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Weichselian *Juniperus* in the Frøslev alluvial fan (Denmark)

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In the southern part of Jutland pieces of *Juniperus* wood have been found over long stretches in a trench dug for a Danish gas pipe line system. Radiocarbon-dating, comparison with palaeobotanical records known from other localities, and the stratigraphical sequence in the area, point to a probable age of between the Brørup/Odderade interstadial(s) and ca. 45.000 years B.P.

The morphology of the alluvial fan near Frøslev and its stratigraphy makes it reasonable to assume that the fan has not been affected by the Middle Weichselian ice and its meltwater streams.

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During the construction of a gas pipe line system near Frøslev in southern Jutland charred fragments of wood were found in several localities (fig. 2). The preliminary conclusion in the field was that the pieces of wood might be of Middle or maybe Early Pleniglacial age (van der Hammen 1971, van der Hammen, Maarleveld, Vogel & Zagwijn 1967) (Middle Weichselian: Doppert, Ruegg, van Staalduinen, Zagwijn & Zandstra 1975). Only a few organic deposits from the Middle and Early Pleniglacial are known in Denmark (Houmark-Nielsen & Kolstrup 1981, Lykke-Andersen 1981) and it was therefore decided to have some samples radio-carbon dated and that the second author would make wood anatomical investigations of pieces from various localities.

Geological outline

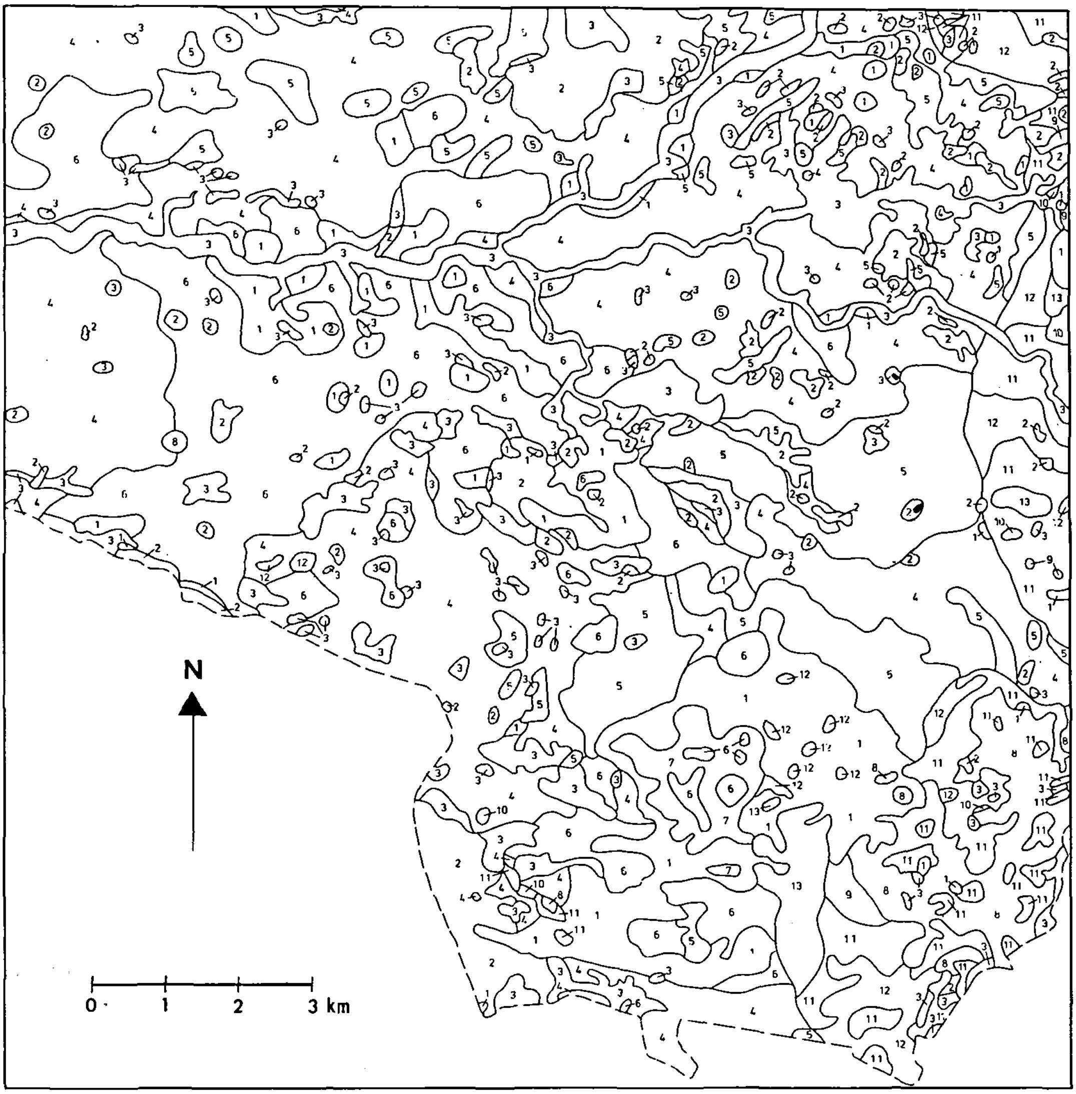
In fig. 1 the geology of the surroundings of the southern 13 km of the gas pipe line trench is given according to Hansen (1965), and in fig. 2 contour lines with an interval of 5 meters are shown for the same area.

