FOSSIL ROOTS OF SEQUOIA TYPE FROM TWO LOCALITIES OF THE MIOCENE DELTA DEPOSITS OF THE SØBY AREA, DENMARK

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Roots of Sequoia type (*Taxodioxylon gypsaceum* (Goepp.) Kräusel and *Taxodioxylon* sp.) are described from two localities of the southern part of the Søby mining area SE of Herning, central Jylland: the south face of the abandoned browncoal pit of Carl Nielsen Ltd. at Fasterholt and the NW corner of the pit ("Klynholt lejet") N of Fasterholtgaard. The root horizons in question occur at about the same stratigraphical level, i. e. the uppermost part of the Odderup formation; more precisely, in the sands which overlie the browncoal-bearing sequence of the Søby area.

The fossil roots indicate a Tertiary age and a rather well-drained local environment. From this environmental conclusion it follows that the sequence of the NW corner of "Klynholt lejet" is transgressive, beginning with the root horizon, continuing with browncoal and ending with a thin clay. This again has a bearing on the interpretation of the environment of this region during the introductory phase of the brackish-marine transgression (Hodde clay and Gram clay) which followed after the deposition of the Odderup formation.

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Description of the fossil localities (BEK)

The present study of root wood of Sequoia type by P. Wagner involves material from two localities: section K6 in the browncoal pit of Carl Nielsen

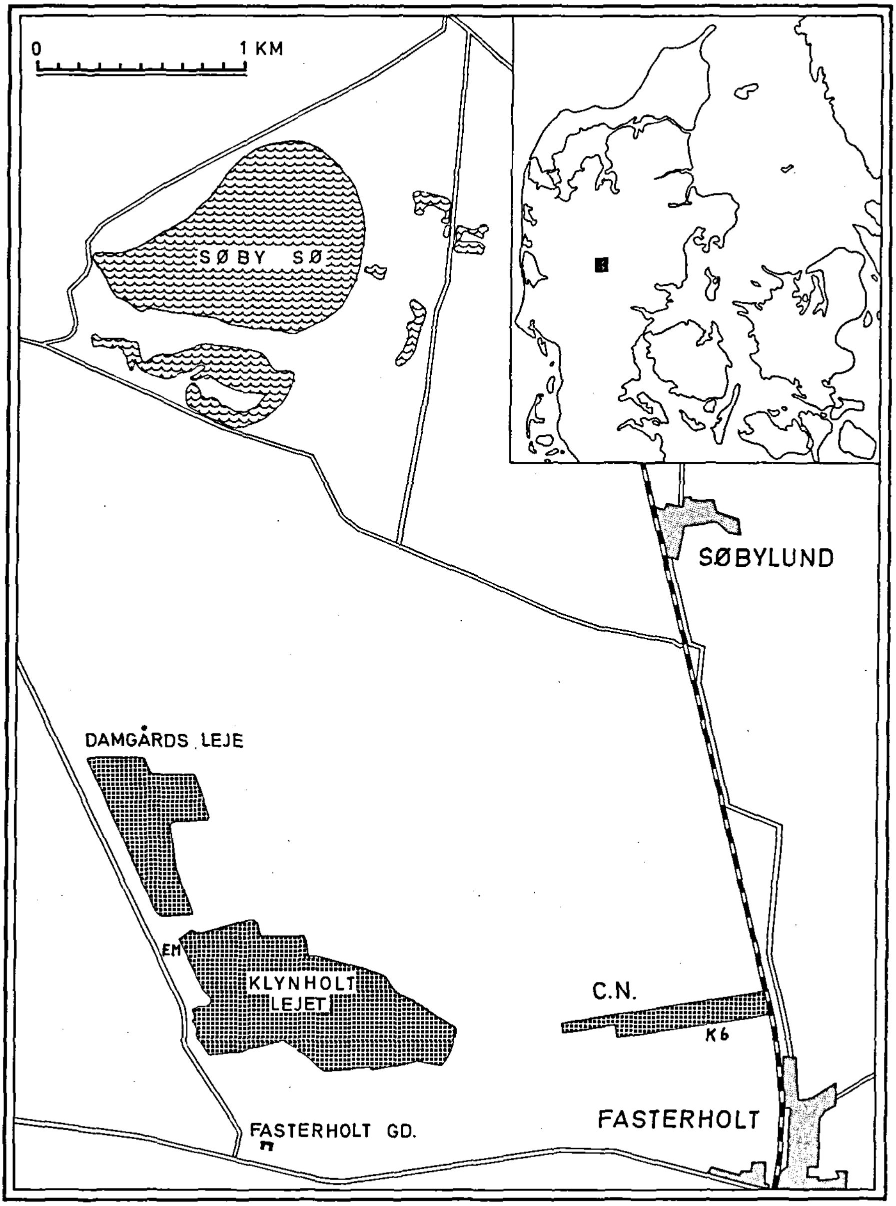

Fig. 1. Locality map of the Søby mining area showing: the browncoal pit of Carl Nielsen Ltd. at Fasterholt, and the area of "Klynholt lejet". Sections K6 and EM are indicated. L. Jans del.

Ltd. near Fasterholt ("Midtkrafts leje") (fig. 1: CN) and section EM in the northwestern end of "Klynholt lejet". Both localities are situated within the southern part of the Søby mining district, about 10 km SE of the town of Herning (fig. 1.). The finding places are situated approximately at the same stratigraphical level, at the top of the Odderup Formation (ref. Rasmussen, 1961), i.e., in the uppermost part of the sands overlying the browncoal sequence of the Fasterholt region. Koch, Friedrich, Christensen & Friis (1973) have described this sand sequence as "Øvre Deltasand", (uppermost fluviatile sands), a sequence of tabular cross-bedded sands situated between the browncoals and the Hodde clay. It is referred to the Middle Miocene (Koch & Friedrich, 1970 and 1971, Koch, et. al., 1973).

The browncoal pit of Carl Nielsen Ltd, section K6

Just north of Fasterholt railway station to the west of the railway, there is a large disused browncoal pit which is now entirely filled with water. This pit was abandoned in 1970. The south face of the pit runs in a straight line about E–W. This face marks the last section which was exposed before the mine was closed down. This face was designated by the letter K in the nomenclature which was used by the palaeobotanical Department, Aarhus University, during the field work in this pit 1968–1970 (Koch & Friedrich, 1970). Section K6 was recorded about 300 m to the west of the railway end (east end) of the pit. At section K6 a sequence was exposed which in

Table 1: The sequence above the upper browncoal seam of the productive member at Fasterholt. Record of section K6, the browncoal pit of Carl Nielsen Ltd. at Fasterholt.

Series	Thickness	Deposits and structures
	c. 1 m	Humus at present ground surface Windblown sand (sheet): Iron Podsol
Quaternary	c. 7 m	Periglacial structures (Cryoturbation) Glaciofluviatile sands and gravels Ventifacts
^^^^^	Unconformity	^^^^^^^^^^^^^^^^^^^^^^^^
Tertiary	c. 10 m	Humus with fossil roots – Periglacial structures (Cryoturbation) Fluviatile quartzsands
(Middle Miocene)		Uppermost seam of the browncoal sequence

general agrees with the standard section of 1969 which was published by Koch & Friedrich (1970, Table 1). The upper part of this section is reproduced in table 1.

