SUMMARY

Patterns and processes in a Pleistocene fluvio-aeolian environment (Roer Valley Graben, south-eastern Netherlands)

Introduction

The Roer Valley Graben in the south-eastern Netherlands is an area of active tectonic subsidence. In this region, an up to 35-m thick terrestrial fluvio-aeolian sedimentary record of Middle and Late-Quaternary age recorded the interplay of tectonic subsidence and climate changes. The fine-grained sediments were previously known as Nuenen Group deposits in the Quaternary lithostratigraphic framework of the Netherlands. They form an important archive of terrestrial landscape development in a changing climate. The subsiding Roer Valley Graben has been saved from glacial erosion, because it is situated south of the maximum extent of the Pleistocene ice sheets. This makes it a key area for correlating the fragmentary glacial record of northern Europe with the lake and loess records in the eastern and southern part of the continent. In addition, the Roer Valley Graben may contain part of the so-called 'missing' record of upper Middle-Pleistocene sediments (representing Marine Isotope Stages 10 to 7) in continental north-western Europe. In 1998, the State Geological Survey of the Netherlands (TNO-NITG) initiated this study, because a lack of sedimentary information hampered detailed geological mapping and applied research in the area.

The main objectives of this study were:

- To develop a well-defined and applicable lithostratigraphic framework for the fluvio-aeolian deposits in the Roer Valley Graben (Chapter 2);
- To reconstruct the prevailing sedimentary processes, local depositional pattern and palaeo-environmental development in the Roer Valley Graben during the Middle and Late Quaternary (Chapters 3, 4, 5);
- To construct a geochronological framework for the Middle- and Upper-Quaternary deposits in the Roer Valley Graben and to assess the influence of regional tectonic movements and climate changes on the depositional environment and sedimentation rate in the area (Chapters 4, 5).

These goals were achieved by a characterisation and interpretation of the lithological properties, sedimentary structures, palaeo-ecological data and geochemical and mineralogical properties of the Nuenen Group deposits and comparison of this information to data from other studies in similar depositional settings. Optically Stimulated Luminescence (OSL) dating of quartz grains provided an opportunity to establish a reliable timeframe for the sedimentation of the terrestrial fluvio-aeolian deposits in the Roer Valley Graben.
Lithostratigraphy

Application of the traditional lithostratigraphic framework to subdivide the Middle- and Upper-Quaternary terrestrial fine-grained deposits in the Netherlands is problematic. Deposits of many formations cannot be distinguished from each other, based on lithological characteristics and stratigraphic position alone. To overcome this problem, Chapter 2 presents a new, well-defined lithostratigraphy for these deposits, based on detailed research in the central part of the Roer Valley Graben. The traditional lithostratigraphic subdivision of the fine-grained deposits in this area into three formations (Eindhoven Formation, Asten Formation and Twente Formation) was based on a combination of litho-, bio- and chronostratigraphic evidence and the presumed widespread presence of a horizon of organic-rich interglacial sediments of Eemian age. To avoid intermingling of criteria regarding lithological characteristics, genesis and age, all fine-grained sediments are now incorporated into the new Boxtel Formation. The implications for the lithostratigraphic framework in other parts of the country are explored and discussed. Eight lithostratigraphic members are introduced that describe the most characteristic parts of the formation. To fully illustrate the sedimentary sequence in the Roer Valley Graben, two new members are defined there. The Best Member incorporates floodloam deposits alternating with sandy aeolian deposits in the lower part of the Boxtel Formation. The Liempde Member includes reworked aeolian loess and sandy loess deposits ('Brabant loam') that occur in the upper part of the sedimentary sequence.

Sedimentary processes and depositional pattern

Chapter 3 details the sedimentary structures and depositional environment of the sediments, using undisturbed sediment cores and cone penetration tests (CPTs). Seven sedimentary facies are distinguished, ranging from sandy fluvial deposits to loamy aeolian deposits and organics. Wet-aeolian sand-sheet and loam deposits are the two most widespread facies. The aeolian sand is characterised by horizontal alternating bedding, attributed to deposition of sand and silty sand on an alternating wet and dry surface. Dominant processes include sand-ripple lamination and adhesion lamination. The loam is usually massive and interpreted as a reworked loess deposit. Not only sedimentary data (Chapter 3), but also mineralogical and geochemical data (Chapter 5) reveal an upward change from a fluvial depositional environment to a dominance of aeolian deposits. This change may be related to increased tectonic uplift and the onset of large-scale volcanism in the Ardennes-Eifel region and a north-eastward shift of the lower courses of the rivers Rhine and Meuse between 800 and 500 ka. Reworked Na-rich deposits with an unstable heavy mineral assemblage form the main source material for the aeolian deposits in the Roer Valley Graben. The most likely provenance is the area north and west of the Roer Valley Graben, where Quaternary Rhine deposits were present near the surface. Na-poor sediments with a stable heavy mineral assemblage from the Campine High in the south-west may have acted as a secondary sediment source. Sedimentation and preservation in the Roer Valley Graben predominantly took place under humid surface conditions. These
conditions occurred: 1) in a periglacial climate with permafrost; 2) at the transition from a warm-temperate to a cool climate.