It can be seen that the area contains part of a large fan with a rather flat surface which slopes gently towards the west and northwest, and that the main types of surface sediments are eolian sand, fresh-water sand, and fresh-water gravel. For conveniance this fan is called the Frøslev alluvial fan or the Frøslev fan. Newer field investigations have revealed that along the gas pipe line trench the eolian deposits of Hansen's map are of the Younger Cover Sand type, and part of the fresh-water deposits are of the Older Cover Sand type (Kolstrup in press, Kolstrup & Jørgensen 1982). The fresh-water gravel of Hansen along the trench usually consists of a mixture of sand and gravel which is involuted (cryoturbated) in many places. In the contour line map of fig. 2 the revised geology is outlined together with localities where wood has been seen in the trench, which is approximately 1.8 meters deep.

Stratigraphical outline

The upper part of the stratigraphical sequence found in the pipe line trench in the Frøslev fan is given in fig. 3.

The periglacial phenomena, mainly cryoturbations, extend downward from the sand and gravel layer below the Frøslev gravel bed, and it is therefore difficult to unravel a general lithostratigraphy for the sediments underlying the sequence shown in fig. 3. It is noted, however, that wood fragments are found at a lithostratigraphic level somewhat below the lower sand and gravel of fig. 3. As the trench is less than two meters deep, it is



POSTGLACIAL DEPOSITS

1) eolian sand

2) peat

3) fresh-water mud,-clay -sand, and-gravel

LATE-GLACIAL DEPOSITS

4) fresh-water sand

5) fresh-water gravel

6) eolian sand over fresh- water sand

7) eolian sand over fresh- water gravel

GLACIAL DEPOSITS

8) clayey till

9) sandy till

10) gravelly till

11) layered sand

12) layered gravel

13) eolian sand over layered sand

Fig. 1. Outline of the geology around the southern 13 km of the gas pipe line trench according to Hansen (1965). Reproduced with permission of the Geological Survey of Denmark.

