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Special issue paper

The puzzle of Weichselian vegetation types poor in trees

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Abstract

Palaeobotanical records of many Weichselian deposits indicate stands of vegetation poor in trees and with elements from a range of different environments. The scarcity of trees seems in cases to contradict the prevailing temperature regime as suggested, for example, by records deduced from beetles. Alternative explanations for the recorded combination of plant species are considered. Examples of the influence of periglacial forms and processes on vegetation are given, followed by a more speculative account of the effect of swift climatic changes during the Weichselian. Unstable environmental and climatic conditions are thought to have been particularly effective in controlling the composition of what is today considered to have been a singular combination of plant species. Unstable conditions are also thought to have played a role in hampering the development of continuous palaeobotanical records in NW-Europe. The palaeobotanical data derive from a variety of geographical environments, and as a result it is almost impossible to integrate the scattered findings into a coherent whole so as to elucidate the former ecological conditions. It is suggested that in future investigations one must look for additional possibilities of correlation, such as phases of aeolian activity, deposition of charcoal resulting from natural fires or other discernible events of restricted duration.

Preface

In his dissertation Thomas van der Hammen (1951) dealt with Late-Glacial and Pleniglacial vegetation types and to a certain extent also with geological features which can be related to the periglacial zone. In line with that paper it will be attempted here to further relate certain kinds of former vegetation to geological, in particular periglacial phenomena.

Organic Weichselian deposits poor in fossils of trees and with a particular composition of plant species, are found in a variety of geological settings scattered over NW-Europe. The records are usually discontinuous and their fossil content often represents species which at present occur in different environments and which thereby indicate seemingly contradictory information on the past environment they represent. The paleoecological reconstructions from such disjunct and confusing data must consider and integrate the ecological requirements of different species and relate the results to the various environmental and geological parameters.

Introduction

Pollen records from Weichselian organic deposits dating from between ca 55,000 BP and ca 12,000 BP in NW-Europe show very high pollen percentages of non-arboreal pollen, in particular Cypera-

ceae and Poaceae. In addition, pollen and seeds of various herbs and water plants are found together with low values of pollen of trees like *Pinus, Salix* and *Betula*. Often the percentages of the latter three types amount to about 10% or less of the pollen sum (arboreal and terrestrial non-arboreal types included). The presence of *Pinus* pollen is usually regarded as being the result of long distance transport and that of *Salix* and *Betula* as representing local dwarf species in many cases.

The conclusion is that trees were lacking or very scanty during a period of the Weichselian of more than 40,000 years. This is somewhat surprising because most of Scandinavia was unglaciated during part of the middle Weichselian (e.g., Lundquist 1981) and even at the time of the maximum ice extension the conditions at the fringe of the ice cap were sufficiently mild to cause the melting in bulk of ice built up under harsh climatic conditions farther to the north. Besides, in some parts of the record the presence of various plants and Coleoptera points to sufficiently warm summers to allow for the growth of tall trees (e.g., Coope 1975, Godwin 1975, Kolstrup 1979) and it seems as if the climatic conditions were warm enough for stands of dwarf birch and willow to develop in NW-Europe (almost) throughout the Weichselian. The relatively poor representation of these plants and, during certain periods, also of taller trees is, therefore, somewhat surprising.

It has been suggested that the scarcity of trees was the result of a too 'continental' climate, i.e., that the winters were too cold. If so, it can only be a part of the explanation because in some intervals *Armeria maritima* is found, which points to relatively mild mean January temperatures (Iversen 1954). Besides, trees are found today in the Canadian and USSR taigas under very severe winter conditions. A prevalence of strong, persistent windy conditions is another possibility, but it is difficult to imagine that high winds would account for the scarcity of trees throughout that period. Dry conditions may also be partly responsible, but, again, it is hard to accept only one single cause to have been operative during the whole period. Moreover, organic deposits representing different time-spans are regularly encountered which suggests that locally sufficiently wet conditions prevailed for plant growth and for the subsequent accumulation and preservation of organic remains.

