Summary

Introduction

Late Pliocene and Early Pleistocene fluvial deposits of the Rhine-Meuse system are widely distributed in the southern, central and western part of the Netherlands and have been surveyed for over a century. As a consequence of the position close to the hinge line of the southern North Sea Basin, the Pliocene and Early Pleistocene sedimentary record in these areas forms an excellent source of information of both the marine and fluvial depositional history. At the basin scale this record forms a complex geological archive that reveals the mixed influences of the main controlling factors on the depositional history: climate, source-area uplift, basin subsidence and eustacy. Therefore it is not surprising that the depositional history of the Rhine-Meuse system has played a significant role in the development of concepts for the sedimentary evolution and stratigraphical subdivisions of the Late Pliocene and Early Pleistocene time. However, it should be realised that the complex tectonic structure, the position of the depositional realm near the basin hinge line, repeated climate changes, and the nature of the autogenic fluvial processes have resulted in a fragmentary and discontinuous sedimentary record. Consequently, the preserved deposits often represent only short segments of geological time and contain a great number of depositional gaps of varying duration.

The Late Pliocene and Early Pleistocene litho- and chronostratigraphical concepts in the Netherlands, developed over the last century, are mainly based on the combined results of palaeontological research (i.e. plant macro remains, pollen, large- and small-mammal remains, molluscs) and sediment-petrographical studies (i.e. heavy-minerals and analyses of gravel components). Immediately from the beginning of the investigations it became clear that the fluvial record in the southern Netherlands encompasses signs of climatic change. Plant macro-remains and pollen analyses have played a major role in these investigations through their application for the reconstruction of former vegetation. However, the pollen record is generally interpreted by a rather direct relationship of vegetation development to climate change. This is well illustrated by comparing the pollen-based temperature curves, derived from the fluvial record, with the frequent changes of climate shown by the marine oxygen isotope curves. Generally, it can be stated that the innate fragmentary character of the fluvial sequences was underestimated in many former investigations. Eventually, the results of the different mapping and stratigraphically orientated studies have led to integration of bio-, chrono-, and lithostratigraphical criteria in the stratigraphical concepts and correlation schemes. This is a commonly observed practice in mapping Quaternary deposits. In order to overcome these problems a reassessment of the Upper Pliocene and Lower Pleistocene lithostratigraphy and key-reference sites of the pollen-based stratigraphical subdivisions is necessary. It is the aim of the present study to contribute to such a revision. Derived from this general objective three main goals are identified:

- The revision of the lithostratigraphy of the Lower Pleistocene mixed Rhine-Meuse deposits, together with the deposits supplied by river systems of Belgian origin, and their interrelationships.
- To review the sedimentary development of the Lower Pleistocene fluvial deposits that form the key reference sites for the pollen-based subdivision of the Early Pleistocene.
- The compilation of the fluvial history that is predominantly based on the lithostratigraphical interrelationships of the Upper Pliocene and Lower Pleistocene fluvial and marine deposits.

The main area studied is situated in the southern part of the Netherlands which forms the continuation of the Lower Rhine Embayment (LRE) in Germany. This area is generally subsiding and forms the most south-easterly extension of the North Sea Basin (Fig. 2.1). Tectonically, the LRE is part of the Roer Valley Rift System which continues into the Netherlands as two main tectonically defined structures: the subsiding Roer Valley Graben (RVG) and the much less subsided and strongly fault-dissected area of the Peel Block.

Lithostratigraphy

The Upper Pliocene to Lower Pleistocene fluvial deposits in the Netherlands result from the interplay of four main fluvial systems. Three of them dominate the fluvial development in the southern part of the Netherlands: the Rhine, Meuse, and the rivers that drained the central and northern part of Belgium. The fourth is the Eridanos fluvio-deltaic system that originated in the Baltic region and supplied sediment to the North Sea Basin onwards from the Middle Neogene until its starvation at the end of the Early Pleistocene (Fig. 1.1). Deposits of the Eridanos river occur in the northern and central part of the Netherlands and interdigitate with those of the Rhine-Meuse system.