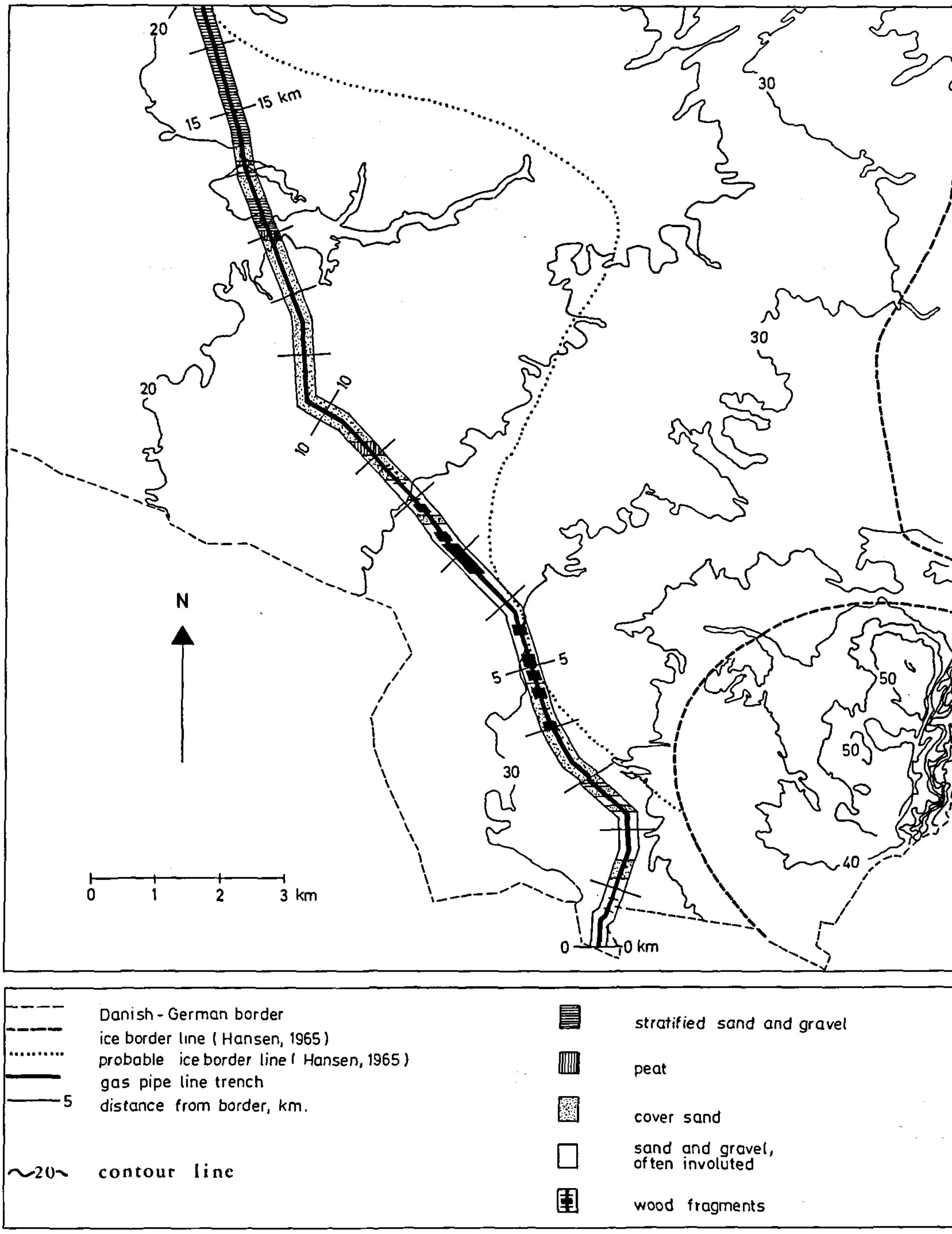


Fig. 2. Map of the same area as fig. 1. Contour lines with an interval of 5 meters, revised geology, and wood occurrences are shown. The contour lines are reproduced from map 1211 IV, 1:25.000 with permission of Geodætisk Institut (A 83).

LITHOSTRATIGRAPHY		CHRONOSTRATIGRAPHY
SOIL OR PEAT		HOLOCENE
YOUNGER COVER SAND II		LATE DRYAS
LOAMY SAND OR PEAT		ALLERØD
YOUNGER COVER SAND I		EARLIER DRYAS
LOWER LOAMY BED		BØLLING
OLDER COVER SAND II		
FRØSLEV	FRØSLEV GRAVEL BED	
COMPLEX	(periglacial processes) SAND AND GRAVEL	PLENIGLACIAL
OLDER COVER SAND I		
WIND POLISHED PEBBLES SAND AND GRAVEL		

Fig. 3. Outline of the stratigraphy in the Frøslev alluvial fan.

therefore not surprising that the wood pieces are most frequently recorded where the eolian sand cover is thin or absent (fig. 2).

The wood fragments

Field observations

Pieces of wood, charred wood, and charcoal were found almost continuously over long stretches in the pipe line trench (fig. 2). The layer in which they were recorded was often involuted (fig. 4) and it was therefore often disrupted. Mostly the pieces were found in a fluviatile unit of sand and gravel; sometimes they were even concentrated on the fore-sets of ripples (fig. 5) and in single localities two horizons, one above the other, contain wood pieces (fig. 5). In most sites the wood is dispersed in a sandy gravelly layer where its concentration may vary from moderate to rather low, but in other places a layer more than four cm thick of almost pure wood material is found. This evidence shows that, in most places, the wood has been transported to the present sites by water. In two sites the wood may be in primary position, namely at km 5.085 and km 8.715 from the Danish-German border. In both these localities small pieces of wood are restricted to a layer a few centimeters thick which shows faint bioturbation, and larger pieces of wood are arranged vertically from a few centimeters below to a few centimeters above the layer containing the wood (figs 6 and 7).

From these figures it can also be seen that no periglacial phenomena extend downward from the layers immediately above the layer containing the wood.

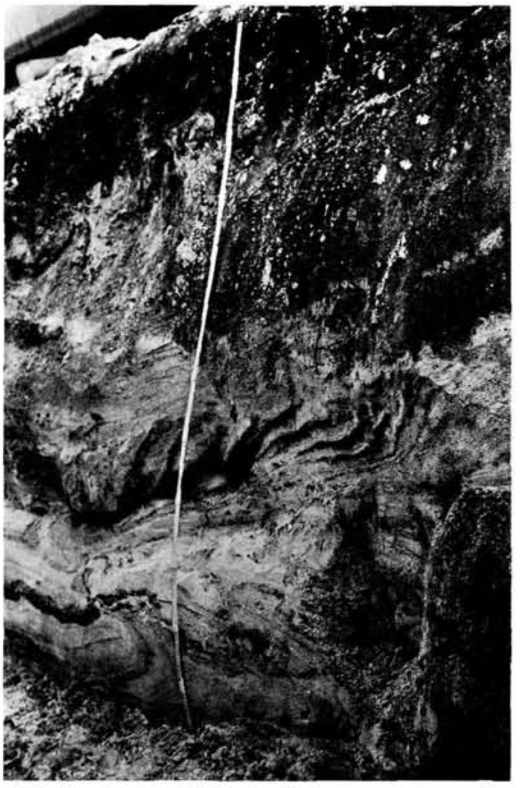


Fig. 5. Slightly involuted sediment with wood fragments in two horizons (black) and wood pieces on fore-sets in the upper horizon. The ruler is two meters long (km 7.030).

