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Rapid climatic events as recorded in Middle Weichselian thermokarst lake sediments

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Abstract

From a Middle Weichselian sediment sequence in the opencast brown coal mine of Reichwalde (eastern Germany), a ~40 cm thick thermokarst gyttja deposit has been sampled. The AMS ^{14}C dates, although at the limit of detection, indicate an early Middle Weichselian age of the gyttja. Pollen, botanical, and zoological (e.g. chironomids) macroremains have been analyzed. Botanical and chironomid taxa indicate warm climatic conditions in the bottom part of the sequence. For this lower part the botanical data suggest a minimum mean July temperature of 12–14 °C. Following this, a cooling is indicated, coinciding with an increased clastic deposition in the lake. A return to permafrost conditions is reconstructed for the upper part of the sequence. The combined evidence strongly suggests a degradation of permafrost due to increased warming in response to a D/O event as a forcing factor for the thermokarst lake formation.

1. Introduction

The Weichselian Early, Middle, and Late Pleniglacial have been correlated, respectively, with Oxygen Isotope Stages 4, 3, and 2 of the marine $\delta^{18}O$ record (Martinson et al., 1987; Behre and van der Plicht, 1992, Table 1). Investigations of the Greenland ice cores over this interval revealed many rapid climate oscillations in the oxygen isotope record (Johnsen et al., 1992; Dansgaard et al., 1993), the so-called Dansgaard/Oeschger (D/O) events. A D/O event typically starts with an abrupt warming of Greenland by 5–10 °C over a few decades or less, followed by a gradual cooling over several hundreds to more than a thousand years and often ends with an abrupt final reduction of temperature back to cold (stadial) conditions (Ganopolski and Rahmstorf, 2001). Climate studies based on marine cores from the Atlantic Ocean (Bond et al., 1993) also have shown these short-term climatic fluctuations. The period between the successive D/O events is most often around 1500 years or a multiple thereof (Bond et al., 1997, 1999; Grootes and Stuiver, 1997).

However, the majority of these climate oscillations are not reflected in the NW European continental palynological record, except at more southerly locations, where interstadial periods seem to have been registered better in pollen records, e.g., Les Echets, La Grand Pile, and the Velay region (e.g. De Beaulieu and Reille, 1984, 1992; Guiot et al., 1989; Reille and de Beaulieu, 1990; Reille et al., 2000). In the northwestern European terrestrial record only three to five interstadials have been recognized during the Weichselian Pleniglacial (e.g. van der Hammen et al., 1967; van der Hammen, 1971; Zagwijn, 1974; Kolstrup and Wijmstra, 1977; Vandenberghe, 1985; Ran, 1990; Behre and van der Plicht, 1992). Correlation between the ice-core record and the terrestrial botanical record therefore remains unclear.

Based on the ice-core records it is likely that there were intervals during the Pleniglacial when climate in NW Europe was suitable for the development of boreal forests. However, pollen and macroremain analyses have shown that such forests were not present (e.g. Kolstrup, 1990; Bos et al., 2001). This absence seems to conflict with the

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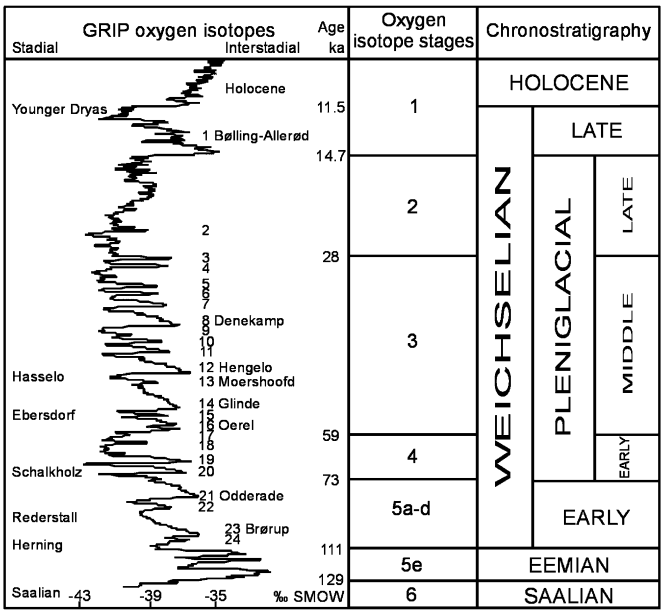
Table 1
Chronostratigraphy of the Weichselian and comparison with the $\delta^{18}O$ record of the GRIP ice core (Johnsen et al., 1992), the Oxygen Isotope Stages (Martinson et al., 1987) and the terrestrial Interstadials and Stadials (e.g. Ran and van Huissteden, 1990; Behre and van der Plicht, 1992; Dansgaard et al., 1993). Ages follow Martinson et al. (1987) and Walker et al. (1999)



