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# Multiple oscillations during the Lateglacial as recorded in a multi-proxy, high-resolution record of the Moervaart palaeolake (NW Belgium)

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ABSTRACT

This paper presents the results of multi-disciplinary research carried out on the deposits of Moervaart depression, NW Belgium, one of the largest palaeolakes (~25 km$^2$) that existed during the Lateglacial interstadial in NW Europe. The multi-proxy study, including physical (organic matter and calcium carbonate, magnetic susceptibility, micromorphological), botanical (pollen, macrofossils, diatoms), zoological (ostracods, molluscs, chironomids) and chemical analyses (stable carbon and oxygen isotopes) has resulted in a detailed reconstruction of the Lateglacial landscape as well of the local conditions that prevailed in the lake itself. A chronology of the record was provided by radiocarbon dating and comparison with radiocarbon dates of the nearby Rieme site. These yielded a good match with the regional biostratigraphy.

During the Lateglacial, vegetation and geomorphology of the landscape in general changed from a tundra landscape to a boreal forest. The vegetation development, however, was interrupted by a number of cold reversals. Three centennial-scale cold oscillations are present in the record: 1) the so-called Older Dryas corresponding to GI-1d in the Greenland ice-cores, 2) a short and pronounced cold event during the early Allerød, which could be correlated to GI-1c2 and 3) a cooling event during the late Allerød probably corresponding to the Intra Allerød Cold Period (IACP) or GI-1b. The latter most likely was responsible for the disappearance of the Moervaart palaeolake.



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## 1. Introduction

The Moervaart region is situated in the sandy lowland of NW Belgium at the southern margin of the Great NW European Plain, which is mainly covered by coversands (Fig. 1a–c). It is an important area for Lateglacial and early Holocene geoarchaeological research, as it is one of the few areas in NW Europe in which high-resolution and high-quality palaeoenvironmental data are available in close spatial relationships with prehistoric hunter-gatherer sites (Crombé and Verbruggen, 2002; Crombé et al., 2011).

Partly building on former palaeoecological studies in the area (Verbruggen, 1979; Denys et al., 1990; Verbruggen et al., 1996), the Moervaart region recently has been the subject of a new multi-disciplinary research project that focussed on understanding the geomorphological, hydrological and ecological evolution of the landscape. Detailed investigations were conducted into the palaeotopography (Werbrouck et al., 2011; Crombé et al., 2013), palaeotopography (De Smedt et al., 2011, 2012; Zwertvaegher et al., 2013) and palaeovegetation (Bos et al., 2013; Demiddele et al., 2016) of the area, which were subsequently combined with extensive radiocarbon and OSL-dating (Derese et al., 2010; Crombé et al., 2012, 2014).

As part of this research, a high-quality lacustrine sediment record was retrieved from the centre of the Moervaart depression, a large, Lateglacial palaeolake bordering the southern side of the Great Coversand Ridge of Maldegem-Stekene (Fig. 1d). This paper compiles the results of a multi-proxy research project carried out on the sediments of this palaeolake (Fig. 1d). The aim of this study is to reconstruct the Lateglacial landscape of the surrounding area, as well as the local conditions that prevailed in the lake itself. As the observed variations in former vegetation patterns are likely linked to climate changes (major and minor) occurring during the Lateglacial and Early Holocene, the results of this study will also be compared with the Greenland ice-core data and previously published climatological, palaeoenvironmental and lake-level data from the NW European coversand region.

## 2. Study area

The Moervaart region is characterised by a complex and dynamic palaeolandscape consisting of four major features (Figs. 1d and 2a,b): (1) an extensive coversand ridge, i.e., the Great Coversand Ridge of Maldegem-Stekene (De Moor and Heyse, 1978; Verbruggen et al., 1996; Crombé et al., 2012), including numerous shallow dune-slacks and ponds; (2) a large but shallow freshwater inland palaeolake, i.e. the Moervaart palaeolake, immediately south of the Great Coversand Ridge (Heyse, 1979, 1983); (3) an anastomosing river system consisting of numerous shallow gullies, connected to the palaeolake; and (4) a deep meandering palaeochannel of a river named the Kale (upper course) or Durme (lower course), which currently runs through the palaeolake area from west to southeast where it joins the river Scheldt.

