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Geology of the Søby-Fasterholt area

TEXT

BY
B. ESKE KOCH
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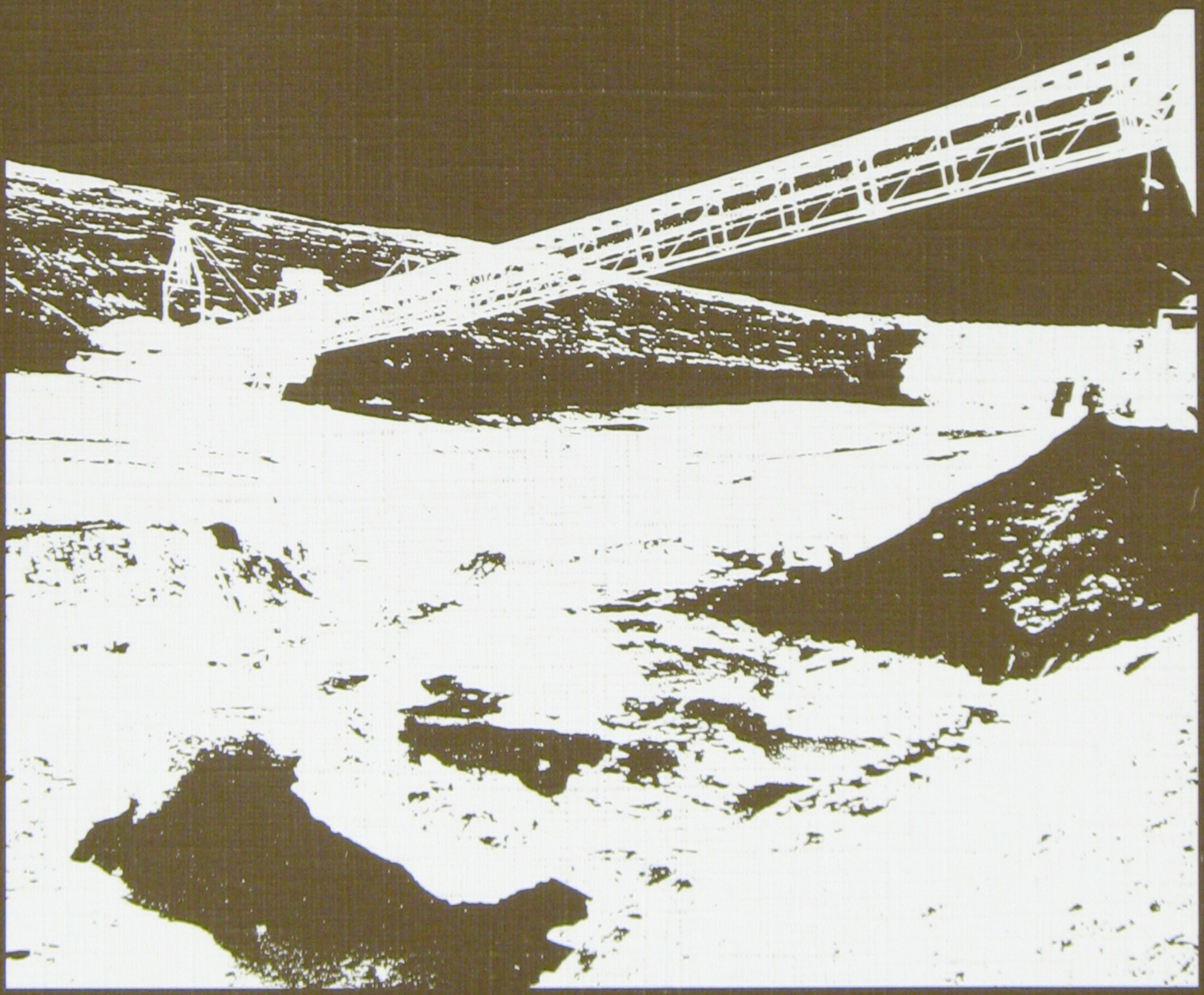

Danmarks Geologiske Undersøgelse · København 1989

So eine Arbeit wird eigentlich nie fertig,
man muss sie für fertig erklären,
wenn man nach Zeit und Umstände
das Mögliche getan hat.

Goethe, 1787

Text-Fig. 1. The browncoal pit of Carl Nielsen Ltd. at Fasterholt 1969.

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A paleontological and geological investigation on the Miocene browncoal bearing sequence of the Søby-Fasterholt area, Central Jutland, Denmark

BY
B. ESKE KOCH
with contributions by E. Fjeldsø Christensen and Erik Thomsen

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Jutland, Denmark, Miocene, paleobotany,
stratigraphy, brown coal, deltaic environment,
coastal environment, tectonics.

Vignet:
Mining procedure in the former browncoal pit (Carl Nielsen Ltd.) at Fasterholt.

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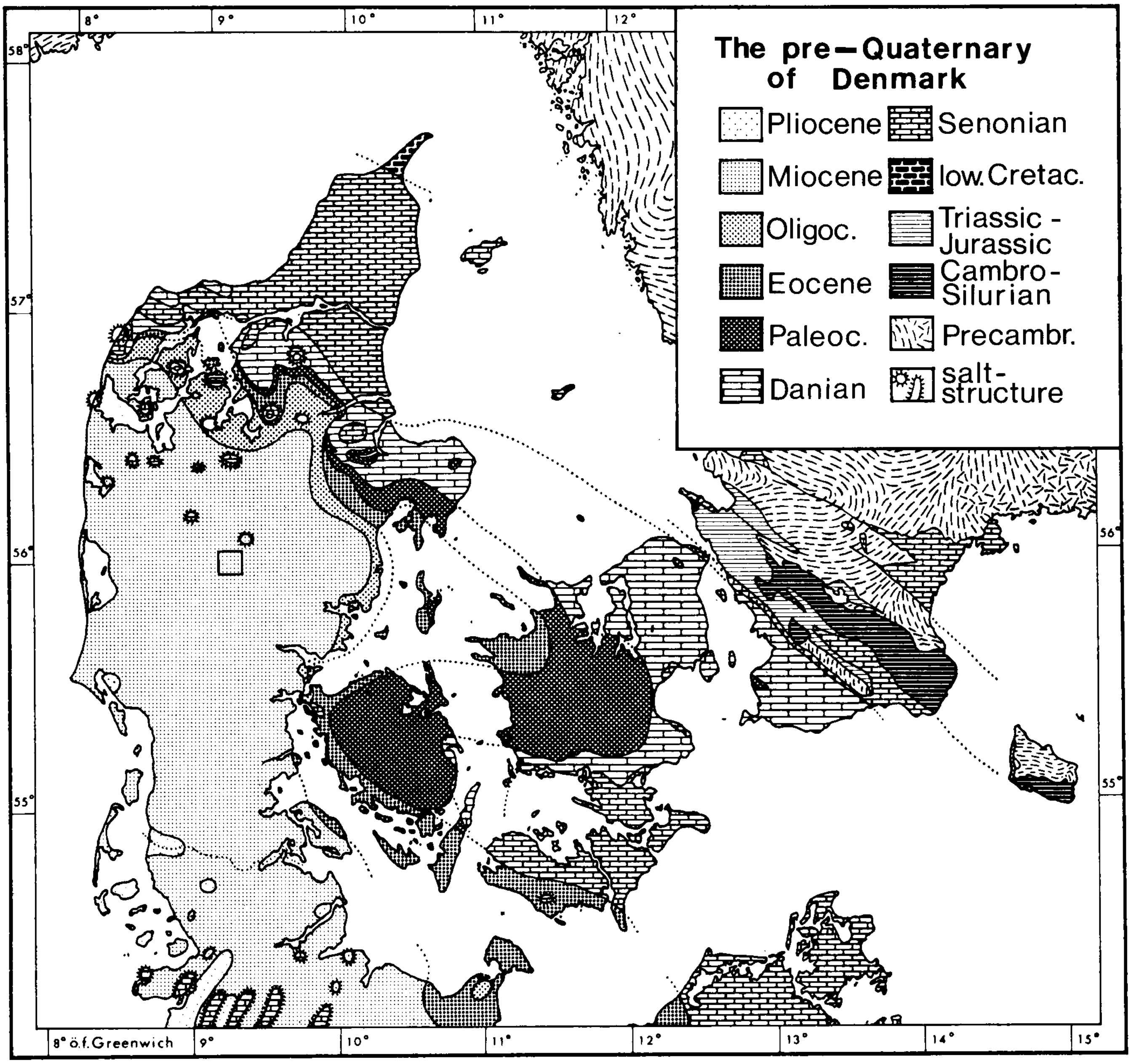
Contents

Abstract

A general description of the Quaternary and Neogene of Central Jutland follows after an introductory survey of previous investigations in the area and the general regional geology of the Neogene of Denmark. The Quaternary morphology and especially the solifluction deposits and periglacial structures are described.

The Tertiary deltaic browncoal bearing deposits of the Søby-Fasterholt area are described in detail (lithostratigraphy) based upon exposures, wells and the petrography of the browncoal seams. The Miocene marine Hodde Formation and the outcrops of the Gram Formation of the Søby-Fasterholt area are described in general. The Fasterholt Flora especially, but also the Damgaard Flora and the Søby Flora, is discussed in an extended chapter on the biostratigraphy, and the pollen-stratigraphy is compared to the Lower Rhenian region. Finally, The exposures revealing pre-Weichselian disharmonic folding and faulting caused by compression are described and compiled.



Text-Fig. 2. Geological map of the Pre-Quaternary surface of Denmark and neighbouring areas of NW-Germany and Sweden. The square on the Jutland peninsula indicates the Søby-Fasterholt area. Compiled after H. Wienberg Rasmussen (1966).

1. Introduction

The present paper reports on an investigation carried out in the Søby-Fasterholt mining area since 1967, continuously supported by the Danish Natural Science Research Council and the University of Aarhus, Denmark.

In 1968 several providing factors interacted with each other to bring this investigation to a start: 1) The Geological Institute of the University of Aarhus (founded in 1961) had been consolidated including the Phytopalaeontological Department of this institute. – 2) Some projects were needed to serve as sources of problems for the bachelor's thesis of the first years of geology students. – 3) The Danish Natural Science Research Council had been founded and could give us support. – 4) The decline of the brown coal mining in Jutland called for special action just during these years.

From the beginning we tentatively defined the purpose of our project (The Søby-Fasterholt brown coal project) as follows:

"To contribute to the extension of the knowledge of the geological environments of brown coal deposition based upon the occurrences of Central Jutland". And later, in the annual report to the Danish Natural Science Research Council 1974: "By means of palaeobotanical and geological investigations to extend our knowledge concerning the geological environments of brown coal deposition, based upon the brown coal bearing sequence of Central Jutland". This declaration provided investigation on different problems:

1. Investigations of the fossil flora deriving in the brown coal bearing deposits of Central Jutland. This would give insight into the climatic, edaphic and other environmental factors, and of the type of vegetation from which the original peat- and gytja sediment was derived.
2. A general geological investigation of the brown coal bearing sedimentary sequence of Central Jutland and its structure, composition and differentiation into various facies. The brown coal facies especially would be thoroughly investigated.
3. Stratigraphical investigation of the brown coal bearing sequence of Central Jutland involving all available and suitable methods. This must be based upon drillings to a wide extent.

In 1968 only three open pit brown coal mines were productive in Jutland and were available for investigation: The mine of Carl Nielsen Ltd. at Fasterholt (the Midtkraft mining area) and the two mines of Hoffmann & Sons (the Vestkraft mining area) at the settlement of Søbylund and at the village of Kølkær, both just to the east of the lake Søby Sø (ref. Text-Fig. 20).

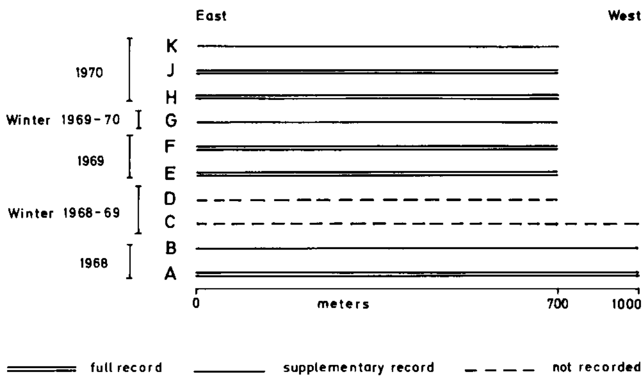
Besides, a number of mining fronts were available in abandoned pits in the Klynholt- and Damgaard mining areas and still showed good exposures.

During 1967-68 the senior author assisted by Dr. W.L. Friedrich carried out the initial field work in the productive mines, and we were highly stimulated by our discovery of a rich fossil diaspore flora (the Fasterholt Flora) (W.L. Friedrich) and a fossil leaf flora (B.E. Koch) in the Carl Nielsen Ltd. pit. Continuous field record was carried out from the summer 1968, and the field work inclusive the extensive fossil collection was definitely stabilized when the Danish Natural Science Research Council in the spring of 1969 gave an extended financial support, a support which was given continuously till 1979.

In the summer of 1969 mining in the pits of Hoffmann & Sons was abandoned while extensive field work continued in the Carl Nielsen Ltd. pit until closing of this mine in the summer 1970. Fossil collecting continued to the 1st of August the same year owing to a special grant from the Danish Natural Science Research Council making it possible for us to keep the pit dry for an extra month (July). This action secured an extra large collection of fossil seeds and fruits from the Fasterholt Flora.

The palaeontological and geological studies during 1968-1970 were located mainly at the pit of Carl Nielsen Ltd. at Fasterholt. The geological record was facilitated by the regular and well organized mining procedure of this pit (Text-Fig. 3B). The mining trench was about 30 m deep, about 90 m wide, and 1000 m long in 1968, respectively 700 m long in 1969-1970. The bottom of the trench was divided into 3 terraces, 3 different sections (outcrops) of 3 successive fronts being exposed at a particular moment (ref. Text-Figs. 1 and 3B). Hence, the outcrop of each front was studied and recorded in three stages (upper, middle, and lower section). Consequently all profiles of our record has been reconstructed from three fragments. The trench prograded southwards in strips of about 20 metres, and the terraces consequently also were about 20 metres wide.

The succession of mining fronts which were recorded, marked by letters from A and onwards, is il-



Text-Fig. 3A. Diagram illustrating the system of mining fronts exposed during the 1968-1970 field work. The distance between the fronts were abt. 20 metres. Browncoal pit of Carl Nielsen Ltd., Fasterholt.

lustrated in Text-Fig. 3A. The profile of each front was measured in 50 m intervals, and documented by rock samples taken with 100 m intervals. Special sampling was made continuously for coal petrography and for palynological analysis and sporadically for other phenomena. The observations were extensively supported by photography (black and white, as well as colour-diapositives). The recorded profiles are marked by a letter indicating the front (exposure) plus a number. The succession of numbers (profiles) of each front begins at the east end of the pit with 0, progressing towards west, with exceptions for profiles intercalated later and out of succession. The total registration deriving in this project is kept in the files of the Geological Survey of Denmark.

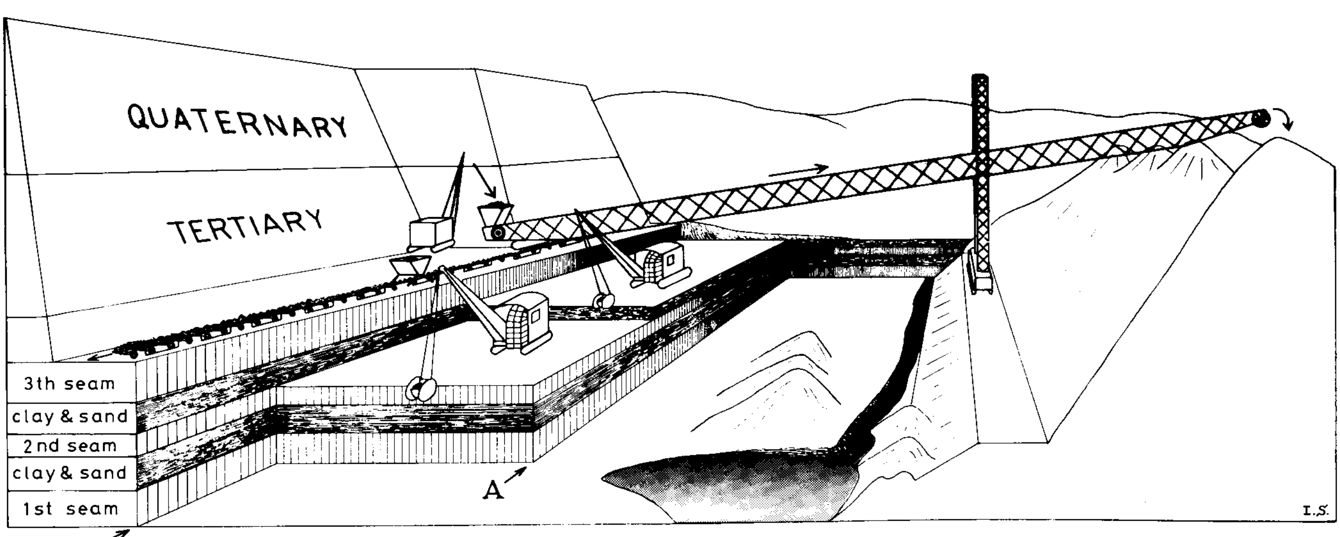
The block which in this way was recorded regularly during 1968-1970, and which can be reconstructed in detail, is 180 metres wide (N-S direction) and 700 metres long (E-W direction) (fronts A-B: 1000 metres) and about 30 metres thick (ref. Koch & Friedrich 1970, Fig. 3-4).

To conduct this recording procedure Mr. E. Fjeldsø Christensen entered our staff in 1969. During these years also a number of students assisted in the field by sampling and sieving fossils from the sands and collecting fossils from the clays. In the laboratory our technicians Mrs. Inger Hammerich and Mr. S. Røj Jacobsen were assisted by students during the primary preservation procedure which the bulk collections of fossil diaspores underwent soon after the collection (sieving). This procedure is described in Koch & Friedrich 1971, page 6.

At this late stage of collecting of the Fasterholt Flora Dr. F. Holý (Prague) was our guest (1970) and taught us to catch also the smallest seeds and fruits which to the majority had escaped our sieves. He introduced Ms. E.M. Friis to the collecting and the study of this small seed fraction which to a wide extent needed a technical and study procedure of its own.

After the brown coal mining had closed down and the artificial suppression of the ground water level ceased, the open pit mines became submerged. During the following years the groundwater level continued to rise and also made itself felt in the remaining part of the Søby-Fasterholt area where the ground-water level rose slowly until 1975. This was what we expected, and from the summer of 1970 we continued the field work in the older pits where good exposures still existed. This includes the Søren Pedersen pit at Munkballe, the Klynholt mining area, the Damgaard mining area, besides the west- and south fronts of the entire Søby-Fasterholt area.

The most important events during this later field campaign were 1) The discovery of the marine Hodde Clay (Upper Middle Miocene) (Klynholt north-front, Damgaard N and -S, the entire west-front) above the



Text-Fig. 3B. Sketch showing the mining procedure and the resulting topography of the mining trench of the Carl Nielsen Ltd. browncoal pit at Fasterholt. W.F. (Koch & Friedrich, 1970).

brown coal bearing delta sequence, and later also the overlying Gram Clay (Upper Miocene) (Klynholt south-front). 2) E. Fjeldsø Christensen's discovery of a new fossil flora (the Søby Flora) in the Damgaard N pit, just below the Hodde Clay.