Organic deposits from at least two different interglacial periods (Marine Isotope Stage (MIS) 5e and MIS 9) have been preserved in the central part of the Roer Valley Graben. During the Eemian (MIS 5e) clastic and organic deposition took place in the early part (E2-E3) and last part of the interglacial (E5-E6A-E6B). The sedimentary sequence contains a widespread hiatus during the E4A-E4B-E5 regional pollen zones (Chapters 4, 5). During MIS 9, clastic and organic deposition was restricted to the last part of the interglacial period (Chapter 5). Sedimentological and palynological data reveal that both the presence and extent of deposits from interglacial periods are related to the local groundwater level history and clastic sediment flux. Regional changes in these environmental factors are probably related to changes in the global oceanic-atmospheric circulation pattern.

Optically Stimulated Luminescence dating

Optically Stimulated Luminescence (OSL) dating has been applied to provide an absolute time frame for the Middle- and Late-Quaternary deposits in the area (Chapters 4, 5). This method is very suitable to date these deposits, because:

- The aeolian depositional environment of most of the clastic sediments ensured sufficient exposure to daylight during sediment transport to enable complete bleaching of the grains;
- The clastic sediments consist almost exclusively of quartz grains, which causes very low natural radiation doses and permits reliable OSL dating far back in time.

Two quartz OSL dating series are presented (Chapter 5) that indicate a Middle- to Late-Quaternary age of the fluvi-aeolian and aeolian deposits in the Roer Valley Graben. The whole sequence of fine-grained deposits of the Boxtel Formation is correlated with Marine Isotope Stages 14 to 1 (570 ka to present; Chapter 6). The fluvi-aeolian deposits in the lower part of the Boxtel Formation (Best Member) have been formed contemporaneously with the coarse-grained Meuse deposits of the Beegden Formation and date from MIS 14 to MIS 12 (570-420 ka). As a consequence, fluvial Rhine-Meuse deposits (Sterksel Formation) in the Roer Valley Graben must date from MIS 15 (570 ka) and older. Correlation of the morphological boundary between the Main and Middle Terraces along the rivers Rhine and Meuse (previously dated at ~750 ka) with the lithostratigraphic boundary between the Sterksel and Beegden Formation in the Roer Valley Graben (dated at ~570 ka) is therefore erroneous (Chapter 5). The two widespread organic layers in the Boxtel Formation are dated at 114 ± 12 ka (MIS 5e, Eemian) and ~300 ka (MIS 9), respectively. The age of the upper organic layer is supported by its stratigraphic position and palynological signature, which makes this study the first to present a reliable OSL dating result for terrestrial Eemian deposits in the Netherlands (Chapter 4).
Conclusions

The Roer Valley Graben contains a well-preserved Middle- and Late-Quaternary sedimentary record, reflecting changing depositional patterns and sedimentary processes in a fluvio-aeolian environment. The following results were obtained:

- A well-defined lithostratigraphic subdivision of the deposits, involving the definition of the Boxtel Formation and two new lithostratigraphic members: the Best Member and Liempde Member;
- A reconstruction of the provenance of the fluvial and aeolian sediments, prevailing sedimentary processes and the development of the local depositional environment;
- A chronological framework of the deposits, based on quartz OSL dates and correlated with regional tectonic events and cyclic climate change.

The strength of the research approach has been the integration of lithological and sedimentary information with palaeo-ecological data and reliable geochronological information. This permitted to interpret this fragmentary terrestrial record in terms of repeated phases of deposition and non-deposition. Fluvio-aeolian sequences allow the use of chronometric dating such as quartz OSL to date sediments with ages well beyond 100 ka. These records are therefore a valuable addition to existing long terrestrial records (e.g. lacustrine sequences) that usually only provide biostratigraphical information. Because of its geographical position in a subsidence area, just south of the region that was severely affected by glacial remoulding by the Pleistocene ice sheets, the Roer Valley Graben contains important parts of the 'missing' late-Middle Pleistocene record in continental north-western Europe (sediments from MIS 10 to MIS 7). The sedimentary sequence in the Roer Valley Graben thus forms a possible link between the glacial record of northern Europe, the $\delta^{18}$O climate records of the deep sea and the continuous lacustrine and loess sequences in the eastern and southern part of the continent.