Fig. 4. Involuted sediment of loam, sand, and gravel. The black parts contain wood fragments (km 0.450). The visible part of the spade is ca. 1 meter long.

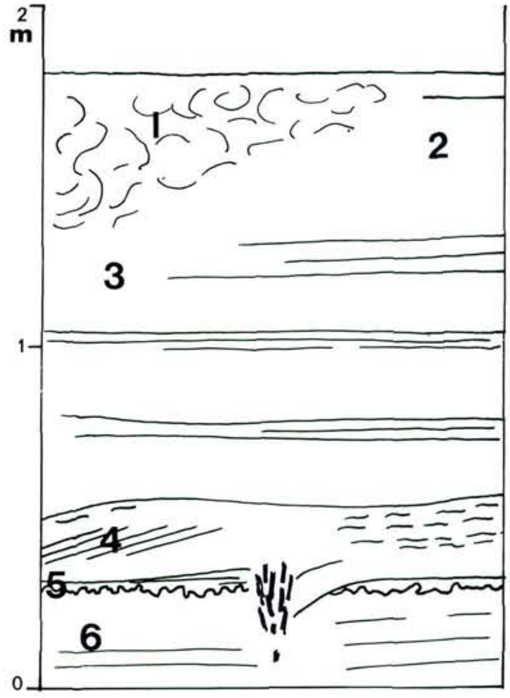


Fig. 6. Profile sketch of site at km 8.715 with wood fragments probably *in situ* (black vertical parts in lower part of profile). The top soil is removed. (1) involuted sand, (2) indistinct, horizontal layers of 75–125 μm sand alternating with layers of 150–250 μm sand, dotted gray and ochre, individual layers well-sorted, coarser grains well-rounded and polished, eolian of Older Cover Sand type, (3) as (2) but light ochre, (4) gray, well-sorted, well- to subrounded sand, 125 μm dominant, eolian or fluvial?, (5) dark gray, 105 μm, well-sorted slightly bioturbated sand layer with small pieces of wood, incipient soil development in eolian sand, and (6) indistinctly horizontally layered sand with dominance around 105 μm, well-sorted, subrounded-subangular, larger grains polished, eolian.

Macroscopic description

The wood fragments are between less than one millimeter to approximately 10 centimeters long and up to 4 centimeters thick. Circular or partly circular sections have not been found and it is therefore concluded that the diameter of some pieces must originally have been more than 4 cm.

The state of preservation ranges from very soft (can be squeezed out with the fingers) to hard (a knife is necessary to cut it even when wet or moist). Some pieces could be broken into long flakes while others are massive.

Microscopical investigation

Microscopical investigations have been made on wood pieces from sites at km 0.750, 3.945, 4.285, 4.405, 5.350, 7.110 and 8.715. Between five and ten of the best preserved pieces, suitable for wood identification were selected from each sample. Each piece of wood was cleansed in distilled water and examined under a binocular microscope with low magnification in order to reveal the main structures. Then transverse sections (TS), radial longitudinal sections (RLS), and tangential longitudinal sections (TLS) were cut with a razor blade. Each section was placed in glycerine on a slide ready for identification.

The diagnostic features are:

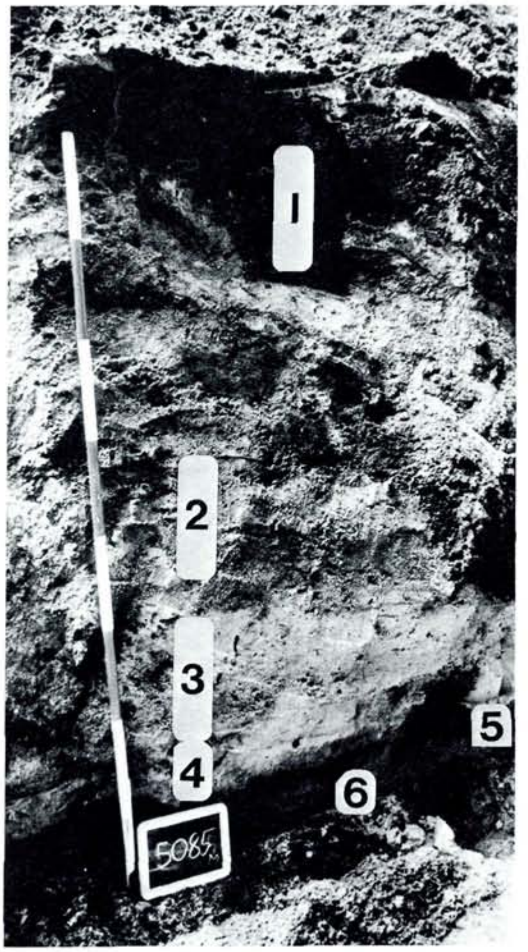
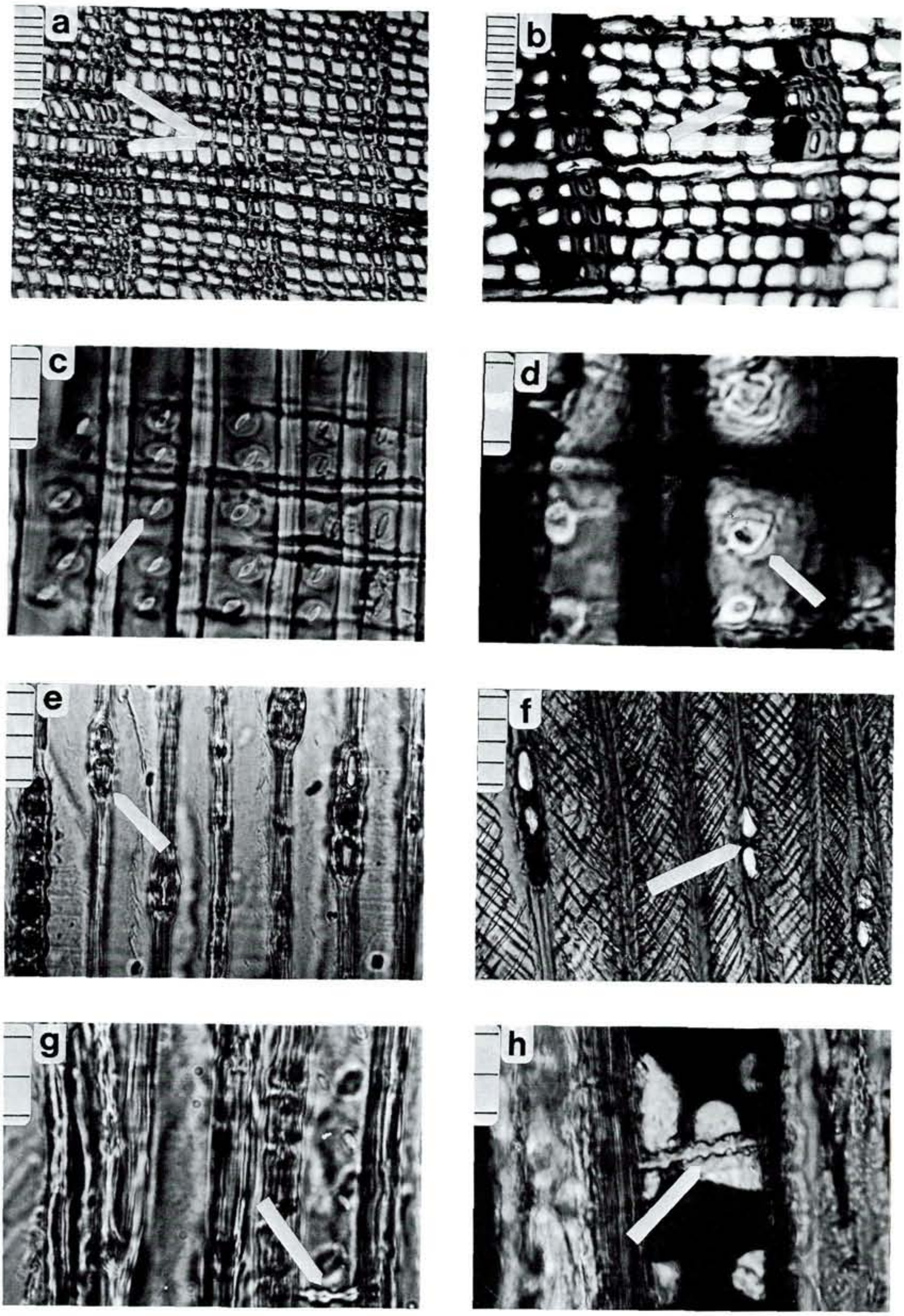


Fig. 7. Photo of profile at km 5.085 with wood fragments probably *in situ* (black part in right hand lower part of profile). (1) involuted fine sand, sand, and gravel, (2) medium sorted, 375 μm sand with a little gravel, dark ochre, fluviatile, (3) as (2) but gray-light ochre, (4) light gray, well-sorted, well to subrounded 105 μm sand, eolian, (5) as (4) but gray with small pieces of wood and faint bioturbation, (6) as (4). The topsoil is removed. The units of the ranging pole are 20 cm long.


a
b
c
d
e
f
g
h

TS: No resin ducts; parenchyma conspicuous in the latewood; rather narrow annual rings. Fig. 8b.

RLS: Cross field pits of cupressoid type; rays homocellular; cross field pits mostly vertically one above another, 1–4 in each cross field; horizontal walls of parenchyma cells either thin and smooth or with nodose thickenings. Fig. 8d, h.

TLS: Low uniseriate rays. Fig. 8f.

From these characteristics it was decided that the wood remains represent *Juniperus* sp. (compare e.g., Greguss 1955, Schmidt 1941). As identification of the various species of *Juniperus* is almost impossible a further distinction was not attempted.