During field work of a separate sedimentological project undertaken under the conduction of Professor Gunnar Larsen, Aarhus, Ms E.M. Friis sieved out a small diaspore flora (the Damgaard Flora) from the sands below the Hodde Clay in the pit of Damgaard S.

In 1970 the first two drillings were set up as terminal points of an E-W profile line crossing the southern part of the Søby-Fasterholt area in order to establish a stratigraphical correlation between our main locality, the Carl Nielsen Ltd. pit at Fasterholt, and the localities of the western part of the area (Lavsbjerg Hill) as well as the nearest at this time recorded marine fossiliferous locality, situated to the west of the Fasterholt Plantage (drilling Fasterholt Plantage, file no. 95.1942 and drilling Fasterholt Plantage I, file no. 95.1941 (1970). These drillings were conducted by The Geological Survey of Denmark.

During the years 1971-1973 an extensive collection of fossil plants and fossiliferous gytja-blocks was made by E. Fjeldsø Christensen in the pit of Damgaard N. This material was named the Søby-Flora, the preparation and determination of which started during the winter 1971-1972. In the same period, the geology of the Damgaard-Klynholt mining areas was studied in detail in the field and in cooperation with the Geological Survey of Denmark 3 more wells were drilled on the east-west profile in the winter 1972-1973. Probings to 15 meters below the surface were in the same period set on 10 places in the region between the Klynholt- and the Damgaard mining areas. Hence detailed geological information was obtained. Later (1978-79) a number of probes to 15 metres below the surface were set up along the south front of the Klynholt area and in the vicinity of the Damgaard N pit. These probes were all conducted by Mr. S. Meldgård Christensen (Dept. of Paleontology, Aarhus Univ.).

The study of the field records, fossils and samples led to cooperation with a number of colleagues: The trace fossils from the substratum of the Hodde Clay were studied from a palaeoecological point of view by U. Asgaard & R. Bromley (Copenhagen) (preliminarily published 1974). The root-stump horizons were studied by P. Wagner (Copenhagen) (Wagner & Koch 1974). Dr. L. Banke Rasmussen (Copenhagen) studied our collection of marine fossil molluscs from the Gram Clay of Lavsbjerg (Rasmussen 1979). E. Heller (Copenhagen) and Eske Koch started the construction of isopach-maps of the 3 main brown coal seams based upon the well-file data of the Geological Survey of Denmark. This survey was later continued and finished for the Geol. Surv. of Denmark by A.G. Rasmussen (1982, 1984). Experimental K:Ar-dating from glauconite in the glauconite clay-silt of the Gram Formation of the Lavsbjerg Hill (Upper Miocene) and Oligocene glauconite clays from different localities of Jutland was carried out by Mr. Ole Larsen, (University of Copenhagen). Mr. P. Ingwersen (Geol. Surv. Denmark) made a preliminary palynological analyses from the 5th seam and the soil of the upper root horizon.

The first information concerning material from the Fasterholt Flora was published by Koch & Friedrich (1971, 1972), Friedrich & Koch (1970, 1972), and a preliminary survey of the geological and palaeontological information was published in Danish (Koch et al. 1973) (ref. also Koch & Friedrich 1970).

During the years 1973-1975 conservator Lizzie Thamdrup took care of the sorting and preparation of the Fasterholt Flora.

Supported by grants from the University of Aarhus and the Danish Natural Science Research Council Mr. E. Fjeldsø Christensen concentrated on the study of the Søby Flora for 3 years (1973-1977). He has presented a thorough description of this fossil flora based upon morphological and especially upon cuticular analysis. The latter was improved by inventing a special version of the collodion-peel technique adjusted to the thin and brittle cuticular films of the Søby Flora leaves. He discusses palaeoecology and plant associations based upon a quantitative investigation which was already prepared during the field work. This study also contributes with a detailed discussion about the stratigraphical questions and has been published in 3 parts, the conclusion of which is found chapt. 4.B.7.6, page 126 of the present paper.

A 3 years' grant (1976-1979) from the University of Aarhus made possible an intense study of the small seed fraction of the Fasterholt Flora carried out by Ms. E.M. Friis. She extended the floral list with 53 species and 23 unspecified genera with careful determinations. A number of publications presenting these studies has appeared (Friis 1975, 1976, 1977a, 1977b, 1979, 1985). Friis especially discusses the palaeovegetation, palaeoecological and palaeoclimatological aspects of this flora. A thorough systematical survey of the fossil collections of the thesis (1979) was published in 1985. The descriptions are generally supported by SEM-information encountering about 120 species from the Fasterholt Flora, besides smaller collections of seeds and fructifications from the Damgaard Flora and the Søby Flora and two deep wells.

The Danish Natural Science Research Council gave a grant to Mr. E.Thomsen to support a revision and extension of his bachelor of science thesis on the brown coal petrography and facies analysis of brown coal seams nos. 1-3 of the Carl Nielsen Ltd. pit. This study included a 6-month-employment at the Brown Coal Section, Geologisches Landesamt, Nordrhein-Westfalen in Krefeld. (West Germany). Here the study continued under the supervision of Dr.M. Wolf and Dr. G.

von der Brelie. This investigation was terminated with a thesis (Thomsen, 1980) which presents a coal petrographical facies-analysis of the browncoal seams of the Carl Nielsen Ltd. pit at Fasterholt and the west front of Klynholt. The head-lines of this study is found in chapt. 4.B.2.2.1. page 38 of the present paper.

At this moment the study of the Fasterholt Flora is continued by W.L. Friedrich and B. Eske Koch concentrating on determination of the remaining part of the seed/fruit sieve-fraction. This work especially concentrates on numerical statistical methods. Handling large numbers of fossils W.L Friedrich involves computer techniques.

Since 1975 all these studies were intensely supported by conservator S. Bo Andersen. His skilled technical experiments with modification of existing methods and invention of new ones as well as adaptation of new chemical manufactures for our purpose have facilitated and encouraged these studies very much.

It remains to refer to the support which this study of the browncoal bearing deposits of the Søby-Fasterholt area has received when the Danish Natural Science Research Council and the University of Aarhus paid all costs connected with the Symposium: "The continental Miocene of Central Jutland (Denmark): Geology – Brown coal facies – Stratigraphy – Paleontology", Aarhus, June 11-16, 1979. We highly appreciate the contributions to the discussion of our results, and the lectures, and other information with which the participants have supported this paper (ref. Proceedings of Symposium: The continental Miocene of Central Jutland, June the 11th – 16th, Aarhus University, 1979). This concerns especially our foreign colleagues Dr. G. von der Brelie (Krefeld), Dr. J. van der Burgh (Utrecht) ,Dr. J. Gregor (Munich), Dr. H. Hager (Krefeld), Dr. W. Hinsch (Kiel), Dr. W. Hiltmann (Hannover), Dr. E. Knobloch (Prague), Dr. M. Wolf (Krefeld) who stayed in Aarhus through the whole week; and from Copenhagen especially Dr. L. Banke Rasmussen who gave the introductory lecture.

During the latest years sedimentological and geochemical investigation of the Hodde Clay has been in progress (E. Fuglsang Nielsen, 1985). In the mid-seventies the senior author began a stratigraphical study based on fossil pollen, and was greatly encouraged by Dr. G. von der Brelie (Krefeld). The author studied the principles of pollen determination and the pollen-stratigraphical method of G. von der Brelie at his laboratory (Geologisches Landesamt Nordrhein-Westfalen, Krefeld) assisted by Mrs. H. von Schilling. The results of this study was discussed during several visits to Krefeld and on the symposium in Aarhus, 1979, (Koch, 1979). Also Mr. Erik Thomsen learned about Miocene pollen determination in relation to brown coal facies analysis at the laboratory of G. von der Brelie. This was done together with his coal petrographical training by Dr. M. Teichmüller, Krefeld (1978).

Pollen-stratigraphical and coal-petrographical facies analysis of the browncoal seams of the quarry of Carl Nielsen Ltd. at Fasterholt were carried out parallel and independently on the same samples by Koch and Thomsen. This allowed mutual control of the pollen-determinations and in relation to the methods of G. von der Brelie, which had been used during his pollen stratigraphical investigations of the Lower Rhenian area. This way secured the best possible foundation for comparative studies. The pollen-stratigraphical results are published in the present paper (ref. chapt. 4.B.7.) (preliminarily published in Koch, 1984).

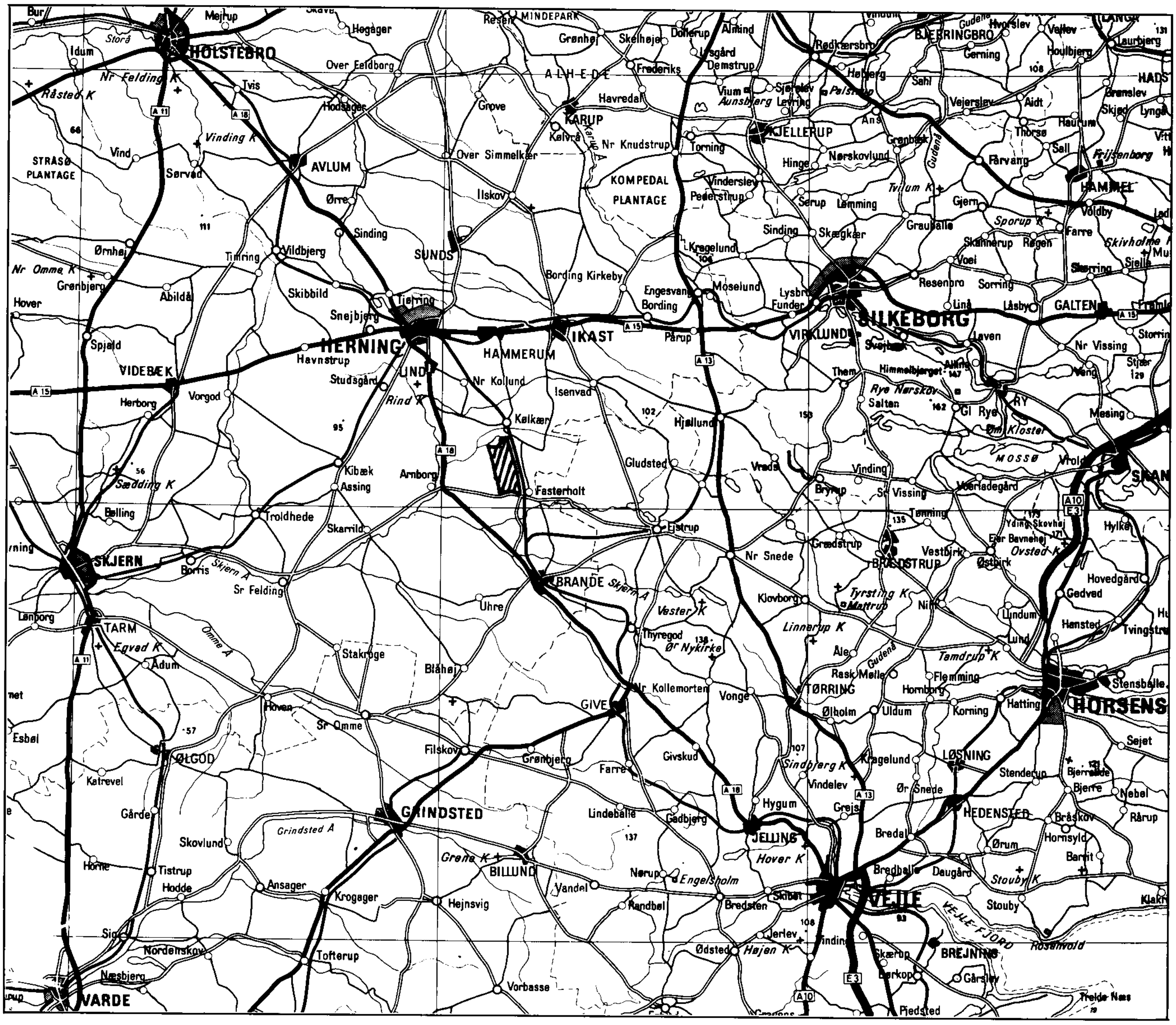
H. Friis, O.B. Nielsen, E.M. Friis and C. Balme in 1980 published combined analyses of the sediments and its fossils of the well Lavsbjerg Øst (DGU file no. 95.1995). (H. Friis: sands, Nielsen: clays, E.M. Friis: megafossils and Balme: palynology). Though restricted to a single well, an important new (but in principle not representative) information about the Miocene sequence down to 120 m below surface and its lithostratigraphy was presented.

2. A historical summary of the Investigations of the Brown Coal bearing sequence of Jutland and its Fossil Flora

Only a few publications have appeared concerning the Miocene brown coal flora from Jutland and for the geology of the brown coal bearing sequence in general.

How long the occurrence of brown coal in Jutland has been known and was exploited locally is uncertain. A few natural exposures that are described in the literature, must have been recognized locally for a long time. The pre-Quaternary deposits of Denmark are in general covered by a considerable thickness of till and other Quaternary deposits. The majority of the exposures of brown coal beds are located in the deeply incised valleys (The Thorsø-Borresø valley: Silkeborg Vesterskov and Silkeborg Sønderskov and the lake Slåensø. The Salten valley: The exposure in Tyskerbakken ("Salten profilet") and the St. Knasbjerg hill near Gammel Ry. The Bryrup valley: Vorret and Lystrupsminde). All these localities have been mentioned by Mathiesen (1965), (ref. also Hartz 1909).

In Central Jutland especially the banks of the major rivers are the places to look for exposures of the Mio-

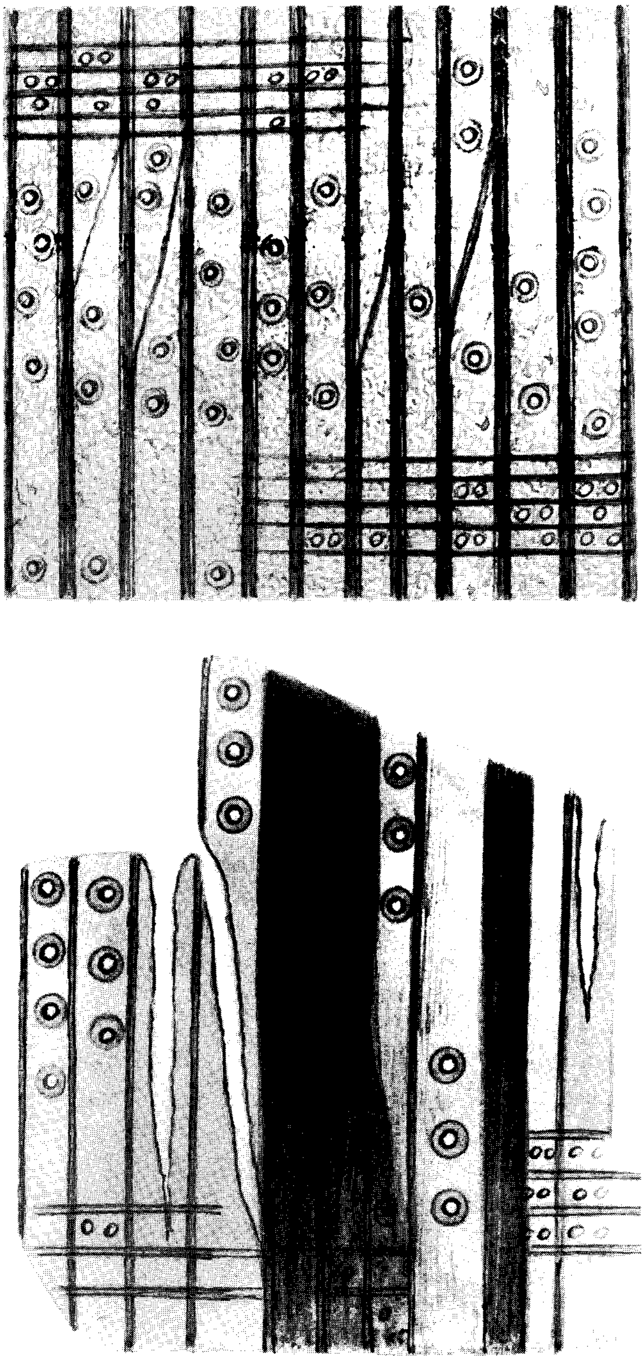


Text-Fig. 4. Topographical map (1:300 000, Geodetic Institute, Copenhagen) of Central Jutland for referring to the position of the localities mentioned. The Søby-Fasterholt mining area is indicated by the hatched area.

cene deposits (ref. the geological map of Denmark, Text-Fig. 2). Hence, reference to an exposure in the bank of the Skjern Å (river) at Sandfeldgaard (farm) is found in older literature (Dalgas 1868) (Text-Fig. 7), and Hartz mentions several exposures along the same river in this area (Hartz 1909). The nearly white, cross-bedded, relatively pure quartzsand and – gravel (so-called micasands, in Danish: Glimmersand) is a major component of the Neogene Series of Jutland. A considerable part of the brown coal bearing formation (the Odderup Formation, Rasmussen, 1961) consists of this sand. And this is geographically wide in extent and obvious in natural exposures and in gravel pits owing to its nearly white appearance. Towards the east in Jutland in the belt of young glacial (Weichselian) topography, it is for example exposed in the Aarhus region (Låsby), in the Gudenå river valley (Voervadbro), in Grejsdalen (valley) at Vejle. In the Silkeborg region it is widely distributed in a superficial position and commonly exposed. Here the well-known erosional unconformity between the non-marine Miocene and the Quaternary with a pavement of ventifacts can occasionally be recognized (e.g. in the south slope of the Funder valley in Silkeborg Vesterskov and in Grejsdalen (valley) at Vejle.

The first information about a brown coal bed in situ in Jutland given by a professional geologist, comes from the first Danish professor of geology, J.G. Forchhammer (professor at the University of Copenhagen 1828-1865) in his survey of the Geology of Denmark (Forchhammer 1835). In this treatise he mentions the occurrence of a "genuine" brown coal bed occurring "in the parish of Them at Salten Langsøe" (lake). Concerning the plant fossils which occur in the brown coal bearing sequence of Jutland, Chr. Vaupell delivered a manuscript to the Royal Danish Society of Science and Letters in 1853 entitled: "A botanical investigation of the fossil wood that can be found in the clay- and sandbeds in Denmark and which has been washed ashore on the Danish coasts from the sea together with the amber" (ref. Vaupell 1896 (1853)). The paper was printed posthumously in Danish. (The title has been translated by the present author). His paper refers to fossil wood from several localities and of different age under the term brown coal (lignite). Fossil wood from the brown coal bearing formation was described from Them (near Salten) under the name *Pinites Fausbøllianus*. The geological occurrence of these fossils (lignite) was not understood by Vaupell. He assumes a connection between the allochtonous amber which is often found on the Danish coasts and the lignite fossils.