For those conversant with present-day plant communities, the combination of vegetational components of Weichselian Pleniglacial records poor in trees holds much contradictory information. However, the Pleniglacial vegetation type in question seems to have existed with relatively few changes in composition during more than 40,000 years, and it may thus represent a combination of life forms that were well adapted to the environment they represent. In this connection, therefore, one might not so much wonder why the past vegetation types were different from the present ones, but rather attempt to establish what kind of environment would provide appropriate conditions for the past combination of life forms.

Distribution of Weichselian organic deposits in northern and central Europe

By now there are many known deposits in northern Europe with organic material representing various elements of Weichselian vegetations poor in trees. The Late-Glacial part of the record in particular is frequently encountered, but there are also many older deposits, most of which can be related to various geological environments such as abandoned water courses (e.g., Bussloo: Kolstrup & Wijmstra 1977, Riel: Vandenberghe 1985), alluvial fans (e.g., Eerbeek: Kolstrup & Wijmstra 1977, Van der Meer et al. 1984), pre-existing depressions (e.g., Oerel/Niedersachsen: Behre & Lade 1986), valleys (e.g., Mauern: Brande 1975), kettle holes (e.g., NE-Sweden: Lagerbäck & Robertsson 1988), lakes (e.g., Samerberg: Grüger 1979) and moist and wet parts of cover sand areas (e.g., de Maten: Kolstrup 1980, Orten: Kolstrup et al., in prep., Ramsel: Vandenberghe & Gullentops 1977). Many localities are known from borings (for example De Beaulieu & Reille 1984, Brinkkemper et al. 1987, Van der Hammen 1971, De Gans & Cleveringa 1981, Menke 1976, De Ruiter 1975, Vogel & Van der Hammen 1967, Welten 1982, Woillard 1978, Zagwijn 1974).

Since many of the newly found radiocarbon dated deposits cannot readily be time-correlated to the traditional subdivision into interstadials as outlined in Van der Hammen et al. (1967) and Zagwijn & Paepe (1968), and since it is becoming increasingly recognised that the Weichselian is a climatically complex period, there is a tendency to investigate not only the palynomorphs but also other microscopic remains as well as macroscopic ones, thereby greatly increasing our knowledge of the past environmental conditions (e.g., Brinkkemper et al. 1987, Van Huissteden et al. 1986, Küttel et al. 1986, Lagerbäck & Robertsson 1988, Löscher et al. 1980, Robertsson 1988, Tobolski 1984). Although this list is far from exhaustive it is nevertheless clear that Weichselian organic sediments are found in many localities scattered over northern and central Europe.

Some features influencing Ice-Age vegetation and the palaeoecological reconstruction

In this chapter a number of factors that possibly contributed to the floral composition such as periglacial phenomena, unstable climatic conditions, fires and exploitation of the vegetation cover by people are discussed.

Periglacial conditions

Present

In the present arctic and alpine regions there are three types of permafrost: continuous in the coldest parts (as a rule of thumb, the mean annual temperatures are under − 5° C to − 6° C); discontinuous in somewhat warmer areas (generally speaking, the mean annual temperature is somewhat below 0° C); sporadic in the fringe area.

In the permafrost zone the two most conspicuous and immediately recognizable morphological features are frost-mounds of various types, and patterned ground. The frost-mounds range from annual, 1–2 m high forms to perennial ones such as palsas (with peat) and pingos; a shared feature is that they rise as mounds above the surrounding area owing to the growth of an ice core. In the northern part of the Mackenzie River Delta where continuous permafrost is present the largest pingo is 49 m high and has a diameter of 300 m (Mackay 1986) (see Fig. 1). The environment permitting, the pingo will grow in height until the slopes become too steep and surface material starts to move down the sides to accumulate along the fringe. In this beginning process of decay, the ice of the core becomes exposed to the air and sun, and melting can continue till the cone form has disappeared and only the sediment accumulated from the slopes remains as a ring-wall (rampart) around a pool or small lake.

In the continuous permafrost regime of the Arctic Coastal Plain pingos abound, and according to Brown & Kreig (1983, p. 198):

> Pingos provide a botanical contrast on the Arctic Coastal Plain with the thaw lakes and wet sedge meadows. The steep sides provide such good drainage that the plant cover is very similar to if not essentially the same as the rich sedge-grass-forb meadows of alpine slopes in the Brooks Range to the south. South-facing exposures and the summits provide habitats for species quite 'out of place' on the Arctic Coastal Plain (Koranda, 1960).