The junction between the Quaternary, glacio-fluviatile sequence and the Tertiary deltaic sands is a faintly undulating erosional surface with a ventifact pavement (Koch & Friedrich, 1970, fig. 9). This junction surface has a small culmination at section K6, below which there are preserved remnants of a fossil humus zone (mould) consisting of sand with about 5 % organic matter (coal) (fig. 2). This humus zone is intact for a very short distance only in the outcrop at K6. Generally the humus and the Tertiary sand just

Fig. 2. Fossil humus zone (H) on top of the Tertiary sequence (T) at section K6, overlain by Quaternary glacio-fluviatile beds (Q). An unconformity separates the Tertiary from the Quaternary (arrows). Here a few stones from the "ventifact layer" are seen.

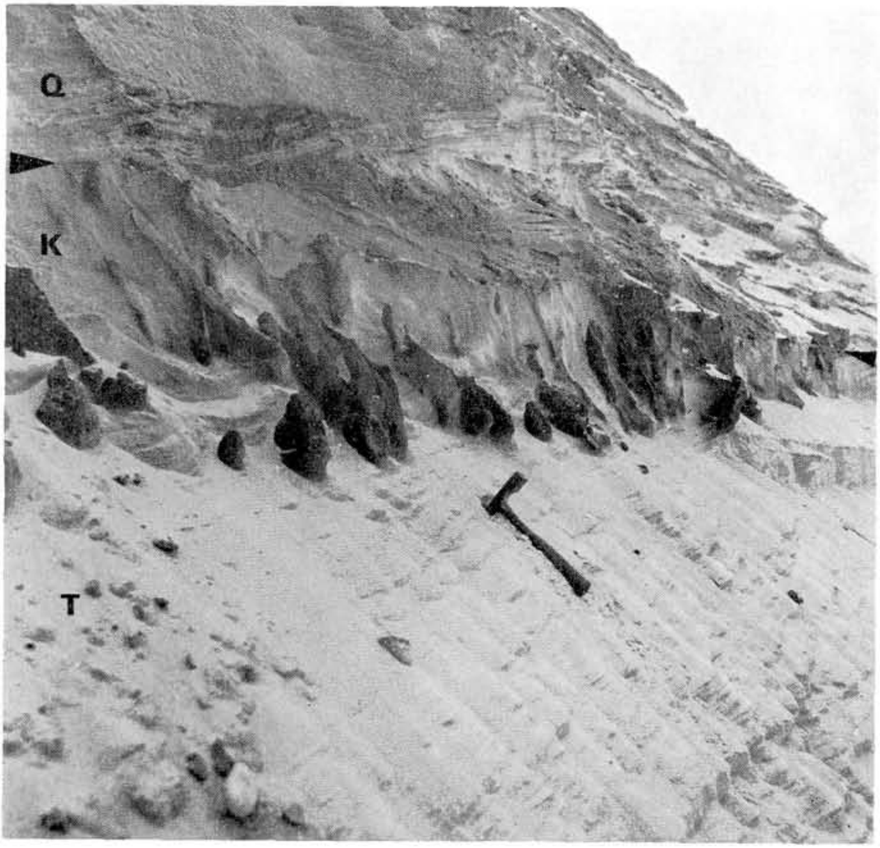

Fig. 3. Junction between the Tertiary fluviatile sequence (T) and the Quaternary glacio-fluviatile sand and gravel (Q). The limit is marked by arrows! On top of the Tertiary sequence there is a zone of periglacial structures (K) (ref. fig. 3). Fossil roots of Sequoia type are preserved here and have protected relics of a fossil humus.

below the junction with the Quaternary series are disturbed by periglacial structures (German: "Brodelboden" or "Taschenboden").

In the culmination the saccate periglacial structures have a dark grey coloured core representing a relic of the humus zone. A number of wedge-, column-, wall- or funnel shaped relics of the humus zone (fig. 3) proved to contain fibrous lignite remains, in some cases a woody root (sample 2950, 2963, Geol. Inst. Aarhus Univ.) several cm thick and with steep inclination. A number of such woody roots converged upwards towards the same area and hence they may have belonged to the same (unpreserved) tree-stump. The stumps may have been part of a former deposit situated a short distance above the Quaternary-Tertiary junction. This phenomenon has been dealt with in a regional geological description by Koch, Friedrich, Christensen & Friis (1973).

The organic matter of the humus zone is uniformly scattered in this deposit (fig. 2). An original fluviatile structure (cross-bedding) is not visible. Thus, the bed with its content of organic matter cannot be considered to be of fluviatile or lacustrine origin.

The determination of the root wood to *Taxodioxylon gypsaceum* (Goepp.) Kräusel implies a biotope without permanent water cover or regular flooding; under the conditions in question this suggests a relatively well drained habitat. Hence the designation "fossil humus" or "fossil mould" probably is the right interpretation of this partly transformed sediment of coal and sand. The organic matter in the bed probably derives from the Tertiary vegetation of which the roots bear witness. Whether or not the root horizon was succeeded by browncoal as in section EM, "Klynholt lejet", cannot be inferred.

Although the Tertiary sand is the main constituent of the humus bed, and the fossil roots extend further down into this sand, the age of roots and humus does not appear directly from the geological information provided by the outcrop since these phenomena are found directly below a pronounced erosional unconformity between the Quaternary and the Tertiary beds. However, the investigation of the fossil root wood has provided conclusive evidence towards the solution of this problem.

The west border of "Klynholt lejet", section EM

"Klynholt lejet" covers the SW end of the Søby mining district. In the NW corner of "Klynholt lejet" there are two browncoal pits filled with water. The southern of these pits forms the NW end of the exhausted mining area of "Klynholt lejet", which is today a sterile desert. At the W end of this pit an exposed section (EM) remains (fig. 1: EM).

The section given in table 2 was compiled from the author's observations from 1970 combined with a detailed survey made by E. M. Friis in 1971 (unpublished report). The lowermost part of the profile recorded in the table 2, i.e. the sequence down to the upper seam of the browncoal sequence, has been added from the DGU (Geological Survey of Denmark) drilling "Fasterholtgaard Nr. 1 (7.3.1973)" correlated with browncoal drilling 4 – Søby 586 (DGU well log office).

The relevant deposits in the present case are the browncoal bed 0.8 m thick that occurs near the top of the Tertiary sequence and its underlying bed consisting of alternative layers of sand and brown clay ("gytja"). The fossil roots that P. Wagner describes in the following chapter (samples 1009, 1011, 10004, Geol. Inst., Aarhus University) extend from the bottom of

Fig. 4. Section EM in the northwest corner of "Klynholt lejet" with the browncoal seam (B) and fossil roots extending downwards into the underlying sand-gytja bed (G). T: Tertiary fluviatile sand. Q: Quaternary glacio-fluviatile beds. Arrows indicate the Quaternary-Tertiary junction.

this browncoal bed to a few metres down into the underlying deposits (fig. 5).

The browncoal bed in question consists of 2 units. According to E. M. Friis (written communication, 1971) the lower one is 0.65 m and consists of regular browncoal. It is overlain by 0.15 m "clayey coal". Combustion analysis of the latter deposit (sample 1007, Geol. Inst. Aarhus Univ.) gave 6–7 % organic matter, which justifies the description "black clay" or "coaly clay". The residue consists of a fine red "clay". In a sample of the regular browncoal of the lower part of this bed the content of organic matter

Table 2. The sequence above the upper browncoal seam of the productive member. Record of section EM, NE-corner of Klynholt lejet.