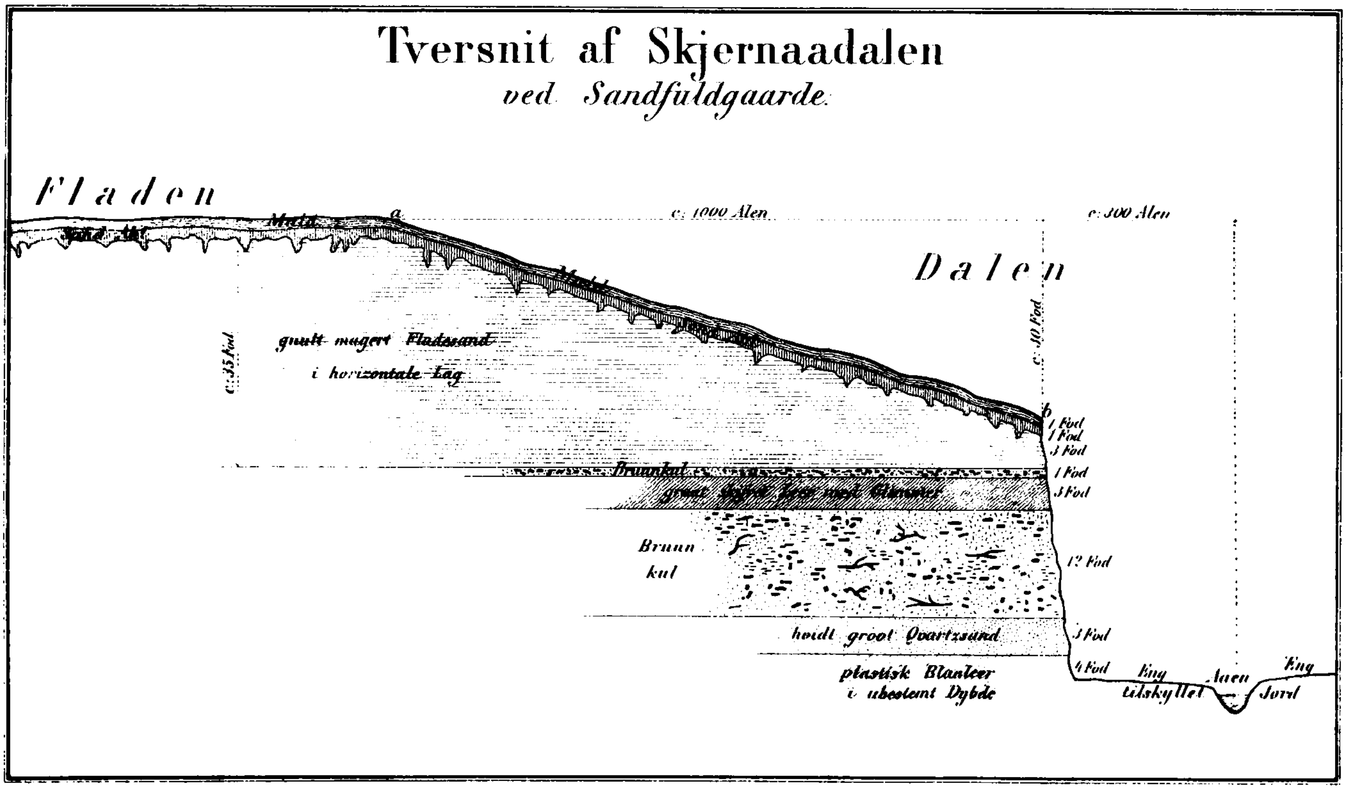
Concerning the age of the brown coal bearing formation, it seems that Forchhammer in 1835 could give no more than a hint. He discusses the brown coal bed from the vicinity of Them under the so-called "Rullestens-formation" and assumes this formation to extend into the Miocene as well as into the Quaternary.



Text-Fig. 5-6. Anatomical drawings of Pinites Fausbøllianus Vaupell. Reproduced from unpublished illustrations (Vaupell, 1853). Botanical Museum, Copenhagen.

In his contribution to the 3rd and 9th Scandinavian Geologists Meeting (1842 and 1863 resp.) Forchhammer mentions the brown coal bearing deposits as "Ravbruunkuls formationen" (trans. from Danish: Amber-brown coal formation) (1842) and "Bruunkuls formationen" (trans. from Danish: The Brown coal formation) (1865), which he (1863) subdivides into 1) glimmerler and limonitsand (trans. from Danish: Mica clay and limonitic sand) and 2) Plastisk ler (trans. from Danish: Plastic clay); this succession indicates the assumed chronological order.

The term Miocene had been introduced into the geological science by Ch. Lyell in 1832 and entered the



Text-Fig. 7. Outcrop of the Browncoal Bearing Sequence in an erosional escarpment in the valley of the (river) Skern Å of Sandfeldgaarde near the town of Brande, Central Jutland. The first published outcrop mentioning the browncoal of Jutland. Original plate of Dalgas, 1868.

geology of Denmark in 1854, when H.E. Beyrich (Berlin) reports to Forchhammer, that a collection of fossil marine molluscs from Sylt, sent by Forchhammer for determination, should be regarded Miocene (ref.Garboe 1961).

Concerning the age determination of the "Brunkulsformation" the official endeavours appear from a prize dissertation on this subject which was arranged by the University of Copenhagen of the year 1853 on the initiative of Forchhammer (ref. Garboe 1961).

Sandfeldgaard (farm) at Brande (at Skjern å (river)) in the middle of the 19th century became a keylocality for the exploration of the younger Tertiary. From this locality E. Dalgas (1868) reports on a 4 metres thick brown coal bed occurring in the Skjern Å valley (Text-Fig. 7) and an exposure of brown coal at Vorgood Å (river) near Troldhede (Nr. Vium).

In 1874 a report from O. Mörch was published ("The fossils from the Tertiary deposits of Denmark" (trans. from Danish by the present author) – 11th Scandinavian Geologists Meeting 1873) in which marine fossils from the micaceous clay from Sandfeldgaarde were referred to the Miocene (ref. Ravn 1897). The continued investigations through the seventies and eighties on the geology of Denmark in general, contributed to order the stratigraphical succession of the exposures of deposits in situ, which had been recognized up to then. Like the activities of E. Dalgas in Central – and Western Jutland this also contributed in general to improve the understanding for and interest in the geological problems of the Tertiary of this region. Especially the knowledge of the geographical extension of these deposits widened during this period.

When J.P.J. Ravn in the nineties succeeded O. Mörch in the paleontological investigation of the Tertiary of Jutland, the succession within the Tertiary sequence attained the pattern, the main features of which we still recognize to-day. It is sufficient to refer to K. Rørdam: Geologi og Jordbundslære, Vol. II: Danmarks Geologi, 1909, that presents the information of that time, or to K. Grönwall (1908). Both of these references refer to the opinion of J.P.J. Ravn, as it was published 1906 (Ravn, 1906), here cited:

Upper Miocene	Micaceous clay at Skjaerum Mølle, Sandfeldgårde, Skanderborg, Alkaersig, Forsom, and Esbjerg.
Middle Miocene	Micaceous sand at Skyum and Viborg. Micaceous clay and -sand at Varde. Micaceous clay at Skive (sand in ? Salling). ? Black, sandy, micaceous clay at Mariager Fjord and at Ulstrup.
Lower Miocene	Brown coal bearing deposits in Central and Western Jutland. ? Micaceous sand and – clay in the south eastern Jutland.

	Dark, glauconitic clay at Cilleborg, Stavrslund, Røkkendal, and Ulstrup.
Upper Oligocene	Micaceous clay at Nordentoft, Silstrup, and Sundby (Mors).
	? Tertiary deposits at Albækhoved.
	? Diatomite (Mo clay).
	Black, micaceous clay at Aarhus, Odder, and Jelshøj.
Middle Oligocene	Grey, plastic clay at Branden, Skive, Lundhede, Resen, and Ulstrup.
	? Grey, plastic clay at Mariager Fjord.
Lower Oligocene	The majority of the localities with plastic clay in East Jutland between Fredericia and Mols peninsula.
Eocene and	? Marl at Viborg and Aarhus
Paleocene	Marl at Fredericia.

This table demonstrates that the Miocene of Jutland at this moment had become stratigraphically differentiated and that the brown coal bearing deposits were considered to be the Lower Miocene. It should be noticed that a number of localities the geological succession of which today are included in the Måde Series: The Hodde Clay, the glauconitic clay, and the Gram Clay was referred to the younger (Upper) Miocene (Rørdam, 1909). Hence, the general relative age-relation between the younger Miocene formations and the brown coal bearing formation (the Odderup formation of today) have been retained to modern times.

At the turn of the last century the investigation of N. Hartz on "The Tertiary and Diluvial Flora" (Hartz, 1909) as a pioneer study brought a new insight on the paleontology of the browncoal bearing deposits of Jutland on a qualified botanical basis. At this time the Tertiary paleobotany had advanced vigorously since the great eighties when many classical, voluminous paleobotanical reports had appeared (e.g. J.W. Dawson, 1883 etc., Heer, 1883, Lesquereux, 1883, Nathorst, 1885, Ward, 1886, 1887). After a while this massive amount of new knowledge reached Denmark and contributed to the general understanding of the origin of the brown coal and associated deposits.

Here it should be reasonable to refer to M. Vahl (1904), who in a lecture to the Geological Society of Denmark, gave an account of the similarity between the flora and environmental conditions in the American Dismal Swamps and the Tertiary brown coal flora of Denmark and its facies. He refers e.g. to Lesquereux's opinion concerning this recent American swamp as "an initial brown coal basin" (Lesquereux, 1852). Vahl described the main elements of this flora including *Taxodium distichum* and *Nyssa biflora* as the dominants in the swamps, and the existence of dryer habitats with *Acer rubrum, Nyssa virginiana, Persea pubescens* besides species of *Quercus, Alnus, Salix, Carpinus, Populus,* and *Fraxinus,* and common lianes as *Vitis* and *Smilax.*

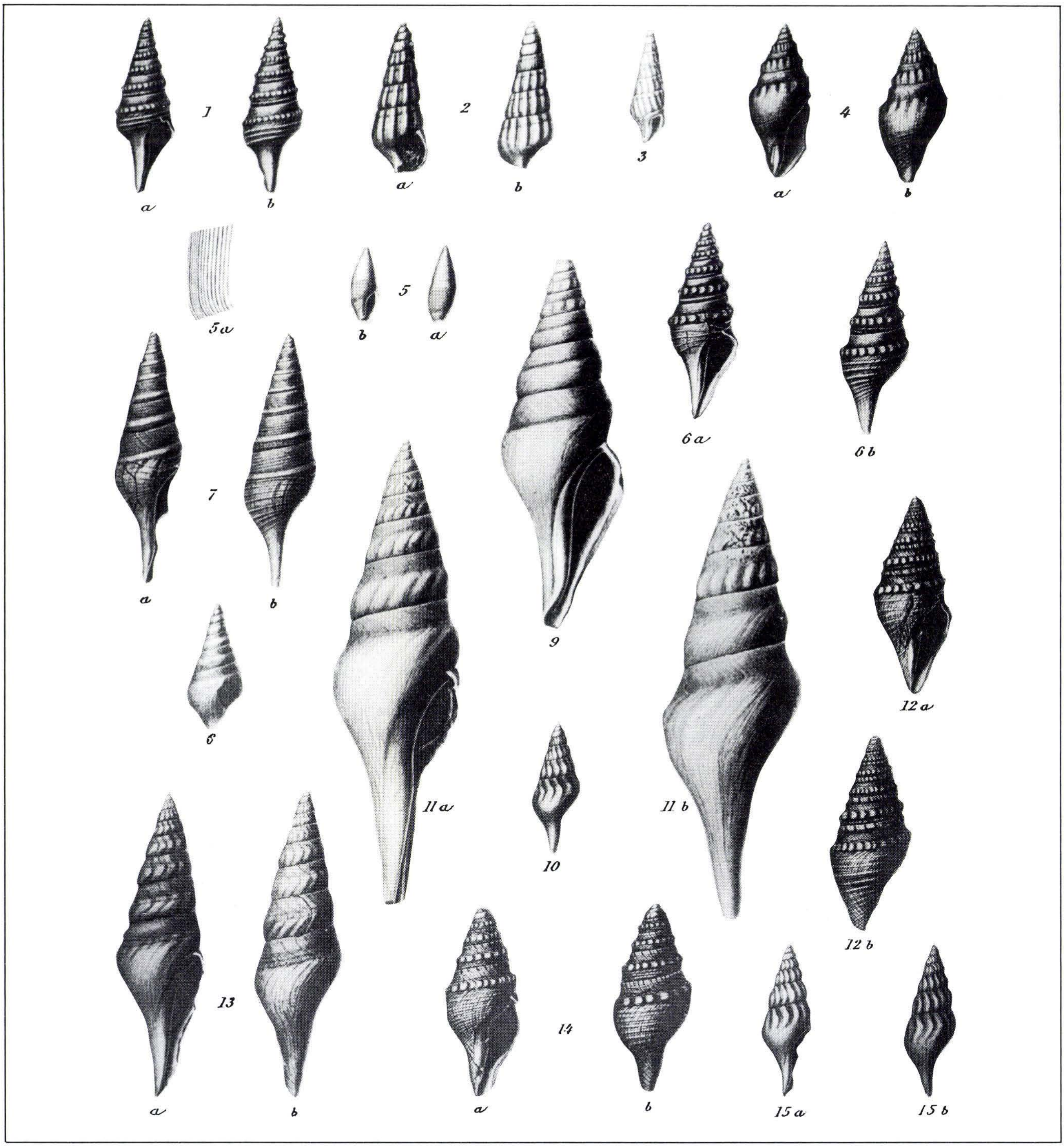
Directly, Hartz's brown coal flora is not convincing enough to support the opinion which Vahl had referred to. When we make a survey of Hartz's collection with the background of our recent knowledge, it is far too small to allow for any detailed comparison or to serve as a premise for any paleontological conclusions. Besides, the floral list of any brown coal flora of the younger Tertiary contains an outstanding element of common aquatic- and swamp plants like the following which were recognized by Hartz: *Hydrocharis, Carpolithes Johnstrupi* (syn. *Myrica* sp.), *Stratiotes, Ceratophyllum, Sparganium, Brasenia.* It is important to note that characteristical representatives (genera) of the swamps of Southwest United States were found by Hartz: *Carpolithes nyssoides* (syn. *Nyssa* sp.), *Vitis,* and *Glyptostrobus* (the seeds of Hartz, 1909, pl. 3 Figs. 3-4, which were determined to *Sequoia Langsdorffii*). A recent survey of this collection should conclude that Hartz's small collection of brown coal fossils would be acceptable as representative of the Miocene of North- and Western Europe, especially considering the time for the original publication (1909).

Hartz (1909) gives a survey of the localities with brown coal and drilling logs that were known in the first decennium of our century. In relation to the present investigation, the information about the Sandfeldgaarde area is especially interesting owing to its relevancy and similarity with the geological succession of the Søby-Fasterholt area as we have found it. Also Hartz's considerations about the origin of these deposits is interesting.

The shortage of fuel during World War I resulted in an extensive mining of brown coal in Jutland, and subsequently extended information about the brown coal bearing sequence. Besides the numerous small private open pit mines the Danish State authorities opened a number of larger mines, e.g. the mines of Skibbild near Fasterholt (ref. Mathiesen 1965). Investigations in the field and collection of fossils were carried out 1917-1920 by J.P.J. Ravn, V.Milthers, T.Bjerring-Petersen, F.J. Mathiesen, and others; and further in 1924 by A. Mentz. The Danish State enterprises also (in 1921) involved a drilling program sponsored by the Ministry of the Interior (Technical Committee). It was carried out by the Geological Survey of Denmark and Dr. V. Milthers (state geologist) was the leader of this drilling program. 629 borings were carried out in the more promising areas, e.g. the Sandfeldgaarde area to the west of Brande. The logs from these drillings became the foundation on which to start when the Geological Survey of Denmark again, in 1941, had to undertake brown coal prospecting.

This first period of mining activity did not markedly enrich the geological literature, but a paleobotanical investigation was commenced by F.J. Mathiesen, based upon fossil collections from Moselund (near Engesvang), the pits of Skibbild (near Fasterholt), Silkeborg Vesterskov, Ry Sønderskov, Lystrupsminde (near Bryrup), and the mines of Troldhede. A preliminary paper was rewarded with a prize by the Royal Danish Society of Science and Letters 1923. The description of this outstanding fossil plant material was published in his old days comprising three volumes (Mathiesen 1965, 1970, 1975; all in the English language). The collections from Moselund was considerably enlarged by K. Skou in 1937. The investigation of the Moselund flora belongs to the classical foundation of our knowledge concerning the Younger Tertiary flora of Denmark. A Miocene age was assumed but it has since been an open question to which part of the Miocene it belongs.

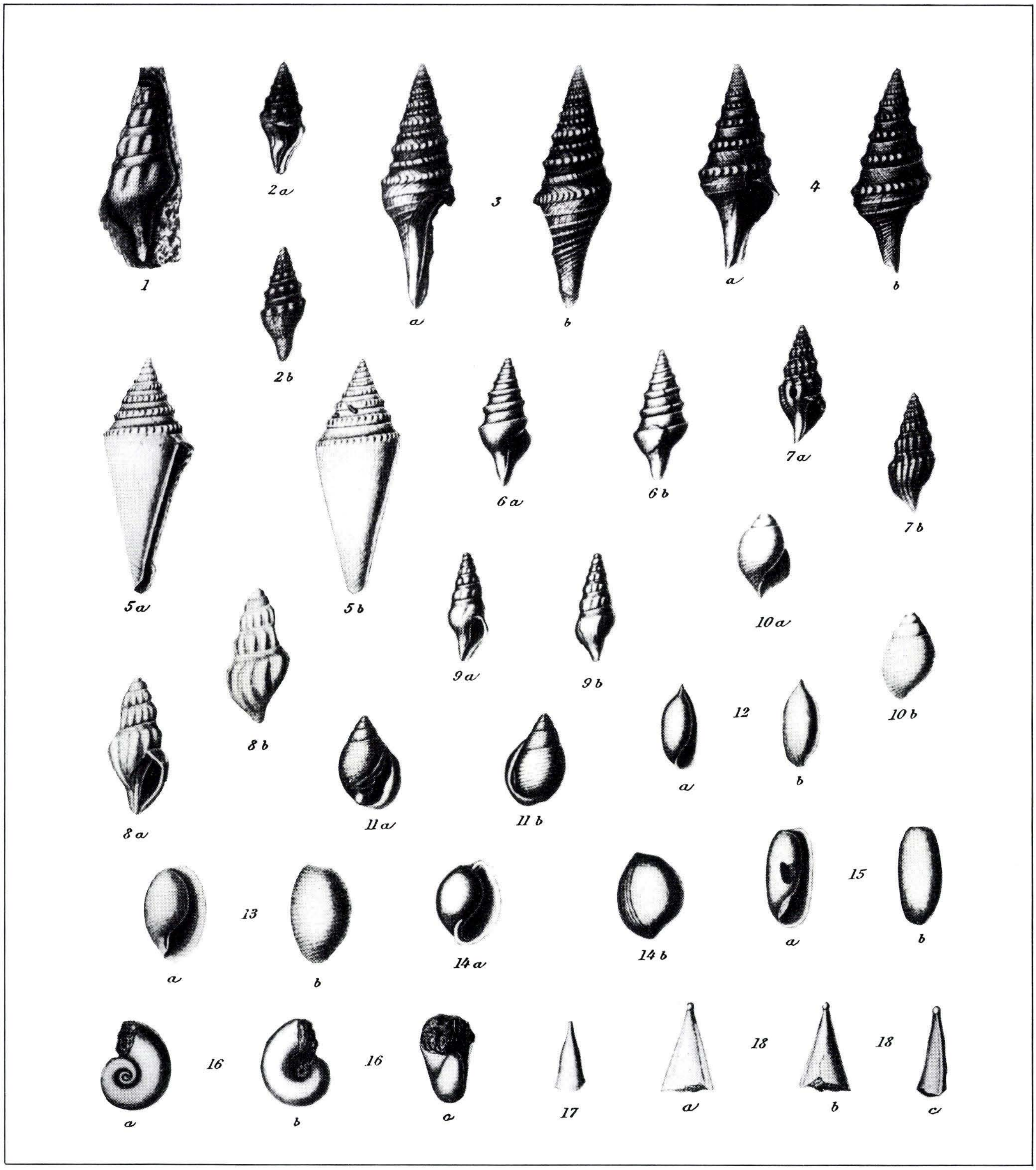
World War II again intensified the brown coal mining of Central Jutland to an increasing extent. In 1941 the Geological Survey of Denmark started a systematic prospecting comprising a comprehensive drilling pro-

