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Periglacial environmental developments between 30 and 20 ka BP in Denmark

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Abstract

A sedimentary sequence from eastern Denmark covers the time span from somewhat before 30 ka BP until 20 ka BP, based on thermoluminescence (TL) age estimates. The sequence is composed of loess and sandloess alternating with water-laid sediments in the lower part and with slope deposits in the upper part. Pollen is present in some of the layers. Integration of the evidence from this sequence with data from other north and central European localities of the same period suggests that from 30 till 20 ka BP there was much reworking of sediments by wind. The presence of slope deposits and frost-wedge casts points to (intermittent?) permafrost between about 24 and 20 ka BP, and possibly also for a period between 27 and 24 ka BP. Although soil surface conditions were unstable, vegetation was probably present during almost the entire period; the dominant cover was herbs, grasses and sedges.

Introduction

During the period from 30 to 20 ka BP, glaciers were spreading from the mountains of Scandinavia and Scotland; periglacial conditions prevailed south of the glaciated areas. The sedimentary records from this period are usually discontinuous, and, as a consequence, palaeoenvironments have to be deduced using data from different localities and disciplines. At Kobbelgård, on the island of Møn in eastern Denmark (Fig. 1), a sequence has been found which provides a record from somewhat before 30 ka BP through to 20 ka BP. This paper presents the results from this locality and compares them with data from the same period elsewhere.

The Kobbelgård sequence

The depositional sequence at Kobbelgård is presented in detail by Kolstrup & Houmark-Nielsen (1991); therefore only a brief outline is given here. The sequence contains aeolian, water-laid and slope deposits, with pollen in some layers.

A sketch showing part of the exposed coastal cliff is given in Fig. 2. Deposits of silt and fine sand are relatively frequent. These sediments are well-sorted (Fig. 3) and rich in carbonate. The coarser grains are rounded and frosted, sometimes with marks from intergranular collision, and part of the deposits somewhat resemble the 'limon à doublets' in France (Lautridou & Giresse 1981). These sediments are interpreted as mainly aeolian, loess and sandloess.

Thermoluminescence (TL) dating techniques give age estimates of 27 ± 3, 24 ± 3 and 20 ± 2 ka BP,