In the fringe zone of a permafrost area perennially frozen ground is almost exclusively found beneath peat layers because of the insulation effect of the peat. The result is the local formation of frost mounds (palsas) which might provide special growing sites in that kind of region.

In areas of patterned ground (looking like much enlarged reticulate or foveolate systems) the underlying permafrost prevents free drainage, but due to small differences in relief and hydrological conditions a diversified flora may be present within the individual nets of the polygons (K.R. Everett in Brown & Kreig, 1983). Drainage systems tend to follow and erode along the ice wedges (the 'nets' in the pattern) and the supra-permafrost water of adjacent polygons may become drained, which results in changes of the local hydrological conditions. Not only in such situations, but, for example,

Fig. 1. Ibyuk Pingo in the Mackenzie River Delta. The diameter of the form is 300 m and it is 49 m high. Pingos are common today in the Coastal Plain of Alaska and in the northern part of the Northwest Territories of Canada. Vegetation grows on the slopes, and south facing exposures and the summits provided habitats for species that are normally found in more favourable macro-climatic conditions.

also in areas of solifluction and aeolian activity pioneer plants can repeatedly find a habitat on newly exposed ground. It follows that in the dynamic permafrost environment, with a build-up and decay of forms combined with erosion and deposition, neither the presence of 'out of place' species and pioneer species nor the beginning and termination of plant growth and deposit accumulation are necessarily attributable to climatic fluctuations but may follow upon changes within the local environment.

Past

Two periods of (probably continuous) permafrost conditions are known to have existed in parts of NW-Europe during the Weichselian, the one some thousand years around 20,000 BP (Van der Hammen et al. 1967, Kolstrup 1980) and the other at some time within the 50–60,000 BP period (Van der Hammen et al. 1967).

However, in most Weichselian sedimentary units there are no indications of the action of frost and thaw. This does not necessarily mean an absence of permafrost, but it is feasible that periods without permafrost may have existed; only their age and duration need to be pin-pointed. Yet, although the former existense of permafrost is only positively known with certainty from a number of periods, the possibility of local occurrences of permafrost should be considered in conjunction with the palaeo-ecological reconstruction. The lack of indications of frost and thaw in a given sediment unit can for example, be interpreted as the result of a few decimetres thick snow cover protecting the ground during the coldest part of the winters, so that the effect of sudden, severe cold spells was warded off before reaching the ground and the development of frost features became hampered. Also the plants were thus protected except for parts not covered by the snow (such as the crowns of shrubs and the trees).

Climatic change in relation to time lags and soil development

Present

In most parts of the world the soil development and vegetation are at present in reasonable equilibrium with the environmental conditions. The balance is

the result of a long period of fairly stable conditions, subject only to minor climatic fluctuations and natural disasters of restricted magnitude.

Minor changes in the mean annual temperature and moisture conditions may have occurred during the last 10,000 years, but, generally speaking, these changes are only moderate as compared to the changes that could have occurred in similar time spans during the Pleniglacial (see e.g., Dansgaard et al. 1971).

Past

It is conceivable that swift changes in climatic conditions may have been one of the underlying factors controlling the composition of vegetation in for example Europe. If temperature and moisture changes great enough to disturb existing biosystems, were of frequent occurrence, they would prevent stable plant communities to become established and this would result in rapid changes in the 'succession' of 'ecosystems'. In such circumstances a discontinuous vegetation cover might naturally exist under climatic conditions in which it is unheard of at present. Where the vegetation cover was discontinuous and the top soil not too wet, surface run-off and deflation could take place. The fluvial and aeolian deposits that build up the Quaternary sections in former depressions suggest that such activities occurred repeatedly to create raw-soil habitats. Swift changes in the environment can not only explain the incidence and rate of erosion and deposition but also to a certain extent the poor representation of trees. Not only do trees usually need time to migrate, they also require an adequate soil development to have taken place before they can settle in an area. Saplings furthermore also benefit from the shelter from the wind that other trees can provide.