Three main criteria (i.e. lithology, stratigraphical position and provenance) enable a lithostratigraphically defined subdivision of the fluvial deposits in the southern Netherlands into three different formations. In comparison to former lithostratigraphical schemes, one of the most conspicuous alterations concern the definition of two new formations that include the Upper Pliocene and Lower Pleistocene fluvial and estuarine deposits in the southern part of the Netherlands: the Waalre Formation and the Stramproy Formation. Because the Waalre Formation occurs downstream of the Rhine-Meuse confluence, it consists of mixed deposits laid down by both rivers. The heavy-mineral composition of this unit is typified by dominant unstable associations (i.e. garnet, epidote, saussurite/alterite and hornblende) (Fig. 2.4). The Stramproy Formation includes all deposits formed by northward-flowing rivers that drained the central and northern part of Belgium. The heavy-mineral content is dominantly stable (i.e., tourmaline, staurolite, metamorphic minerals, zircone and other stable heavy-minerals) (Fig. 2.7). The lower and upper boundaries of both formations are formed by regionally extensive and marked stratigraphical horizons, such as the underlying deposits of the Reuver Bed that form part of the Kieseloolite Formation, and the unconformity at the base of the Sterksel Formation.

The Kieseloolite Formation remains unaltered for the larger part of its extent. Compared to former definitions, only the uppermost part, recently termed the Oebel Beds in Germany, is excluded. The Oebel Beds are characterised by a dominance of unstable heavy-minerals and reflect the major change in provenance of the supplying river Rhine system that resulted from the extension of the pre-Rhine catchment into the Alpine area. The continuation of these 'Alpine'-influenced Rhine deposits into the Netherlands is represented by the lowermost part of the Waalre Formation (indicated here as subunit WA-1).Two additional subunits of the Waalre Formation (respectively WA-2 and WA-3) can be distinguished within the Roer Valley Graben (Fig. 2.8). The deposits of the Waalre and Stramproy Formations repeatedly interdigitate, indicating that parts of both formations were deposited concurrently.

A result of the large overprint of the Rhine-Meuse sediment is that the deposits of the Belgian rivers loose their lithological characteristics a short distance after their confluence with the Rhine-Meuse system. This observation is of importance because it indicates that the deposits of the Stramproy Formation can only be preserved when they are not mixed with those of the Rhine-Meuse system. So, their occurrence within some intervals in the RVG, demonstrates that the Rhine-Meuse system did not deposit sediment in the area during these periods, either because of sediment bypass or as a result of shifting of the main stream belts to positions outside the RVG.

The Waalre Formation consists of stacked fluvial fining-upward cycles, each with a coarse-grained basal part that grades upwards into regionally extensive floodbasin fines. However, a detailed subdivision of the Waalre Formation into members or beds, based on these fluvial fining-upward sequences, is generally not possible and goes beyond the resolution of the applied lithostratigraphical classification. The primary reason is that all the sediment that forms part of the formation shows a uniform petrographical composition. Secondly, the different deposits of this fluvial system bear a lithological variability that does not correspond to lithostratigraphical levels but to facies units within those levels. A similar reasoning holds true for the Stramproy Formation.

Both the Stramproy and Waalre Formations include extensive estuarine deposits that grade into the marine deposits of the Maassluis Formation in the south-western and western part of the Netherlands. The complex pattern of marine, estuarine and fluvial deposits in these areas indicate that their development is affected by Early Pleistocene sea-level changes.

Differences in the subsurface composition can easily be shown in regional lithostratigraphical schemes. They provide information, such as stratigraphical position and thickness, and spatial interrelations (e.g. intercalations between formations and their deposits). Such regional lithostratigraphical information contributes to the understanding of the three-dimensional geometry of the defined rock units and provide the fundamental major building-blocks for compiling subsurface models and the geological history of the area.

Sedimentary and pollen-analytical characteristics of Early Pleistocene key reference sites.
Upper Pliocene and Lower Pleistocene fluvial deposits situated on the Peel Block are exposed in several clay pits along the Dutch-German border area. They form key reference localities for some pollen-defined Late Pliocene and Early Pleistocene stages and substages.

