A continent-wide framework for local and regional stratigraphies

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Introduction

1.1 Scope and objectives

Age and chronology are unifying themes in interdisciplinary studies on palaeoreconstructions of the terrestrial Quaternary[1] record. Its sediments, fossils and landforms contain the history of environments, climate, tectonic activity and human occupation of the last *c*. 2.6 Ma of the geological time scale[2]. Unfortunately, the complete pattern of palaeoenvironmental and palaeoclimatic change in time and space from the European continent is almost invariably poorly represented due to the highly fragmentary and genetically diverse nature of its record. Terrestrial Pleistocene stratigraphy and correlation is constrained by the predominance of (erosional) unconformities, a lack of usable index fossils and few geochronometric control points. These characteristics restrict to a large degree the availability of objective criteria for classification into natural, correlative units.
Moreover, the customary means of dating and correlation by dividing the local and regional stratigraphies of Europe into interpreted glacials and interglacials, necessarily based on multiple criteria, has never been documented in a satisfactory way. Attempts to correlate the climate-based units from one region to another have led to many discrepancies. Loess/palaeosol sequences in the non-glaciated areas show more climatic cycles than the glacial sequences in the Alps and in northern Europe, implying that the latter are deficient. Furthermore, most of the local Pleistocene stratigraphies are co-controlled by independent regional geographical, geological and (neo-)tectonic factors. For example, the fluvial terrace stratigraphies, closely linked with the loess stratigraphy of Central Europe, are complicated by (neo-)tectonic activity in these regions.

1. *How to reduce the difficulties and uncertainties associated with the subdivision and dating of the Pleistocene terrestrial record?*

> 'The ideal situation would be to find absolute age markers at all horizons in all environments, so that we could have a calendar of events divided into say 1000 years segments, giving complete correlation of sediments, processes and events over the earth's surface' (R.G. West 1968).

West's utopian situation became somewhat more realistic, when in the 1970s, the dating of the fluctuations in $^{18}O/^{16}O$ ratios from the shells of fossil foraminifera in ocean floor sediments[3] became an important stratigraphical tool. Technological and methodological advances in dating and subsequent calibration and tuning with astronomical - and polarity time scales since provided the marine isotope record an accurate high resolution chronology valid for the last 5 million years or beyond (Lourens *et al.* 1996). The development and present existence of the global chronostratigraphical time scale (*Fig. 1.1*) as a standard is crucial for the timing of palaeoclimatic and –environmental events, and a prerequisite for the refinement of the chronostratigraphy of the terrestrial Quaternary deposits, although the resolution might not be as high as West's 1000 years.
Within the overall context of an apparent continuous registration of the climatic history in the deep-ocean and ice-core records, the