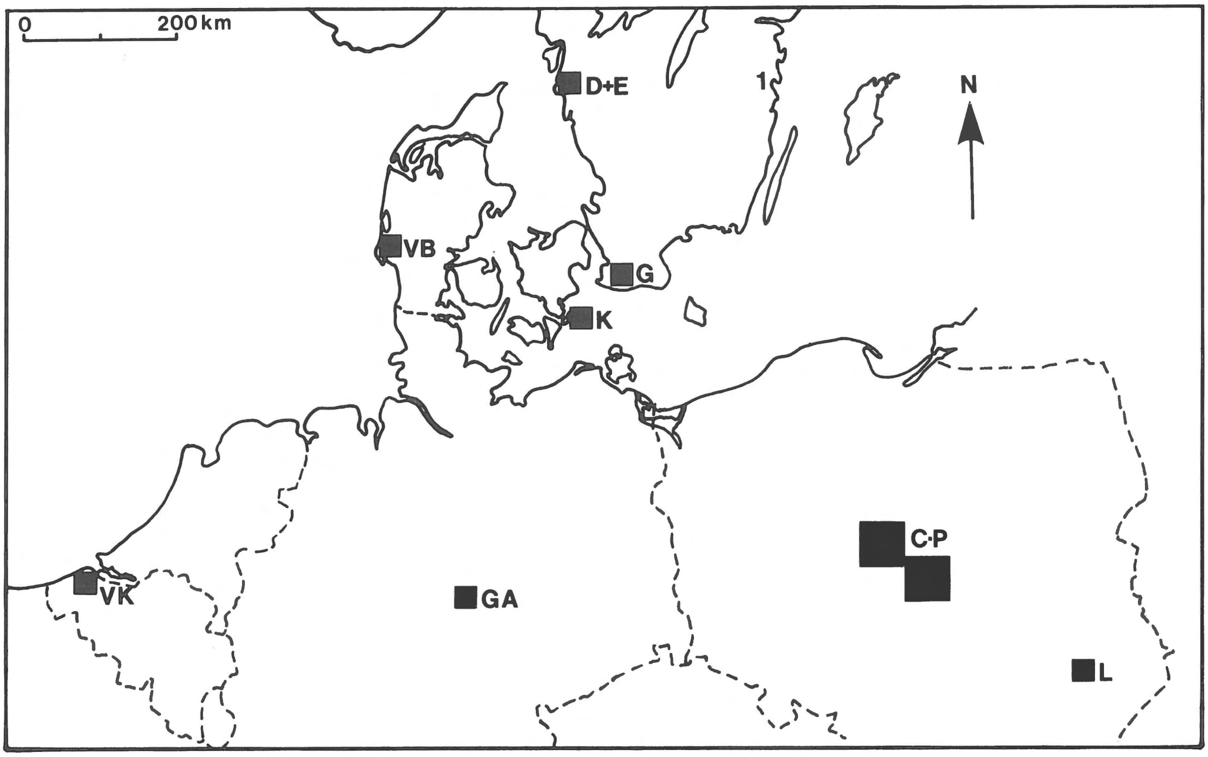

Fig. 1. Map showing the localities Dösebacka—Ellesbo (D + E), Gärdslöv (G), Kobbelgård (K), Vesterbæk (VB), Vijvekapelle (VK), Goldenen Aue (GA), Central Poland (C-P) and Lazek (L) used in the palaeoenvironmental reconstruction for the period between 30 and 20 ka BP in and around Denmark.

respectively, at three different levels (Mejdahl 1991), and an AMS (Accelerator Mass Spectrometry) date provided by the Physical Institute of the University of Aarhus gives a maximum age of 29.8 ± 1 ka BP.

The lower part of the section consists of clay overlain by c. 2.2 m of sandloess and loess which in turn are overlain by a clayey layer. This lower part is separated from the overlying depression fill by a disconformity which cannot be explained satisfactorily at present. Possibly it represents periglacial (thermokarst) or glacial activity. TL age estimates from above and below the disconformity show that it was formed between 27 ± 3 ka and 24 ± 3 ka BP.

The upper part of the section makes up the fill of a depression. In the lower part of this fill, aeolian deposits alternate with water-laid sediments including clayey layers and a gravel layer. It is possible that some of the aeolian material was blown into a pool. The upper aeolian deposits alternate with diamict sediments interpreted as slope deposits. This part of the sequence is TL-dated between 24 ± 3 and 20 ± 2 ka BP. As frost wedges formed elsewhere in northern Europe during this time, it is likely that permafrost promoted the slope processes.

Detailed palynological results of some TL-dated intervals are published by Kolstrup & Houmark-Nielsen (1991). The pollen analysis showed low percentages of tree pollen, notably from willow (*Salix*) and birch (*Betula*), which were probably dwarf forms. In the depression, *Sparganium* and *Myriophyllum* were present periodically, together with other water plants. In drier parts of the area and possibly also within the depression during drier periods, there were grasses, sedges and various herbs such as Brassicaceae and Caryophyllaceae. The relative frequencies of *Artemisia,* Chenopodiaceae and *Thalictrum* increase upwards, which may indicate increasingly unstable surface conditions and possibly also increasing drought.