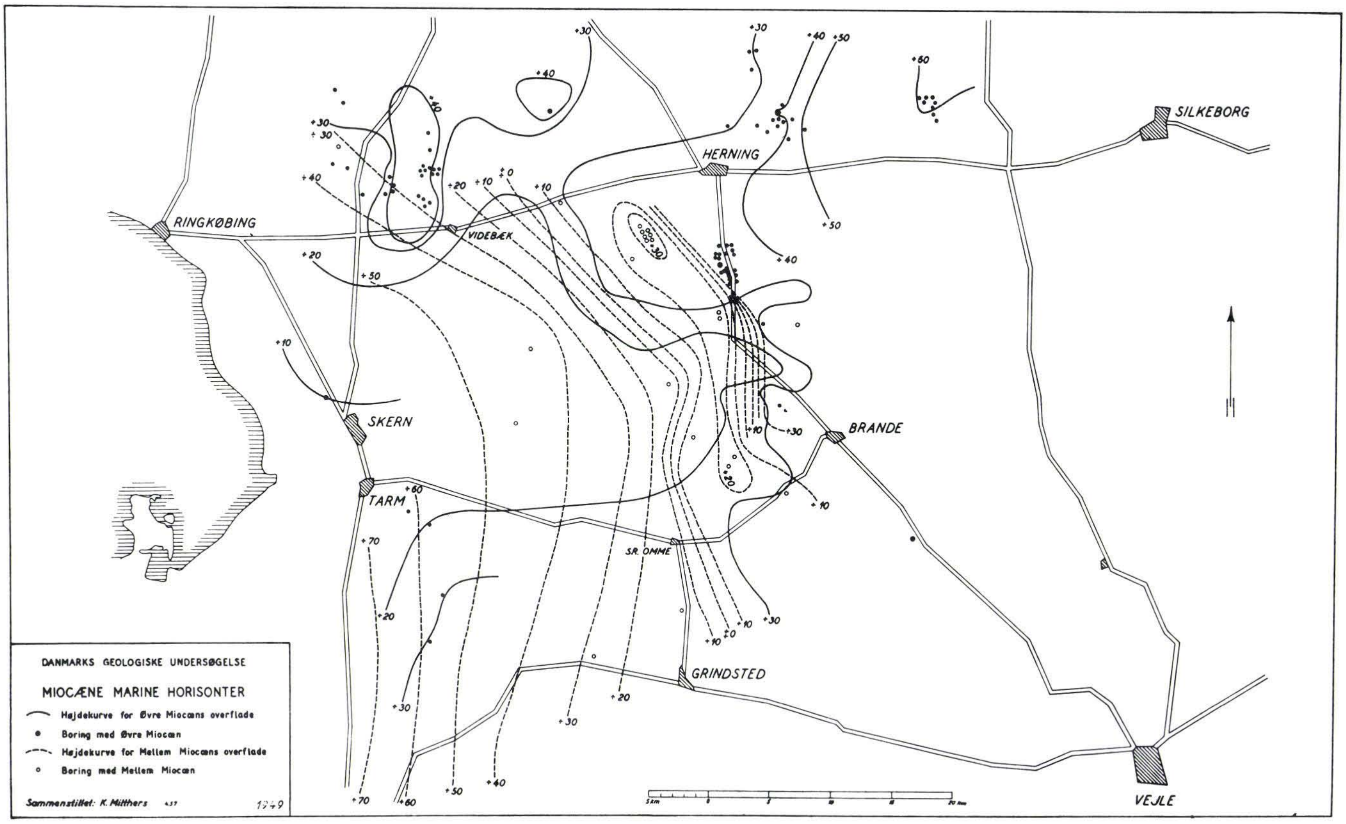


Text-Fig. 8-9. Plates no. VII and VIII of J.P.J. Ravn, (1907): Molluskfaunaen i Jyllands Tertiæraflejringer (The Molluscs of the Tertiary Deposits of Jutland). This was the first biostratigraphical study of the Miocene of Jutland. O.B.B. Photo.

gram under the leadership of state geologist, Dr. K. Milthers. Considerable uncertainty still existed concerning the Neogene stratigraphy of Jutland. K. Milthers (1941) argued for a Pliocene age of the brown coal bearing deposits of Central Jutland based on an incorrect assumption that the Younger Miocene marine micaceous clays (the Hodde Clay and the Gram Clay) might underlie the brown coal bearing sequence (K. Milthers 1941). This opinion changed during the advance of the drilling program and in 1944 K. Milthers (1944) was convinced that, on the contrary, the brown coal bearing sequence of Central Jutland stratigraphically is situated below the marine younger Miocene deposits.

From the beginning of the prospecting program in 1941 and until the middle of 1944 the Geological Survey of Denmark had set about 4000 drillings in the vicinity of Videbæk and in the triangular area Herning – Sdr. Omme – Nr. Snede. At the end of the program in 1949 the area of prospecting had been somewhat extended, and about 10.000 drillings and probes had been set. An important result was the recording of the





Text-Fig. 10. Isopach map showing the contours of the marine Upper Miocene (solid line) and marine Middle Miocene (dashed line) of Central Western Jutland. Based on the sum of information collected from browncoal prospecting drillings by the late Dr. K. Milthers (ref. Heller, 1961a) during the Geological Survey of Denmark prospecting 1941-1949.

marine Upper Miocene in more than 100 boreholes and marine Middle Miocene in about 10 boreholes. The drillings made possible the construction of a standard section valid for a considerable part of the Miocene sequence, exclusive of the marine Lower Miocene (Klintinghoved Formation) (ref. Heller 1961):

(L. Banke Rasmussen, 1961):	K. Milthers:
(Gram Clay)	Gram Clay/Astarte clay (marine, Upper Miocene)
(Gram Clay)	Green, glauconitic clay
(Hodde Formation)	Black, bituminous clay
(Hodde Formation)	Quartz gravel
(Odderup Formation)	Upper brown coal formation (Middle Miocene)
(Arnum Formation)	Fossiliferous sand and clay (marine Middle Miocene)
(Ribe Formation)	Lower brown coal formation

We here recognize the Middle and Upper Miocene units that Rasmussen (1961) erected for the same succession based on his extended studies. The present authors are also acquainted with the upper units of this scheme from the field work in the Søby-Fasterholt area, but have not definitely recorded the older marine fossiliferous deposits (the Arnum Formation) in the drillings, (e.g. Fasterholt bjerge, file no. 95.1942), which reached to about 90 metres below the lowermost brown coal seam. The Lavsbjerg Øst and Fasterholt bjerge boreholes have recorded clay between 66 m and 79 resp. 74 m b.s. with a content of scattered dinocysts (Piasecki, pers. comm.) which together with the sedimentological information (Friis et al. 1980) indicate a marine origin (ref. p. 188 of the present paper). Larsen & Friis, 1973, recorded a small content of glauconite from the sands below the brown coal bearing sequence.

Based upon the knowledge that was produced from the drillings Dr. K. Milthers made an attempt to clarify the problems of the depositional environment of the browncoal and its evolution. According to Heller (1961a) Dr. K. Milthers saw a connection between the deposition of the original brown coal sediments (ooze resp. peat) and the transgressive shifting of the coast; in other words, a sedimentary reaction upon the subsidence of the regional depositional basin. This idea is indispensable for any continued investigation of the brown coal bearing sequence and the history of its depositional environment, and is also accepted by the present authors.

A third systematical prospecting program was carried out during the period 1958-1963 including a drilling program which spread in all directions from earlier investigated areas; Drilling progressed towards the north up to a line between the towns of Holstebro-Viborg, towards the south to the Grindsted region, towards the east up to the line Thyregod – Bording, and towards the west as far as the resource allowed (Heller, 196la). Dr. K. Milthers became seriously ill a few months after the appropriation had been given, and died two years later without reaching a sufficient survey from his considerable experience to allow for a publication. This tragic event was a serious draw back making things enormously more difficult for the successors of the brown coal investigations. The prospecting program fortunately continued under the leadership of Dr. Milthers' second in command, Erik Heller (ref. Heller 1961a, 1961b), and was carried through.

In these big projects only a few geologists and paleontologists were in service. It was a struggle to keep up with data obtained from numerous rigs and brown coal pits. These conditions together with the death of Dr. K. Milthers is the reason why only a few publications have appeared based upon the records of this drilling project.

On the scientific staff serving the last brown coal campaign there was also the paleobotanist, Mr. P. Ingwersen, who has made a comprehensive record of the geological and paleontological information from the many brown coal pits supplemented with a large collection of samples for pollen-analysis. This large material is still under investigation, and the extensive and time-consuming work of creating a pollen-herbarium for comparative study for basic determination of the fossil pollen flora has been accomplished. As a result of this investigation some preliminary publications have appeared (Ingwersen 1949, 1954). Ingwersen's publication of 1954 is the first contribution to the fossil flora of the brown coal bearing sequence of Jutland based upon fossil pollen and spores and the first study of pre-Quaternary pollen of the Danish region.

The state geologist Dr. Th. Sorgenfrei, a great dynamic force among the geologists of Denmark in the fifties and sixties, and his pupils became a successfully coordinated potential, during this period of the general expansion of science and techniques. They also gave their contributions to the solution of the Neogene geology of Denmark as follows below.

A big step towards the establishment of a solid stratigraphical frame for the Miocene of Denmark was accomplished by the voluminous publications of Th. Sorgenfrei (1940, 1958) and L.B. Rasmussen (1961, 1966, 1968) on the marine Miocene faunas, their geological environments and stratigraphical implications. Sorgenfrei introduced biometrical and statistical methods in the study of our Tertiary marine faunas and Rasmussen's differentiated stratigraphical model including the superior facies (Rasmussen 1961, 1966) (ref. Text-Fig. 13) represents an obvious progress in comparison with the generalized models of his predecessors (e.g. K. Milthers, ref. Heller 1961a) being more in accordance with the dynamics of a sedimentary basin containing synchronous facies. Larsen & Dinesen (1959) made a combined study of the sedimentology and foraminifera of the succession around the Oligocene/Miocene boundary in the Vejle fjord region and Gunnar Larsen's sedimentological studies of the Neogene deposits (Larsen 1963, 1970, Christensen & Larsen 1960) became a new facet in the studies of the brown coal bearing Neogene deposits. In 1975 Radwanski, Friis and Larsen published new sedimentological information based upon modern environmental interpretation on the Miocene marine deposits at Hagenør and Børup cliffs at Lillebælt.

After 1961 a Geological Institute has functioned within the University of Aarhus and for the Phytopaleontological Department (erected 1962, leader: B. Eske Koch) and the Sedimentological Department (erected 1968, leader: Gunnar Larsen) the Neogene of Jutland was a natural challenge. For the paleobotanists the brown coal bearing sequence with its potential for fossil floras was the working field since 1968 (ref. chapter 1). The work was carried on parallel to the sedimentological investigations of Larsen and his pupils (ref. Larsen & Kuyp 1971, Larsen & Friis 1973) and in cooperation with L.B. Rasmussen, P. Ingwersen, and E. Heller of the Geological Survey of Denmark, O. Larsen, U. Asgaard & R. Bromley (A.& B. 1974), and P. Wagner (Wagner & Koch 1974) from the University of Copenhagen.

In the period in which the Søby-Fasterholt brown coal project of the Phytopaleontological Department of Aarhus University carried out the investigations of the present paper, some younger colleagues from the geological institutions of Copenhagen started investigations of special problems of the Neogene geology of Denmark. Among them P. Nyhuus Kristoffersen (Geol. Surv. Denmark) was concentrating on the Neogene foraminifera (Kristoffersen 1972, 1973), S. Piasecki (Geol. Surv, Greenland) studied the dinoflagellate cysts of the Hodde Clay (Piasecki 1980), and Birthe Dinesen (Technical Highschool of Denmark) with the geochemical investigation of the Hodde-Gram Clay succession (Dinesen 1976).

During the latest years a younger generation of students and younger geologists have presented new information e.g. E. Fuglsang Nielsen, 1984 has published detailed petrological information on the Hodde Clay successfully involving stereoscopic X-ray photography for the study of the bioturbation patterns, their orientation and qualitative representation.

In this company the members of the Søby-Fasterholt brown coal project (B. Eske Koch, W.L. Friedrich, E. Fjeldsø Christensen, E.M. Friis, E. Thomsen, A. Grambo Rasmussen) strived to continue the succession of scientific activities described in this chapter, with the present publication as a milestone. Concerning the progress of the studies on the Miocene fossil flora, the brown coal petrology and -facies, as well as the stratigraphy of the non-marine Miocene deposits of Central Jutland, ref. chapt. 1 (Introduction to this paper), and chapt. 6 (References).

3. An Outline of the Neogene of Denmark

as a background for the study of the Geology of the Søby-Fasterholt area.

During the Neogene (Miocene and Pliocene) the geological history of Europe was to a great extent influenced by the upfolding of the Alps which had reached an advanced stage by this time. The effects of alpine tectonics reached far outside the alpine zone strictly spoken, and were felt also in Northern Europe by faulting, e.g. by reactivation of older fault-systems. Probably it also influenced the subsidence of the sedimentary basins as an initiating factor. In Europe the sedimentary deposits at this time are located in a number of basins of which the North Sea basin is in question here.

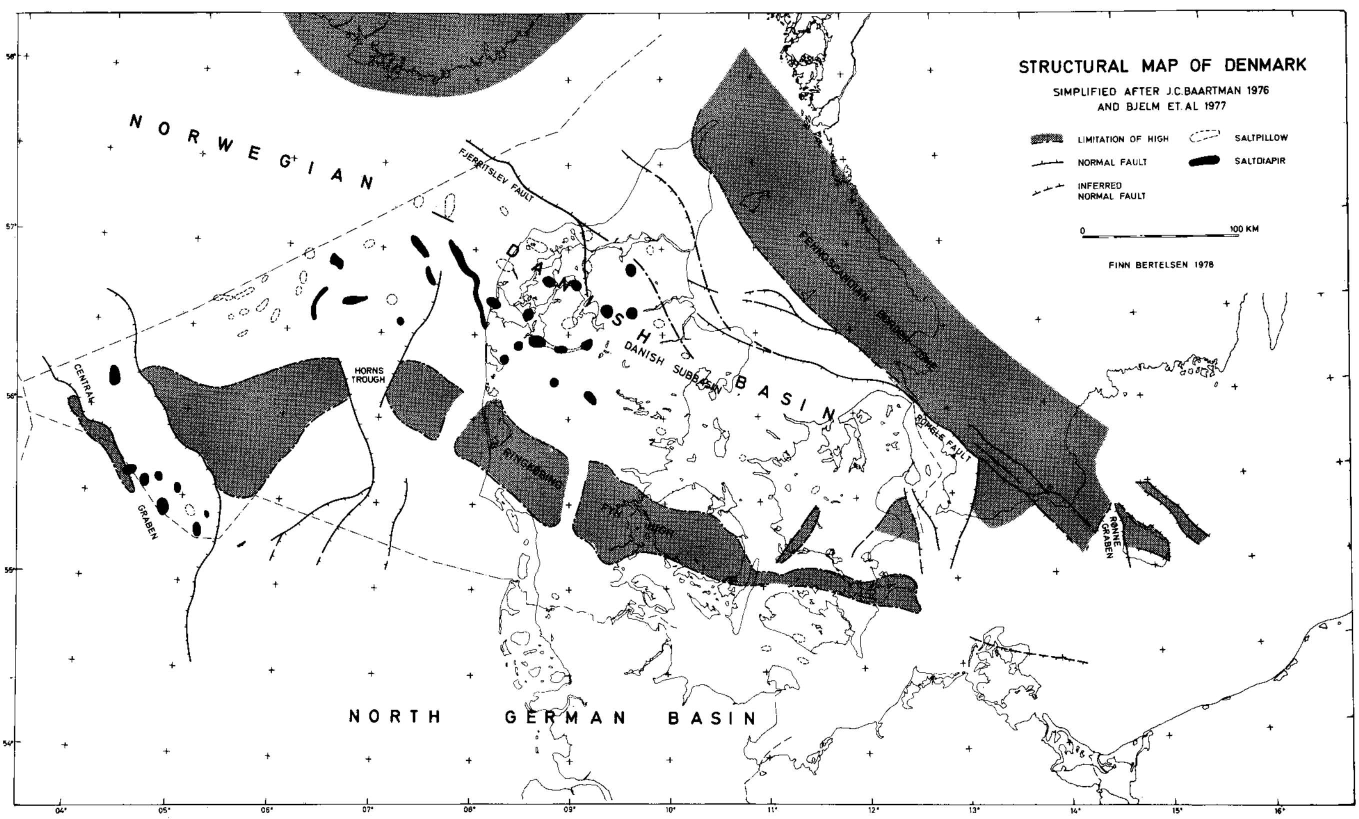
Another important dynamic factor affecting the Tertiary geological history of Northern and Western Europe is the widening of the Atlantic Ocean as a result from "sea-floor spreading" mechanism.

In the North Sea basin Paleogene rifting had faded out at the beginning of the Neogene and was followed by a period of rapid, regional subsidence (Ziegler 1975). In consequence, the Neogene deposits of the North Sea region are very thick (Rasmussen, 1974, Childs & Reed 1975) and wedge out eastwards over the West Jutland area.

The structural pattern of the deposits of the North Sea basin is complicated by the existence of a deep-seated high (horst) running in a NW--SE direction from the western North Sea by Ringkøbing (W. Jutland) and Funen island into southern Zealand and Falster island, and disappearing towards the SE. This high is named the Ringkøbing-Fyn High (horst) and is cut by northerly trending secondary troughs (Grabens) as e.g. Grindsted Graben and Horn Graben (ref. Text-Fig. 11).

During the Paleogene, tectonic activity occurred in the north western and western part of the basin (Ziegler 1975) and also the optimal sedimentary deposition during Neogene when the subsidence of the basin was accelerated (Ziegler 1975, L. Banke Ramussen 1974, 1978; Childs and Reed 1975).

At the beginning of the Neogene epoch the sedimentary infilling of the North Sea basin had reached an advanced stage. Hence, the coastal zone on the east, oscillated over Jutland and in regressive periods was displaced to a position west of extant Jutland (ref. Text-Fig. 12).

