial synthems in the Rhineland that are characterised by the dominance of derived volcanic minerals, in particular brown hornblende, associated with the increase of East Eifel volcanic activity starting from about 570 ka and hence post-dating MIS 16/15 boundary level,
- This increase in volcanic activity follows the tectonic-induced transition of the Middle Rhine and Lower Rhine Embayment Upper Terrace (HT) sequence group to the Middle Terrace (MT) sequence group in these type areas. It also corresponds to the northward shift of the Lower Rhine course geographically separating the Lower Rhine Sterksel and Urk alluvial sequence group. The MIS 16/15 boundary level probably lies within the hiatus between their aggradation phases,
- The pronounced warm-climate soil complexes in the Lower Rhine Embayment HT3 and HT4 terrace sequences ('*Ville*') is equivalent to the pedocomplexes PKVIII and PKVII in Central Europe and probably correspond to the period MIS 15 to 13,
- The lake sequences of Harreskov and Ølgod (Andersen 1965) in Denmark rest on glacial sediments and their forest vegetation climaxes are very similar to that of the lowermost in the Polish Plain Ferdynandovian glacial lake sequence.

This evidence on the timing of the early Middle Pleistocene event markers and their correspondence with the MIS suggests that the transition of MIS16/15 is, at least for eastern Europe, a relevant boundary level for subdividing the period into a part A and a part B (*Fig. 6.3*). A complicating factor forms the *Mimomys-Arvicola* boundary which is post-dating the first Bt-soil horizons developed on the Central European loess units of cycle H and in the Middle Rhine Kärlich loess sequence F and therefore cannot be attributed to the first substage (e) of MIS 15. In addition, the position of the MIS 16/15 boundary level within the 'Cromerian Complex' Stage remains unclear. This will be discussed further in *section 6.4.2*.

6.4 Middle Pleistocene local-scale event correlations and integration of Palaeolithic sites

With the wide-spread evidence of the large-scale events representing the Middle Pleistocene loess depositional cycles in Eurasia and Central Europe, the glacial depositional cycles in northern Europe and the marine transgressional cycles in the North Sea basin, arranged within the MIS-fixed time frame (*Fig. 6.3*), a suitable chronology on the basis of event-stratigraphical criteria and indirect correlation for both the loess stratigraphy and the classical European glacial models has been established. This also corresponds to the megacycle principle of Kukla and Çilek (1996) based on the loess depositional cycles in China and Eurasia, although the lower boundaries of the units are set at the base of the Central European loess units: megacycle (MC) 1 starts with loess unit C, MC2 with loess unit F and MC3 with loess unit H. The loess units are equivalent to the Fennoscandian glacial sequences C (Saalian), F (Elsterian) and H (Donian), respectively.

The global correlations prove that a substantial part of the time represented in the Middle Pleistocene terrestrial records is locked in unconformities and intermediate sequences which are predominantly locally controlled and preserved. The correlation scheme in *Figure 6.3* will be used as a guide for summarising the development and stratigraphical positions of the local-scale Northwest and Central European events. The interpretation and correlation of these events have given much debate among researchers (*chapter 2*). Although their palaeoclimatic information, such as vegetational forest climaxes of warm-stage character in lakes and mires, modes of river deposition and soil complexes, also involve higher order (short-term) cyclicities/oscillations and local neo-tectonic effects, they nevertheless should correspond to the global-scale MIS-fixed framework. The nearest reference vegetational proxy records are those of Lac du Bouchet (Southeast France) and Tenaghi Philippon (Greece) which are also shown in *Figure 6.3* for comparison. Latitudinal and altitudinal differences in vegetational and soil development should be taken into account. Correlations of local evidence should be achieved by following the post-depositional succession from a large-scale MIS-fixed basal, un-

conformity-bounded, unit or a dated level upwards. The largest hiatuses are expected after levelling of glacial relief and below the next global-scale unconformity since erosional processes of their related events have generally removed the upper parts of the preceding post-depositional succession.
Within the scope of this research project, referred to in the preface, some conclusions on the stratigraphical position of Palaeolithic sites in Northwest and Central Europe within the MIS-fixed time frame are also integrated in *Figure 6.3* and discussed below.

6.4.1 Stratigraphical position of Late Middle Pleistocene local events (MIS 11-6: 423-128 ka)

The late Middle Pleistocene 'superstage'[6] spans about 300 ka and is correlative to MIS 11-6 between the boundary levels of MIS 12/11 (termination V at 423 ka) and MIS 6/5 (termination II at 128 ka). Its sequences are based by the Elsterian Fennoscandian glacial sequence F in northern Europe and CE loess sequence F, and equivalents, in the non-glaciated areas.