In the present study special attention is paid to the key reference sites of the Tiglian and Eburonian Stages in the Tegelen-Maalbeek area on the Peel Block south of Venlo. The Lower Pleistocene fluvial deposits in this area form part of the Waalre

Formation (Fig. 4.4). The preserved sequence consists of a coarse-grained gravel-bearing basal part that fines upwards into clayey floodplain deposits up to 10 m thick. Three main facies types can be distinguished within these fine-grained deposits. Flood-basin fines are relatively wide-spread and consist of massive clay deposits with crumbly to prismatically structured horizons representing initial soil formation. In some cases thin intercalated peat layers occur. The second facies type is characterised by up to 10m thick sequences of bedded clay that forms the fill of abandoned channels (i.e. oxbows). The third facies type consists of crevasse-splay deposits and/or overbank fines. They are typified by being irregularly distributed and having a strongly varying lithology over short distances. All facies types are closely related and grade gradually into each other, although distinct boundaries occur occasionally. The complete pattern of facies types within the floodplain fines at the top of the Waalre Formation in the Tegelen-Maalbeek area represents the final stage of the fluvial deposits preserved in the district.

New and existing pollen data from three pits in the area (i.e. the Maalbeek, Laumans and Russel-Tiglia-Egypte pits) have been assessed in relation to their associated facies development and the lithostratigraphical position of the deposits.

Pollen analytical studies of the clay deposits of the Maalbeek pit show that the three distinct pollen assemblage zones of the Tiglian Stage (respectively, pollen zone T-A, T-B, and T-C) occur in the exposed sequence of fine-grained floodplain deposits. The lowermost part consists of flood-basin fines and shows the by Fagus typified pollen zone T-A. The overlying, lithologically similar, flood-basin fines show a pollen assemblage that is characteristic of pollen zone T-B. It shows high values of non-arboreal pollen with Artemisia in a more or less continuous curve, and low percentages of tree-pollen. These up to 9 m thick flood basin deposits are partly overlain and incised by a channel that is filled with a strongly bedded clay deposit, containing well-visible white coloured enrichments of siderite (Fig. 4.5). The bedded clay is interpreted as the fill of an abandoned channel (i.e. oxbow) and contains a pollen assemblage typified by the presence of Pterocarya that corresponds to pollen zone T-C. The oxbow fill is overlain by crevasse-splay deposits. They also yield pollen assemblages that resemble that of pollen zone T-C.
Thus, at the Maalbeek pit the three well-established major pollen zones of the formerly defined Tiglian Stage occur together in the uppermost fine-grained floodplain deposits at the top of the Waalre Formation. However, it remains uncertain whether these three pollen zones each form part of one of the long-lasting chronostratigraphical substages ‘Tiglian A’, ‘Tiglian B’, and ‘Tiglian C’ identified in previous investigations. Such an equation would imply an unlikely long depositional phase of the floodplain fines or the presence of large depositional gaps within the uppermost floodplain deposits of the Tegelen-Maalbeek area.

A forced extrapolation of the pollen record from the relatively thinly developed fluvial sequence at Tegelen-Maalbeek to the thick stacked fluvial sequences in the RVG is difficult. This is emphasised by the fact that the lowermost part of the Waalre Formation, formerly interpreted as ‘Tiglian A’, in the RVG, near Eindhoven, appears to equate to the Late Pliocene subunit WA-1 (i.e. the continuation of the Oebel Beds in Germany). Furthermore, the part of the sequence at Maalbeek now interpreted as pollen zone T-B was formerly interpreted as an element of the post-Tiglian ‘Eburonian’ Stage. However, this interpretation is no longer tenable because the overlying deposits are typified by pollen assemblages that correspond to pollen zone T-C. In addition, the finds of molars from Anancus arvernensis (forest elephant) and Tapirus arvernensis (tapir), found in this particular part of the flood-basin fines of Maalbeek, indicate deposition of the clay earlier in the Pleistocene. Both mammals became extinct during the Pretiglian and earliest Tiglian Substages. A correlation in the 1960s of the pollen zone T-B part of the Maalbeek sequence with what was termed ‘Tiglian B’ to the sequences in the RVG is also very unlikely. These ‘Tiglian B’ deposits in the RVG parallel the influxes of material from the Stramproy Formation that demonstrate primarily a change in provenance. Generally, the ‘Tiglian B’ Substage is weakly defined and a positive correlation from Maalbeek to the sequences of the RVG cannot be made. Moreover, it must be stated that apart from the signals of climate change, the pollen content of the flood-basin fines at Maalbeek is at least partly determined by existing local environmental conditions.