Series	Thickness	Deposits and structures
Quaternary	abt. 3.3 m	Humus and rubbish at present ground surface Iron Podsol (sand) Fluviatile sands
	1 m	Laminated sand and silt
		Pavement with ventifacts
	1.5 m	Fluviatile sands Pebbles erosion (current-ripples)
	0.8 m	Black clay Browncoal (Xylite)
Tertiary	*0.15 m*	*Cross-bedded fine sand with fossil tree roots*
	0.45 m	Laminated, fine sand
Water level summer 1971	c. 2 m	Schlieritic fine sand with secundary brown colouring, alternating with brown clay (gytja)
Water level 7.11.1970	c. 1 m	Brown, micaceous clay
	c. 11 m below the surface	Uppermost seam of the browncoal sequence

is 94–95 % (sample 2962, Geol. Inst., Aarhus Univ.) and also in this case the residue is a fine red "clay". This browncoal has a high content of thin flakes of lignite in a black, earthy matrix. This rock could be classified as Lignite or Xylite. Tentatively we can classify this browncoal as a Forest-Lignite, the "Waldbraunkohle" of Teichmüller (1958) and Teichmüller & Thomson (1958) in which the content of wood (branches and overturned trunks) has been greatly transformed with the production of only small fragments. According to P. Wagner these fragments are poorly preserved and the tissues are rather disintegrated, e.g. the rays are totally dissolved. Hence the conditions of formation of the original peat involved considerable chemical transformation of the organic material of the sediment. Consequently oxydizing conditions must have prevailed, at least sporadically, in the depositional environment.

The fossil roots (samples 1009, 10004, Geol. Inst. Aarhus Univ.) in the

Fig. 5. Detail of section EM, "Klynholt lejet" with the browncoal seam (B) and fossil roots (r) extending down into the underlying sequence of sand (white) and gytja (brown) (G).

underlying sand-gytja bed descend from the bottom of the browncoal bed and distinctly converge upwards towards common "points of origin", where the dissolved stumps originally stood and where, under the changing conditions they were successively embedded in and transformed with the peat sediment. Roots of this kind have also been recognized which unite into a coaly mass representing a basal remain of desintegrated stump. The most extensive roots run steeply downwards and can be traced a few metres down into the underlying beds, becoming thinner until they finally disappear. Also some more superficial roots with low gradient belong to the converging bunches of roots, but only shorter fragments of these are pre-

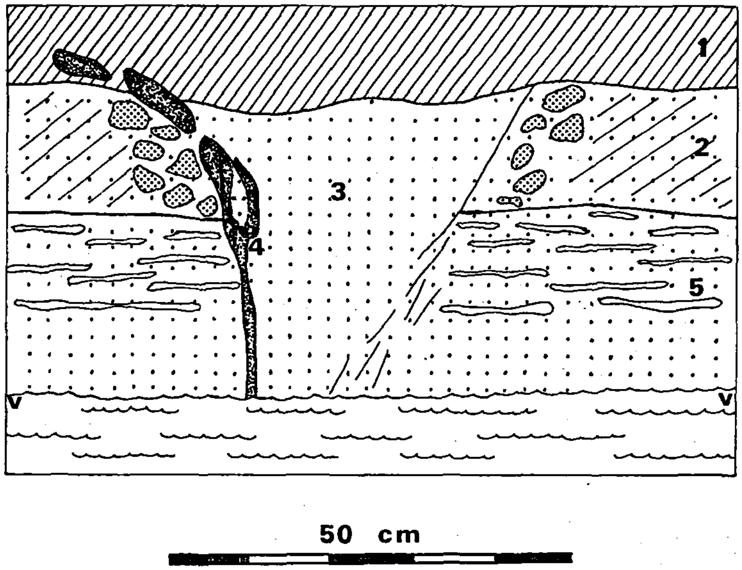

Fig. 6. Sketch of a main root of a stump in its environment (after E. M. Friis). Most of the root has been totally dissolved and replaced by sand. 1: Browncoal. 2: Cross-bedded, coarse sand. 3: Sand cast of a main root branch of a stump. 4: Encoaled remnant of the root branch (3). 5: Laminated, fine sand. v-v: water level in the summer 1971. The scale is valid in horizontal direction only. For the thickness of the strata, ref. table 2. J. Lützhøft del.

served. A few of the long roots are seen to derive from partly preserved, thicker structures, that must represent the remains of a thicker stump, (sample 1011, Geol. Inst., Aarhus University). E. M. Friis (1971) has given a sketch of such a structure reproduced in fig. 6. Most of this structure is filled with sand with "shadows" of grey and black original and secondary structures. The black lignitic material at the periphery is represented by sample 1011 in P. Wagner's description.

Description and determination of the fossil samples (PW)

Methods

Samples were soaked in ethanol and cut by hand with a razor. Sections were embedded in glycerine and examined in a Leitz Ortholux microscope.

Taxodioxylon gypsaceum (Göppert) Kräusel

This sample from section K6, the browncoal pit of Carl Nielsen Ltd., Fasterholt, (2963, Geol. Inst. Aarhus Univ.) was in a good state of preservation.

Description

Transverse section (plate 1 A):

The growth rings are well delimited, the width varies between 250 and 750 μm (13–19 tracheids), and the transition from early to late wood is rather abrupt; the late wood consists of 3–5 layers of tracheids. The tracheids are squarish to elongated hexagonal, in the late wood radially flattened. No intercellular spaces between the cells are seen. Early wood tracheids are 51 μm (66–28 μm) × 36 μm (47–32 μm) (radial × tangential diameter), the late wood tracheids 18 μm (23–16 μm) × 35 μm (44–25 μm), the thickness of the wall in the early wood is 2.2 μm (2.5–1.0 μm), in the late wood 4.7 μm (5.5–4.0 μm). The rays are uniseriate, rarely biseriate. The tangential and horizontal walls of the radially extended, rectangular ray cells are smooth. Xylem parenchyma cells are scattered throughout the growth ring, but are somewhat crowded in the late wood; they are diffuse or arranged in tangential bands (2–4 cells) squarish to lengthy hexagonal like the tracheids, 35 μm (52–19 μm) × 35 μm (45–20 μm) (radial × tangential diameter). Resin ducts were not observed.

Tangential section (plate 1 B):

The tracheids in the early wood lack pits in the tangential walls. In the late wood two types of bordered pits occur, sc. pits with circular aperture, diameter 3–4 μm, diameter of outer border 10–12 μm, and pits with oculiform, oblique to vertical aperture, diameter 4.5 × 1.5 μm, outer border 8–10 μm.

The rays are mainly uniseriate, in a few cases 1 or 2 cell-rows are biseriate (about 1 % of the examined rays have 1 or 2 biseriate rows). The heights of the rays are shown below (533 rays examined).

Height (in cells)	1	2	3	4	5	6
Number (%)..................	20.2	29.2	18.7	13.1	7.1	5.2
Height (in cells)	7	8	9	10	11	12
Number (%)..................	2.0	1.6	0.9	0.6	0.6	0.3

The ray cells are squarish to rectangular (vertically elongated), frequently with rounded corners, thereby leaving triangular intercellular spaces between two superimposed ray cells and the neighbouring tracheids. The width of the cells is 19 μm (23–15 μm) in the central cells, 31–15 μm in the marginal cells. The height varies between 19 and 26 μm (15–35 μm), in rare cases marginal cells 51–53 μm high are found.