In the Moervaart region, due to the prevailing western and northwestern winds, longitudinal coversand ridges developed during the Weichselian Pleniglacial and Lateglacial (Heyse, 1979). One of the largest coversand ridges within NW Belgium, the Great Coversand Ridge of Maldegem-Stekene, is over 80 km long and locally 3 km wide. It is characterised by a complex microrelief of small dunes and irregularly elongated depressions and dune slacks (Heyse, 1983; Crombé and Verbruggen, 2002; Bos et al., 2013). Its height varies between ca. 5 m and 15 m above present sea level, although its average relative elevation is only 3–4 m. On the top of this massive sand ridge numerous shallow, closed depressions, forming temporary slacks or ponds, were created as a result of local aeolian erosion (so-called blow-outs). Two of these smaller depressions situated within the Moervaart region (Rieme and Wachtebeke "Heidebos") were investigated in detail (Bos et al., 2013; Derese et al., 2010). Besides these shallow dune-slacks, directly south of the Great Coversand Ridge of Maldegem-Stekene, a great number of larger lakes formed during the Lateglacial in depressions when the previously open, northern exit route for surface waters became blocked by the formation of the Great Coversand Ridge (De Moor and Heyse, 1978; Verbruggen et al., 1996). The Moervaart palaeolake was by far the largest within northwestern Belgium (length: ~15 km, width: ~2.5 km, 25 $km^2$, Fig. 1d), with the deepest part located in the centre along the northern lakeside (De Moor and Heyse, 1978; Verbruggen, 1971, 2005; Crombé et al., 2013).

Numerous prehistoric sites dating from the Lateglacial (Final Palaeolithic, ca. 14,000–13,000 cal. BP) have been discovered in the Moervaart region concentrated along the lake edge on the southern steep slope of this dune complex (Fig. 2a) (Crombé et al., 2011). Most typical for the Lateglacial is the high density of *Federmesser* Culture sites associated with the Allerød period (Crombé and Verbruggen, 2002; Crombé et al., 2011), forming an almost continuous site-complex of temporary campsites stretching along the Maldegem-Stekene coversand ridge and on some small interfluvial levees (over ca. 15 km, Fig. 2a).

## 3. Material and methods

### 3.1. Fieldwork, sedimentological and physical analyses

An extensive fieldwork survey (Fig. 2b, Bats et al., 2009, 2010; Crombé et al., 2013) allowed reconstruction of the general morphology and succession of the palaeolake sediments in the Moervaart depression. For a more detail study a 70 m long north-south oriented trench was dug across the deepest part (i.e., Moerbeke *Suikerfabriek*, Fig. 2b; 51°10′08″/3°55′43″) in which palaeoecological sampling was conducted at three different sites, P3/M3/MB8 (Fig. 3), S2 and S4 (Fig. 4). The most complete and best preserved P3/M3/MB8 *master sequence* (Fig. 3 was collected at the deepest point. The M3 sequence was used for macroscopic (botanical macroremains and *Bithynia* molluscs) analyses, AMS $^{14}C$ radiocarbon dating and oxygen and carbon isotope measurements on ostracod valves; the P3 sequence for microscopic analyses (pollen, chironomids and diatoms); and the MB8 sequence for magnetic susceptibility profiling. Sampling for micromorphological analysis was performed on the sediments directly north of the master sequence (Fig. 3). Two complementary sequences, S2 and S4, retrieved respectively 12 m and 14.5 m north of P3/M3/MB8 (Fig. 1 in Supplement), were sampled for more extensive ostracod and mollusc analyses. These locations were correlated to the master sequence by visually following the layers.

The different layers in the Moervaart trench were visually described according to the following parameters: (1) lithology (colour and grain-size determination), (2) sedimentological features and post-depositional deformation, (3) thickness and bed form and (4) character of lower and upper boundaries of sediment beds (transitional, sharp or erosional) and presence of internal erosional surfaces (Fig. 3, Table 1 and Fig. 2 in Supplement). To aid lithological description, volumetric magnetic susceptibility ($\kappa$) was measured on the MB8 sequence at 2.5 mm intervals with a Bartington MS2 susceptibility meter (Dearing, 1999). Furthermore, organic carbon and $CaCO_3$ contents were determined on samples with 1 cm resolution by automated loss-on-ignition (LOI) using a PrepASH 229 Precisa following Heiri et al. (2001).

For micromorphological research, samples of the different layers (Fig. 3) were collected in Kubiëna boxes (6 × 9 cm). Samples were oven-dried (50–60 °C), impregnated under vacuum with an