Pollen evidence from the flood-basin deposits at Laumans pit are generally interpreted as forming part of the uppermost part of the Late ‘Tiglian C’ Substage (pollen zone T-C5 and T-C6). These pollen assemblages are typified by the dominance of pine and spruce and as such cannot be correlated with any specific glacial-interglacial cycle. Furthermore, it should be noted that the larger part of the relatively poor pollen content of the Laumans pit flood-basin deposits consists of broken and partly corroded palynomorphs. It is thought that this has resulted from post-depositional geochemical processes because the deposits are severely affected by oxidation of siderites. The flood-basin fines at both Laumans and Maalbeek pits occur in the uppermost fine-grained portion of the Waalre Formation, and based on lateral mapping, it is clear that both these deposits occur in a similar lithostratigraphical position.

The sedimentary development at the classical type site of the ‘Tiglian C’ Substage, the Russel-Tiglia-Egypte pit, is closely comparable to that at other sites in the Tegelen-Maalbeek district. In this pit, abandoned since the late 1960s, the floodplain fines at the top of the Waalre Formation consist from bottom to top of bedded clay that forms an oxbow lake infill that is overlain by a complex of crevasse-splay and overbank deposits. The latter subsequently grade into a clayey floodbasin deposit with two peat layers (Fig. 4.10).

The nearly continuous presence of Pterocayra pollen in the larger part of the pollen sequence at this site is characteristic of pollen zone T-C and several subzones that are defined in the oxbow fill and overlying crevasse/overbank deposits. From bottom to top, the pollen diagram from Russel-Tiglia-Egypte shows a gradual decrease in tree pollen that may be explained as indicating a cooling towards the uppermost part of the flood-basin deposit with two thin peat layers. On the other hand, the opening of the vegetation that is shown in the pollen diagram may also reflect the changing environmental conditions during deposition of this alluvial sequence. The uppermost flood-basin fines represent a wet environment, probably with open water, while grasses and sedges dominate the two phases of local peat growth. The Russel-Tiglia-Egypte pollen diagram is also well-known for the so-called cold phase identified as pollen zone T-C4^{c}. This zone is situated at the base of the crevasse/overbank deposits, the basal sand layer of which is poor in pollen. However, it is likely that the sand layer represents the onset of crevassing in the nearly filled oxbow lake instead of a depositional hiatus reflecting a major period of cold climate.

Taken these considerations into account, it is concluded that the extrapolation of the known pollen zones of the uppermost flood-basin fines of the Waalre Formation in the Tegelen-Maalbeek area into regional significant long-lasting chronostratigraphical stages and substages is no longer tenable. In addition, an unambiguous pollen-based correlation from the Tegelen-Maalbeek area to the Lower Pleistocene fluvial sequences in the RVG still harbours many uncertainties. In summary, it can be stated that the up-scaling of the pollen record from the fragmented and discontinuous Lower Pleistocene fluvial sequences into a detailed chronostratigraphical framework exceeds the resolution of the pollen analytical method.

Fluvial history

The Late Pliocene and Early Pleistocene fluvial history of the Netherlands and the southern North Sea Basin results from the interplay of four major river systems. In the southern part of the Netherlands fluvial deposition took place by the Rhine, Meuse and the northward-draining Belgian Rivers, while the Eridanos fluvio-deltaic system is of importance in the central and northern part of the Netherlands. As a consequence of the clear differences in lithology and petrographical composition, the deposits of each of the four rivers can be recognised and mapped separately as long as they are not confluent. Both the lithostratigraphical framework and the results of regional mapping show the mutual interrelationships of the various fluvial sediment bodies and thus provide a key for unravelling the fluvial history through this critical period.

The main line for the fluvial history is the continuous NW-orientated advance of the fluvial domain that already had begun during the Late Miocene in the Lower Rhine Embayment. By the end of the Pliocene the Rhine-Meuse system already dominated a large area of the southern Netherlands (i.e. the area of the Peel Block and RVG), while fluvial deposition by the Eridanos system took place in the extreme north-easternmost part of the country (Fig. 6.9). At the Plio-Pleistocene transition the larger part of the Netherlands was still situated in the marine realm (Maassluis Formation). Through time a continuous extension of the fluvial domains occurred so that by the end of the Early Pleistocene the coastline was situated in the central northern part of the North Sea Basin. However, this process of the retreating coastline was not a uniform and unilaterally orientated process. Superimposed on the general trend were multiple south-eastward and subsequently north-westward shifts of the marine-fluvial transition, induced by shorter-term sea-level changes, that occurred repeatedly during the Early Pleistocene. In addition, regional tectonic movements in the LRE and adjacent parts of the southern Netherlands influenced the position of the major pathways of the Rhine-Meuse drainage system.