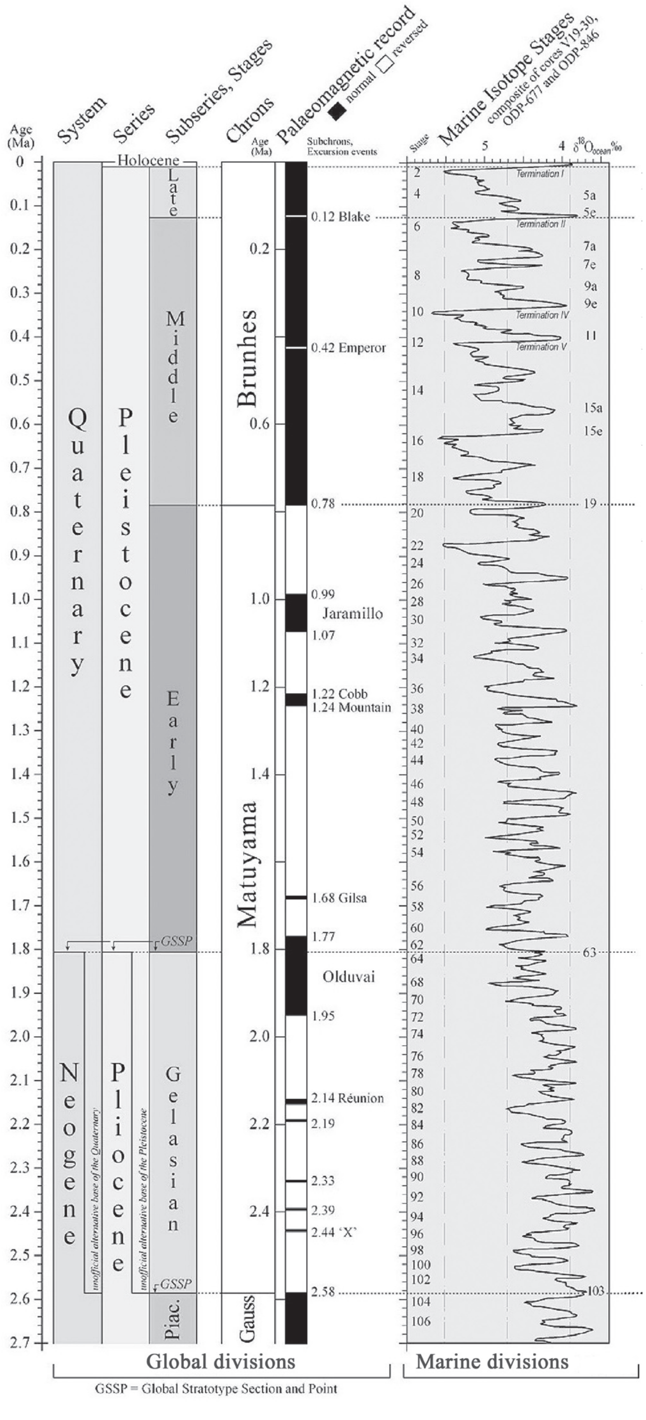

Figure 1.1 Global chronostratigraphical correlation table for the last 2.7 million years (Subcommission on Quaternary Stratigraphy, International Commission on Stratigraphy, Gibbard *et al.* 2004).

applicability of (conventional) climatostratigraphy to the terrestrial record is now seen as inadequate to interpret and reveal a relatively high-resolution sequence, in particular in the formerly glaciated areas. Nor does it resolve the problems of deficiencies and time-transgressive boundaries. The palaeoclimatic stages in many land-based stratigraphies are, in fact, not time stages but rather represent palaeoclimatic events of different origin, type and scale order. Unfortunately, the terrestrial stratigraphy can only indirectly be correlated with the oceanic record, because of the lack of chronological controls. Nevertheless, the classic glacial models are coarse structures, whilst the terrestrial climate-based stages and their associated depositional sequences have to match in some way the global template of the marine isotope and polarity stratigraphical frameworks. This offers opportunities for correlation with the wide-spread climate-driven sedimentary sequences in the glacial stratigraphy, in the loess/palaeosol stratigraphy, in the coastal marine stratigraphy as well as for correlation with local pollen records from suitable localities, for example, ('postglacial') lake sequences.

2. *How do the observations on the continent match the oceanic record?*

Both questions have been starting points (and likewise challenges) for this thesis. They initiated the need to search for an alternative approach, supplementary to the traditional climatostratigraphical procedure. Obviously climate is the only common denominator that can be used to compare the terrestrial and the marine sequences. Subsidiary, non-interpretive classifications are required that better represent the continental Pleistocene record and that potentially offer opportunities for large-scale time/space interpretations and eventually for correlation with the global oceanic record. One of the research objectives then has been the integration of multidisciplinary local data into an informal stratigraphical framework for Northwest and Central Europe using sequence – and event-stratigraphical criteria. Such an overall framework requires a material basis with uniformly defined units for interpretation. Moreover, the framework should be attended to an unambiguous nomenclature. Existing (and available), local datasets from several natural type regions in Northwest and Central Europe have for this purpose been gathered, reviewed and (re-)evaluated[4]. Stratigraphical units within the type regions are arranged on the basis of superposition, criteria of regional significance (e.g. bounding unconformities), correlation and independent dating. Then, interpretation of environmental facies changes arises for discussion in order to reconstruct regional sequences of events which can be associated with climatic cycles and (neo-) tectonic rearrangements of different magnitude and duration.
Using this framework, the intention of this thesis is to refine the (chrono)stratigraphical positions of the depositional sequences and unconformities associated with the classical Northwest European palaeoclimatic stages of the Middle Pleistocene[5], i.e. part of the Cromerian, the Elsterian, the Holsteinian and the Saalian stages. Their correlation with the loess/palaeosol cycles in Central Europe and the Alpine glacial stages is dealt with. Finally, optimal matching of the event-based continental stratigraphy for the Middle Pleistocene is sought with the marine isotope stages (MIS) of the ocean-core chronostratigraphy.