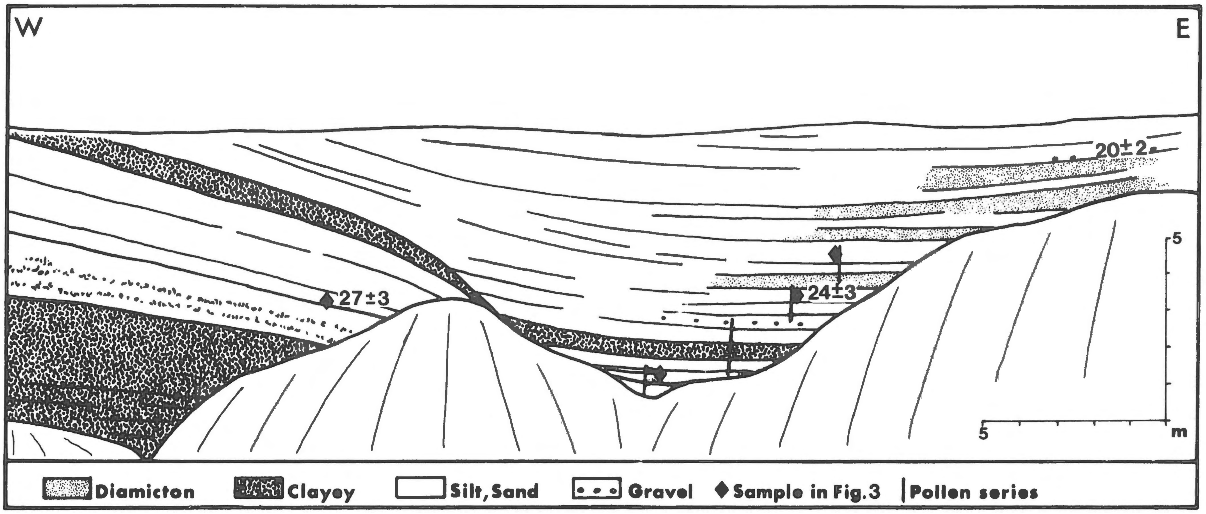

Fig. 2. Sketch of part of the Kobbelgård coastal cliff section. TL ages are indicated in 1000 years (ka) BP. The location of the AMS-dated sample of ≤ 29.8 ± 1 ka BP is 0.6 m below the TL date of 24 ± 3 ka BP.

Other records

Provided the numerical datings are reliable, the Kobbelgård sequence appears to be the most complete sedimentary record from between 30 and 20 ka BP at a single locality in northern Europe. Integration of the Kobbelgård data with data from coeval sequences elsewhere (Fig. 1) can, therefore, provide a more complete palaeoenvironmental record for Denmark and neighbouring areas.

The primary aeolian sand which fills a frost-wedge cast at Vesterbæk near Varde in Jutland gave a TL age of 24 ± 3 ka BP, as the time of wedge growth (Kolstrup & Mejdahl 1986). Gozdzik (1986) reported that similar wedges have been formed during the late 20 000s BP in Poland. The formation

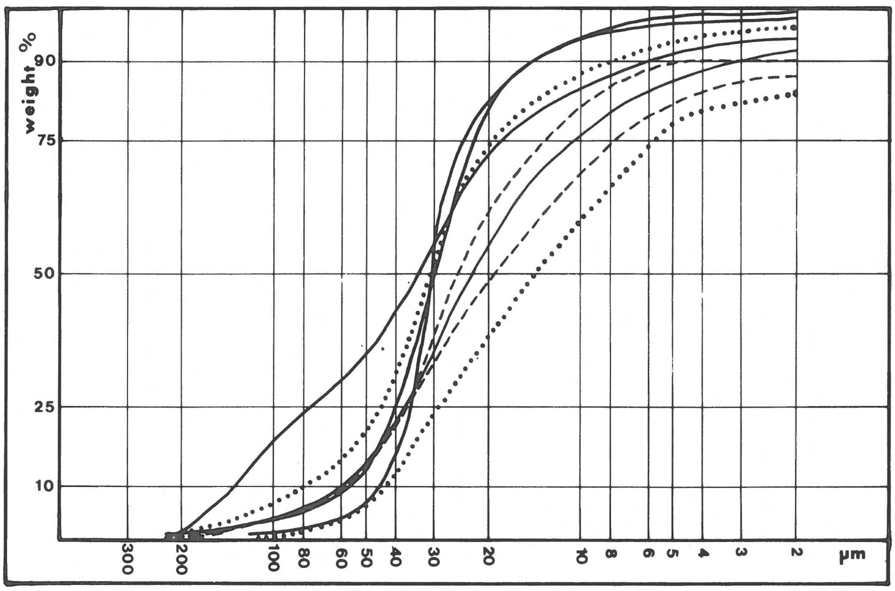

Fig. 3. Grain size analysis of four loess/sandloess samples from Kobbelgård (full lines) compared with two loess samples (dotted lines) from Poland (Mojski 1961) and two loess samples (dashed lines) from the Harz Mountains in Germany (Steinmüller 1967).

of such wedges requires permafrost, and this supports the hypothesis that permafrost facilitated slope processes at Kobbelgård. Slope deposits which are radiocarbon-dated at 23 ka BP and younger in Poland (Manikowska 1991), may likewise have been formed due to permafrost.

