7 Conclusions

W.E. Weterhoff

7.1 Introduction

The general aims of this study are focused on the revision of the lithostratigraphical framework of Upper Pliocene and Lower Pleistocene fluvial deposits in the southern part of the Netherlands. The results of sedimentological-based review of the key reference sites which form the basis of the Early Pleistocene pollen-defined stratigraphical subdivisions, and the compilation of the Early Pleistocene depositional history of the southern part of the North Sea Basin.

7.2 The lithostratigraphical framework

The revised lithostratigraphical scheme of Upper Pliocene and Lower Pleistocene fluvial deposits in the southern part of the Netherlands (chapter 2) provides a firm framework for unravelling the depositional history at the margins of the northern North Sea Basin (chapter 6). The Upper Pliocene and Lower Pleistocene fluvial and marine deposits can easily be mapped at the formation level. Consequently, these lithostratigraphical units form the building-blocks for subsurface modelling and characterisation of the subsurface composition. The main constituents of the units identified are distinguished on the basis of their lithostratigraphical provenance and their stratigraphical position. Regarding the fluvial deposits involved, the lithostratigraphical framework clearly demonstrates that the complex composition of the subsurface geology in the River Valley Group (RVG) and adjacent areas results from the interplay of systems i.e., the Rhine, the Meuse, and the rivers that originate in Belgium. In addition, the deposits of the Rhine-Meuse system clearly intergrade with those of the Eridanos fluvio-deltaic system in the central and western part of the Netherlands. The latter originates in the Baltic region.

The deposits of the pre-Rhine fluvial system are assigned to the Kieseloolite formation and represent the north-western directed advance of the river system during the Pliocene. The capturing process of the pre-Rhine to the Alpine drainage system took place during the Late Pliocene. As a result, a marked change of the petrographical composition of sediment transported by the Rhine occurred. This change shows a complete change from deposits of the Kieseloolite Formation, dominated by heavy mud-minerals, to the unstable heavy-mineral-dominated deposits of the Waalre Formation. Since the latter occurs downstream of the Rhine-Meuse confluence, it consists of mixed deposits laid down by both rivers. Within the RVG three informal subunits of the Waalre Formation can be recognised, termed respectively WA-1, WA-2, and WA-3. The lowermost subunit (WA-1) is correlated with the Late Pliocene Oevel Beds in Germany. Subunit WA-1 (Oevel Beds) is defined by its lithological and petrographical characteristics and its lithostratigraphical position underlying the Reveuer Bed, a flood-basin clay deposit at the top of the Kieseloolite Formation. As a result, the uppermost part of the latter formation occurs within in the Upper Pliocene i.e. the upper boundary of the Kieseloolite Formation is situated (well) below the Plio-Pleistocene boundary deposits of subunit WA-1 have been observed at several places in the RVG. They occur as far west as the area around Eindhoven which is much further westwards than previously thought.

The distinction between the Waalre Formation subunits WA-2 and WA-3 is primarily based on the stratigraphical position in the northern part of the RVG. They are separated by major intercalations of marine deposits (Maassluis Formation) and fluvial deposits supplied by the Belgian rivers (Stramproy Formation) which occur at the same level. The Stramproy Formation comprises all the Lower Pleistocene deposits supplied by rivers that drained the central and northern part of Belgium. In the southern and eastern part of the RVG the Waalre and Stramproy formations repeatedly intergrade, indicating that parts of both formations were deposited concurrently. Owing to the substantial overprint of the Rhine-Meuse deposits on the deposits of the Belgian rivers the lithological characteristics of the later are soon indistinguishable after their confinement with the Rhine-Meuse system. This observation is of importance because it indicates that the Stramproy Formation deposits can only be preserved when they are not intermixed with those of the Rhine-Meuse system. Thus, the presence of the Stramproy Formation at times in the RVG demonstrates that Rhine-Meuse deposition did not occur in the area during these periods, either because of sediment bypasses or as a result of shifting of its main stream belts to positions outside the RVG. This phenomenon is well-demonstrated by the thick Stramproy Formation deposits (up to 100 m) in the southern part of the RVG which proves that the Rhine-Meuse system had abandoned the southern part of the RVG for a large part of the Early Pleistocene.