Re TS: The widths of the annual rings were found to vary between 0.06 mm and 0.48 mm. In one piece five consecutive annual rings each 0.07 mm wide were found next to a similar number which were 0.33 mm each.

Kjeld Christensen, Nationalmuseet, kindly investigated the widths of annual rings in recent *Juniperus* wood from various localities.

In a sample from Mols Bjerge (Denmark) he counted 71 rings with a mean annual width of 0.42 mm. A sample from Hemsedal (Norway), altitude 300–500 meters, had 115 rings with a mean width of 0.4 mm. A second sample from the same Norwegian area, at an altitude of 1200–1300 meters, had ca. 500 rings. This sample seems to originate from stem wood close to the ground. The mean widths along the longest radius are in hundred year intervals: years 1–100: 0.26 mm, years 100–200: 0.38 mm, years 200–300: 0.30 mm, years 300–400: 0,19 mm, and years 400–500: 0.33 mm. Along the shortest radius the mean annual width is ca. 0.16 mm. A sample from 2100 meters altitude in the Zellertal in Tyrol had 40 annual rings with a mean of 0.13 mm. Measurements made by Kihlman (1890) in Russian Lappland gave widths between 0.15 mm and 0.39 mm.

However, the spring-wood in most of the microscopic rings of the fossil wood was compacted and a measure of the original ring width was therefore impossible to establish. The compaction may be due to a combination of decay and drying out of the wood, and pressure from the overlying sediments.

Re RLS: The samples showed various stages of decay. Thus it was very difficult to establish proof of the important diagnostic feature of the cross field pits, because the tracheidal secondary wall in some samples was decomposed so much that there was no sign of bordered pits. These walls showed innumerable cracks. Fig. 8c, d, f.

Re TLS and RLS: The diagnostic features indicated that there was *Juniperus* wood in all samples. There was, however, a quantitative difference between the wood elements. In the samples with the larger elements, the parenchyma cells were shorter and thicker than in other samples. It can not be decided whether this difference can be ascribed to internal variations within the same tree or species (stem wood, branch wood, root wood, or juvenile wood), or whether it represents the presence of more than one species.

The majority of the identified wood was *Juniperus*. The samples contained single pieces of deciduous wood as well, but due to advanced decay it was only possible to identify it as either *Alnus* or *Betula*.

The abundance of *Juniperus* fragments in this part of Denmark and the two probable *in situ* sites strongly suggest that it once grew on the Frøslev alluvial fan.

Dating of the wood

A comparison between the lithostratigraphies from the Frøslev fan and that of the cover sand areas in The Netherlands (e.g., van der Hammen et al. 1967, Doppert et al. 1975) makes it reason-

◀ Fig. 8. Diagnostic features of recent *Juniperus* compared to the sampled wood. a: Transverse section of recent *Juniperus communis* L. b: Transverse section of sampled wood. Early wood not compressed. Note the rather narrow annual rings and the parenchyma cells, filled with dark substance (arrows). c and d: Radial longitudinal sections of recent *Juniperus* (c) and of sampled wood (d) showing cupressoid pits (arrows) in the cross field between horizontal ray cells and vertical tracheids. e and f: Tangential longitudinal sections of recent *Juniperus communis* L. (e) and of sampled wood (f) showing low, uniseriate rays (arrows). Note the many cracks in the cell walls of the sampled wood due to decay. g and h: Tangential longitudinal sections of recent *Juniperus communis* (g) and of sampled wood (h) showing nodose thickenings of the horizontal walls of the parenchyma cells (arrows). Each unit in the scales in the upper left corners is 0.01 mm long.

able to assume that the *Juniperus* pieces are of Middle Pleniglacial age or maybe older.

If the wood fragments date from the Eemian or an Early Weichselian interstadial it might be expected by comparison with macro-remains and pollen diagrams known from other localities that conifer wood remains would include at least some of the species of *Abies, Picea, Pinus, Larix,* and *Taxus* (Andersen 1961, Averdieck 1967, Jessen & Milthers 1928, Mamakowa, Mook & Srodoń 1975, Zagwijn 1961; compare also Menke 1976). But the microscopical investigations show that *Juniperus* was probably the only or by far the most dominant conifer in the area.

If the *Juniperus* growth was older than Early Weichsel and Eem it might be expected either that macro-remains from these periods would be represented among the wood as well, or that indications for a warmer period would be present at a stratigraphic level above the *Juniperus* wood horizon; but nowhere in the pipe line trench were peat layers or (part of) soils found between the *Juniperus* layer and the cover sand sequence outlined in fig. 3.

Radio-carbon datings have been made on samples from km 5.350 (54°50'48''N, 9°16'22''E), km 7.110 (54°51'32''N, 9°15'21''E), and km 8.715 (54°52'11''N, 9°14'24''E) by the ^{14}C-Laboratory in Groningen, The Netherlands.