In Poland and Germany, loesses were deposited between 30 and 20 ka BP. A few grain-size distributions from these loesses (Mojski 1961, Steinmüller 1967) are compared with Kobbelgård data in Fig. 3. Aeolian sands are also reported from this part of Europe (e.g., Kozarski 1990), as well as from more western countries. In Belgium and the Netherlands, the aeolian deposits consist almost exclusively of cover sands (e.g. Van der Hammen et al. 1967, Vandenberghe et al. 1974), which in some localities overlie deposits from anastomosing rivers (Van Huissteden 1990).

At Ellesbo near Göteborg in Sweden, Hillefors (1974) found a depression filled with fine, laminated aeolian sand and some gravel. A pollen sample from slightly organic aeolian sand contained a relatively high proportion of *Artemisia* in addition to pollen of Poaceae, *Betula* and *Pinus.* This sample gave a radiocarbon date of 30.3 (+ 7.6/– 1.8) ka BP. At Dösebacka, near Ellesbo, Hillefors (1974) found clays and silts which represent a former fresh-water pond with *Pediastrum* algae and which were radiocarbon-dated at c. 24 ka BP. Slope deposits were also found at these localities. The sediments are covered by till, and the glacial advance is therefore younger than the dated sediments.

In a core from Gärdslöv, a more southerly Swedish locality, sediments with organic matter are covered by till (Miller 1977). This matter has been radiocarbon-dated between c. 27.5 and 21.3 ka BP. It includes a high proportion of redeposited palynomorphs.

Near the Goldenen Aue south of the Harz Mountains in Germany, Steinmüller (1967) found a series of aeolian sediments, slope deposits and organic material, which contained pollen and plant macrofossils and which was radiocarbon-dated at c. 24 ka BP. The pollen composition is relatively rich in *Artemisia,* Caryophyllaceae and *Pinus,* and the macrofossils include *Juncus, Luzula, Salix, Betula nana* and many other plants.

A peat deposit from Lazek in southern Poland was radiocarbon-dated at 25.58 (+ 3.27/– 2.42) ka BP (Mamakowa 1968). It includes pollen from *Pinus, Betula nana, Juniperus,* and *Salix* as well as from Poaceae and Cyperaceae, and from various herbs such as *Artemisia* and other Asteraceae, *Rumex,* Chenopodiaceae, Brassicaceae, *Thalictrum* and others. It thus shows many similarities to the Kobbelgård and Goldenen Aue vegetation records.

Organic deposits at Vijvekapelle in Belgium, dated between 30 and 24 ka BP, also have high pollen percentages of Poaceae and Cyperaceae, together with various herbs (Vandenberghe et al. 1974, Vandenberghe & Gullentops 1977, Kolstrup 1980).

All above-mentioned records have low percentages of tree pollen, which in most cases probably represent dwarf species only, except perhaps for southern Poland. The records show high percentages of pollen from Poaceae, Cyperaceae and many herbs. This suggests that southern Scandinavia and the northern part of central Europe were not desert-like, barren regions at that time. More likely, the conditions for accumulation and preservation of organic matter were restricted to relatively few, protected and humid places. The records suggest that vegetation with short plants was common. The conclusion on the presence of vegetation is indirectly supported by the many Danish finds of mammoths which were radiocarbon-dated between 30 and 21.5 ka BP (Aaris-Sørensen et al. 1990). The pollen in the stomach of the Siberian Beresovka mammoth showed that these animals may have fed upon a wide range of plants (Kuprijanova 1957 in Heintz 1958). Clearly, the vegetation in northern Europe must have provided sufficient food for these animals.