The xylem parenchyma cells occur in solitary strands or in tangential bands 2–4 cells wide (plate 1 A and B). The transverse walls are smooth or almost so; real nodular walls of Taxodium-type were not observed. In the tangential walls pits with an elliptic aperture (5.0 × 3.0 μm), and sometimes with an outer border (diameter: 8–9 μm) (half bordered pits) were seen. The cells contain a few great or several small spherical resin bodies.

Radial section. (Plate 1 C):
The tracheids show in the early wood two, sometimes three rows of bordered pits, diameter 15.0–17.5 μm, with circular aperture and distinct tori; where the pits are crowded, they tend to be somewhat flattened vertically. Between the opposite pits distinct crassulae are seen. Solitary bordered pits, however, are also observed. In the late wood the bordered pits are arranged in a single row, they are somewhat smaller (diameter 10–11 μm) and the aperture is eyeshaped (5.5 × 2.5 μm). Spiral thickenings were not observed.

The rays consist of procumbent parenchyma cells, radial dimension 135 μm (433–86 μm), the height varies between 19 and 26 μm (15–53 μm). The horizontal walls are entirely smooth, thickness of the double wall is 2.8 μm (2–3.5 μm). Indentures were not seen. The tangential walls are smooth or almost so, nodular walls were not found.

The form and size of the cross field pits varies according to their position in the growth ring (fig. 7, 8 A and B, plate 1 D). In the broad spring wood tracheids there are in the central cross fields (1)–2–3 taxodioid pits arranged in one horizontal row, in the marginal cross fields there are 2–7 pits arranged in one or two rows or scattered. The long axis (9–12 μm) of the eyeshaped aperture is horizontal or almost so; the outer border is often difficult to recognize because of the decay of the wall. In the middle of the growth ring the pits form an angle of 45° with the long axis of the ray cells, their shape is often a transition-type between the taxodioid and cupressoid type. In the late wood only one pit per cross field is found, cupressoid, the aperture vertical or almost so. The variation in size of the cross field pits is given below:

Direction of the long axis	Type of pit	Aperture	Outer border
Horizontal	Taxodioid	9–12 × 7–3.5 μm	9–12 × 9–7 μm
45°	Taxodioid	8–7.5 × 3–2.5 μm	8–7.5 × 7 μm
	Cupressoid	7–6.5 × 3–2.5 μm	9–8 × 7–6 μm
Vertical	Cupressoid	5.5–4.5 × 2–1.5 μm	7–5 × 7–5 μm

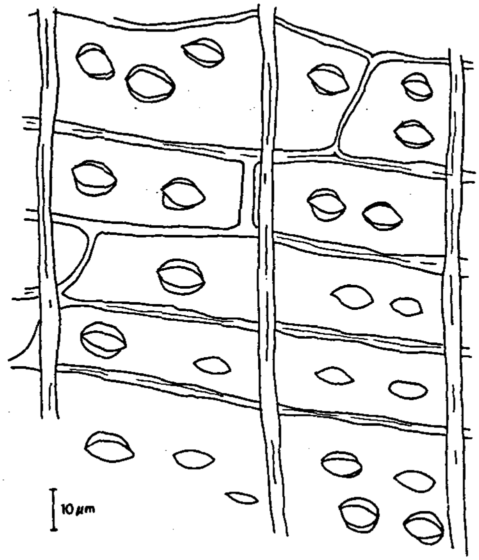

Fig. 7. Cross fields with taxodioid pits from early wood in sample 2963.

In the first formed tracheids in the growth ring, glyptostroboid pits are sometimes seen. The xylem parenchyma cells show in their radial walls pits of the same type as those described in their tangential walls. The transverse walls are smooth or almost so.

Determination

According to the keys for identification of extant species by Kräusel (1949) and Greguss (1955) the sample is identified as belonging to the genus *Sequoia* sensu latiore because of the opposite bordered pits in the tracheids, the smooth tangential and horizontal walls in the ray cells and the smooth transverse walls in the axial parenchyma. Because of the taxodioid crossfield pits, the sample is according to the above mentioned keys, identified as *Sequoia sempervirens* (Lamb.) Endl.

According to the keys for identification of fossil form species by Slyper (1933) and Kräusel (loc.cit.) the sample is determined as *Taxodioxylon gypsaceum* (Göppert) Kräusel (= *Taxodioxylon sequoianum* (Mercklin) Gothan).

Judging from the description of the profile in which the sample was found, it is likely that it consists of root wood. As descriptions (and keys) are often based on stem wood, samples of root wood from *Sequoia sempervirens* and *Sequoia gigantea* Decaisne have been examined with reference to the variation of the anatomical characteristics in this part of the tree. Unfortunately, however, I have not been able to obtain more than one sample

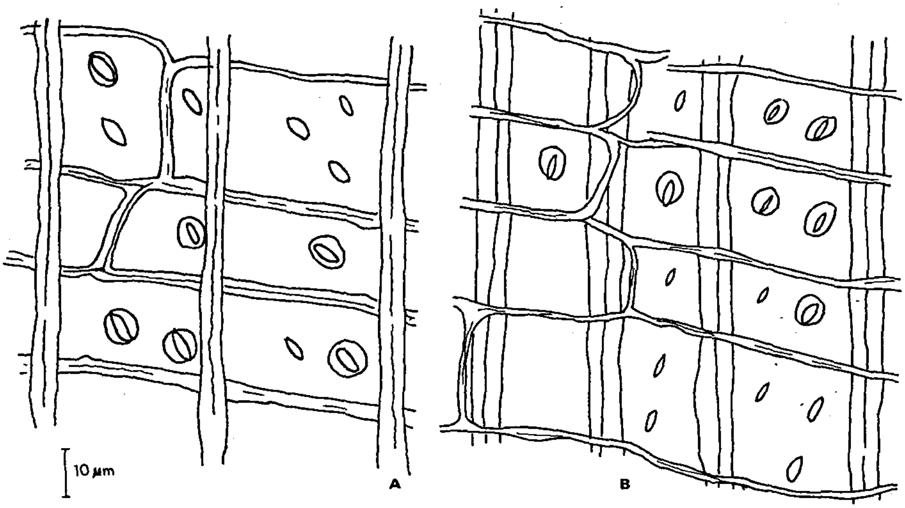

Fig. 8. Cross fields from the middle of a growth ring with taxodioid and cupressoid pits (a) and from late wood with cupressoid pits (b).

from each species, and both originate from roots less than ten years old from trees growing outside their natural habitats; the results should therefore be viewed with reservation. In the root wood of *S. sempervirens* and *S. gigantea* the tracheidal bordered pits are opposite, the radial and horizontal walls of the ray cells and the transverse walls of the xylem parenchyma cells smooth; no indentures are seen. The high rays, known from the stem wood (20–70 cells high), are entirely lacking in both species, and rays more than 20 cells high were not found.