The results of the datings are:

GrN-11103 Krathuse	
>42.000 B.P.	(km 5.350)
GrN-11104 Sofiedal 1	
>49.000 B.P.	(km 7.110)
GrN-11105 Sofiedal 2	
$47.000\ ^{+\ 5300}_{-\ 3200}$ B.P.	(km 8.715)

A comparison with other localities in the northwest European cover sand area reveals that no *Juniperus* fragments younger than Brørup/Odderade and older than ca. 45.000 B.P. have yet been found elsewhere. A number of pollen sequences represent the Moershoofd Interstadial Complex (van der Hammen 1971, Kolstrup & Wijmstra 1977, Odgaard 1982, Zagwijn 1974) but only low percentages of *Juniperus* pollen are found. Furthermore it is not known which other plants were present at the time of *Juniperus* growth near Frøslev. Even though *Juniperus* may have been fairly abundant there must have been other plants at that time as well. But only the more resistant conifer wood is preserved well enough to allow identification.

The low percentages of *Juniperus* in the pollen diagrams representing the Moershoofd Interstadial Complex might argue against the wood fragments being of this age. On the other hand the palaeovegetation may have been different in various areas at that time, and it is possible that pollen diagrams from moist and wet depressions almost exclusively represent pollen sedimentation from the local vegetation.

From the radio-carbon datings and the above considerations it seems reasonable to assume that *Juniperus* grew on the alluvial fan near Frøslev after the Brørup/Odderade interstadial(s) and before 45.000 years B.P., possibly during the early part of the Moershoofd Interstadial Complex.

Palaeoenvironment

The environmental conditions are rather more difficult to unravel. As it is unknown which other plants grew near Frøslev at that time no information for a reconstruction of the growing conditions can be gained from this source, and furthermore it is not known which *Juniperus* species the wood fragments originate from.

The best preserved annual rings were found in flakes of wood and it was therefore not possible to obtain a transverse section with a large number of consecutive rings that might reveal indications of the environmental conditions. And since the spring-wood was often compressed a comparison with recent Juniperus ring widths cannot be very precise. The few well preserved series, however, did not suggest extreme growth conditions and it was noted that the rings of the fossil wood were not radically different from the recent samples mentioned above.

As mentioned above, sections from some of the samples showed quantitative differences in the size of the cells. Unfortunately the material does not allow inferences as to whether this is due to external influences (more favourable growing conditions, e.g., milder or moister climate) or internal conditions.

The state of preservation of the wood fragments suggests that they have probably been covered by ground water during most of the time since deposition, but this conclusion does not help to reveal the conditions during the time in question either.

A slight indication of dry conditions might be suggested by the presence of eolian deposits below and on the wood pieces in the two probable in *situ sites* (compare also the lower part of the Moershoofd Interstadial Complex in The Netherlands; Kolstrup & Wijmstra 1977), but drought need not be the reason for the accumulation of these deposits.

All in all it seems that conclusions concerning the environmental conditions during the *Juniperus* growth cannot be made until more evidence is available.

On the other hand, the co-occurrence of wood pieces and charcoal might provide a plausible explanation for the termination of the *Juniperus* growth as it might indicate that a fire swept over the area and burned the outer parts of the *Juniperus* while the central parts were left undamaged but unable to regenerate.

Palaeogeographic implications

The Frøslev alluvial fan (which continues southward into Germany) constitutes a separate fan of the Tinglev outwash plain. The geological maps of this area (Hansen 1965, Milthers 1948) suggest that ice covered at least the eastern part of this fan during the Weichselian (fig. 2).

A comparison between the stratigraphy in the Frøslev fan and the rest of the Tinglev outwash plain shows that the stratigraphical sequences are similar from the Frøslev gravel bed upwards. Below that level fluvial sand and gravel in primary position is found in the Tinglev area north of the Frøslev fan while the Frøslev fan has a rather complex stratigraphy comparable to Dutch sequences.

It is difficult to assess the thickness of fluviatile accumulations in the Frøslev fan after the *Juniperus* growth because the wood fragments are usually incorporated in these deposits. However, the concentration of wood pieces at a certain level suggests that the wood has probably not been reworked repeatedly and it seems, therefore, that fluvial deposits younger than the *Juniperus* growth amounts to less than two meters in most localities along the pipe line trench. Stratigraphical investigations further indicate that the sand and gravel which contains the *Juniperus* fragments were deposited some time before the Older Cover Sand I and the sediments underlying this unit are consequently older than the glaciation (Kolstrup, in press). This implies that very little, if any, sediment representing the melting of the Weichselian ice is present along this part of the gas pipe line trench.

Additional information concerning the geology of the Frøslev fan is given by Nielsen & Sonnenborg (1982) who outline the geology along a pipe line trench between Frøslev and Gråsten in a technical report. The stretch they investigated starts near the Danish-German border at approximately the same site as the pipe line in fig. 2 and from this site it crosses the Frøslev fan (including some 4 to 5 km of the area within the eastern ice border line of Hansen (1965) in fig. 2) in a north-easterly direction.