Comparable selective work on the relation and equation of terrestrial sequences to the global isotope scale has been dealt with by many other authors, including Kukla (1975, 1977, 1987), Turner (1975, 1996), Bowen (1978), Sibrava *et al*. (1986), Zubakov and Borzenkova (1991), Ehlers (1999), Gibbard and West (2000) and Vandenberghe (2000). The present thesis is another contribution to this issue, yet based upon a different approach, i.e. the application of genetic sequence[6] - and event-stratigraphical principles and attempting comprehensiveness by systematically comparing existing (Middle Pleistocene) evidence from different natural type regions in Northwest and Central Europe.
Within the scope of this research project this procedure is of great help in the improvement of time control over the scattered Palaeolithic evidence in the study area which, as another component of the terrestrial record, dates far back into the Middle Pleistocene (*Fig. 1.2*).

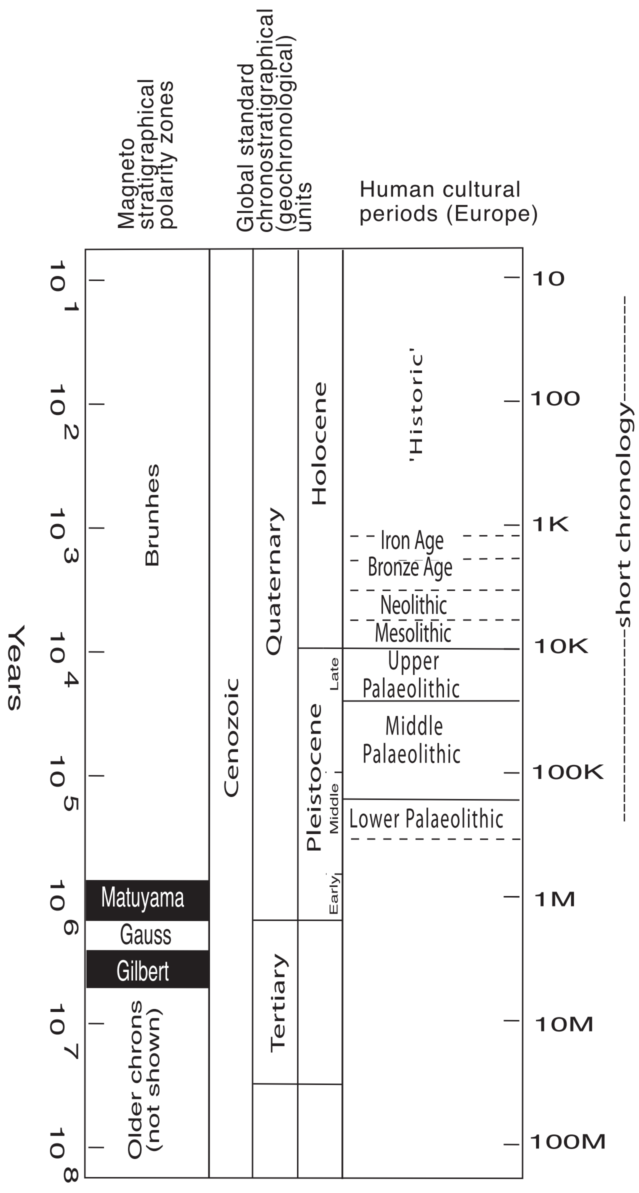

Figure 1.2 Comparison of archaeological and geological subdivision (modified after Stein and Linse 1993).

1.2 Outline of this thesis

Chapter 2 begins with an introduction to the main principles and methods concerning the Quaternary subdivision, chronology and terminology (*sections 2.1 and 2.2*). Before developing alternative concepts and starting supplementary stratigraphical procedures, the availability of objective criteria in the terrestrial geological succession and their suitability for large-scale interpretations is as-

sessed in the *sections 2.3* up to *2.5*. Considerations of these prerequisites involve three basic issues:
- The nature of the terrestrial record,
- Scale and resolution of research, both spatial and temporal,
- Aims of subdivision, i.e. the reconstruction of a land-based sequence of past climate and landscapes compatible with the marine isotope stratigraphy.

Three supplementary procedures (unconformity-bounded, genetic sequence and event stratigraphy) applicable for the reconstruction of large-scale stratigraphical frameworks are dealt with in more detail in *section 2.6*. The potential of these units and syn- and post-sedimentary features in relation to global chrono- and (climate type) event correlation is also considered. They largely determine the success of a spatio-temporal framework reflecting the palaeoclimatic and palaeoenvironmental events on the European continent.

