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Sedimentary architecture and chronostratigraphy of a late Quaternary incised-valley fill: A case study of the late Middle and Late Pleistocene Rhine system in the Netherlands

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ABSTRACT

This paper describes the sedimentary architecture, chronostratigraphy and palaeogeography of the late Middle and Late Pleistocene (Marine Isotope Stage/MIS 6-2) incised Rhine-valley fill in the central Netherlands based on six geological transects, luminescence dating, biostratigraphical data and a 3D geological model. The incised-valley fill consists of a ca. 50 m thick and 10–20 km wide sand-dominated succession and includes a well-developed sequence dating from the Last Interglacial: known as the Eemian in northwest Europe.

The lower part of the valley fill contains coarse-grained fluvio-glacial and fluvial Rhine sediments that were deposited under Late Saalian (MIS 6) cold-climatic periglacial conditions and during the transition into the warm Eemian interglacial (MIS 5e-d). This unit is overlain by fine-grained fresh-water flood-basin deposits, which are transgressed by a fine-grained estuarine unit that formed during marine high-stand. This ca. 10 m thick sequence reflects gradual drowning of the Eemian interglacial fluvial Rhine system and transformation into an estuary due to relative sea-level rise. The chronological data suggests a delay in timing of regional Eemian interglacial transgression and sea-level high-stand of several thousand years, when compared to eustatic sea-level. As a result of this glacio-isostatic controlled delay, formation of the interglacial lower deltaic system took only place for a relative short period of time: progradation was therefore limited. During the cooler Weichselian Early Glacial period (MIS 5d-a) deposition of deltaic sediments continued and extensive westward progradation of the Rhine system occurred.

Major parts of the Eemian and Weichselian Early Glacial deposits were eroded and buried as a result of sea-level lowering and climate cooling during the early Middle Weichselian (MIS 4-3). Near complete sedimentary preservation occurred along the margins of the incised valley allowing the detailed reconstruction presented here.

1. Introduction

River deltas and estuaries are world-wide occurring environments where rivers connect to seas and oceans. Their deposits make up an important part of the geological record and are formed in complex sedimentary environments where marine, estuarine and fluvial depositional processes alternate both in space and time. The resulting strong heterogeneous nature of these deposits is critical in determining for example physical characteristics (i.e. net-to-gross ratio, permeability and porosity) in hydrocarbon reservoirs (e.g. Martinius et al., 2005; Thrana et al., 2014), shallow subsurface aquifers (e.g. Bierkens, 1996; Sanchez-Vila et al., 2006), and aggregate resources mining (Van der Meulen et al., 2005). There is a

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particular need for high-resolution records, for systems that have been subjected to changes in external forcings, to better understand lower-deltaic sediment records, their preservation over longer timescales and to facilitate their interpretation for various fields of application. Quaternary sequences are suitable candidates for such investigations, as they are still within the practical range of high-density data collection and dating (Blum and Törnqvist, 2000). The Middle and Late Pleistocene southern North Sea Basin record of the Rhine-Meuse system is an example of a record where these prerequisites are met (e.g. Törnqvist et al., 2000, 2003; Wallinga et al., 2004; Busschers et al., 2005, 2007, 2008; Hijma et al., 2012; Peeters et al., 2015).

This record consists of several tens of metres of mostly sandy deposits that were supplied to the basin under cold periglacial conditions (Cohen et al., 2014). Parts of this Rhine-Meuse record contain an embedded sequence of Last Interglacial sediments that were formed under near-coastal conditions (Busschers et al., 2007). Large amounts of digitally available borehole information and series of geological maps (Van der Meulen et al., 2013; TNO-GSN, 2014) and more recently also 3D geological models (Stafleu et al., 2011; Gunnink et al., 2013) now allow study of these sediments at an unprecedented high level of detail. In addition, Rhine sediments have proven to be suitable for luminescence-dating (Wallinga et al., 2004; Busschers et al., 2007) and the well-defined pollen-based regional biostratigraphical framework (Zagwijn, 1961, 1996; Van Leeuwen et al., 2000) enables construction of a high-resolution chronostratigraphical framework. The combination of high data-density and chronological control allows linking of the sedimentary development of the Rhine-Meuse system, and in particular the developments of the Last Interglacial part, to records of climate change, sea-level change and glacio-isostasy.

Deposition of the late Middle and Late Pleistocene Rhine sediments occurred in two local depocentres referred to as the Central Depocentre and the Southern Depocentre (Fig. 1) (Busschers et al., 2007; Peeters et al., 2015). Both the on- and offshore parts of the Southern Depocentre were previously studied in detail (Busschers et al., 2007; Hijma et al., 2012). In this area, however, only basal fragments of the Last Interglacial Meuse sequence have been preserved due to strong truncation by the Meuse itself and later also by the Rhine during the Weichselian, preventing a detailed reconstruction of its sedimentary evolution during the Last Interglacial. In the Central Depocentre, however, a 5–10 m thick unit of Last Interglacial sediments occurs embedded within Late Saalian and Weichselian Pleniglacial age coarse-grained fluvial sands (e.g. Wiggers, 1955; Westerhoff et al., 1987). Here, the Last Interglacial sequence is regarded part of an incised-valley fill (cf. Blum, 1993; Zaitlin et al., 1994; Blum et al., 2013), consisting of several stacked and laterally occurring units of fine-grained fluvial and estuarine flood basin and shallow-marine deposits (Peeters et al., 2015). Previous work primarily focused on the shallow-marine infill of the inherited sub-glacially scoured basins (e.g. Cleveringa et al., 2000; De Gans et al., 2000; Van Leeuwen et al., 2000) and the upstream fluvial dominated part of the sequence in the IJssel basin (e.g. Busschers et al., 2007, 2008). The sedimentary architecture of the lower delta plain of the Rhine -