Bi(tri)-seriate rays are also absent. In the root wood only uniseriate rays were observed; one or two cell rows, however, are sometimes biseriate. In *S. sempervirens* the cross field pits of the early wood are taxodioid, the long axis of the aperture varies between 10 and 13 μm. In *S. gigantea* the cross-field pits of the early wood are taxodioid or nearly so, real cupressoid pits are extremely rare; the diameter of the aperture varies between 6 and 10 μm. Differentiation of *S. sempervirens* and *S. gigantea* on basis of anatomical characters is very difficult (Schwarz & Weide 1962, Kräusel 1949). It has even been claimed with reference to the great variation in the diagnostically significant characteristics that it is impossible (Bailey & Faull 1934). Having surveyed existing literature critically and examined fossil as well as recent material, both Kräusel and Schwarz & Weide considered one feature to be decisive in the recognition of the two species: in *S. sempervirens* the taxodioid crossfield pits are much more frequent (64 % of the examined pits (Kräusel)) than in *S. gigantea,* where cupressoid crossfield pits are prevalent.

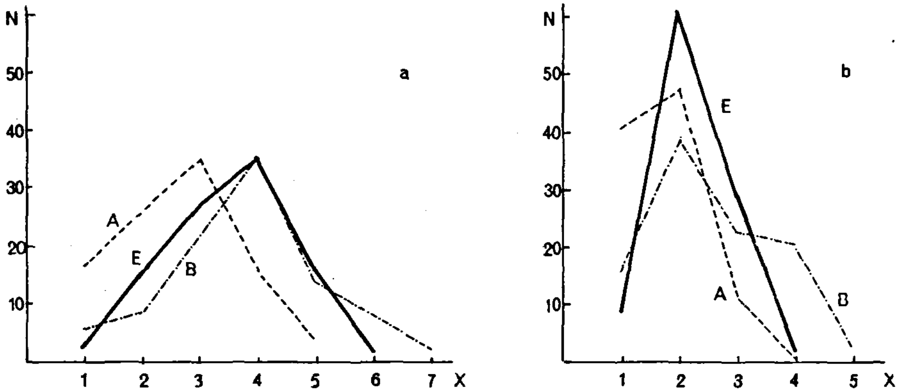

Fig. 9. Graphs showing the variations in number of pits in marginal (a) and central cross fields (b). X: number of pits; N: number of observations in per Cent; A: *Sequoia gigantea* Decaisne; B: *Sequoia sempervirens* (Lamb) Endl.; E: sample 2963.

As mentioned above the cupressoid cross field pits are rare in the early wood of the examined sample of root wood from *S. gigantea,* and this characteristic is therefore hardly suitable for distinguishing between root wood of the two species. This is in accordance with Gothan's statement, that this characteristic is applicable to old stem wood only (Gothan 1905).

Kräusel (1949) further stated, that the number of pits in the cross field in *S. sempervirens* varies between 2 and 6 and in *S. gigantea* between 2 and 3. This is also mentioned by Slyper and Greguss. The number cf pits per cross field was counted in 300 cross fields in *S. sempervirens, S. gigantea* and in sample 2963. The results are illustrated in fig. 9. It is seen that the number of pits in the central cross fields in *S. gigantea* is 1–2, in *S. sempervirens* 2–4, and in fossil sample 2963, 2–3. In the marginal cross fields the variation in number of pits in sample 2963 closely resembles the variation in *S. sempervirens.* Although this characteristic is not decisive, I find that a low percentage of cross fields with one pit indicates a *S. sempervirens*-type of wood.

Van der Burgh (1973) pointed out, with reference to Huard 1966, that thin horizontal walls in the rays are characteristic of *Sequoia sempervirens* (and *Taxodioxylon gypsaceum*); in the examined samples of the recent species I found no difference in wall thickness in the ray cells (double wall thickness in both species: 2–3, 5 μm), and the feature was not used in the differentiation of the two types of wood.

In part agreement with Greguss (1957), Huard (1966) has shown that the two species may be distinguished from each other by means of the length of the long axis in the cross field pits (*S. sempervirens* and the closely related form species *Taxodioxylon gypsaceum:* 9–14 μm, *S. gigantea/T. gi-*

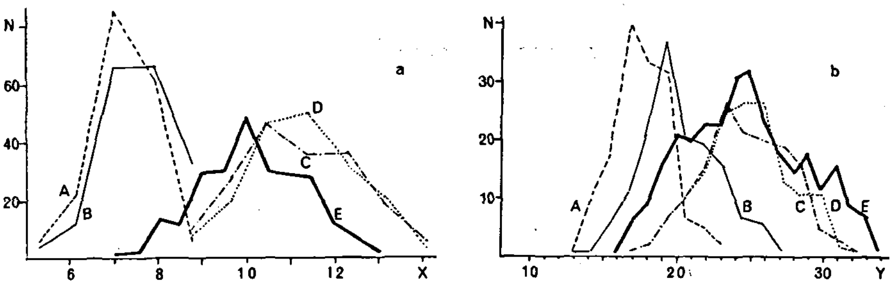

Fig. 10. a: Graphs showing variations in length of the long axis (X) of the cross field pits b: Graphs showing the variations in heights of ray cells (Y). X and Y are given in μm. N: number of observations; A: *Sequoia gigantea* Decaisne; B: *Taxodioxylon giganteoides* Huard; C: *Sequoia sempervirens* (Lamb) Endl.; D: *Taxodioxylon gypsaceum* (Göppert) Kräusel; E: sample 2963. Graphs A, B, C and D from Huard 1966).

ganteoides: 5–9 μm) and the height of the ray cells (*S. sempervirens/ T. gypsaceum:* 18–32 μm, *S. gigantea/T. giganteoides:* 13–22 μm).

Heights of 303 ray cells and lengths of the long axis of 251 cross field-pits all, according to Huard (1966), from the three first formed tracheids in the growth ring, are given in fig. 10 together with Huard's results. It is seen here, that the variation in these two characteristics in the examined sample corresponds to the variation in *S. sempervirens/T. gypsaceum* and, as the low frequency of cross fields with one pit also indicates that species, I am of the opinion that the sample should be referred to *Taxodioxylon gypsaceum* (Göppert) Kräusel 1949. The sample cannot be referred to any of the species recorded since Kräusel's critical catalogue (1949), listed by Huard (1966) and Prakash 1968. However, *Taxodioxylon gypsaceum* is recorded from the Danish Neogene Tertiary lignite by Mathiesen (1970).

Taxodioxylon sp.

This sample from Klynholt-lejet, (sample 10.004, Geol. Inst. Aarhus Univ.) was in a poor state of preservation. The sample showed a marked tendency to break up in flakes when sectioned.

Description

Transverse section (plate 2 A):

The wood consists almost entirely of tracheids, whose form and spatial arrangement is strongly distorted and disturbed; it is possible, however, in some parts of the section to ascertain that the tracheids are arranged in files. No growth rings were found. A few resin-filled cells (parenchyma cells?) were seen scattered among the tracheids. The rays are uniseriate and their courses irregular. The horizontal and tangential walls of the ray cells are smooth.

Tangential section (plate 2 B):
The tangential walls of the tracheids are smooth, on rare occasions circular bordered pits, aperture diameter ca. 3 μm, outer border 6–7 μm, occur. The tangential diameter of the tracheids varies between 24 and 41 μm, a few tracheids with a greater diameter (up to 82 μm) have been observed. All rays are uniseriate. The heights of the rays are shown below (236 rays examined):

Height in cells	1	2	3	4	5
Number in %	14.8	47.0	23.7	9.2	5.1

In the best preserved parts of the sample the ray cells are often higher than broad, ellipsoid or barrelshaped, 20 μm (26–16 μm) × 17 μm (22–12 μm) (height × width); in rays consisting of two cells, the cell form may be almost circular, in the higher rays (4–5 cells) it is nearly rectangular, but the radial walls are somewhat convex. There are 3–12 tracheids between the rays.