The Waalre Formation particularly consists of stacked fluvial fining-upward cycles, each consisting of a coarse-grained basal part that fines upwards into regionally extensive flood-basin 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 exceeds the resolution of the applied lithostratigraphical classification. The primary reason is that all the sediment that forms part of the formation show a uniform petrographical composition. Secondly, the different deposits of this fluvial system are lithologically variable and this does not correspond to lithostratigraphical levels but to facies units within those units. A similar reasoning holds for the Stramproy Formation. Although there are some weakly developed regional lithological differences within this formation, a lithostratigraphical subdivision makes no sense as long as their bounding surfaces cannot be mapped using lithostratigraphical criteria alone.

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 country. The complex pattern of marine, estuarine and fluvial deposits in these areas indicates that they are 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 of the regional spatial intercalations (between formations and their deposits). Such regional lithostratigraphical information contributes to the understanding of the three-dimensional geometry of the different rock units forming blocks for compiling subsurface models and the geological history of the district.

7.3 The Early Pleistocene key reference sites

Several exposures in clay pits along the Dutch-German border area near Tegelen (south of Venlo) form key reference sites for pollen-defined Early Pleistocene chronostatigraphical stages and sub-stages. Of particular concern are the sites where the Tiglian and Eburonian Stages and parts of their sub-stages have been defined. Field observations in pits enlarged since the late 1980s have been defined. Non-marine deposits of the Upper Pliocene and Lower Pleistocene fluvial deposits in these areas indicate that they are affected by early Pleistocene sea-level changes. The pollen content of the uppermost fluvial strata of the Waalre Formation investigated at the Tegelen-Maalbeek area are at least, in part, determined by the sedimentary facies development of the deposits. There are signs of climate change recorded in the pollen-analytical evidence, but the supposed substantial differences in age between the three different Tiglian Stage pollen zones of the area difficult to explain from the sedimentary record. All newly and previously obtained pollen evidence from the Tegelen-Maalbeek area is derived from the uppermost part of the Waalre Formation and it is not likely that this fining-upward sequence had formed during a prolonged period of several hundreds of thousands of years as is generally believed for the duration of the Tiglian Stage. This statement is well-illustrated by the sedimentological interpretation of the fluvial sequence at the Tegelen C Substage stratotype in the now abandoned Bussel/Tiglian-Erythropit. From the bottom to top this sequence consists of bedded clay deposited in an esker lake and it over lain by a complex of crevasse-splay and overbank deposits. This grades progressively into a fluvial-basin clay. The lack of pollen in the uppermost part of this sequence is interpreted to result from sedimentary processes (i.e. the onset of crevassing), instead of a depositional hiatus during a period of cold climate. Furthermore, it has been demonstrated that these fluvial-basin deposits show severe oxidation of the large amounts of siderite they contain. It is argued that these hydrogeochemical processes may have preferentially influenced the preservation of the pollen in the deposits.
Extrapolation and correlation of the palynological record from the Tegelen-Maalbeek area to the much thicker, stacked Early Pleistocene fluvial deposits is still highly problematic. The innate fragmentary and discontinuous fluvial record in the BVG is the main reason that this arises. In addition, the resolution of the pollen evidence obtained is not sufficient to characterise and correlate individual clastic deposits of the Lower Pleistocene fluvial sequences. Consequently, it is unlikely that the fluvial record of the BVG can provide a reliable framework for the chronostratigraphical subdivision of the Early Pleistocene.

7.4 The fluvial history of the southern North Sea Basin

The lithostratigraphical framework presented in this study provides the key for the fluvial history of the Netherlands and the southern part of the North Sea basin (Chapter 5, 6). During the Pliocene the Rhine and Meuse were confluent north of Aachen on the Rurscholle. Their deposits (i.e. Rieseloolite Formation) occur in the BVG and the adjacent Peel Block. They grade into shallow marine deposits (Rousterhout Formation in the northern part of the BVG and the area to the west).

The remarkable petrographical change of the Rhine sediments that took place in the course of the Late Pliocene allows the continuation of the Oebele Beds to be mapped from the German part of the Lower Rhine Embayment (LRE) into the BVG as far as Eindhoven. These deposits, characterised by Rhine’s mineralogy form the lower part of the Waalre Formation. One main course of the Rhine-Meuse system was situated in the BVG and a second on the Venloer Scholle/Peel Block, while a third course of the Rhine is thought to have been located in the eastern part of the Waalre Formation. The shallow marine sediments in the northern BVG, so-called Beerse member of the Belgian lithostratigraphical scheme. The shallow marine sediments in the northern BVG, and the repeated intercalations of these marine deposits that occur in the Waalre Formation, indicate that sea-level changes affected the lower alluvial plain of the Rhine-Meuse system during the Early Pleistocene.