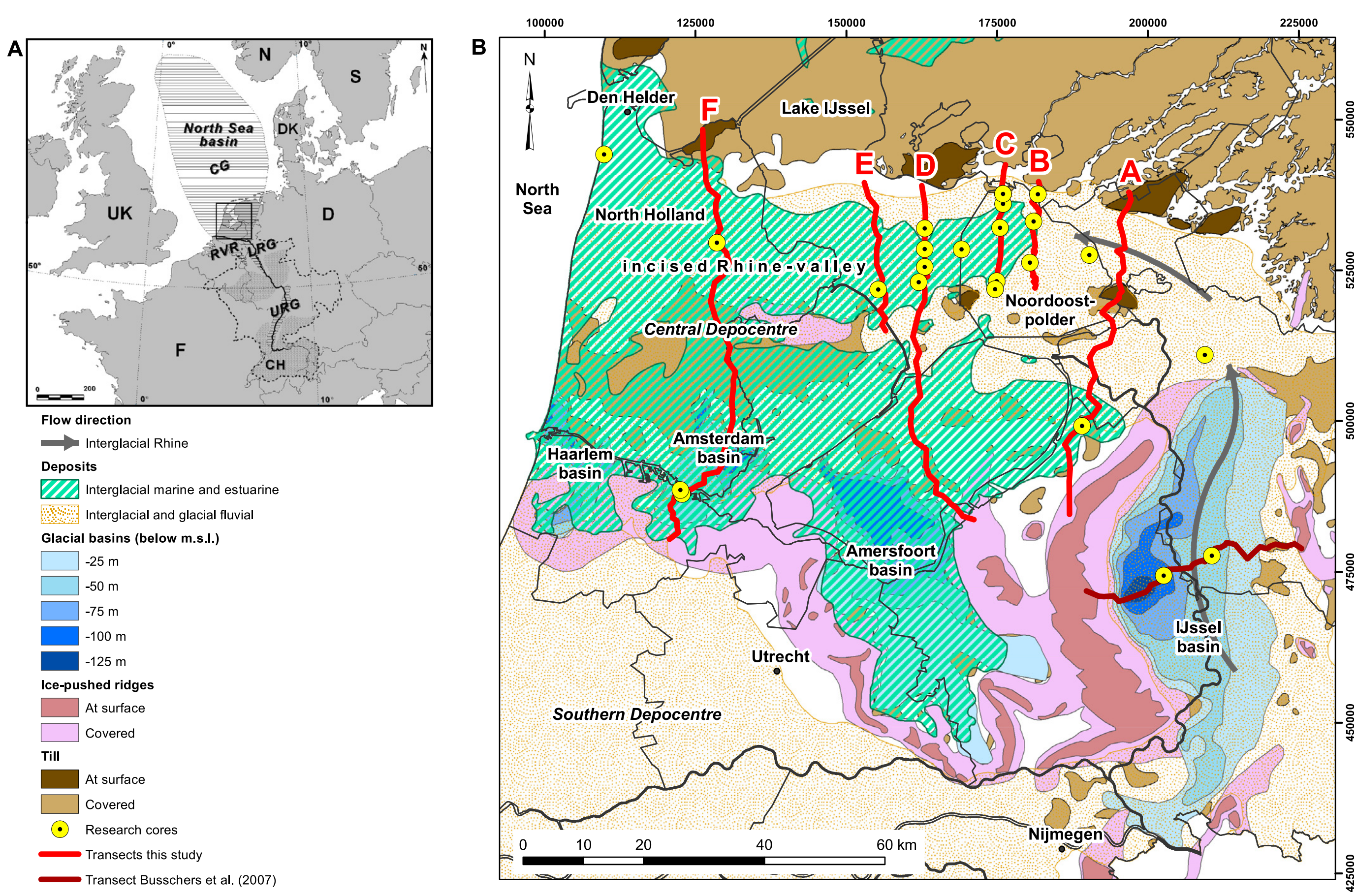

Fig. 1. A) The present Rhine drainage basin and its tectonic setting (cf. Ziegler, 1994). Upper Rhine Graben: URG; Lower Rhine Graben: LRG; Roer Valley Graben: RVR; Central Graben: CG. B) Late Pleistocene Rhine and Eemian interglacial marine and estuarine deposits in relation to its inherited Saalian glacio-topography in the central Netherlands. After Peeters et al. (2015), with map data from Gunnink et al. (2013).