Fire/exploitation by people

Present

Another possible explanation of the combination of elements in Pleniglacial vegetation is the incidence of fire. In NW-America today natural fires ignited by lightning occur regularly both in the taiga and the tundra and they may burn the soil to a depth of one foot (Tedrow 1977, p. 56). A comparison with Greenland, on the other hand, reveals that there fires caused by lightning do not occur (Fredskild, 1989, *pers. comm.*).

Past

If fires burned during the Weichselian (and the *Juniperus* finds in Frøslev suggest that there was a major fire at least once: Kolstrup & Havemann 1984) such natural phenomena may have seriously damaged delicate ecological balances.

From investigations in caves and rock shelters (e.g., Renault-Miskovsky & Leroi-Gourhan 1981) it is known that human beings and herbivorous animals lived in Europe during part of the Weichselian. Vegetation thus served as food as well as for other purposes (fuel, bedding etc.). This pressure on the surroudings may probably also have had a slight impact on the vegetation.

Scarcity of Pleniglacial organic deposits and potential environmental inference from disjoined records

In present-day arctic and alpine areas, parts of the landscape are covered by peat which locally can be quite extensive and reach a thickness of up to 3 m. Apart from being the result of about 10,000 years of accumulation under reasonably stable conditions, the peat layers are often found on top of permafrost where ground ice prevents free drainage. If these surroundings were taken out of the present 'ice–box' situation and subjected to a warmer climate, the permafrost would disappear and the decay of organic material would accelerate. Where the subsoil permitted free drainage conceivably even thick peat layers might 'burn off' in due time by exposure to the air.

The above implies, among other things, that a peat deposit of limited thickness, which during the Pleniglacial owed its growth to the presence of an underlying impermeable permafrost, would have but little chance to become preserved after a climatic warming.

Admittedly, even if peat was present in NW-

Europe during the Pleniglacial there is nothing to suggest that it ever became as thick in any locality as it is now in certain arctic regions. Neither is it yet possible to estimate how extensive the peat deposits were at a given time, but scientists in search of botanical Ice-Age records in northwestern Europe have discovered that peat deposits representing stands of vegetation of a non-interglacial character are hard to come by. One reason for this may be that deep-dug, open pits are usually related to the exploitation of sediments with a value for construction purposes (mostly sand and gravel) where an adequate drainage reduced the possibility of accumulation and preservation of organic material in periods without permafrost. However, unstable conditions caused by erosion and quick climatic changes mentioned above may also have been important as restricting factors to plant growth and accumulation.

The palaeobotanical records remaining to the present represent moist and wet conditions in most cases, sometimes with a minor xeric component, and it has previously been suggested that organic material of various Weichselian ages accumulated and became preserved predominantly in moist and wet environments (e.g., Kolstrup 1982, Vandenberghe 1985). Therefore, the life forms that lived in and immediately around moist and wet sites are the ones we know best. Comparisons with recent arctic/subarctic and alpine/subalpine regions show that the life in wetter environments in which organic material accumulates only represents a portion of the many different (sub)environments within the areas as a whole. As a consequence, our palaeoecological cognisance has a tendency to become biased towards a certain group of (sub)environments.

The fossil records furthermore suggest that most deposits representing vegetation poor in trees represent only short periods, probably of no more than a few thousand years duration. Since there is a time-span of more than 40,000 years during which growth and accumulation of vegetation could have taken place, the scarcity and discontinuity of the records in NW-Europe is striking. Conceivably some of the fossil organic deposits found today represent stands of vegetation that became covered by sediment while still 'active' and thus became protected. This could be a partial explanation why so many short-time records are represented. It is also likely that the moist and wet conditions which existed during the deposition of the organic material did not become appreciably dryer during any longer time-span after deposition began.