Xylem parenchyma cells occur in solitary strands (in a single case a tangential plate consisting of three neighbouring strands was observed), the cells are 405–238 μm long, 26–35 μm wide and their transverse walls are smooth or, in a few cases slightly beaded (fig. 11 A and B). Pits in the tangential walls were not observed with certainty. The cells are frequently filled with a strand of resin matter, but may in other cases be filled with several resin spheres.

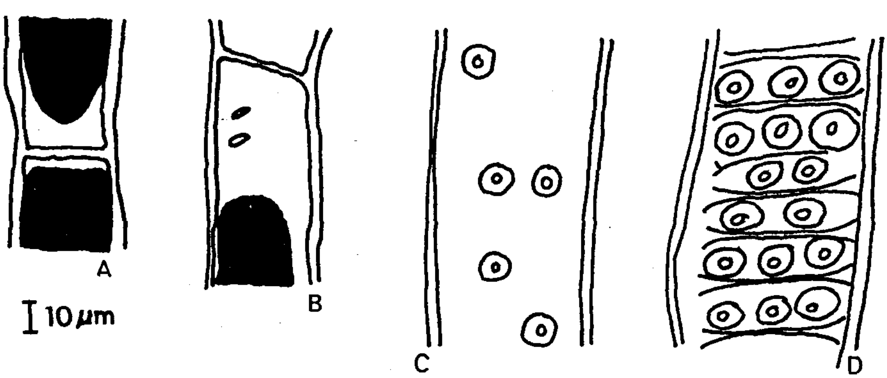

Fig. 11. A and B: Transverse wall in xylem parenchyma cells in tangential (A) and radial (B) view. C and D: Tracheid walls in radial view; C: wall with solitary bordered pits, D: wall with opposite bordered pits and crassulae. Sample 10004.

Radial section (plate 2 C):
The width of the tracheids varies between 40 and 74 μm (thickness of the wall 1.0–1.5 μm), among these broad tracheids 1–3 narrow tracheids (20–14 μm wide) with rather thick walls (2.5 μm) occur occasionally. Assuming that the narrow tracheids represent late wood, which is nowhere clearly defined, the width of the growth rings varies between 400 and 600 μm. The bordered tracheidal pits can be arranged in different ways (fig. 11 C and D). In some parts of the tracheid walls they are crowded in 2 or 4 rows with distinct crassulae, in other parts they are few, solitary or in pairs, without crassulae; the bordered pits tend to be more crowded in the overlapping ends of the tracheids. In the narrow tracheids, they are always arranged in a single row. The bordered pits are circular or elliptical; the aperture is circular or eyeshaped.

Variation in size is given below:

	Diameter of outer border	Aperture	
		circular	eyeshaped
Circular bordered pits	14–11 μm	4.0–3.5 μm	4.5–3.5 × 4.0–3.5 μm
Ellipsoid bordered pits	14–11 × 12–11 μm		5.0–3.5 × 3.5–3.0 μm

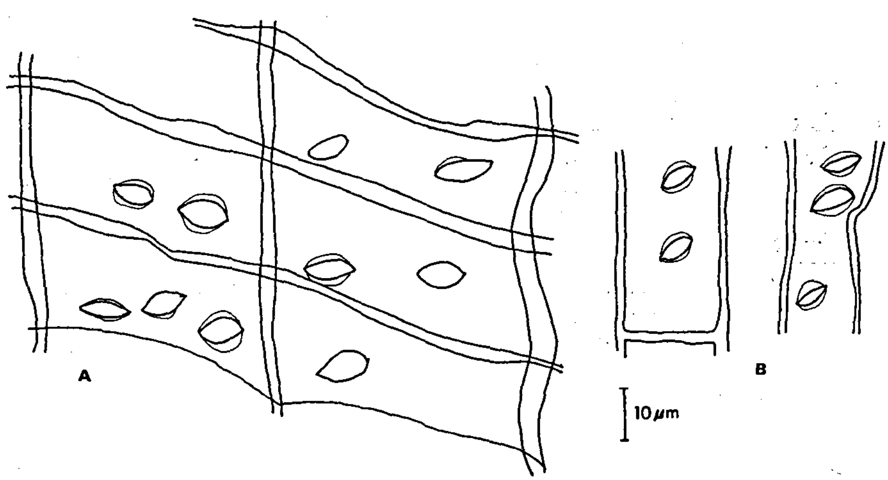

Fig. 12. A: Cross fields with taxodioid pits. B: Xylem parenchyma cell walls in radial view showing half-bordered pits. Sample 10004.

In the narrow tracheids the bordered pits are elliptical 10.0–9.0 × 7.0–6.0 μm, the aperture is eyeshaped 5.0–3.0 × 3.0–2.0 μm.

The rays consist of procumbent parenchyma cells. Because of the irregular course of the cells, the radial dimension could not be measured, as it was impossible to follow a ray cell over its full length; the height varies between 16 and 26 μm. The horizontal and tangential walls are smooth, indentures were not observed. The double wall thickness is 2–2.5 μm. Even at great magnifications it was very difficult and often impossible to ascertain the form and type of the cross field pits since the outer border was frequently invisible, owing to the decay of the cell walls. Of the identified pits the greatest part (90 %) is clearly taxodioid or nearly so, with horizontal or slightly oblique eyeshaped aperture (fig. 12 A and plate 2 D). A few (10 %), occuring mainly in the narrow tracheids, are cupressoid with oblique apertures.

The size variation is given below:

Position of cross field	Type of pit	Aperture	Outer border
Central	Taxodioid	12.0–6.5 × 6.5–3.0 μm	12.0–6.5 × 9.0–5.0 μm
	Cupressoid	3.5–2.0 × 2.0–1.5 μm	8.5–8.0 × 6.0–5.0 μm
Marginal	Taxodioid	11.5–7.0 × 7.5–3.0 μm	11.5–7.0 × 8.0–4.5 μm
	Cupressoid	9.0–7.0 × 4.0–3.0 μm	10.0–7.5 × 6.0–5.0 μm

The numbers of pits in the cross field are given below (as in only a few cases the radial wall was preserved in the entire cross field, only 93 cross fields were examined):

Numbers of the pits in the cross field	1	2	3	4	5	6
Marginal fields %	4.2	7.0	22.5	42.3	21.6	2.8
Central fields %		9.1	54.6	31.8	4.6	
Total %	3.2	7.5	30.1	39.8	17.4	2.2

The transverse walls of the xylem parenchyma cells are smooth. In the radial walls oculiform half-bordered pits are seen, the aperture is 8.5–7.0 μm × 4.0–2.5 μm (fig. 12 B).

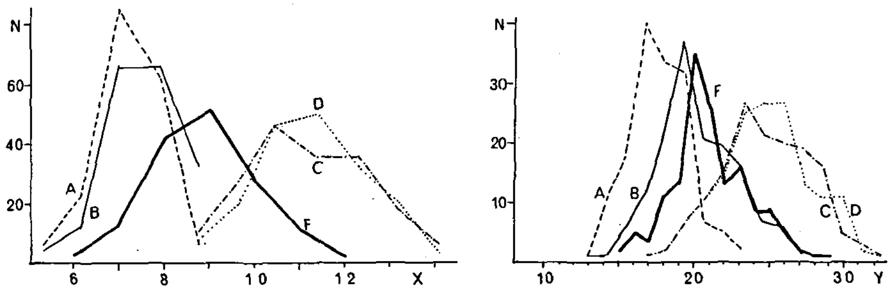

Fig. 13. a: Graphs showing variations in length of the long axis (X) of the cross field pits. b: Graphs showing variations in heights of ray cells (Y). X and Y are given in μm. N: number of observations; A: *Sequoia gigantea* Decaisne; B: *Taxodioxylon giganteoides* Huard; C: *Sequoia sempervirens* (Lamb) Endl.; D: *Taxodioxylon gypsaceum* (Göppert) Kräusel; F: sample 10004. Graphs A, B, C and D from Huard (1966).