The best reference for warm palaeoclimatic events in Europe is the Lac du Bouchet pollen record, which shows seven forest vegetation climaxes during this time interval. The last occurrence of *Pterocarya* pollen in the forest assemblage zone of the Praclaux event (MIS 11) is a significant biostratigraphical marker for correlation. MIS 11 represents a period of marine transgression in the North Sea basin, small-scale fluvial deposition (with characteristic temperate freshwater molluscs), soil formation and local lake sedimentation showing a single climatic optimum in their pollen content and containing *Pterocarya* in a late-temperate phase. These sequences form the lower boundary of the late Middle Pleistocene in the glaciated type regions.

Firm evidence for large-scale (4th order) climatic events intermediate between the Holsteinian North Sea sea-level maximum and Saalian glaciation is largely missing in the European lowland areas because, next to the poor accessibility, extensive glaciation limits are not recorded. The cold MIS 10 and MIS 8 apparently constitute ice-free periods in the Northwest European lowlands. In Poland, on the other hand, evidence is found for ice-sheet expansions beyond the Fennoscandian Shield during the cold MIS 10, the Liwiec glaciation (Lindner 1988), separated by warm intervals. Unfortunately, the intercalated organic sediments here are not superimposed, which hampers correlation (Krzyszkowski 1991). In the western part of northern Alpine Foreland the Rissian II or '*Doppelwall Riss*' glaciation has been assigned to MIS 10 (Ellwanger *et al.* 1995).
Glacioeustatic sea-level maxima in the North Sea did not reach the present coast-line. There are, however, indications of high sea-level stands on the Atlantic coast and in the Channel area. Oceanic climate influence was very limited during MIS 7, because of the absence of *Abies* from the, few available, pollen spectra. Nevertheless, Meijer and Cleveringa (2003) on the basis of AAR data from molluscs report a marine transgression in the Netherlands during a warm event, introduced as Oostermeer, dated within MIS 7.
Most lake basins became silted up after MIS 11. At least the first part of one warm-climatic episode following the Holsteinian Stage is recorded in the North Sea basin margins at Wacken and Pritzwalk. These Wacken and Dömnitz warm events may be assigned to MIS 9(c). Further biostratigraphical evidence is predominantly preserved in upland small-scale basins related to local salt-tectonic features, denudation and volcanics, all of which show slightly non-standard pollen spectra, and in travertine springs, e.g. Bilzingsleben. The lake sequence of Bilshausen in the Thuringian Basin spans the entire MIS 9 (*section 5.2.3*). The age of the Middle Rhine Kärlich Seeufer (landslide) lake sequence can be dated in a warm event younger than 370 ka, implying that its vegetation optimum also corresponds to MIS 9. The lake and mire sequences of the Schöningen section (*section 5.4*) reveals at least two warm-climate type forest climaxes separated by major unconformities: the Reinsdorf warm climate event and the Schöningen warm climate event which can be attributed to MIS 9 and MIS 7, respectively. The stratigraphical positions of other local pollen evidence, e.g. Hoogeveen, Zbojno, is too uncertain to reach a firm conclusion regarding their ages, although their forest climaxes may point to correlation with MIS 9. Zagwijn (1990) tentatively considered the Hoogeveen temperate interval to belong to MIS 7. This period is also correlated with fine-grained fluvial deposits of the river Meuse at Maastricht/Belvédère in the Netherlands, that contain Palaeolithic artefacts, and is TL-dated to about 250 ka (Huxtable 1992). This age determination is in accordance with U/Th dates of 177-234 ka from the Schöningen peat deposits (Heijnis 1994).

Several late Middle Pleistocene archeological sites span the period MIS 11 to 6. On typological grounds, as well as on dated geological evidence, at least two phases of occupation can be distinguished during this period between the Elsterian and the Saalian glacial maxima (*Fig. 6.3*):

- One group dates from MIS 11 to 9. There is evidence for occupation during the late-temperate phases of two climatic optima. The first optimum coincides with the Holsteinian North Sea marine transgression and biogenic lake deposits that can be tentatively correlated to MIS 11c, globally dated around 420-400 ka BP. It should be noted that only British examples are known: Hoxne and Clacton-on-Sea. Archaeological findings from more eastward German sites, at Kärlich-Seeufer, Schöningen 13 (=Reinsdorf) and Bilzingsleben II, date from a later climatic optimum, which is probably MIS 9 (substage c: *c.* 330 ka BP). These late Middle Pleistocene Palaeolithic sites are the oldest known on the Central European continent.
- The second group of late Middle Pleistocene Palaeolithic sites can beyond doubt be attributed to MIS 7 and early 6, between 250-160 ka BP. They are preserved in travertine, fluvial terrace sediments and buried soils, formed under alternatively warm-temperate and boreal climate conditions.