Palaeoenvironmental developments in and around Denmark

The thickness and geographical extent of the aeolian deposits show that erosion and deposition by wind must have been very common in northern and central Europe between 30 and 20 ka BP. This is corroborated by the relative abundance of dust in Greenland ice cores (Hammer et al. 1985, Dans-

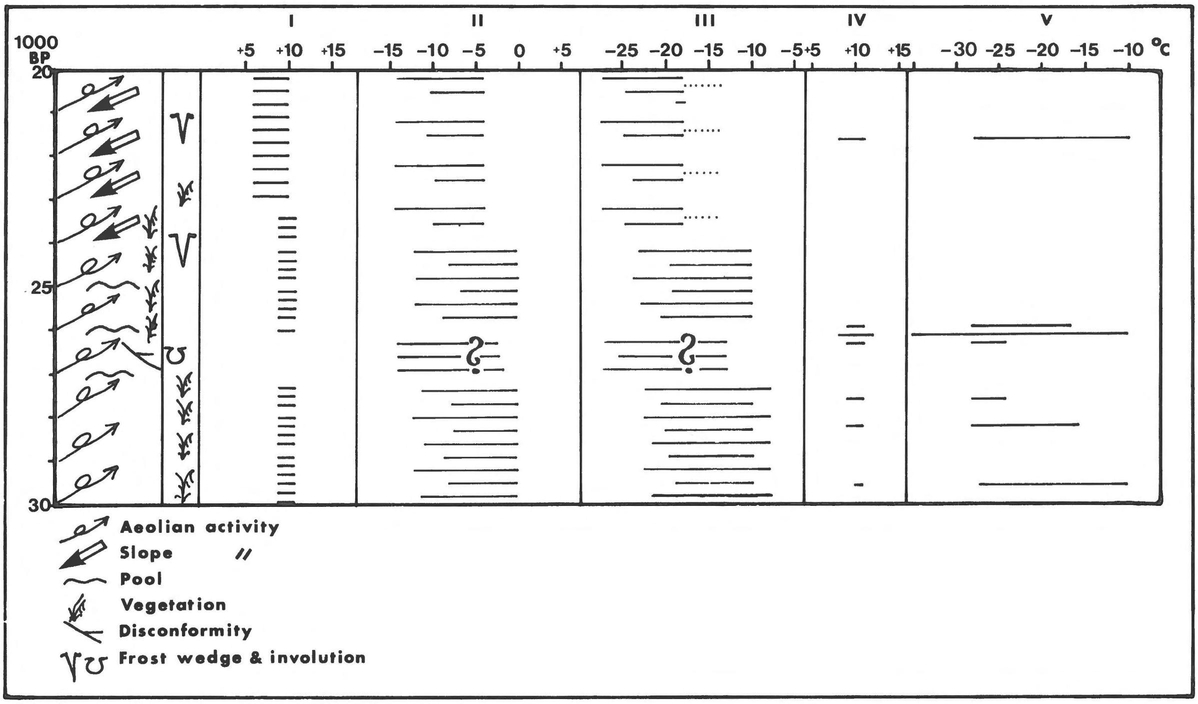

Fig. 4. Palaeoenvironmental reconstruction for Denmark and neighbouring areas shown in Fig. 1. The column at the far left outlines reconstructed parameters for Kobbelgård. The narrow column gives additional features from the other localities. Columns I–III indicate ranges for mean temperature estimates. I: mean July, II: mean annual and III: mean January. Columns IV–V show estimates of mean July and mean January temperatures, respectively, deduced from British coleoptera finds (Coope 1987).

gaard 1987). The aeolian activity (Fig. 4) points to unstable soil surface conditions in the north-European lowlands. It is not known whether reworking by wind took place in unvegetated areas between vegetated ones, or whether it occurred periodically or even seasonally.

Slope deposits are present within sequences dated between 24 and 20 ka BP. The presence of frost-wedge casts from this period suggests that permafrost prevented drainage and locally (periodically?) created relatively humid conditions which promoted slope processes. The overall impression is that soil surface instability increased from the mid 20 000s as a result of active-layer processes. It is not yet known whether there was an uninterrupted period of permafrost during the late 20 000s, corresponding to the upper part of the record, or whether shorter permafrost periods alternated with periods without permafrost. The two possibilities have different implications for palaeoclimatic reconstruction. Alternations between permafrost and non-permafrost regimes may imply soil temperatures close to the requirements for the formation of permafrost, whereas continued presence of permafrost might imply colder conditions. In any case, the cold periods must have been sufficiently severe and lengthy to form a permafrost layer in which frost wedges could develop. The minimum demands for this seem to be those recorded in NW Canada (Mackay 1988), where frost wedges form in silty and clayey sediments if the ground is frozen to 3–5 m depth only, provided the soil surface is free of vegetation and snow, and temperatures are sufficiently severe.