During the Late Pliocene the rivers Rhine and Meuse were confluent north of Aachen on the RVG/Rurscholle and laid down mixed deposits of the Kieseloolite Formation downstream in the RVG and on the Peel Block. The contribution of the Belgian rivers during this period to the RVG is not known precisely because their deposits cannot be mapped separately from those of the Rhine-Meuse. This results from their very similar lithological composition in that period. The differentiation is only possible after the major change in petrographical composition of the Rhine deposits (Waalre Formation) that took place during the Late Pliocene.

The Rhine had three main pathways in the LRE: a southern one situated on the Rurscholle and RVG, a second across the Venloer Block and Peel Block and a third situated in the easternmost part of the LRE. As a result of tectonic movements the most southerly situated Rhine branch slipped from the Rurscholle during the earliest part of the Pleistocene. As a result the Meuse deposited a huge fan-like sediment body that continued from the East Meuse Valley on the Rurscholle and subsequently the Venloer Scholle in Germany. This process prevented the Rhine from adopting a pathway through the southern part of the RVG in the Netherlands. In that area the resulting accommodation space was filled in by deposits laid down by the Belgian rivers. This situation continued until the end of the Early Pleistocene and resulted in a sequence of Belgian river deposit (Stramproy Formation) in the RVG up to 100 m thick, while thick sequences of Meuse deposits (Holzweiler Formation) were laid down in the adjacent areas in Germany. During the same time the Rhine continued to follow its route across the Peel Block and in the eastern part of the LRE. The Rhine course across this block supplied sediment to the northern part of the RVG for a relatively long time. In the RVG, as in the area to the west, the fluvial deposition of the Rhine-Meuse system grades into estuarine and tidal-influenced environments. At the southern limits of its distribution area, Rhine deposits repeatedly interdigitate with those of the Belgian rivers.

The easternmost course of the Rhine in the LRE had its continuation in the central and western part of the Netherlands. The upper part of the Waalre Formation in the northernmost part of the RVG, and the area to the west, consists of extensive flood-basin depressions where predominantly fine-grained deposits accumulated. It is likely that these flood basins were fed by sediment supplying channel belts situated in the central part of the Netherlands. The continuing north-westwards shift of the Rhine's main depositional area enabled the Belgian rivers to deposit material over the previously formed Rhine-Meuse deposits in large parts of the southern and western Netherlands. The Rhine-Meuse deposits in the central and western part of the country are intercalated with that of the Eridanos system (Peize Formation), the latter showing a major south-westward advance during the Early Pleistocene. Further to the northwest and in the present North Sea, the Rhine-Meuse deposits became intermixed with those of the Eridanos river. The latter is by far the larger river, a factor that causes clear signs of Rhine material to be rapidly lost in the north-western part of the country.

The Early Pleistocene fluvial deposition in the LRE and the Netherlands is characterised by a rather low ratio between accommodation space and sediment supply. Consequently the larger part of the deposits transported by the Rhine-Meuse system by-passed the Netherlands and was laid down further north in the North Sea Basin. The RVG formed a temporarily exception on this general trend. Here relatively thick sequences of stacked fluvial deposits have been preserved from the Early Pleistocene time.

The lower Rhine-Meuse alluvial plain and its continuation into the marine realm were strongly controlled by climatic-induced sea-level changes, which give rise to regional changes of base level. As can be deduced from the preserved depositional record in today's onshore areas, it seems likely that erosion predominated in the coastal zone during marine lowstands throughout long periods of the Early Pleistocene. In contrast, fine-grained floodplain deposition seems to have been dominant during sea-level highstand periods. However, during the Early Pleistocene multiple changes of climate occurred and it remains uncertain whether the response of the fluvial system to these changes preserves a similar cyclic pattern. Base-level changes primarily affect the lower end of fluvial systems, but during low-stand situations the Rhine-Meuse system in the central part of the Netherlands was situated far upstream from the coastline. Autogenic fluvial system processes may have dominated over the allogenic cycles in the then more upstream situated areas.

The preserved Lower Pleistocene fluvial deposits are discontinuous, representing only short fragments of the total geological time involved. Nevertheless, the framework for the Early Pleistocene Rhine-Meuse system in the southern Netherlands presented here forms a solid foundation for the explanation of the regional palaeogeographical development.