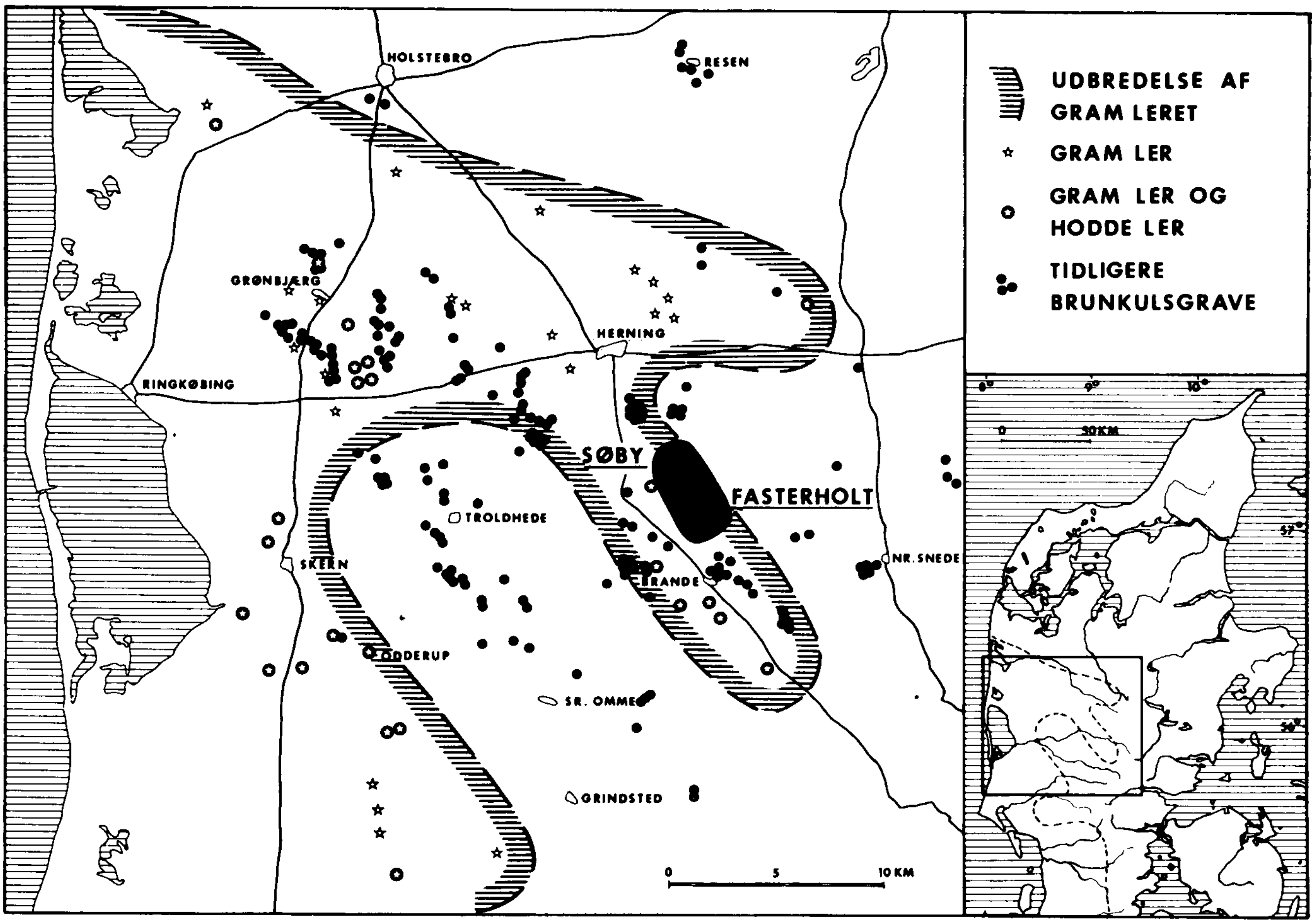


Text-Fig. 11. Structural map of Denmark. F. Berthelsen, 1978.

During the Miocene, the coast of the North-Sea oscillated over Jutland in east-westerly direction in 3 transgressions and 2 regressions (L. Banke Rasmussen 1961, 1966, 1979 (Text-Fig. 13), W. Hinsch 1973, a,b, 1974 (Text-Figs. 16-19), W. Hinsch & D. Ortlam 1974 (Text-Figs. 14-15). The Lower Miocene transgression, represented by the Klintinghoved-(Sorgenfrei 1940, 1958, 1961) and Vejle fjord (Larsen & Dinesen 1959) Formations, passed over Jutland entirely at least in its southern regions. The Middle Miocene Arnum Formation (Sorgenfrei 1958) and the Upper Middle Miocene Hodde Formation (L. Banke Rasmussen 1961) only occur in western Jutland with the eastern boundaries of their max. extension situated in Central Jutland, and no signs of a wider eastward extension of these two transgressions have been found. The intervening regressions (the Odderup Formation (Rasmussen 1961)) and the Ribe Formation (Sorgenfrei 1958)) passed westwards over the recent west coast of Jutland as far as we can judge from the extension of the psammitic delta-sequences. These formations have received generally their sediments from the east (and northeast?). This is indicated by the Scandinavian origin of the delta-sediments (Larsen 1963); and a route of transport through the recent Baltic Sea region has been used, proved by the bulk occurrence or pebbles of worn fragments of Ordovician marine fossils and silicified limestone deriving in the East Sea region to the east of Bornholm (Spjeldnæs in Koch et al. 1973, Spjeldnæs 1975). As mentioned by the latter author the suggested Baltic Sea route of transport may not be the only one, but other routes from Scandinavia possibly existed. These kinds of fossiliferous pebbles have been known for a long time from localities scattered through Jutland and Schleswig-Holstein, and reference can be made to Wolff (1919), Ravn (1928), Jørgensen (1941), Andersen (1944), Larsen (1963), Koch & Friedrich (1970), Koch et al. (1973), H. Friis (1973).

The stratigraphical model published by L. Banke Rasmussen 1961 and 1966 (Text-Fig. 13), though diagrammatic, shows the east to west relationship between the Miocene formations in question, and their variation in relative thickness. Hence the marine facies make up the larger part of the Miocene sequence along the west coast of Jutland with gradual change eastwards where deltaic facies gradually replace marine sediments. In central Jutland the deltaic facies dominates the Miocene sequence, and they can be traced into eastern Jutland e.g. the Aarhus region. The original eastern extensions of this (these) delta(s) is (are) not known.

It must be stated that the eastern limits of the Miocene formations on the distributional maps are not



Text-Fig. 12. Map demonstrating the general distribution of the Hodde Clay (Upper Middle Miocene) and Gram Clay (Upper Miocene) with recent and former outcrops in central and Western Jutland. Compiled from Rasmussen, 1966 and Heller, 1961a; and published in Koch et al. 1973.

necessarily the furthest eastward extension of the Miocene transgressions in question, because of extensive glacial erosion was active later in the geological history. But e.g. the rate of the wedging out of the Hodde Formation, as we know it in the Central Jutland, indicates that the deviation between the boundary is of a small scale. The transgression causing sedimentation of the Hodde Formation presumably did not proceed far eastward beyond the Søby-Fasterholt area in Central Jutland. Similarly the Hodde Clay has never been found displaced within the Quaternary glacial deposits east of this region as is the case to the contrary with all the older formations found below the Quaternary deposits in Denmark.

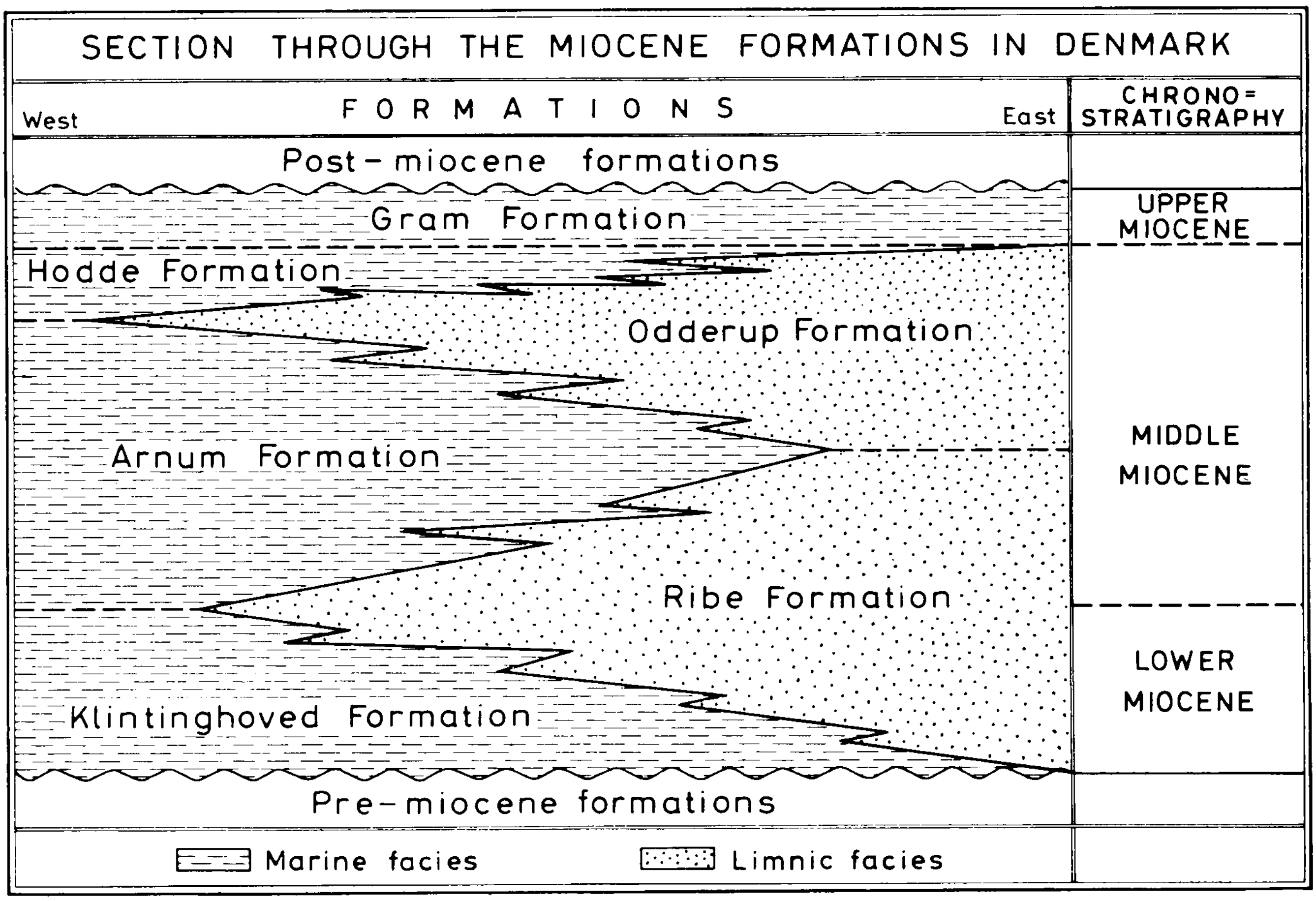
The non-marine sequence presumably represents a delta or deltaic system of large dimensions. The distribution (width) reaches from the western Limfjorden area through Jutland to Holstein (Germany) where the synonymes for the non-marine formations of Text-Fig. 13 are "Obere-" and "Untere Braunkohlensande" (ref. Hinsch 1973).

The deposits in question are preferably of sands with fluviatile depositional structures and subordinate intercalations of black and brown micaceous clays. A small amount of glauconite has been found at a single locality that may indicate fresh marine environment (Larsen & Friis 1973), but may also be displaced Oligocene glauconite. Indigenous marine fauna has not been detected in these formations. As mentioned (page 91) secondary fossils deriving in the Ordovician deposits of the Baltic Sea region are common, as well as small pieces of flint and silicified weathering debris derived from the Senonian White Chalk and Danian Bryozoan Limestone. All of them came from the east-northeast quarter of the compass card.

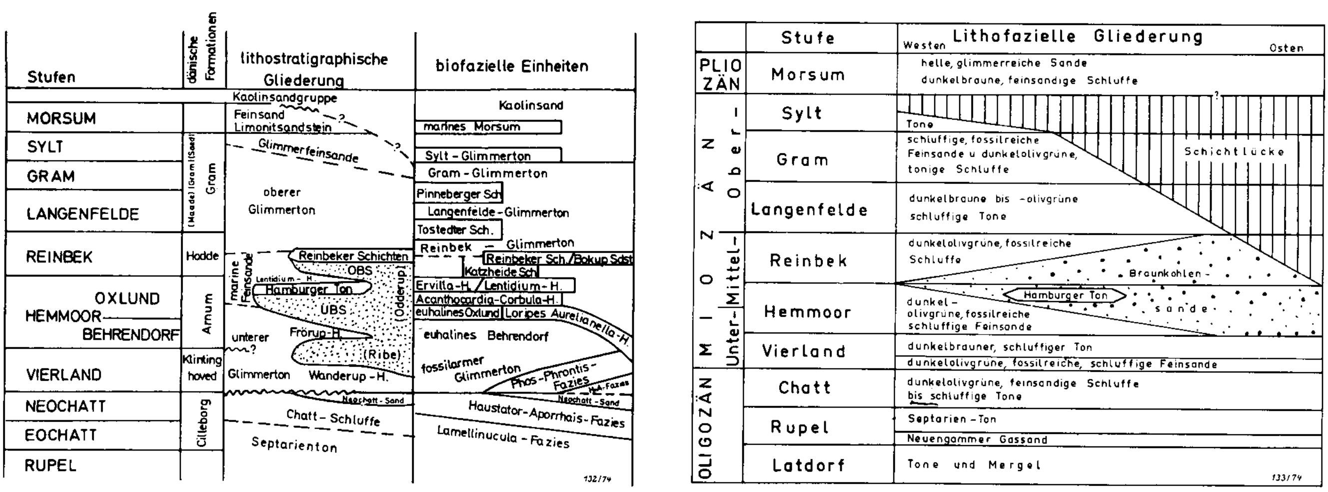
The dimensions of this delta together with the other available criteria point to the conclusion that the Miocene Jutland-delta belongs to a large river, or maybe to a multiple river system, with some main channel following the depression of the recent Baltic Sea and passing between the recent islands of Gothia and Bornholm. To imagine the Miocene environment of Central- and Western Jutland we must turn to a delta of dimensions like the recent Mississippi. The deposition of the brown coal presumably occurred along the coastal border region. Brown coal seams of moderate dimensions and of high ash and sulfur content in deltaic sediments like those of Central Jutland seem to be connected with marginal zones of deltas (ref. Ahrens, Lotsch & Tzschoppe, 1968).

The delta sequence has proven to contain rich fossil floras. The sands sporadically contain lenses rich in fossil seeds, fruits, twigs (the Fasterholt Flora), and commonly larger pieces or stems of driftwood. The clays and gytjas have in several cases been found to be rich in fossil leaves, compressed fruits and seeds. The outstanding examples are as follows:

1) From Moselund, 10 km west of Silkeborg a fossil



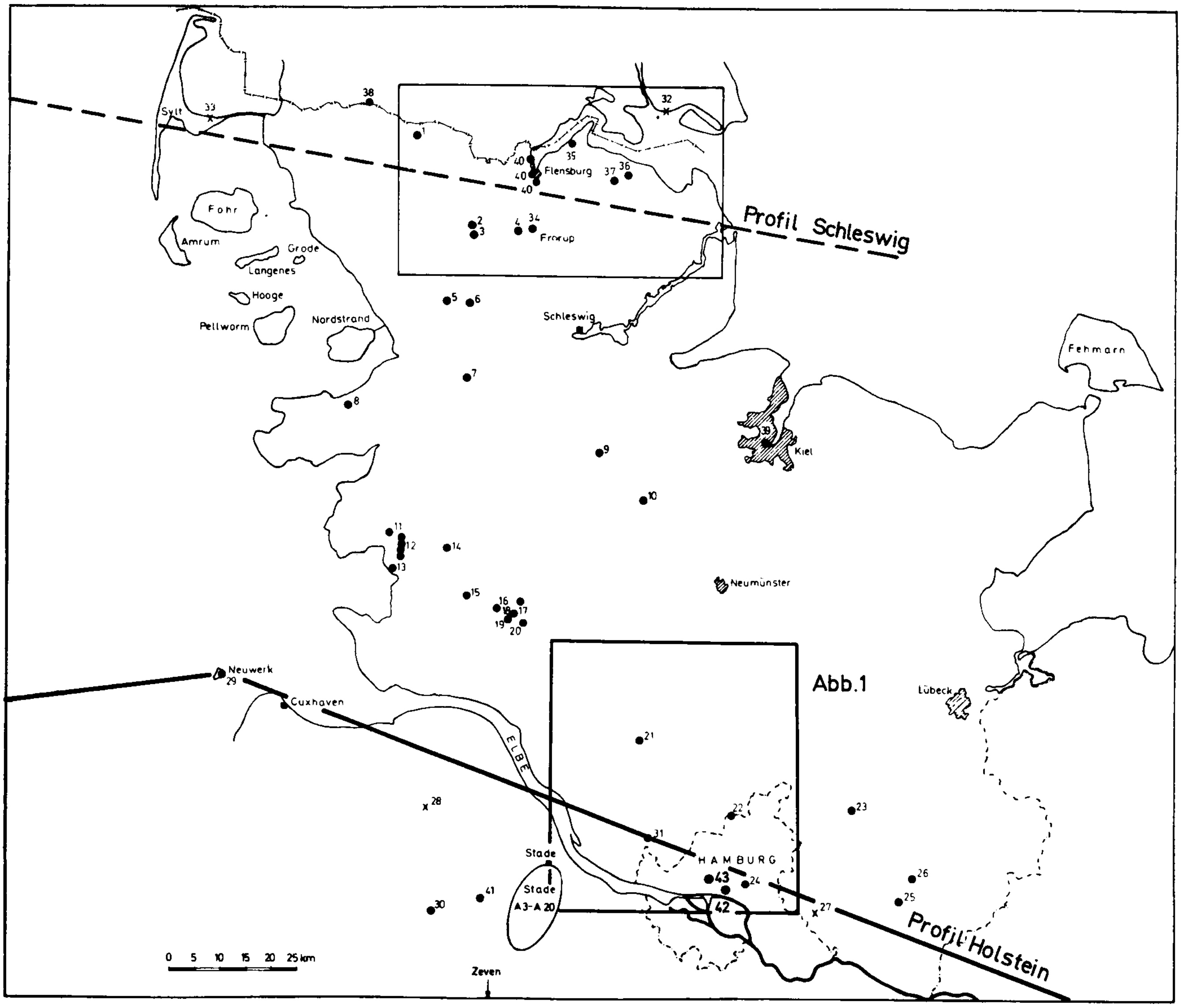
Text-Fig. 13. East-West cross-section of the stratigraphy and facies of Central Jutland. L. Banke Rasmussen, 1966.



Text-Fig. 14-15. Divisions of the Upper Tertiary Sequence of Schleswig-Holstein and Lower Saxonia (Nieder Sachsen) (from Hinsch & Ortlam, 1974).

flora was described by Mathiesen (1965, 1970, 1975) from a local lens of humous clay, presumably of lacustrine origin, embedded in the deltaic light grey quartz sands. A local origin of the flora is indicated by the well preserved leaves which had been briefly transported before deposition and by a high frequency of Pteridophytes. The age has not been definitely determined but Mathiesen assumed the flora to belong to the Miocene and perhaps older than the bulk of the productive brown coal layers of Central Jutland, i.e. the younger parts of the Ribe formation.