temperature regime as reconstructed from pollen, macro-remains, and beetles and often has been the subject of speculations (e.g. Coope, 1975, 2000; Kolstrup and Wijmstra, 1977; Kolstrup, 1990; Ran, 1990; Van Geel, 1996; Bos et al., 2001, 2004). A variety of factors has been suggested to explain the virtual absence of trees in NW Europe during the Pleniglacial: (1) too dry and continental climate, (2) wind stress, (3) heavy grazing pressure from large mammals, (4) highly dynamic soil conditions due to periodic permafrost, (5) the suddenness and intensity of the climatic warming, and (6) the short duration of the warming intervals that left too little time for trees to migrate from their refugia in southern Europe. The latter two arguments suggest that vegetation response was not rapid enough to react to the short-lasting warming events. However, fast migrating biotic proxies such as Chironomidae and aquatic botanical taxa could be able to register even very abrupt warming events.

An abrupt climate warming following a prolonged cold (stadial) period could lead to permafrost degradation and the formation of thermokarst lakes (so-called thaw lakes). This suggests that the response to a sudden and relatively short climate warming could be documented in the infill of such a thaw lake. However, not every thermokarst lake is the result of external forcing mechanisms like a climatic warming. The formation of thermokarst lakes can also be due to internal forcing mechanisms, such as natural fires, erosion by river cut banks and inundations (Hopkins and Kidd, 1988).

To test whether thermokarst formation is internally or externally driven, the thermokarst infilling can be analyzed for temperature-dependent proxies. If thermokarst initiation was triggered by climate warming, then evidence of such a thermal spike should be present in especially the lower parts of the thermokarst infilling. Given the short duration of the Pleniglacial warm spikes in the ice-core record, one may assume that the bulk of the thermokarst infilling might already represent the waning stage of the thermal spike and the development toward a succeeding cold phase.

Our hypothesis is that, analogous and synchronous to the D/O events registered in the ice and marine cores, rapid climate warming occurred over northwestern Europe and that these rapid climate oscillations could have been recorded as thermokarst features.

2. Geological setting

The opencast lignite mines in the Niederlausitz, eastern Germany, reveal extensive Weichselian sediment series deposited in a fluvial and partly aeolian context (Fig. 1). These sediments are subject to an ongoing research program into the fluvial, palaeoenvironmental, and climatological history of the region (Mol, 1997a, b; Bos et al., 2001; Kasse et al., 2003). The sequence in these quarries consists of local deposits from the rivers Spree and Neiβe. The latter flowed in a western direction through the ice marginal valley during part of the Middle Pleniglacial (Fig. 1).

Within the Weichselian fluvial and aeolian deposits frequent organic intercalations occur, which can be used for the reconstruction of the Pleniglacial vegetation and climate (Bos et al., 2001). In the opencast lignite mine of Reichwalde some of the organic sediments were interpreted as thermokarst lake deposits. The identification of former thermokarst situations and thermokarst sediments is complicated. Over the past decade we developed several diagnostic criteria by which thermokarst phenomena could be distinguished. These criteria are: (1) strong deformations and ice-wedge casts below the thermokarst deposit ascribed to the degradation of the permafrost; (2) a sharp contact between the deformations and the overlying thermokarst infilling; (3) an abrupt and undeformed organic infilling of the thermokarst depression with gyttja reflecting an immediate presence of a lake after the permafrost degradation. A gradual deepening of the lake and a concomitant drowning of the vegetation in such case should be lacking; and (4) the infill is mostly horizontally laminated.

3. Material and methods

During a 2-month field work campaign in the Reichwalde opencast lignite mine (Fig. 1) in June 1999, the sequence in the eastern wall of the mine was logged. Five stacked fluvial and aeolian units were identified, and the