In the area of the Frøslev alluvial fan these authors distinguish three subdivisions of the stretch: 1) Vilmkær-Frøslev (south-west), 2) Frøslev-Frøslev Kådnermark (a little more than one kilometer in the middle), and 3) Frøslev Kådnermark-Smedeby Mark (north-east). The descriptions of 1) and 3) are similar in that sand and gravel which is often involuted (cryoturbated) is present in the lower part of the profile and cover sand is found more or less continuously on the involuted layer. Between Frøslev and Frøslev Kådnermark cover sand overlies diamict sediments of sandy and locally clayey materials which are interpreted as till (Nielsen & Sonnenborg 1982).

As the area between Frøslev Kådnermark and Smedeby Mark contains the same sedimentary sequence and the same involuted horizon as found in the western part of the fan it seems reasonable to assume that this northwestern part has not been glaciated by the main Weichselian ice advance either.

This conclusion is in contradiction to the proposed position of the ice front of between less than one and about five kilometers to the east of the trench in fig. 2.

If, however, the ice front was situated further to the east, outside or just touching the Frøslev alluvial fan this would be compatible with both the morphology and the stratigraphy of the fan. The till between Frøslev and Frøslev Kådnermark would consequently date from an earlier glaciation.

If the proposal of a more eastern ice front holds it implies new questions as to the time of formation of the fan, the source area of its sediments, and the conditions under which it formed.

Conclusions

The construction of the gas pipe line system in Denmark offers a unique opportunity to study the stratigraphy in all types of landscapes including areas in which open pits are absent. The Frøslev alluvial fan does not contain resource materials for construction purposes to such an extent that it is profitable to exploit it and open pits are therefore scarce. The stratigraphical outline and the geological considerations given above for the Frøslev fan are therefore based on observations for the gas pipe line trench alone.

In the trench the stratigraphical outline of fig. 3 has been established, and this outline together with the presence and the age of *Juniperus* wood fragments found at a somewhat lower level makes it possible to advance the idea that the Frøslev alluvial fan has probably not been influenced by meltwater streams from the Weichselian glacial maximum. Irregularities which can be ascribed to the presence of dunes are found in the 40 meters contour line of the fan. Apart from these irregularities the fan has a smooth, gently westward sloping face without major knickpoints or irregularities which might be ascribed to glacial advances, and the profiles in Nielsen & Sonnenborg's report (1982) show that the sediments are principally the same on both sides of the suggested ice border line of the geological map (i.e., it seems that on the map Late Glacial fresh-water sand = glacial layered sand; Late-Glacial fresh-water gravel = glacial layered gravel; eolian sand on Late-Glacial fresh-water sand = eolian sand on glacial layered sand). This, together with the absence of indications for meltwater streams which might be related to the glacial advance suggested by Hansen (1965), might mean that the fan has developed independantly of the Weichselian ice cap, that, in fact, most of the sediments in the Frøslev fan are older than the Middle Weichselian ice advance into the south Danish area.

During the maximum extension of the Weichselian ice the Frøslev fan may thus have been a periglacial area rather close to the ice front.

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Dansk sammendrag

I området omkring Frøslev i den sydlige del af Tinglev hedeslette udgør dæksande og fluviatilt sand og grus, der ofte er kryoturberet, de vigtigste sedimenttyper. Højdekurvekort over Tinglev hedeslette viser, at det danske område omkring Frøslev udgør en del af en selvstændig aflejringskegle, der her benævnes Frøslevkeglen (Frøslev alluvial fan).

Geologiske observationer under udgravningerne til naturgasledningen i 1981 har gjort det muligt at stykke den stratigrafi sammen, som er vist i fig. 3. I et stratigrafisk niveau et stykke under denne sekvens blev der over lange stræk fundet stykker af enebærtræ, og det konkluderes, at enebærvæksten dateres til tiden mellem Brørup/Odderade interstadial(erne) og ca. 45.000 år før nu.

Træstykkerne, som findes i alle størrelser op til 10 × 4 cm, forekommer som regel i en fluviatil aflejring af sand og grus; men i to lokaliteter ser det ud til, at selve det daværende voksested er repræsenteret, og det er rimeligt at antage, at der en gang var enebærbevoksning på Frøslevkeglen.

Det ser ud til, at det kryoturberede lag lige under Frøslev gruslaget (Frøslev gravel bed i fig. 3) repræsenterer den kuldeperiode, som herskede, da isen nåede sin største udbredelse i den øvre del af Weichsel, og det er overraskende at konstatere, at der langs gasledningen tilsyneladende ikke findes smeltevandssedimenter, der kan relateres til denne is.

Denne mangel på smeltevandssedimenter samt keglens uforstyrrede morfologi tyder på, at isen og dens smeltevand ikke har påvirket Frøslevkeglens vesthældning under Weichselmaksimet. I stedet ser det ud til, at største delen af Frøslevkeglens sedimenter er ældre end hovedfremstødet, og at denne kegle har ligget som et periglacialt område uden for isranden.

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