Determination

Like sample 2963, the present sample is identified according to the keys of Kräusel (1949) and Greguss (1955) as belonging to *Sequoia sempervirens,* because of the opposite, bordered pits in the tracheids, the smooth tangential and horizontal walls of the ray cells, the smooth transverse walls of the xylem parenchyma cells and the prevailing taxodioid cross field-pits. It should be pointed out that the small height of the rays falls within the variation described by Bailey & Faull (1934). According to the keys for identification of fossil form species by Kräusel (1949) and Slyper (1933) the sample is determined as *Taxodioxylon gypsaceum* (Göppert) Kräusel. Judging from its field occurrence it is likely that it consists of root wood, and a differentiation between *S. gigantea* and *S. sempervirens* according to Huard's (1966) results was attempted. The results of the measurements are illustrated in fig. 13. It was not possible to limit the measurements to the three first formed tracheids in the growth ring, because of the difficult discernable growth rings and the poorly preserved radial walls in the rays. It is seen, however, that the curve showing the variation in height of the ray cells fits the corresponding curve of *Taxodioxylon giganteoides* Huard. The peak of the curve showing the length of the long axis of the cross field pits is intermediate between the curves showing the same characteristic in *S. sempervirens*/*T. gypsaceum* and *S. gigantea*/*T. giganteoides.* As the low percentage of cross fields with one pit points to *S. sempervirens*/*T. gypsaceum,* I do not find it reasonable to refer the sample to either of these two species, but refer it to the form genus *Taxodioxylon* Hartig 1848 em. Gothan 1905. Referring to Jacquiot (1960), Prakash et al. (1971) described root wood under the name of *Sequoioxylon* Torrey 1923, disregarding the fact that this genus is defined by the occurrence of traumatic resin ducts, present in neither the sample described by Jacquiot nor the sample described by Prakash et al.

This use of the name should therefore be avoided and I prefer to retain the form genus *Taxodioxylon* Hartig 1848 em. Gothan 1905, even for wood of Sequoia-type. The sample cannot be referred to any of the species recorded since Kräusel's critical catalogue, by Huard (1966) and Prakash (1968).

Two more samples from Klynholt were examined. Sample 1009 was almost identical with the sample described (10004), apart from the fact that the state of preservation was generally worse. This sample should also be referred to *Taxodioxylon* Hartig 1848 em. Gothan 1905 of Sequoia-type. (Smooth transverse walls in the xylem parenchyma).

Sample 1011 was very poorly preserved; the tracheids were compressed radially and partly dissolved, like the rays. It was impossible to obtain information concerning the tracheidal bordered pits, the ray cells and the xylem parenchyma in such detail as to allow determination.

Conclusion (BEK & PW)

This investigation of fossil roots contributes both to our knowledge of the fossil flora of the browncoal sequence of the Søby area and also to the geological and palaeontological investigation of this area with the following conclusions:

1. The described root wood belongs to the family Taxodiaceae and can be determined as a Sequoia type of the form genus *Taxodioxylon.* Hence it belongs to the Tertiary. This applies to both localities in question. It is of special importance for section K6, the browncoal pit of Carl Nielsen Ltd. at Fasterholt, where the geological conditions at the finding place did not allow us immediately to exclude a Quaternary age of the root horizon. At an earlier date P. Ingwersen (personal communication) made a brief palynological survey of the humus bed of section K6 in which the roots were found. He found a large representation of pollen of genera, which, in our latitude, must be regarded as Tertiary. The fossil roots as well as the humus zone must consequently belong to the Tertiary sequence.

2. The Tertiary age and the similarrity (Sequoia type) of the fossil roots add a new criterion to the local correlation of the sequences in "Klynholt lejet" and at Fasterholt.

3. The fossil root wood allows a conclusion concerning the geological environment at that date. The root wood is of Sequoia type, and cannot reasonably be assigned to any other genus of the Taxodiaceae. Identification of the material to this family is definitive and the other representatives of the

Taxodiaceae of the Fasterholt flora (*Taxodium* and *Glyptostrobus*) can be excluded in this case. Moreover, the root wood from section K6 at Fasterholt even shows important characteristics which have a closer resemblance to the recent *Sequoia sempervirens* (Lamb.) Endl. than to *Sequoiadendron giganteum* (Lindl.) Buchholz (Huard, 1966, v.d. Burgh 1973). This indicates that the biotopes (ref. sections K6 and EM) were relatively well drained, approaching the variation in groundmoisture which is normal for a delta environment (as opposed to the requirements of the other taxodiaceous genera of the Fasterholt flora: *Taxodium* and *Glyptostrobus* which thrive today in open swamp or frequently flooded and extremely wet ground). The observation of the steep inclination of the fossil roots, which in section EM reached 2–3 m down into the substratum (fig. 5) independantly supports this conclusion, indicating the relatively low groundwater level in the lifetime of the vegetation.

4. The fossil roots under the browncoal bed of section EM of "Klynholt lejet" belong to a partly disintegrated stump horizon. No stump bases or anastomosing major root branches have been recognized; the most that has been seen are some larger root structures with scattered remains of the wood structure which represent the proximal end of larger root branches (fig. 6). The preservation of the wood of the roots is relatively poor. The Sequoia-type of roots indicates a relatively well drained biotope. The browncoal seam bears witness to increasing ground moisture at the locality, probably the consequence of rising ground water level, which has destroyed the *Sequoia* stand. The branches and overturned trunks were reduced to peat and are found as relics (lignite pieces) in the browncoal, where presumably the stumps have also been absorbed. The sedimentation of the peat took place under oxydizing conditions, as is indicated by the absence (disintegration) of the stumps, the earthy texture and the high content of minute, poorly preserved wood fragments of the earthy coal. The browncoal did not involve an open swamp. However, the black clay which overlies the browncoal indicates that the rising water level terminated peat formation and that the establishment of an open water cover resulted in clay sedimentation. Hence, this sequence indicates a relatively well-drained situation followed by rising ground water leading finally to a water cover (a transgressive sequence!)

5. The Hodde Clay basin of "Damgaards leje" wedges out southwards in the direction of section EM. Because of the relative situation of section EM and the Hodde clay basin in "Damgaards leje" (fig. 1), and the succession of the described sequence, which indicates an evolution from well-drained to swamp conditions, it is tempting to correlate the succession of section EM as a border facies synchronous with the initial Hodde Clay transgression of the Søby area. This is an interesting possibility which must be taken into account in the geological-paleontological investigation in progress in this area.