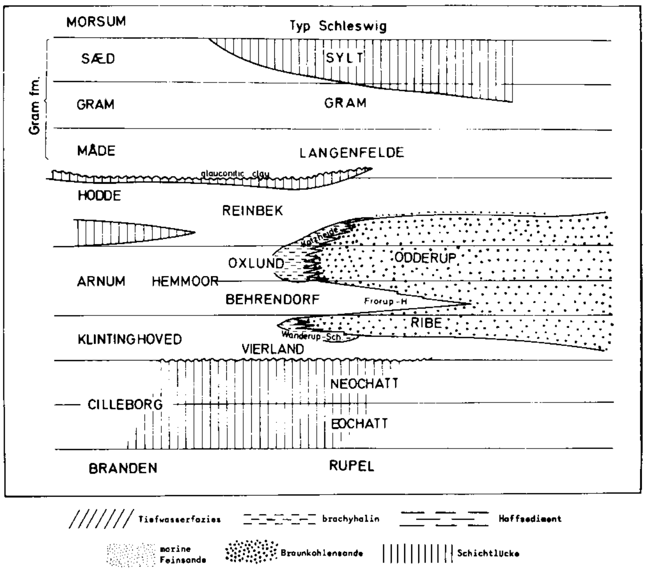
2) A small collection of leaf fossils and cones from a



Text-Fig. 16. Index map showing the geographical position of Schleswig (fig. 17) and Holstein (fig. 19) sections (Hinsch, 1973b).

similar deposit of Silkeborg Vesterskov were treated by Mathiesen in the mentioned papers. Fossil wood was described by Mathiesen (1970) from Fasterholt, Salten (10 km to the south of Silkeborg), Lystrupsminde by Bryrup and from Troldhede.

3) Several levels containing fossil flora have been recorded during the survey of the present investigation (ref. chapter 1) from the Søby-Fasterholt area of which some have been published. Christensen (1975, 1976, 1978) has described the *Søby Flora* (leaf flora) and Friis (1979) the Damgaard Flora (diaspore flora), from the upper part of the Odderup Formation (ref. page 265 and 267). A rich diaspore flora, the *Fasterholt Flora,* has been sieved from a sand bed intercalated between the 2nd and 3rd brown coal seam. This fossil flora has not been described in all its aspects yet but a number of contributions by Koch & Friedrich (1970, 1971), Friedrich & Koch (1972), and Friis (1975, 1976, 1977a,



Text-Fig. 17. Stratigraphical facies chart (Schleswig type) arranged in an E-W cross-section. (For location see fig. 16). (Hinsch, 1973b)

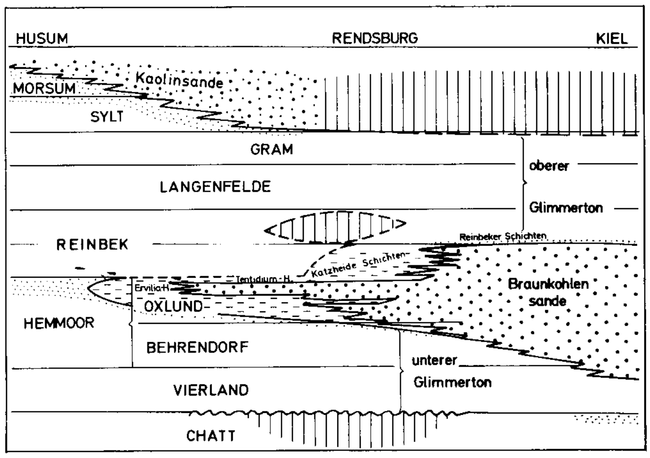
1977b, 1985) have appeared and are commented on elsewhere in this paper (ref. page 225).

4) Paraconformities with stump- and root horizons have been recorded from different levels (Wagner & Koch, 1974).

5) Fossil pollen and sporomorphs are available in most fine grained sediments rich in humous or bituminous detritus (Ingwersen 1954, Friis 1979, Koch 1984 and in the present paper).

The studies of the Neogene fossil floras of NW-Europe is proceeding rapidly, but until now have only contributed to the establishment of head-lines of the stratigraphical chart.

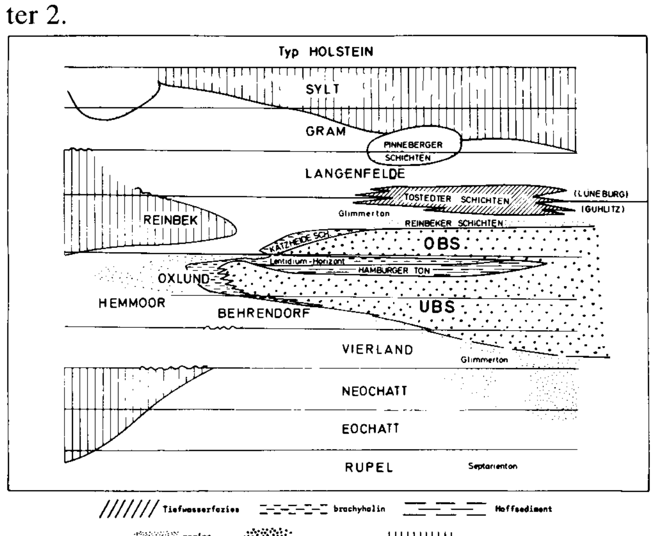
The fossil faunas (molluscs) from the Miocene marine formations have been the foundations on which the stratigraphical dating of the sequences have been based (Sorgenfrei, 1940, 1958 and Rasmussen, 1961,1966,1968). Other stratigraphical investigations are still in progress, especially pertaining to foraminifera (Kristoffersen 1972, 1973) and dinoflagellate cysts (Piasecki 1980). In this connection, reference must also be made to the publications of W. Hinsch concerning the marine Miocene faunas and stratigraphy of the Schleswig-Holstein (Hinsch 1973a, b, 1974, Hinsch & Ortlam 1974). The stratigraphical stages of Northern Europe (the North Sea basin) are still not well correlated with the types of Western- and Southern Europe (Atlantic- and Paratethys regions).



Text-Fig. 18. Stratigraphical facies chart arranged in an E-W cross-section through Husum-Rendsburg-Kiel. (Hinsch, 1973a).

A. Grambo-Rasmussen has in an unpublished thesis (1980) collected the available stratigraphical information regarding the Neogene non-marine browncoal bearing facies of the southern and eastern North Sea basin and its stratigraphical correlations with the marine Neogene deposits. In two published reports (1982, 1984) the same author has presented an account of the available information regarding the brown coal resources left in Central Jutland (Geol. Surv. Denmark for the Danish Ministry of Energy Resources).

Supplementary geological and paleobotanical information regarding Central Jutland can be found in chapter 2.



Text-Fig. 19. Stratigraphical facies chart (Holstein type) arranged in an E-W cross-section (ref. geographical position, fig. 16). (Hinsch, 1973b).

4. The geology of the Søby-Fasterholt mining area, Jutland

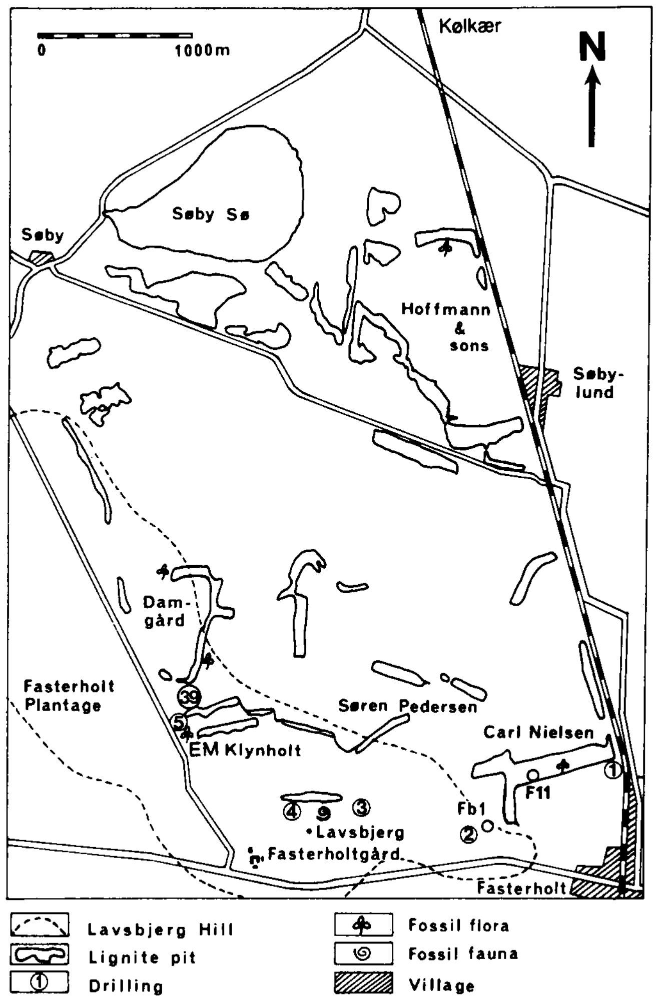
In this connection the Søby-Fasterholt area means the former brown coal mining area about 15 km SSE of the town of Herning in Central Jutland. This area was the basis of the extensive brown coal mining during World War II and the time after (1940-1970). In this area the brown coal bearing sequence of the Odderup Formation (Rasmussen 1961) lies relatively near to the surface with the coal seams 10-24 m deep. This former mining area stretches from the Søby Sø (lake) in the north to the village Fasterholt (and the highway Fasterholt-Arnborg) to the south. Towards the east it extends to the main railway Herning-Brande (-Vejle), and towards the west it is limited by a NNW-trending line from the mansion Fasterholtgaard to the farms of Søby. The latter limit is determined by the geological structure. The Søby-Fasterholt mining area covers about 13 km^2. These shallow brown coal seams continue towards the east and south. Hence many abandoned open pits are found as far to the east as to the vicinity of the village Nørre Snede i.e.to the western border of the younger glacial till – cover of Central and East Jutland (Weichselian or Würm). The brown coal seams continue south of Fasterholt extending to the river Holtum Å where Holocene river erosion has removed the brown coal sequence or caused heavy weathering on the seams. This latter area was mined out during World War I and has not been considered in the recent investigations (ref. Mathiesen 1965).

The topography is typical for Central Jutland consisting of Quaternary outwash-plains and hills that are erosional relicts of the younger Miocene sequence and tills from the Saale (Riss) glaciation. This means relicts left by the eroding temporary melt water rivers of the Weichselian (Würm) glaciation. The plains were until late historical times heathers and moors resting on the sterile sands. The flat hills were named by early students of the topography and Quaternary geology of the area "hill-islands" (Danish: bakkeøer) because of the island-like hills rising over the outwash plains and often abruptly from the plain with steep erosional escarpments eroded by the Weichselian-rivers.

The main part of the Søby-Fasterholt area is part of an outwash plain ("sandur") with a hill ("bakkeø") located in the SW-corner of the quadrangle. The highest point of the hills is called Lavsbjerg. This hill falls gently off towards the north, east, and west. A small eastwards extension ends in a distinct hill near the village Fasterholt (Fasterholt bjerg).

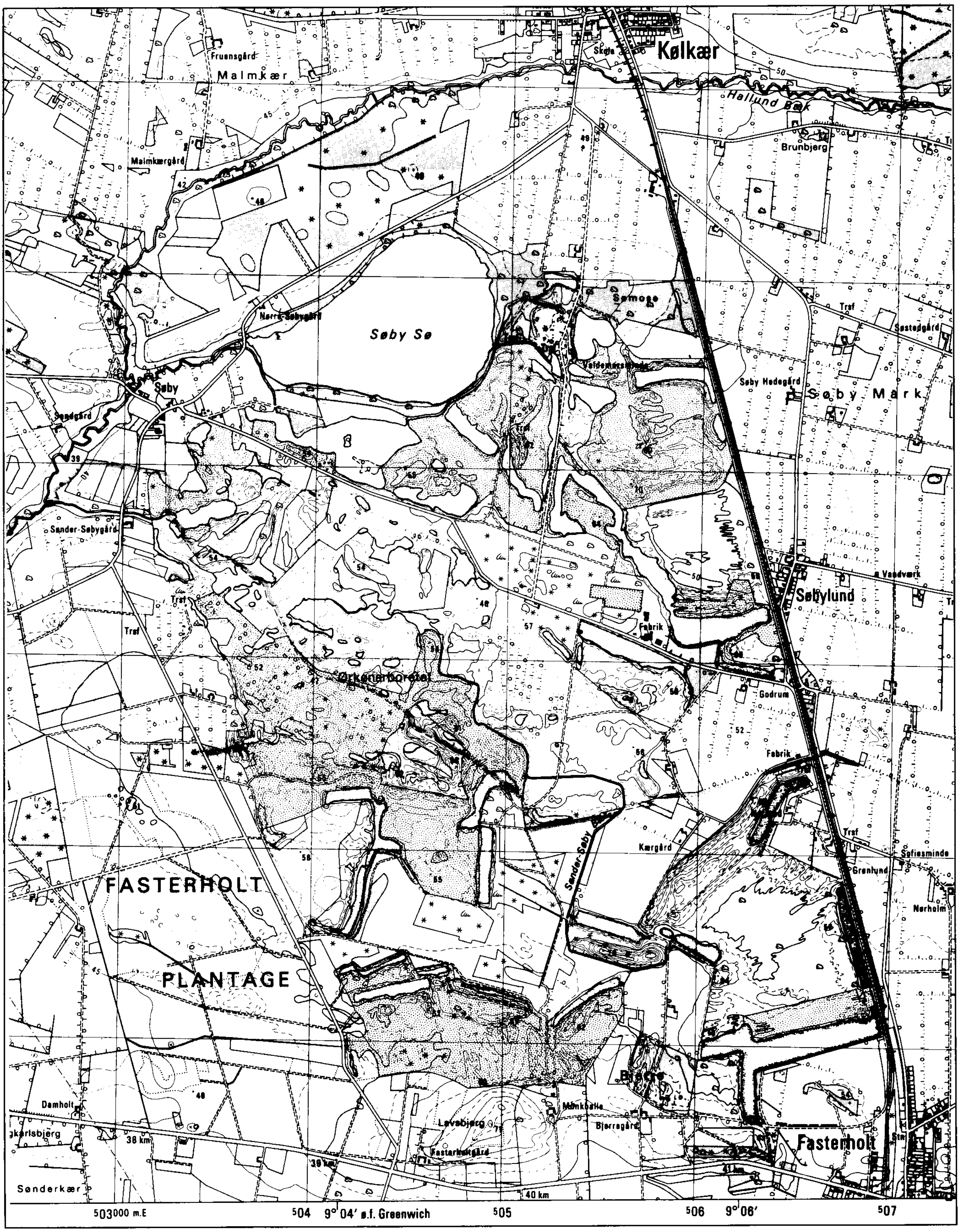
The flat morphology of Lavsbjerg hill ("bakkeø") and gentle slope towards the N and E has been modelled by strong solifluction during the Weichselian (Würm) glaciation. These deposits and structures can be seen at several localities (Atlas-Fig. 16-21).

Owing to this topography the Miocene brown coal bearing sequence of the Søby-Fasterholt area, the Od-



Text-Fig. 21. Sketch-map of the Søby-Fasterholt area with relevant localities (Quarries, drilling sites, fossiliferous localities). E.F.C. del.

1.	*Fasterholt Bjerge borehole*
2.	*Bjerregaard borehole*
3.	*Lavsbjerg Øst borehole*
4.	*Fasterholtgaard 2 (Lavsbjerg) borehole*
5.	*Fasterholtgaard 1 (Klynholt Vest) borehole*
Fb 1	*The Fasterholt Bjerg 1 probe*
EM	*The outcrop EM and probes BI and BII.*
39	*The unmined area with probes 1-10 from Text-Fig. 39.*
F 11	*Type section of the Fasterholt Member.*

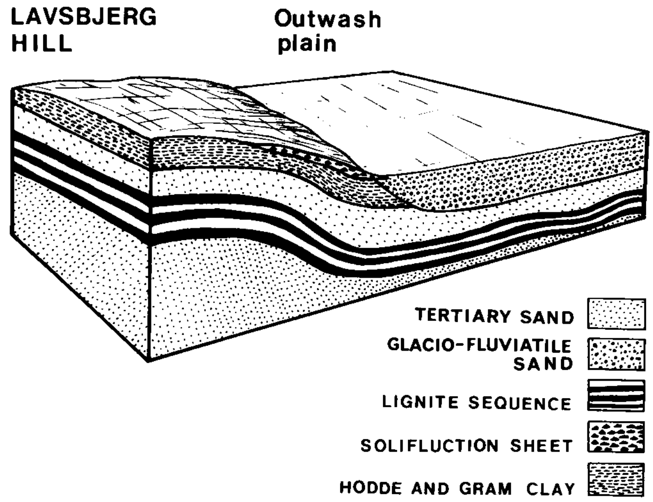


Text-Fig. 20. Topographical contour map of the Søby-Fasterholt area, scale 1:25000, with 5 m contour intervals (unbroken contours), and intercalated 2.5 m contours (stippled). Source: Geodetic Institute of Denmark map 1214 IV SV Kølkær, 1:25000. (1972).

derup Formation, is presumably not complete below the (outwash) plane. The Quaternary erosion has reached down into its uppermost part, i.e. the Tertiary sands above the brown coal seams of which 5-10 metres are left. Below the outwash plain, the brown coal bearing sequence (the Odderup Formation) is overlain by 5-15 metres of Quaternary glacio- fluviatile gravels and sands.

Underneath Lavsbjerg Hill, on the contrary, we find the upper part of the same sequence completely preserved and overlain by a thin transgressional gravel bed and further by the marine sequence of the Hodde Clay (Upper Middle Miocene) and Gram clay (Upper Miocene). These marine clays along the lower parts of Lavsbjerg Hill are only covered by 1 or 2 beds of aeolic sand with a heather soil in between. On the Søby-Fasterholt area, only at Lavsbjerg point is there a sandy till present above the Tertiary beds.

The brown coal seams should be expected to be deeper seated below the Lavsbjerg Hill than under the plain. This is not the case owing to a tectonic structure. The Tertiary sequence rises into a flat anticlinal culmination by the existence of Lavsbjerg Hill.



Text-Fig. 22. A simplified block diagram demonstrating the relationship between geology and topography in the Fasterholt-Klynholt area: An anticlinal structure including the competent Hodde and Gram Clays guiding the erosion from and leaving the Lavsbjerg Hill. Notice the solifluction sheet on the flank of the hill and the Quaternary glaciofluviatile deposits underneath the outwash plane replacing the upper part of the Tertiary sequence. The vertical scale is exaggerated. E.F.C. del.

Nomenclature.

In the present paper the following terms are encountered:

The Browncoal Bearing Sequence =

The browncoal bearing sequence: A general term for the geological sequence of the mining areas of Central Jutland which contains browncoal seams and has been involved in the mining procedure.

The Odderup Formation: Ref. the definition of the Odderup Formation pag. 31 and in Rasmussen (1961).

In the Søby-Fasterholt area the productive browncoal bearing sequence is involved in this formation and is defined as the Fasterholt Member.

The Fasterholt Member: Ref. the definition of this member pag. 32–33 and 34. The Fasterholt Member is the browncoal bearing sequence in the Søby-Fasterholt area with 3 (-4) seams (which have been mined, i.e. the productive browncoal bearing sequence of this area). The Fasterholt Member is a subunit under the Odderup Formation. Ref. type section pp. 36–37.

The productive browncoal bearing sequence: The sequence from which the browncoal seams has been mined. In the Søby-Fasterholt area this is the Fasterholt Member.