Lower Pleistocene Rhine-Meuse deposits also occur in the central and western part of the Netherlands. It is likely that they were supplied by a main Rhine branch situated in the eastern part of the LRE. The Rhine-Meuse deposits in the central and western part of the Netherlands interdigitate with those of the so-called Eridanos system, a large fluvial deltaic system that supplied sediment from the Baltic region to the North Sea Basin. The southernmost advance of the Eridanos system took place during the deposition of Waalre Formation subunit WA-3. However, the main depositional zone of the Eridanos system was situated north-west of the Lower Pleistocene, the main pathway of the Rhine-Meuse system migrated to the north-western part of the Netherlands, while extensive flood-basin areas developed in the northern part of the BVG and the area to the west. Rhine-Meuse fluvial deposits were preserved for a very long time in the westernmost part of the country.

As a result of the north-westward shift of the Rhine-Meuse system’s main course the depositional realm of the Belgian rivers gradually extended to northwards. Thus, the Early Pleistocene Rhine-Meuse fluvial history shows a gradual shift into northern and north-western directions of both the Belgian rivers and the Rhine-Meuse system. The marine depositional zone, which covered the larger part of the Netherlands during the onset of the Early Pleistocene, continues to retreat towards the northwest, so that by the end of the Early Pleistocene the larger part of the southern North Sea Basin was filled by fluvial deposits.

Generally, the Early Pleistocene fluvial deposition in the southern Netherlands is characterised by a low ratio between accommodation space and sediment supply. Large amounts of the transported sediment by-passed the area and were deposited further north and north-west in the North Sea itself (Maasvlies Formation). The BVG is an exception to this general trend throughout much of the Early Pleistocene. Here, a relatively thick sequence of Lower Pleistocene fluvial deposits formed as a result of locally increased accommodation space resulting from tectonic subsidence. Nevertheless, the Lower Pleistocene fluvial sequence in the BVG is fragmentary and discontinuous, either as a result of repeatedly occurring sediment bypass and/or shifts of the main channel belts of the Rhine-Meuse river system to areas outside the BVG. The lower Rhine-Meuse alluvial plain, and its continuation into the area, were strongly controlled by regional changes of base level, which were driven by climatically induced sea-level changes. Based on the conceptual framework described in chapter 6 it seems likely that the fluvial record of the BVG can provide a reliable framework for the chronostratigraphical subdivision of the Early Pleistocene.

7.5 Future research

The results of this study have contributed to a better understanding of the nature of the Upper Pliocene and Lower Pleistocene fluvial sediments in the southern part of the Netherlands. Additional high resolution sedimentological, geological, palynological and palaeomagnetic data may be obtained by grounding high-resolution surveys which include extensive core programmes and shipboard investigations. Additional high resolution studies of stratigraphical and palaeoecological evidence of the BVG and the Rurscholle, Germany may be required to test and refine the proposed model for the Early Pleistocene fluvial record in the area. High-resolution seismic data is needed to improve the lateral correlation of different depositional units and the major bounding surfaces. Furthermore, high-resolution analyses of multiple proxies in both the marine detritus and the onshore fluvial sequences may further contribute to a well-established land-sea correlation and should provide an integrated chronostratigraphical framework for the Pleistocene period. In order for this to be achieved, continuous coring is needed in both the marine detritus and the fluvial records. This requires a multi-disciplinary approach combining palaeomagnetic, biostratigraphical, lithostratigraphical, sedimentological and orbital-timing methods that is advocated for these investigations. Based on the stratigraphy and sedimentary architecture, numerical modelling of the Lower Pleistocene fluvial system can be used to test the hypotheses on the fluvial development. Modelling results can provide additional evidence to amplify the existing explanations. For example, model simulations of sediment-volume partitioning as a function of varying accommodation space may improve insight into the preserved genetic sequences that are arranged in seaward-off-stepping, vertical-stacked and landward-stepping patterns. In addition, detailed reconstructions of the palaeo-catchments may show palaeogeomorphologival and sedimentary changes, and can contribute to a better understanding of the balance between autogenic and allocogenic controlling factors on the fluvial systems. The depositional history of the southern North Sea Basin forms an important archive of the response of fluvial and shallow marine systems on tectonically and climatically controlled changes. Unravelling the complex fluvio-deltaic history of the prograding fluvial systems in the Pleistocene North Sea Basin will contribute to a better anticipation on the use and sustainable management of subsurface resources. It also provides a framework to develop tools to anticipate on the impacts of natural and human-induced changes that will affect future developments of the lower Rhine-Meuse fluvio-deltaic system and of comparable systems elsewhere.