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Dansk sammendrag

Der beskrives fossile trærødder fra A/S Carl Nielsens brunkulsgrav ved Fasterholt og fra en blotning i det nordvestlige hjørne af Klynholt lejet N for Fasterholtgaard (fig. 1). Begge lokaliteter ligger i Søby området SØ for Herning. Der gøres nærmere rede for fundomstændighederne (se Tabel I og II og fig. 2–6). Heraf fremgår det vedrørende lokaliteten ved Fasterholt, at rodhorizontens og det tilhørende muldlags placering i lagserien lige under grænsen mellem det tertiære deltasand og det kvartære smeltevandssand ikke umiddelbart tillod en aldersbestemmelse af rødderne og muldhorizonten her. Muldhorizontens tertiære alder er sandsynliggjort ved pollenanalytisk sondering (afdelingsgeolog P. Ingwersen, DGU).

Begge forekomster tilhører stærkt nedforvitrede stubbehorizonter, som stratigrafisk befinder sig i den øverste del af Odderup formationen (Rasmussen, 1961): øverst i det tertiære deltasand, som i Søby området overlejrer den brunkulsførende lagserie. Yderligere oplysninger om de geologiske forhold kan søges i Koch et. al. 1973.

De fossile trærødder er bestemt til Sequoia type (*Taxodioxylon gypsaceum* (Goepp.) Kräusel og *Taxodioxylon* sp.), på grund af de parvise kammerporer i trakeidernes radialvægge, der også er forsynede med crassulae, de glatte horizontal- og tangentialvægge i marvstrålecellerne, de glatte transversalvægge i det aksiale parenkym og de overvejende taxodioide krydsfeltporer i vårveddet.

Bestemmelsen indebærer, at de fossile trærødder er af tertiær alder. Dette er afgørende for vor fortolkning af den aktuelle tertiære lagserie ved Fasterholt og relationen til forekomsten fra lokaliteten i Klynholt lejet. Endvidere indicerer bestemmelsen et forholdsvis vel drænet voksested indenfor det aktuelle deltamiljø, mens træerne var i live. Dette støttes yderligere af, at rødderne oftest er stejlt stående. På Klynholt lokaliteten kan de lange stejlt stående rødder følges 2–3 m ned i underlaget (fig. 6).

Af denne slutning vedrørende miljøet følger, at lagserien i Klynholt lejets NV hjørne begyndende med stubbehorizonten er transgressiv, idet følgende succession kan noteres:

1) En skov med træer af *Sequoia* sensu lato vokser på forholdsvis vel drænet bund.

2) Moderat forsumpning ødelægger skoven og fører til dannelse af en jordet brunkul med stærkt omdannede vedfragmenter, hvorunder også stubbene opløses, mens de dybere liggende rødder bevares.

3) Åbent vanddække medfører aflejring af sort ler.

Denne transgressive lagfølge i deltalagserien nært syd for den sydlige udkiling af Hoddelers bassinet i Damgårds leje er formodentlig en synkron randfacies i forhold til den initiale transgression, der markeres af det basale gruslag i bassinet. Bestemmelsen af *Sequoia* stubbene er således et vigtigt bidrag til undersøgelsen af det lokale miljø i Søby området under Hodde ler – transgressionens tidligste stadium.

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Plate 1

Sample 2963 Geol. Inst. Aarhus Univ. *Taxodioxylon gypsaceum* (Göppert) Kräusel. Section K 6, the browncoal pit at Fasterholt (Carl Nielsen Ltd).

A: Transverse section × 80.
B: Tangential section × 80.
C: Radial section × 80.
D: Radial section. Crossfield pits × 800.

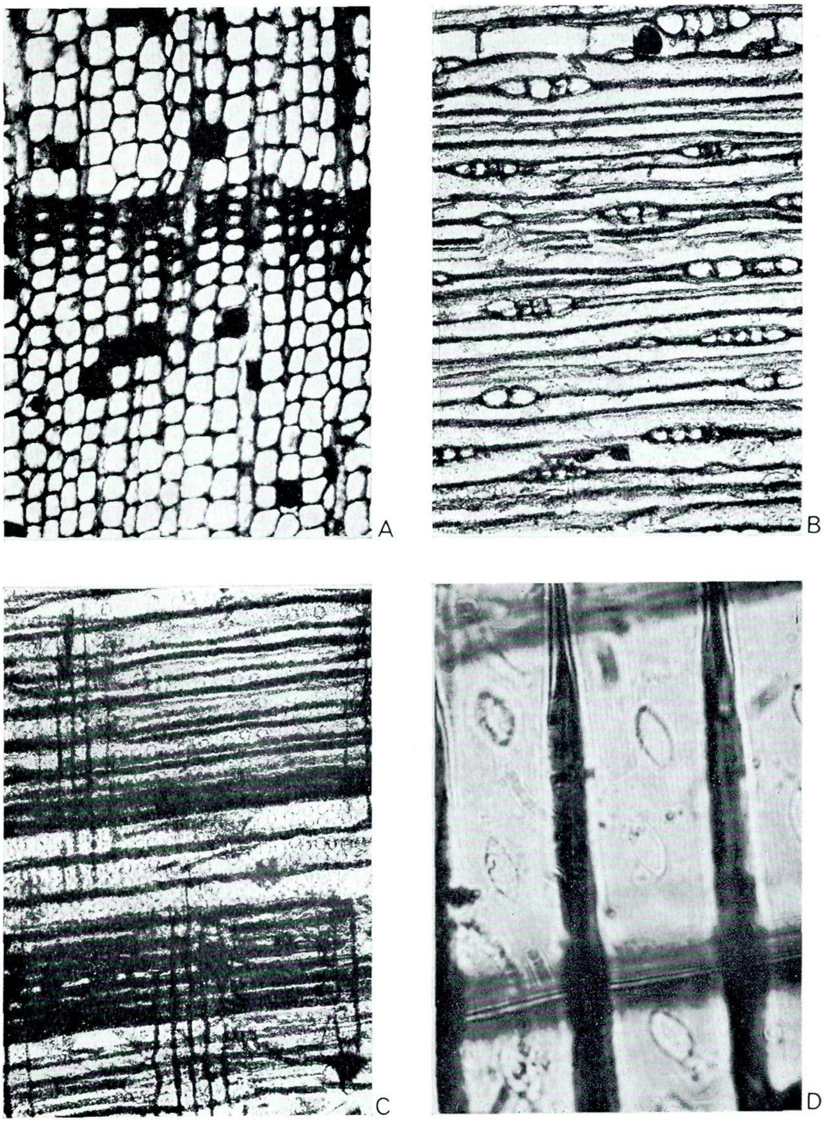
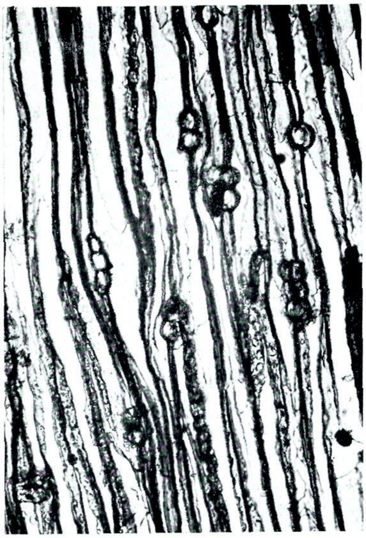

A
B
C
D

Plate 2

Sample 10004 Geol. Inst. Aarhus Univ. *Taxodioxylon* sp. Section EM, "Klynholt lejet".

A: Transverse section × 100.
B: Tangential section × 100.
C: Radial section × 320.
D: Radial section. Crossfield pits × 800.

A



B

C

D