The records indicated previously (in the chapter on Distribution of Weichselian organic deposits) show that even within this wet-and-moist group a variety of local environments are represented. It is conceivable that with time we will occasionally be confronted with contemporaneous deposits with a fossil content providing different, and maybe even contradictory indications of the palaeo-ecological situation. For example, one deposit may indicate a rather dry growing site and/or climate, the other one a wet one. This will seem contradictory if no additional geological information is available, but the first deposit may be from a cover sand area and the other one from an abandoned and regularly flooded water course where the ground-water table is high. With this kind of combined information our data may be considered supplementary and relatable in space and time and available for general environmental and climatic reconstructions of the past.

The following example may elucidate some of the ideas above.

Through an investigation of Stokersdobbe in the Netherlands, Paris et al. (1979) have probably found and recognized a situation which has much in common with that nowadays present on the pingos in northern Canada and in Alaska. Their pollen diagram shows high percentages of *Betula* which probably grew on the slope of the frost mound. The radiocarbon date of 18,000 ± 200 BP places the growth and beginning decay of the pingo at what is generally regarded as one of the coldest parts of the Weichselian at a time when continuous permafrost was present in the Netherlands (Kolstrup 1980). Even though it is possible that the climatic conditions around 18,000 BP were slightly warmer than during the harshest period of the Weichselian (Kolstrup 1980), they were nevertheless probably more severe than during almost any other period of the middle and upper part of the Weichselian.

The presence and ample representation of *Betula* in this deposit is intriguing and at first sight it may seem contradictory that the highest *Betula* pollen percentages of the middle and upper part of the Weichselian date from one of the coldest periods. Yet, by means of a comparison with the periglacial features and the conditions in northern America this phenomenon can be explained.

Large parts of Alaska and the NW-Territories of Canada are underlain by permafrost which is continuous in the northern part and discontinuous farther south. According to Viereck (1983) the landscape in the northernmost part of the Arctic Coastal Plain consists of wet tundra near the coast and moist tundra more inland. Farther south, partly interlocking with the moist tundra, low-scrub and high-scrub communities are present, followed still farther south by taiga. To leave more possibilities open for comparison, it should be emphasised that vegetation is present also poleward. For example, from Ellesmere Island Freedman et al. (1983) report the presence of a number of plant communities dominated by woody, long lived (> 100 years), slow growing plants with a vegetative spreading, growing together with sedges and mosses. Also from the extreme north of Greenland there are vegetational records, viz., Fredskild (1973) and Funder & Abrahamsen (1988) describe stands of vegetation from Peary Land, a most inclement region where kettle holes provide depressions for accumulation of sediment.

The *Betula* pollen in the Stokersdobbe diagram probably represents *B. nana* which is known from both Scandinavia and northern America where it does not thrive in overly harsh conditions. In Scandinavia it is present up to an altitude of 1570 m in Jotunheimen (Hultén 1971), and along the Dalton Highway road corridor to Prudhoe Bay, Alaska, it has its northern limit at approximately 150 km south of the Beaufort Sea (Brown & Kreig 1983). Accordingly, even if *B. nana* grew in a favourable spot and if only this species was involved, its growth on Stokers pingo 18,000 years ago suggests that at that time the climate was more favourable for *B. nana* in the Netherlands than it is today in Jotunheimen above 1600 metres altitude and no worse than on the coastal plain along the Beaufort Sea.

As previously mentioned, the *Betula* pollen counts of the Stokersdobbe pollen diagram are very high compared to other Pleniglacial diagrams, especially considering that the latter records in many cases probably represent warmer climatic periods. The combination of ^{14}C datings and the high *Betula* percentages, therefore, would have been difficult to conceive if the relation to the pingo remnant had not been known. The diagram from Stokersdobbe represents a relatively short time interval and an environment which offered special growth conditions for plants as well as a possibility for preservation of organic material buried at a fast rate.

Time correlation of fragmentary palaeobotanical records poor in trees, a general discussion

Since pollen diagrams are usually correlated on the basis of the percentages and changes in the tree pollen curves, vegetation types poor in trees from many different geological settings and spread over a large area appear problematic. Absolute dating methods, in particular the radio-carbon method, are stretched to their technological limit in attempts to identify the various deposits chronologically. Nevertheless there are still many uncertainties, and correlation based on palynological data remains difficult and has only been tried over short distances (e.g., Mamakowa & Środoń 1977).