4.A. The Quaternary

The Quaternary of the region in question has been treated in detail in the description to the geological map "Brande" (V. Milthers 1939).

During our investigation of the Søby-Fasterholt region the authors have recorded many sections in the brown coal pit of Carl Nielsen Ltd.(The Midtkraft mining area) at Fasterholt (Koch & Friedrich 1970, Koch et al. 1973) and from the northerly situated pits of Hoffmann & Sønner (The Vestkraft mining area) at the villages of Søbylund and Kølkær. In these pits the geology of the sequence of the Quaternary outwash-plain was well demonstrated.

It is quite normal in the sections of the Quaternary of Central and Western Jutland to find a bed of aeolic sand (here about 1 m thick) on top. This uppermost part of the section has undergone severe podsolation. Between this bed and the underlying glacio-fluviatile sequence a thin deposit (lamina) of loess is recorded (5-10 cm thick) (Atlas-Fig. 15). This loess-seam as well as the uppermost part of the glacio-fluviatile sequence has undergone severe deformation by cryoturbation leaving recognizable periglacial soil structures (German: Brodelboden).

Below the loess-seam follows a glacio-fluviatile sequence (Atlas-Fig. 13) from 4 to 14 metres in thickness with cross-bedded sand and gravels arranged in narrow lenticular structures. Grain size varies between lamina from finesand to gravel, the coarsest beds incidentally containing a large fraction of brown coal material varying from coarse gravel to stones (Atlas-Fig. 10).

The glacio-fluviatile beds are easily distinguished from the underlying nearly white sands and gravels of the Tertiary by their light redbrown colour and ochreous weathering colour, originating from their composite mineralogy. The mean dip of the cross-bedding is towards the western half of the compass card indicating a main stream direction westwards.

No regional unconformity has been recognized within this sequence so it is thought to represent the latest glacio-fluviatile episode at this locality. It has been generally accepted that the glacio-fluviatile deposits of Central Jutland belong to the Weichselian (Würmian). Also, this sedimentation must be a relatively late event within this stage, presumably connected with the isostatic reaction from the glaciation as also is the case for the transgression of the Late-glacial Yoldia-sea.

The erosion, witnessed by the pavement of wind worn stones and the disconformity between the Quaternary and the Tertiary represent the last preceding erosional episode(s) that affected this local area and may logically be connected with the isostatic balance established before the load of the Weichselian (Würmian) icecap changed isostacy and brought this area below erosional basis-level, i.e. the latter situation where (glacio-fluviatile) sedimentation dominates over erosion.

The Quaternary glacio-fluviatile sequence is separated from the Tertiary by a disconformity. On the upper surface (the boundary surface) of the Tertiary sands a pavement of wind-worn stones (Atlas-Fig. 10-11) consisting of different rocks occurs: sediments (sandstone, quartzite), eruptive rocks (.e.g. Norwegian rhombporphyry from Oslo fjord region) and metamorphics, like the block association of the hills, but with a higher percentage of quartzites, cherts, and similar resistant rocks. This block assemblage with Norwegian indicator-boulders is well known from the Quaternary of Denmark and indicates that at least a part of the stones has arrived at the locality during the Quaternary with a meltwater river and/or the glaciers as part of a deposit the finer material of which has been removed by deflation. And, that this wind erosion logically also acted in the Quaternary, and presumably at an early stage of the Weichselian ((Würmian) (ref. below). The wind-worn pavement indicates that wind-erosion has been a contributing factor in the modelling of the "fossil surface" of this disconformity. Hence, one (or more) Quaternary erosional episodes have preceded the deposition of the glacio fluviatile sequence. The same conclusion comes out from the "fossil" erosional escarpments (Atlas-Fig. 9), which are exposed on the eastern and northern flank of the Lavsbjerg Hill (Søren Pedersen's brown coal pit and the Damgaard mines (southern and northern pits)) (Atlas-Figs. 9, 17, 79, 101).

This erosion has left the faintly undulating surface of the disconformity between the Quaternary and Tertiary sequences that have been exposed in the Carl Nielsen Ltd. pit in the Midtkraft mining area. This erosional surface has been exposed to an arctic climate because at different places we have found obvious arctic soil structures in the Tertiary deposits just below the disconformity-surface (Atlas-Fig. 12). This was exceptionally well demonstrated in a culmination of the disconformity in the middle of the Carl Nielsen Ltd. pit (section K6) at Fasterholt (Midtkraft mining area). Here, erosion has left relicts of a black soil that contain remnants of root branches in situ, a basal soil and root horizon possibly related to a brown coal or peat bed, which was removed by the erosion. This soil was preliminary dated palynologically by P. Ingwersen (personal communication) and contains enough evidence to prove a Tertiary age. This has recently been confirmed by Koch, 1984. A piece of undisturbed soil without roots was observed (Atlas-Fig. 63), but the general situation is that most of the soil has been disturbed by cryoturbation, and only remnants are left protected by the roots (Atlas-Figs. 64-66) that are deeply fixed in the soil. So, this soil survives as black cores in the cryoturbation structures ("Brodelboden") (Atlas-Fig. 12). The fossil roots have been determined by P. Wagner (Wagner & Koch 1974) to *Taxodioxylon gypsaceum* (Göppert) Kräusel (*Sequoia* sensu latiore), related to roots of the extant *S. sempervirens*. Hence, we have another factor pointing to the Tertiary age of this fossil soil, which was disturbed by cryoturbation. Besides, we find the Tertiary below the disconformity affected by the dynamics of arctic soil processes. This unconformity then proves to be a former surface and presumably it was exposed to erosion during an earlier part of Weichselian, but when, exactly, it was initiated is uncertain.

On the Lavsbjerg Hill the Quaternary deposits of the sections of the brown coal pits (Søren Pedersen, Munkballe; Klynholt mining area and Damgaard mining area) always include as the top unit a bed of aeolic sands in a stage of advanced podsolation. It rests sometimes directly upon the Tertiary, but often on a deposit rich in stones in a finer matrix of an earthy texture, non-plastic and with particles of grain size varying from clay to sand. It has a high content of sharp fragments of stones, especially of fine grained rocks, e.g. flint (Atlas-Fig. 20).Such fragments seem to be scattered parts of stones which can be found in this deposits in different stages of disintegration from strongly fissured stones (Atlas-Fig. 21), through specimens where the segments are a little displaced (Atlas-Fig. 19) and into scattered clusters of such fragments. The majority of sharp fragments occur isolated in the matrix. It might well be explained as stones split by frost action and spread by movement (flow) in the enclosing matrix. The deposit is somewhat laminated. This is obvious in dry condition when a fine but somewhat blurred bedding or orientation is revealed (Atlas-Figs. 19,20). This deposit has always a physical (geographical) connection with the flank of the relict hills and also with the Gram Clay and the Hodde Clay. Its colour may indicate a petrological relationship, i.e. that the dark clay particles of the earthy matrix may be reworked Hodde Clay (and Gram Clay).

Outcrops have been found in Søren Pedersen's pit of Munkballe, in the east end of the Klynholt mining area and in the Damgaard mining area (Atlas-Figs. 16-19).

An outcrop in this area is found just north of the Damgaard Nord pit (at the site of a former farm some hundred metres N of the site of the former mansion of Sønderborg) and just east of the experimental arboretum (Ørkenarboretet) (Atlas-Fig 20). This outcrop seems to be a remnant of a deposit, that has covered most of the abandoned Damgaard mining area and covered the northern slope of the Lavsbjerg Hill. Hence, near to the recent south border of the Damgaard mining area mr. P. Ingwersen (DGU) has recorded an outcrop with a similar deposit covering the white Tertiary sand of the anticline mentioned on page 160.

Supporting this view the eastern continuation of this cover is cut by the north front section of Klynholt (Atlas-Fig. 16). The deposit in question has a considerable thickness (3 1/2m) in the western end of Søren Pedersen's pit at Munkballe (Atlas-Fig. 18), just at the upper part of the eastern hillside of the Lavsbjerg Hill, sloping eastwards down towards the outwash plane. Here, it wedges out in the direction of the slope (towards E) (Atlas-Fig. 17), and we have seen it to continue in the shape of a blunt wedge for a short distance on to and into the uppermost sand of the outwash-plain.

The deposit is always found on the sloping flanks of the original Lavsbjerg Hill (towards N and E), and this location compared with the composition and the texture with stones presumable split up by frost action, the flow structure of this sediment and its time relationship to the outwash-plain sand indicates that we are doing with a solifluction deposit (Quaternary: Weichselian).

Below the aeolic sand bed that covers all other deposits and is the basis of the recent soil we often find a stone horizon with plenty of ventifacts. This is on top of the solifluction deposit just mentioned and in other cases upon the following deposit next in order e.g. the Tertiary delta sands or the Hodde Clay etc. In addition to the ventifact pavement mentioned on page 42 in connection with the disconformity surface between the Quaternary and Tertiary it stresses the fact that heavy Late glacial (Late Pleistocene) wind erosion has contributed to the modelling of the landscape of this region.

The point of Lavsbjerg seems from probing to have a cap of stony till-like material on top, presumably resting on the marine Gram Clay (Upper Miocene).

The west front of the Søby-Fasterholt mining area situated in the vicinity of the road from Fasterholtgaard to Søby is depending on the Quaternary geology of the area. The west front follows the east flank of a stony fluviatile deposit representing a NW-SE fossil river channel, which has been cut so deep as to remove the productive brown coal series; this means a minimum of 20 metres. It was recorded by the Browncoal Section of Geological Survey of Denmark (DGU) in the forties (personal communication with the late dr. K. Milthers, (DGU)). The flank of this river gravel structure has been cut by the brown coal mining and has been observed by the authors in ravines of the west front of the Damgård mining area. The sand overlying the Tertiary (the Klynholt Vest Tongue) in the west front of the north-west end of the Klynholt mining area (e.g. section EM, ref. Wagner & Koch 1974) presumably also belongs to this structure as a marginal facies. It has also been recorded by our probing along the road Fasterholtgaard-Søby. The position of this fluviatile structure as part of the Lavsbjerg Hill indicates that it is older than the outwash plain and the erosional episode that has left Lavsbjerg Hill as an erosional relict. Hence, it is presumably older than the Weichselian outwash-rivers and possibly older than the Weichselian glaciation.

4.B. The Tertiary

The localities where the Tertiary has been exposed during our field work and the extent of these localities appear from the sketch-map Text-Fig. 21.

The Tertiary deposits of the Søby-Fasterholt area are all enclosed within the Miocene as far concern our observations but the lowermost part of the Miocene Series has not yet been recorded. The exposures only gave access to the upper part of the series, while our knowledge of the underlying sequence originates from a number of drillings with cores of which 3 reached 120 m below the surface. The drillings have not penetrated the lower part of the Miocene Series and have not reached the marine Oligocene that should be expected to occur somewhere below this region (Kristoffersen, 1973).

The sediments accessible during the browncoal mining include the productive browncoal bearing sequence, the overlying delta sands (7-10 m), the Hodde Clay (Upper Middle Miocene), and lower Gram Clay (Upper Miocene). The productive sequence has only been accessible in its total thickness (about 10 m) in the Carl Nielsen Ltd. pit at Fasterholt (The Midtkraft mine), and the lowermost of the 3 browncoal seams has only been exposed temporarily in the western part of this pit.

During the present investigation the Tertiary has been studied intensely at our main locality, the Carl Nielsen Ltd. pit at Fasterholt within the Midtkraft mining area (1968-1970), and sporadically in the 2 pits of Hoffmann & Sønner of the mining area to the east of the lake Søby Sø, at the villages Søbylund and Kølkær (1968-1969) respectively. They are all situated on the Quaternary outwash-plain.

During the period of mining (during World War II and the time following: 1940-1970) many pits have been active and have left outcrops spread over the whole Søby-Fasterholt mining area. Informative sections have been found on the Lavsbjerg Hill (ref. Text-Fig. 21) in the pit of Søren Pedersen at Munkballe, the Klynholt mining area, and the Damgaard mining area. Drillings with cores have been set (sponsored by Geological Survey of Denmark) (for detailed information ref. chapt. 4.B.2.2.2., A and B; page 71 resp. 75) at Fasterholt railway station, at Munkballe farm, and at the farm belonging to Ole Chr. Samuelsen to the west of Fasterholt Plantage, all reaching a depth of 120 m. Drillings to 40 m below the surface have been set at Bjerregaard farm, at Lavsbjerg, and at the west front of Klynholt. These drillings are arranged in a zone

FORMATION	MEMBER	LITHOLOGY
GRAM		GRAM CLAY
		GLAUCONITE CLAY
HODDE		HODDE CLAY
ODDERUP	KLYNHOLT VEST TG. / "UPPER SANDS"	LIGNITE / QUARTS SANDS
	FASTERHOLT MEMBER	LIGNITE SAND CLAY
- - - - ARNUM - - -?	"B" MEMBER	SAND
	"C" MEMBER	BLACK CLAY SILT
	"D" MEMBER	SAND
RIBE		

Table 1A. Lithostratigraphical units involved in the Neogene of the Søby-Fasterholt area. A number of provisional units ("quotation marks") have been used in this paper pending sufficient sedimentological support. The boundary between the Arnum- and Odderup Formations has been proposed by Friis et al., 1980.

stretching E-W over the southern end of the Søby-Fasterholt area in order to establish a stratigraphical cross-section correlating the main locality at Fasterholt with the scattered localities on the Lavsbjerg Hill (Text-Fig. 38).

As appears from Text-Fig. 13 the non-marine Miocene Series of Jutland according to Rasmussen (1961, 1966) are represented by the Odderup and Ribe Formations. In our area the marine formations, accessible in exposures, are the Hodde Formation and the Gram Formation, the latter includes a basal glauconitic bed and the overlying Gram Clay. From drillings also the Arnum Formation or equivalent succession probably has been recognized. In the present chapter (4) the exposures of the Søby-Fasterholt area will be described and discussed and the following units will be under consideration: The Odderup Formation with the Fasterholt Member and the underlying sequence. The exposures of the Hodde Formation and the Gram Formation will be described in general based upon our field observations.

1. Odderup Formation (L. B. Rasmussen, 1961)
This formation is synonymous with what the late Dr. K. Milthers (leader of the Browncoal Department, Geological Survey of Denmark during the last mining period) called "Upper Browncoal Formation" and with the more diffuse terms "Brown coal-formation" and "Micasands" (in Danish: "Brunkulsformationen" and "Glimmersand") by the early authors (e.g. Forchhammer, 1863).

The Odderup Formation was defined by Rasmussen in 1961 as the sequence of the interval 28.2-40.3 m below the surface in the "Odderup brickwork" borehole, Geological Survey of Denmark, file no. 103.150. The log of this drilling is as follows (transl. from Danish):

0-09.6	m	Quaternary.
9.6-21.2	–	Grey micaceous clay, Gram Clay, marine.
21.2-23.7	–	Green, glauconitic clay, marine.
23.7-27.8	–	Black micaceous clay, marine.
27.8-28.2	–	Quartz gravel with rollers of flint, marine.
28.2-29.2	–	Browncoal.
29.2-40.3	–	Quartz sand, non-marine.
40.3-59.8	–	Alternating micaceous clay and micaceous silt. From 57 m rich in fossil marine molluscs.
59.8-64.0	–	Quartz sand with gravel in the uppermost part. Fossil shark teeth. 64.0-81.7 –

Micaceous sand from 80 m rich in fossil marine molluscs.

Hence, at the type locality (Odderup brickwork) the

Odderup Formation is 12 m thick and overlain by the Hodde Formation (marine). It rests upon an unfossiliferous sequence occurring to 57 m below the surface of micaceous silt and clay except for the lowermost beds which contain marine fossils.

The underlying sequence (below 57 m) belongs to the Lower Middle Miocene, dated by means of the fossil marine molluscs with a clear affinity to the fauna of the sequence on which Sorgenfrei (1958) defined the Arnum Formation.

The uppermost part of the succession of the stratotype at Odderup brickwork is reproduced by the upper part of the sequence at the Søby-Fasterholt area. The stratotype sequence 28.2-40.3 m in the latter area is equivalated by the 5th browncoal seam of Klynholt Vest (about 1 m thick) and underlain by a maximum 10 m thick sequence of quartz sand (in Klynholt Vest gradually substituted northwards by alternating brown micaceous clay and quartzsand), (ref. Klynholt Vest Tongue, page 37).

But the underlying browncoal sequence at the Søby-Fasterholt area differs from that of the stratotype. In the Søby-Fasterholt area is the very characteristical sequence of 3 browncoal seams with intercalated sand, silt, gytja, and clay beds (in total of about 10 m), resting on a soil and root horizon. In the Odderup brickwork type-sequence are 20 m of micaceous clay and silt, the lowermost 3 m containing marine fossils. The unfossiliferous majority of this sequence might partly be a non-marine, lithostratigraphical equivalent to the browncoal bearing sequence of the Søby-Fasterholt area, but the lithology of the two sequences differs. Consequently, the lithostratigraphical classification of the browncoal bearing sequence in the Søby-Fasterholt area is not readily discernible itself from a formalistic point of view, though similarity with existing units (related facies) can be pointed out.

Underneath the sequence of the Søby-Fasterholt area continues in generally unfossiliferous sands and silts, amounting 30-40 m in thickness, grading into a sequence of clay and silt. Scanty records of marine fossils (a few shark teeth and dinoflagellates) and sedimentological arguments (Friis et al., 1980) point to marine-brackish environment of this clay-silt sequence and a part of the overlying sand-silt sequence. Regardless of the indications of a marine facies, the sequence differs lithologically from the type Arnum Formation. The facies of the Arnum Formation are characterized by high a content of marine shells in sand as well as in clay, and a single bed even consisting solely of fossils (a shell-bed).

The sequence below the browncoal bearing unit reflects a succession of geological events equivalent to that of the beds below the 11 metres of light (white) quartz-sand of the Odderup Formation (type section: 29.2-40.3 m): A succession of silt-fine sands overlying a marine deposit (the Arnum Formation?).

Hence, from a lithological point of view, the sequence underlying the browncoal sequence of the Søby-Fasterholt area differs from the type Arnum Formation, though there may be some related facies.

The provision that the Odderup Formation is limited by the marine Arnum Formation below does not directly imply or definitely support a lithostratigraphical incorporation in the Odderup Formation of the browncoal bearing sequence of the Søby-Fasterholt area. This becomes problematical because the underlying marine sequence of the Søby-Fasterholt area is connected with deposits which do not directly and strictly fit into the definition (lithology) of the Arnum Formation.

The browncoal bearing sequence of the Søby-Fasterholt area is overlain by beds clearly fitting the definition of the Odderup Formation repeating the entire sequence of the stratotype. When these beds at the type locality are separated from the definitely marine beds below by a transitional unfossiliferous succession, it should not be difficult to redefine the Odderup Formation to enclose the browncoal bearing sequence, especially since as Rasmussen's stratigraphical model (1961, 1966) (Text-Fig. 13) implies the Odderup Formation to include the entire limnic (non marine) sequence between the marine Hodde Formation and the marine Arnum or the non-marine Ribe Formations, respectively. This so more so as the lithostratigraphical limit between the Odderup- and Ribe Formations is not yet defined.