6.4.2 Stratigraphical position of early Middle Pleistocene local events (B/M boundary - MIS 12: 780-423 ka)

The early Middle Pleistocene traditionally comprises the sequences that can be palaeomagnetically dated from the base of the Brunhes Chron to and including those deposited during the Elsterian glaciation and its most likely extraglacial equivalent, the Central European loess cycle F. The 'superstage' may regionally be further subdivided into a part A and a part B depending on local and regional stratigraphical evidence.

Part B is correlative to the period MIS 15-12. Its base is formed by the glacial sequences of Donian age in eastern Europe and CE loess unit H and equivalents in the non-glaciated areas. This period is striking by the absence of large-scale cold events prior to the Elsterian glaciation in both the glaciated and extraglacial areas. Central European loess cycle G, as well as Chinese loess records, indicate only minor cold in MIS 14, which is confirmed in the Kärlich G subearial sequence in the Middle Rhine type area. Instead, many local sequences are preserved that reflect several warm climatic events that can be attributed to MIS 15 and MIS 13.

During this period the first evidence of hominid occupation in mid-latitude Europe is also found. This corroborates the conclusion of Roebroeks and Van Kolfschoten (1995) that all sound evidence of early human occupation is found in local sedimentary sequences that post-date the Brunhes/Matuyama palaeomagnetic reversal at about 780 ka (MIS 19). Early Middle Pleistocene sites pre-dating the glacial sequences of the Elsterian/Anglian glaciations probable do not exceed MIS 15 in age (*Fig. 6.3*, *Epilogue*). Their communities, associated with bifacial industries, constitute the oldest occupation group which is geographically located in Atlantic western Europe, along the coasts of the Channel, e.g. at Boxgrove, and in the valleys of some large river systems (Somme, Rhine) draining chalk areas.

Part A is correlative to the period corresponding to MIS 19-16. The Brunhes/Matuyama geomagnetic reversal in various local sequences is a clear chronostratigraphical boundary. However, large-scale palaeoenvironmental or palaeoclimatic signals of the 4th order are missing from this time interval. There is also poor bio- and chronostratigraphical control in the non-glacial sequences. Evidence for this period is related to the last event-stratigraphical boundaries in the Early Pleistocene which can probably be set at a glacial maximum that corresponds to MIS 22 (900 ka) and a neo-tectonic cycle boundary of increased uplift rates that began at about 1.2 Ma. Fluvial terrace complexes corresponding to these intervals (MIS 22-16) include the Middle Rhine - and Lower Rhine Embayment Upper Terrace (HT) sequence groups and the northern Alpine Foreland Younger *Deckenschotter* (*section 4.3.3*). The latter contains fluvioglacial deposits dating from the Alpine Haslach glaciation, probably of MIS 22 age, as well as from the subsequent Mindelian (MIS 16) glaciation.

The stratigraphical position of the Northwest European Cromerian events ('Cromerian Complex' Stage) within the MIS-fixed framework remains unclear. The reason for this is that the Cromerian subdivision is mainly based on the fragmentary occurrence of local warm-climate event signals within the Lower Rhine fluvial environments. The Cromerian substages I (Waardenburg[7]), II (Westerhoven) and III (Rosmalen) lack stratigraphical control and are not related to large-scale continental events that can be matched with the marine isotope stratigraphy. Moreover, warmest Cromerian substage localities, reviewed in Turner (1996), are not completely preserved. This makes them difficult to correlate. As is obvious from other environments in the European type regions, as well as from the marine isotope stratigraphy, there are hiatuses in the Cromerian succession particularly between the warm substages III and IV (Zagwijn 1996). The Cromerian IV (Noordbergum) sediments, comprising marine reworked fluvial deposits, are found above the 'augite datum' in the Rhine deposits, the latter related to Eifel volcanism. These marine sediments, as well as those from Ostend (England), contain the earliest remains of the water vole *Arvicola terrestris cantiana* which makes an MIS 13 age very likely. High sea-level stands during MIS 13 may have occurred in connection with the warm climate conditions indicated by the extremely leached forest-soil complexes found at several Central European localities. The high-sea-level stands interpreted from the warm-stage sequence at West Runton, i.e. above the West Runton Freshwater Bed containing *Mimomys savini* (West 1996), may also coincide to MIS 13 or even indicate a potentially earlier marine transgression in the North Sea. This may well have occurred during MIS 15 (substage a), although there is no direct evidence in the area of a preceding Fennoscandian glaciation. The Cromerian III warm interval is difficult to correlate with other evidence that can be equated to MIS 15. Since its stratigraphical position is associated with the Lower Rhine Embayment *Hauptterrassen* sequence group, pre-dating the MIS 16/15 boundary level, this warm interval, as well as the Cromerian II interval, seem to have occurred during the period between MIS 19 and 16.