An increasing number of records of organic remains and absolute datings suggest that some organic deposits may turn out to belong to hitherto unknown parts of the stratigraphic record which thereby can be completed in time. This implies an increasing awareness of the hazards of correlating stands of vegetation poor in trees from different sites. In areas where glaciers have thoroughly reworked material it may in some cases be difficult even to ensure which Ice-Age a deposit belongs to.

In order to arrive at general, more reliable environmental reconstructions it is crucial that as much information as possible be obtained from a number of coeval deposits. If for example the information drawn from the geological picture, from the records of pollen, macrofossils, insects and diatoms

and from other evidence of two or more sites tallies, then such reconstructions would be strengthened. There is, however, yet a long way to go before this kind of correlation is feasible.

At present the only reasonably reliable tool for correlation is absolute dating, but we may consider using other timing devices and methods. Four of these, which are based on time-restricted events and impacts that affect large areas, and which in one way or another are related to the atmosphere, are discussed below:

- Whole series of ash layers as recorded in Colombia (Hooghiemstra et al. 1984) are rare, but even single, well-defined layers, such as the Laacher Bimstuff in the upper part of the Allerød in parts of Europe, may be good markers (e.g., Usinger 1978), and there are other ash layers in this part of the world (e.g., Juvigné & Wintle 1988).
- In many open profiles organic remains can be dated relative to periglacial phenomena, in particular frost-wedge casts which developed during periods with permafrost and particularly cold air temperatures (see Karte 1981, for a general survey).
- Another possible method might be the use of aeolian deposits. For datings in the Late-Glacial part of the record, these sediments are already widely used, but it has to be established if there are earlier periods reasonably restricted in time, for which aeolian sediments can serve. It has been noted, for instance, that aeolian deposits are frequently mentioned in connection with ^{14}C dates of between 45,000 and about 50,000 BP. This goes for example for a number of localities in the Netherlands (e.g., Eerbeek and Voorthuizen: Kolstrup & Wijmstra 1977, and Riel and other sites: Vandenberghe 1985), Denmark (Frøslev: Kolstrup & Havemann 1984) and also in middle Sweden (Pilgrimstad: Robertsson 1988).

  Lykke-Andersen (1981) reported an ice-pushed geological sequence at Hirtshals in Denmark which shows a marine sequence that is interrupted by a deposit of terrestrial organic sediments which is dated at $47{,}300 \begin{array}{c} +1500 \\ -1200 \end{array}$ BP. From the foraminiferal record Lykke-Andersen (1971) deduced changes in relative sea level as well as in water temperature and salinity. The moss flora from the locality has been investigated by Odgaard (1982). It is evident that there was a short period with relatively low sea level at some time around 47,000 BP. It seems worthwhile through ^{14}C and thermoluminescence dating of deposits, to investigate whether there is a relationship between a possibly increased extension of dry land in northern Europe, a concomitant change in climate, and a possible increase in deposition of aeolian sand around that particular time as compared to other periods.
- Finally evidence may be derived from wind-blown charcoal particles. The fact that natural fires occur frequently in Alaska and Canada and never in Greenland is attributable to different weather conditions. It cannot be excluded that climatic conditions giving rise to thunderstorms and ensuing fires occurred frequently during some parts of the Weichselian and scarcely during other ones. Even under relatively windy conditions a single fire can probably not be distinguished in the deposits but periods with fires might be recognised. Usually a curve of charcoal particle frequencies is not given with the pollen diagrams representing pre-Holocene deposits, but the possibility that additional information may be gained in that way cannot be excluded. The above-mentioned *Juniperus* wood in Frøslev shows that burning did occasionally take place.

Conclusions

The ecological, geomorphological and climatic conditions during the Weichselian are puzzling in more than one way. The deposits represent different periods of time and a variety of local environments and geological situations. Within each record the content of fossils may reveal apparently contradictory environmental information as it may contain, for example, pioneer species and 'out of place' species in unison with parts of what is today regarded as a normal, established, plant communi-

ty. Also the time correlation of records is a puzzle. It is concluded that a maximum of detailed data from various disciplines has to be integrated in order to arrive at a general outline of past environmental developments.

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