Frost wedges develop in permafrost areas during sudden temperature drops. The mean annual air temperature for their development has been put at – 6° C by Péwé (1966) for Alaska, but in other areas with deposits rich in silts and with very little or no vegetation and snow cover, the ground has been reported to crack at higher mean annual air temperatures (e.g. Romanovskij 1976, Burn 1990). Even – 4° C may be a somewhat low figure in such areas.

In Kobbelgård, slope deposits are absent below the level which was TL-dated at 24 ± 3 ka BP (except for single slump folds in clay). The slopes of the depression were steeper in the deeper part than in the upper. If conditions had been the same throughout, mass movement would have been facilitated on the deeper, steeper slopes. The absence of slope deposits in the deeper part could therefore suggest absence of permafrost at Kobbelgård during a period some time before 24 ka BP. If the disconformity between the layers TL-dated at 27 ± 3 and 24 ± 3 ka BP is a result of temporary permafrost (i.e., colder conditions within an already cold period), then this disconformity may have formed when involutions developed in the Netherlands and Belgium (Van der Hammen et al. 1967), and frost wedges in Britain (M.B. Seddon, pers. comm.).

Palynological records for the period between 30 and 20 ka BP show a good representation of Poaceae and Cyperaceae. Considering the pollen production and spreading of various other plants represented in the records, an important part of the spermatophytic vegetation may actually have consisted of herbs, notably Caryophyllaceae, Chenopodiaceae, Asteraceae, Ranunculaceae and Rosaceae. In view of the present environmental and climatic demands of herbs and shrubs represented in the fossil records, it seems likely that the vegetation was not high-arctic and that the mean July temperature was around or not much below 10° C during the periods represented by vegetation, which include the time of permafrost around and after 24 ka BP. Plants tolerating or favouring unstable, raw soil surface conditions are common, and it is likely that there was repeated soil reworking, a conclusion in agreement with the presence of slope deposits and aeolian activity.

The above conclusions, integrated with the data of Kolstrup (1980), are presented tentatively in Fig. 4, together with a record based on coleoptera (beetles) from central England (Coope 1987). It is stressed that the conclusions shown are approximate and that they are based on deposits dated by different techniques which, with time, may turn out to have provided ages that require correction before they are compared.

Between c. 30 and 27 ka BP conditions for plant growth and preservation in southern Scandinavia and northwestern and central northern Europe appear to have been relatively good. In the Netherlands they may have been relatively humid whereas they may have been rather dry (possibly locally) near Göteborg in southern Sweden. The mean July temperature deduced from the palaeobotanical data may have been around 10° C, and the winters do not seem to have been extremely cold. Possibly the winters became colder for some time between 27 and 24 ka BP, giving rise to permafrost. The lack of evidence for periglacial processes during the pre-24 ± 3 ka BP filling of the Kobbelgård depression, might suggest that temperatures could have been temporarily higher, before they became sufficiently low for permafrost formation around 24 ± 3 ka BP.

It seems as if no major changes of mean July temperatures occurred during the palaeobotanically known time intervals. The mean July temperature seems to have been around or only slightly below 10° C, and temperature changes would therefore have resulted mainly from fluctuations in winter conditions. This is in line with the conclusion based on coleoptera (Coope 1987), although some discrepancies exist for the specific time range and temperature values as deduced from the two methods.

Conclusions

Integration of data from a sequence at Kobbelgård in eastern Denmark and from localities in neighbouring countries suggests a periglacial environment with (intermittent?) permafrost, unstable surface conditions and much aeolian activity during the period between 30 and 20 ka BP. In spite of this harsh environment, vegetations consisting of dwarf shrubs, herbs, grasses and sedges were probably present during most of the time, at least in protected places. The mean July temperatures were probably around or not much below 10° C during the periods that are represented by palaeobotanical records. Colder intervals within this already cold period are thought to be primarily the result of lower winter temperatures.

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