6.5 Conclusions and outlook

The proposed use of genetic sequence and event stratigraphical procedures, supplementary to the traditional climatostratigraphy, brings about a better understanding of the stratigraphy of the terrestrial Middle Pleistocene sequences. Regional schemes have been proposed herein for the Northwest and Central European type areas. These schemes have been developed by integration of the multidisciplinary stratigraphical evidence into local and regional scale units recognised and defined on the basis of bounding unconformities and depositional environment. This informal subdivision of genetic sequence units provides tools for interregional correlation of the wide-spread glacial and periglacial subaerial sequences. With the help of a set of interregionally significant 'bio'- and 'chrono'-markers from the often localised intermediate units, a preliminary chronostratigraphical framework has been compiled. Subsequent interpretation of different type events, with reference to spatial and temporal scale as a basis for correlation, brings about a better understanding of the climatic and environmental history of the Middle Pleistocene. Relating the event-stratigraphical framework for Northwest and Central Europe with the marine isotope stratigraphy offers possibilities for refining the relative chronology. At least for the late Middle Pleistocene, the terrestrial equivalents of the 4th order glacial-interglacial depositional cycles can be equated fairly accurately to the MIS. With regard to the chronostratigraphical positions of the classical Northwest European palaeoclimatic stages of the Middle Pleistocene, one of the intentions of this thesis, it is concluded that:

- The Saalian Stage comprises the Fennoscandian, British and Alpine glaciations of cycle C, corresponding to MIS 6, and evidence for two more glacial-interglacial cycles, MIS 10-9 and 8-7 respectively,
- The Holsteinian Stage can be assigned to MIS 11,
- The Elsterian Stage can be equated with MIS12,
- The 'Cromerian Complex' Stage comprises the Donian glaciation of cycle H in eastern Europe which corresponds to MIS 16. The positions of the Cromerian warm substages[8] are difficult to correlate with the marine sequence because of the fragmentary nature of its record.

The marine isotope stratigraphy cannot be defined as the yardstick for the terrestrial chronostratigraphy, it only forms a reference for the timing of the terrestrial climatic stages and events. The time-transgressive boundary levels of the stages lie within the range of the deglaciation intervals for which the terminations give indicative ages. The boundary levels at the MIS 12/11 - and MIS 16/15 transitions are proposed as lower stage boundaries for the late Middle Pleistocene and a subdivision of the early Middle Pleistocene into a part A and B, respectively.

The low-resolution event-stratigraphical framework is provisional and is intended to be an initiative towards a formal subdivision. The evidence, advocated to underpin and refine the terrestrial event-stratigraphical framework, is not straightforward and still faces the problems inherent to its fragmentary and heterogeneous nature. The criteria for identification and definition of genetic sequence and event-stratigraphical units, with large-scale correlation potential, need to be further developed. In many cases this will involve a reinvestigation and reinterpretion of known sites and sequences. Comparison of eastern and western European evidence will improve the understanding of the stratigraphical relationships. Moreover, a better insight can be obtained by including sedimentary facies analysis in geological investigation and classification. An additional aspect is the equipping of the event-stratigraphical schemes with a revised and unambiguous nomenclature and terminology.

Possibilities for further refinement of the timing of the interpreted palaeoclimatic events during the Middle Pleistocene lie in new evidence and techniques. They comprise the recognition of boundaries at clearly defined horizons from both the MIS and the terrestrial stratigraphies. Although it is well known that the terrestrial equivalents of the global scale deglaciation intervals in the MIS are time-transgressive within a range of thousands of years, reduction of the diachronity of the boundary levels may be achieved by research on the various ‘lag’ times of the geological and ecological responses of climatic change. To achieve this, local detailed records are essential for the timing of the periods intermediate of the large-scale events. New high-resolution information can be embedded/integrated as reference records in the terrestrial schemes with regard to local variability of climatic change and neotectonics which can then be equated with the global scale of the marine isotope record.

[1] *This, otherwise, had for long been a well understood reality.*

[2] *With the exception of the marine Noordbergum (= Cromerian IV) intercalation of which the stratigraphical position is unclear.*

[3] *Chronometric controls of the Laurentide Wisconsin glacial deposits in the USA indicate glacial advances during the time periods represented by the MIS 4 and MIS 2, as recorded by the southernmost extensions of end-morainesat various locations ranging between about 65-79 ka respectively 22-14 ka BP (Richmond & Fullerton 1986).*

[4] *Boundaries between thick loess beds and palaeosol complexes based by a B-horizon.*

[5] *And consequently for the absolute ages of many early Palaeolithic levels.*

[6] *Or ‘sub-subseries’.*

[7] *Of Matuyama age.*

[8] *The Cromerian substages II, III and IV within the Brunhes Chron.*