Chapter 3 gives an outline of the contemporary Middle Pleistocene stratigraphy of Northwest and Central Europe. *Section 3.1* discusses the limitations and (time-)stratigraphical problems with regard to the classical European palaeoclimatic models for the Pleistocene terrestrial succession. The material building elements, from which the local and regional stratigraphies are constructed, are dealt with in *section 3.2.* Five broad categories of major depositional settings and their sedimentary products are reviewed, together with some significant local-scale depositional environments and (syn- and post-) depositional features. Moreover, climatic interpretation and large-scale stratigraphical significance of these sequences, from which the Cromerian, Elsterian, Holsteinian and Saalian palaeoclimatic stages are inferred, is discussed. The bio- and chronostratigraphical control on the land-based sequences are considered in the *sections 3.3 and 3.4*, respectively.

In *Chapter 4* the local and regional stratigraphies are informally assigned to a continent-wide framework using multidisciplinary types of correlation and including principles of sequence and event stratigraphy. The approach adopted is to group genetically related sedimentary units, bounded by unconformities of regional extent and significance in the different geotectonic type regions (*section 4.1*). The units are then arranged according to superposition, litho- and biofacies characteristics, interpreted depositional environment and independent dating into a large-scale framework (*section 4.2)*. A compilation of the most up to date versions of the Northwest and Central European local stratigraphies is given in *section 4.3*. Subsequently, in *section 4.4*, relevant genetic sequences are associated with major climate-driven geological events (such as glaciations and marine transgressions) and regional tectonic events; an approach analogous to event stratigraphy. Provisional names for synthems and genetic sequence groups are introduced. They are compiled in a stratigraphical framework in which local-scale palaeoclimatic features are embedded. The main difference from the conventional (climato)stratigraphical systems concerns the hierarchical approach with regard to scale and order/magnitude of the depositional sequences.

The spatial component of climatic and environmental change must come from local key stratigraphical sequences in the fragmentary continental record. Since classification starts in the field, one of the essential steps in data inventories is to return to more or less basic geological procedures and begin with the local identification and description of objective sedimentary units in the (literature on) the sections and cores. Then, data may be structured on the basis of criteria of regional significance (e.g. bounding unconformities) and interpretation and correlation of local depositional sequences can be carried out. Testing of this approach has been done by short fieldwork studies, discussed in *Chapter 5*, in the Neuwied Basin of the Middle Rhine type region (the Kärlich and Ariendorf sections, *section 5.2*) and in the Subhercynic Basin (the Schöningen sections, *section 5.3*), both located in the German uplands. These important sites contain regional information on Middle Pleistocene conditions with potential for interregional correlations (*section 5.4*).

In seeking an overall framework for the Northwest and Central European terrestrial stratigraphy, relations between the different regional event-stratigraphical units and the marine isotopic stages (MIS) are reviewed in *Chapter 6*. The global significance of the continuous marine isotope record (*section 6.1*) is used as a template upon which the local and regional scale records are fitted. Comparison and matching of the land-based Middle Pleistocene framework with the marine isotope stratigraphy is considered in *section 6.2*. Both records are keys to different parts of the climate system. Recognition and timing of the boundaries and events from the MIS's on land may help to improve (chrono)stratigraphical control over the European sedimentary sequences, although they remain of low resolution and are therefore not interchangeable with formal time stages. Two isotopic stage boundary levels are used to fit the large-scale glacial, periglacial and marine depositional cycles within the Middle Pleistocene Subseries (*section 6.3*). Finally, the stratigraphical positions of local terrestrial evidence within the MIS-fixed time framework is dealt with in *section 6.4*.

[1] *With the exception of the last 10,000 ^{14}C years, representing the Holocene Epoch, the Quaternary Period corresponds to the complete Pleistocene Epoch. Therefore their names are used broadly as synonyms in relation to past climatic and environmental change.*

[2] *That is the chronostratigraphical interval corresponding with the Quaternary deposits. Its duration is depending on the definition of the lower boundary which is formally set at 1.8 Ma (see also section 2.2.2).*

[3] *Based on work from Emiliani (1955) and Shackleton and Opdyke (1973).*

[4] *Including relevant sedimentological, faunal and floral evidence next to archaeological data from over 500 European localities*

[5] *Spanning the period from approximately 780 ka to 130 ka ago (Fig. 1.1).*

[6] *As also used in sedimentary basin analysis (section 2.6.2).*