Consequently the "Upper Sands" and the 5th browncoal seam of the Søby-Fasterholt area are recognized in this paper as a part of the Odderup Formation. And as a lower part, the browncoal bearing sequence in the strict sense (the Fasterholt Member) is included. And also the underlying transitional deltaic facies devoid of clear indication of marine derivation (marine fossils, distinct autochtonous glauconite) underlying the definitely limnic (browncoal bearing) sequence and overlying the fossiliferous marine Arnum Formation. Friis et al., 1980 have motivated a lower limit from sedimentological criteria. Within this emendated Odderup Formation the browncoal bearing sequence of the Søby-Fasterholt area shall be defined as the Fasterholt Member(ref. below), and represents the middle part of the formation. The Fasterholt Member, and the underlying sands, here provisionally named the "B-member", can extend the Odderup Formation downwards in the depositional embayment to the north of the Jutland-Funen high. The lower boundary must be based upon the petrographical criteria of Friis et al., 1980 indicating a change in lithology at about 47 m.b.s.

2. Fasterholt Member.
Locus typicus: The browncoal mine of Carl Nielsen Ltd. at Fasterholt, inclusive the neighbouring hill of Fasterholt bjerg. (ref. 4B. 2.1.II).
Age: Middle Miocene.

The browncoal bearing sequence of the Søby-Fasterholt region in the authors' opinion should be included into the Odderup Formation. The authors have found it justifiable to make the well described and characteristical browncoal bearing sequence of the Søby-Fasterholt area a lithostratigraphical unit, the *Fasterholt Member.* The Fasterholt Member as defined in section 4.B.2. (page 34) consists of the productive browncoal sequence with 3 rhythmical browncoal bearing units. These units consist of a lowermost sand, sometimes grading by thin beds of silt and clay into a browncoal bed on top. Locally the 3rd unit may contain a subunit ending in a 4th browncoal seam. The upper and lower limits of the Fasterholt Member are as follows:

Upper limit is a paraconformity with weak, indistinct traces of erosion or weathering, overlain by the Upper Sands of the Odderup Formation.

Lower limit is a paraconformity indicated by a root horizon with stumps in a fossil soil lying on top of an underlying psammitic sequence, here provisionally called the "B-member".

In the drillings down to 120 m below the surface it is possible to distinguish between the following entities found below the Fasterholt Member:

3. The Middle Sands ("B-Member")
is situated between 25.0-66.0 metres below the surface in the southern part of the Søby-Fasterholt area and generally consists of sand varying in grain size. The uppermost 20 metres are dominated by coarse sand and the lower half (about 21 m) consists of medium-fine grained sand. A few metres of clay and sand are found in the uppermost part and in the middle of the member are a few thin beds of clay.

4. The black clay and silt succession ("C-Member")
is situated between 66.0 and about 77.0 m (75-79) and consists dominantly of black micaceous clay with some silt and minor sand intercalations. Fossils: sharks teeth, dinoflagellate cysts.

5. The Lower Sands ("D-Member")
is found below 77.0 metres (75-79) below the earth surface and has been recorded to 120 m below surface. The sequence consists dominantly of sands with intercalated clay beds, few in the upper part but becomes more abundant below 108 m below the surface. A thin browncoal seam has been recorded at about 81 m b.s. The lower boundary of this member has not been defined.

As long as these units are not well known they are mentioned here under provisional names. At present it is not definitely determined where to draw the lower boundary of the Odderup Formation. The Lower Sands Member ("D-Member") may belong to the Ribe Formation.

The corresponding sequence found in the Lavsbjerg Øst borehole at Munkballegård has been sedimentologically analyzed by H. Friis and O. B. Nielsen (Friis, Nielsen, Friis & Balme, 1980). Based upon the succession of mineralogical composition, grain size, conditions of the sedimentary grain fabric and the degree of transformation of the unstable minerals, and the clay minerals, these authors conclude that a prominent part of the succession in question is derived from a marine environment. Namely for what is above preliminarily called "D-Member", "C-Member",and grading through the "B-Member", by marine shallow water deltaic facies, to the following non-marine browncoal bearing sequence. Consequently these marine deposits at 66-77 m below surface are referred to as the Arnum Formation. And a tentative boundary between the Odderup Formation and the Arnum Formation is proposed at 47 m b.s. based on petrographical criteria (Friis et al., 1980). This proposal is incorporated in the survey of the stratigraphical terms accepted in this paper of table 1 A.

4.B.1. The Odderup Formation in the Søby-Fasterholt area

The Odderup Formation sensu stricto occurs continuously over the entire Søby-Fasterholt area and comprises the "Upper Sands", and the 5th browncoal seam in our local terminology. It is dominantly a sequence of light (white) quartz sands of tabular cross bedded units, about 10 m thick in the Fasterholt region and along the south front of Klynholt (Lavsbjerg). Under the outwash plains of the Søby-Fasterholt region Quaternary erosion has cut into the "Upper Sands", removing in most places max. 1-2 metres. Between Søbylund and Kølkær (the Hoffmann & Sons mining area) the "Upper Sands" amounts to 5-7 m, but here the original thickness can not be reasonably estimated.

In the Lavsbjerg Hill area and its eastwards extension to Bjerre (Fasterholt bjerg), the overlying Hodde Clay and Gram Clay cover the Odderup Formation and have prevented erosion and left the "Upper Sands" untouched. In Klynholt and in the Damgaard mining area the "Upper Sands" wedge out towards the NW (4 m in Klynholt Vest), and the facies changes gradually into a sequence of alternating white quartzsand and brown clay (gytja).

On top the "Upper Sands" terminates in a root-horizon and at Klynholt Vest tree stumps are common. This represents a paraconformity separating the "Upper Sands" from the 5th browncoal seam which was preserved from erosion only in a local area in Klynholt Vest.

The browncoal bearing sequence, which is the productive sequence of this area, is defined as the Fasterholt Member in the present paper and is included in an Odderup Formation extended (ref. below, chapter 4.B.2.).

The lower boundary of the Odderup Formation has not been defined with any certainty in this area but according to the general definition (Rasmussen, 1961, 1966) it rests upon the marine deposits supposed to be the Arnum Formation and consists of deltaic sediments with coarse sands as the main ingredient. (ref. 4 B. 1. Odderup Formation). Hence, the coarse to medium grained sands below the Fasterholt Member that are rich in kaolinite, and extend to 47 m below the surface as exemplified by the Lavsbjerg Øst well (Friis et al., 1980) should be a natural part of the Odderup Formation and carry the status of a member.

4.B.2. The Browncoal Bearing Sequence in the Søby-Fasterholt area: The Fasterholt Member and the Upper Sands of the Odderup Formation

The Fasterholt Member is defined as the sequence of sand, clay and browncoal underlying the "Upper Sands" of the Odderup Formation and overlying the sands occurring below also referred to as the "B-Member". The upper boundary of Fasterholt Member is a paraconformity between the uppermost browncoal(-clay) bed of this member and the "Upper Sands" of the Odderup Formation. The lower boundary is a paraconformity characterized by a root horizon with tree-stumps in a fossil soil developed in the uppermost sand bed of the "B-Member". Resting on this soil is the 1st rhythmical unit of the Fasterholt Member.

The Fasterholt Member consists of 3 sedimentary rhythmical units each beginning (from below) with a sandy bed, passing into clay or silt and ending with a browncoal bed on top (a fining upwards sequence); the lacustrine deposits following above the 3rd browncoal seam in the Damgaard N pit may be regarded as a 4th unit in this succession. This unit is synchronous with a lacustrine (but coarsening upwards) sequence of Klynholt Vest and with the "Upper Sands", again overlain by brown coal seam no. 5 in Klynholt Vest. The two lower rhythmical units rest on sediments showing traces of erosion. The 3rd unit is introduced with an abrupt change from coal to sand, with traces of weathering in the surface of the 2nd coal seam (bed no. 2).

The type section of the Fasterholt Member is based upon the continuous outcrop(s) of the open cast mine of Carl Nielsen Ltd. at Fasterholt (Text-Figs. 20-21). The representative profile of F11 (the western part of the pit) is the formal type (ref. page 36-37). It is overlain by the "Upper Sands" of the Odderup Formation which itself is overlain by the marine sequence recorded in drilling Fb. 1 of Fasterholt bjerg. They occur in a continuum, the latter part directly upon the former.

Through the nearly 1 km long and a continuous E-W extension of the pit in question the succession of strata appears rather constant with minor variations in the thickness of the involved beds. Over this distance the outcrops were continuous. In the western end, 750-800 m from the east end of the pit (at the railway at Fasterholt) an additional auxiliary trench stretching southwards from the bottom of the pit (in direction N-S) reached into the foot of the neighbouring hill, Fasterholt bjerg. This hill rises above the outwash plain in which the pit was excavated. Through this trench the road giving access to the pit was running, and here the outcrops from the mining trench continued to the Fasterholt bjerg (hill). In the final stage of the mining in 1970 the 3rd seam was mined out just to the foot of this hill and also the 2nd seam was mined here at a short distance from the hill. Hence, the Fasterholt bjerg is seen to rest upon "Upper Sands" of the Odderup Formation and consists of the well known marine sequence of the Lavsbjerg Hill: Hodde Clay, Glauconitic Clay, Gram Clay and under the Hodde Clay the basal gravel overlying grey sand (ref. drilling Fb. 1, 1979 150 m to the SSW of the south end of the auxiliary trench, ref. page 74, Text-Fig. 46).

In the exposures of the optimal profile (K6-K7) is found a soil of black-grey sand with sequoide roots resting on top of nearly 10 metres of "Upper Sands". The sequence is cut off by the erosional unconformity of the overlying glacio-fluviatile sequence. This occurs at approximately the same level where the drill of Fb. 1 below the Hodde Clay passed through gravel into grey sand of the "Upper Sands" (43 meters above sea level).

Hence, the Fasterholt Member and the "Upper Sands" are exposed in total thickness at profile K6-K7 and is proven to be overlain by the Hodde Clay etc. in the neighbouring Fasterholt bjerg.

The exposures of the Fasterholt Member in the Carl Nielsen Ltd. pit at Fasterholt are the source of our most detailed information of this sequence. And when we

Generalized section of the exposures in the SØBY - FASTERHOLT area.

CHRONO-STRATI-GRAPHY	APPROX. VERTICAL THICKNESS	PROFILE DESCRIPTION	LITHO-LOGY	LITHOLOG. UNITS	FOR-MATIONS	REF.
UPPER MIOCENE	c. 7m	Fossiliferous clay. Marine.		GRAM CLAY	GRAM FORMATION	Rasmussen 1961, 1966 and 1968.
	3.5m	Dark, greenish clay. Rich in glauconite. Marine.		GLAUCONITE CLAY		
MIDDLE MIOCENE	4.4m	Black coal-like Mica clay. Marine or brackish? Quartz gravel.		HODDE CLAY	HODDE FORMATION	Rasmussen 1961, 1966 and 1968. Kristoffersen 1972.
	4-7m	Tabular, crossbedded, coarse-medium grained, light quartz sand.		UPPER SANDS	ODDERUP FORMATION	Rasmussen 1961 Koch and Friedrich 1970 Koch et al. 1973
	10m	3 browncoal seams separated by clay, silt and sand beds.		BROWN-COAL SEQUENCE		
	TOTAL THICKNESS NEVER EXPOSED	Tabular, crossbedded, coarse-medium grained, light quartz sand.		MIDDLE SANDS		

CLAY SILT SAND GRAVEL BROWN-COAL

Tabel 1B

have found it overlain by the Hodde Clay also here, like a number of exposures and drillings in the Lavsbjerg Hill area, we find it justifiable to name a profile of this outcrop the type section of the Fasterholt Member and the "Upper Sands" (ref. below).

This sequence (member) occurs over the entire Søby-Fasterholt mining area. The detailed investigation of this paper concerns the southern part of this mining area in an approximately E-W directed belt from Fasterholt (the Carl Nielsen Ltd. pit) passing the Søren Pedersen pit at Munkballe into the Klynholt area (south and north fronts) and through Klynholt Vest to the northwesterly Damgaard mining area (south and east fronts of Damgaard S, and the pit of Damgaard N). In this area a number of drillings and probes has been set through the Fasterholt Member and the "Upper Sands" (ref. section 4.B.2.2.2 (A and B).

The Fasterholt Member and the "Upper Sands" together exhibit a modification of the Odderup Formation in the Søby-Fasterholt area. The "Upper Sands" are lithologically identical to the 12 m thick white sand of the stratotype for the Odderup Formation (Odderup brickworks). The Fasterholt Member includes the underlying productive browncoal sequence not represented at the stratotype. Also the Odderup Formation in the Søby-Fasterholt area should include the sequence of sand and silt, devoid of marine fossils, which occurs under the Fasterholt Member as a member of its own (ref. Friis et al. 1980).

4.B.2.1. The Browncoal Bearing Sequence of the Søby-Fasterholt area

I. The Outcrops of the Browncoal Pit of Carl Nielsen Ltd. at Fasterholt as it was exposed (1968-1970).

(preliminary publ. by Koch & Friedrich 1970, 1st and 2nd rhythmical units by Koch et al. 1973):
At this locality the Quaternary outwash-sands rest on the Tertiary, the boundary between these Series are marked by a disconformity. Below the Quaternary sands follow the Tertiary "Upper Sands" which in the Søby-Fasterholt area represent a separate unit of the browncoal bearing sequence, overlying the Fasterholt Member.

Table 2

Bed. no.	Thickness in metres E – W	Lithology: Pit of Carl Nielsen Ltd.	Lithology: Fasterholt bjerg	Paleontology
8	7 - 10	Quaternary glaciofluviatile sands	Hodde Clay	
		Pavement of ventifacts Disconformity	Transgressive gravel bed	
7	0.5 - 1	Root horizon		Taxodioxylon gypsaceum (Göppert) Kräusel
7	10 - 7	Sands and fine gravel, white-light grey, quartz predominating; arranged in tabular, cross-bedded structures. Cross-bedding dips eastwards. Enclosed as a minor fraction are pebbles of flint, silicified remnants of Danian limestone and Ordovician fossiliferous limestone with remains of marine fossils or isolated fossils. This bed follows concordantly upon bed 6. In working front K, between profiles 6 and 7 in a culmination of the erosional disconformity allowing for an optimal thickness of this bed, bed no. 7 terminates upwards in a black fossil soil with remains of roots of *Taxodioxylon gypsaceum* (aff. *Sequoia sempervirens*).		Secondary Upper Ordovician marine fossils from the Baltic region (Spjeldnæs in Koch et al. 1973, Spjelnæs 1975).
6	1.8 - 2.5 - 1.8	Brown coal, dark brown homogeneous, entirely consisting of fine-grained detrital components (detritus-coal) (ref. E. Thomsen 1976, 1979, 1980).Very thin powder of silt/fine sand particles of quarts and mica reveals the bedding, causes cleavage. Significant content of inorganic matter (clay) in upper and lower part.		Pollen and spores. Devoid of megascopic fossils.
5b	0.2 - 0.2	Fine-grained sand-silt, white, sometimes brown (secondary) with fine lamellas of black detrital coal particles.		
5a	0.7 - 1.2	Grey silty, micaceous clay.		Plant compression fossils (leaves, fruits, and twigs)
3-4	0.9 - 0.05	Quartzsand, white (bed 4) with secondary brown colouring (humic acids) especially in the bottom (Larsen & Kuyp 1971) (bed 3), fine-medium grained; the bed is one single cross-bedded structure wedging out over a distance of more than 1 km. Cross-bedding of 1st and 2nd order dips west.		Well preserved fossil fruits, seeds, twigs, and cones (*the Fasterholt Flora*).

2	0.7 - 0.2	Brown coal, (xylitic) rich in fragments of wood, which are often rather dissolved; larger branches or stems common, in compressed condition; locally densely packed with N-S orientation (driftwood on ground). Matrix is black, amorphous, gagatic and with conchoidale fracture (ref. E. Thomsen 1976, 1979, 1980). The uppermost 10 cm is black earthy (weathered?) in the eastern part of C.N. pit.	Rich in fossil woods (driftwoods), pollen and spores.
1	1.2 - 2.0	Brown coal, brown compact homogeneous, in the lower part with bedding (cleavage) owing to scattered very thin lamella (powder) of silt-fine sand particles. High content of inorganic matter increasing upwards, the sediment gradually changing into clay (gytja). Irregular transition into bed no. 2.	Pollen and spores. Megascopic plant remains rare. Only twigs observed.
0	0.8 - 0.8	0b: Fine sand-silt, brown (humic matter), micaceous with black lamella of coal detritus. The sand is arranged in lenticular structures interwoven into a meshwork of lamina of coal detritus and silt. Changes rapidly to grey colour by exposure. Related to dy. 0a: Brown humic silt, homogeneous, similar to dy. Sharp undulating limit to the upper lamellated part. This part of the bed is traversed by vertical incoaled roots beginning at the upper limit of the unlaminated silt.	Fossil roots
-1	0.8. - 0.45	Clay. Grey (grading into green or brown), fine, homogeneous. Limit towards bed no. 0 abrupt. Gradual transition into bed no. -2.	
-2	0.65	Clay and sand in composite deposit: Small lenses or irregular bands of coarse dark-light grey sand in a matrix of grey clay. The clay component (matrix) becomes more dominating upwards. It turns gradually into the pure grey clay of bed no. – 1.	
-3	-0.3 - 0.1	Detrital brown coal and sand in composite deposit: Lenses or lamella of fine-grained, light yellow-brown sand embedded in an undulating web of dark brown lamella of detrital brown coal (about 1 cm thick). Sporadic occurrences.	
-4	0.05	Sand, medium grained, olivegreen colour. Sporadic occurrence.	

		Disconformity with shallow erosional furrows or channels of very different extent and thickness, with fillings of white, light brown sand containing driftwood.	Rounded and worn trunks (drift wood) and a few vertical stems (perhaps protruding from beds no. -5 or -6).

-5	1.2	Brown coal, (lignite) redbrown – dark brown, hard compact matrix, rich in small pieces of rather dissolved wood. Compound of several brown coal facies (ref. E. Thomsen 1976, 1979, 1980).	Pollen and Spores
-6	0.5	Brown coal and sand: Composite deposit of lenses of coarse sand interwoven into laminated sandy brown coal. With pieces of wood and stumps.	Fossil wood in pieces. Fossil stumps.

		Paraconformity, finely undulating with narrow, small furrows (groves) after dissolved branches or stems, which in principle belong to bed no. -6.	

The paraconformity with the associated soil and root horizon with stumps and their root branches in principle belonging to bed no. -7 will be described in chapter 4.B.2.1., page 62-65.

As mentioned in chapter 4.B.1. the Odderup Formation, the (white) "Upper Sands" (bed 7), wedge out towards NW in the Søby-Fasterholt area and locally at the west front of the area the facies changes into a few metres of sand and clay alternating (ref. page 32,58,60).

The Fasterholt Member consists of the beds from no. +6 to -6. The "Upper Sands" is described as bed no. 7, enclosing the soil on top.

II. Type Section of the Fasterholt Member

Locus typicus: The type section of the Fasterholt Member is located in the browncoal pit of Carl Nielsen Ltd. at Fasterholt. At this locality the profile F 11, on the F-front (ref. page 9, Text-Figs. 3.A, 24), is nominated the type section of the Fasterholt Member. Profile F 11 is situated at a distance of 340 metres from the east end of the pit, i.e. 365 metres to the west of railway passing northward from Fasterholt railway station. The F-front was exposed in the summer 1969, and is about 100 metres to the north of the present south front of the submerged pit.

Age: Middle Miocene.

Table 3. Log of profile F 11 (ref. Text-Fig. 24).

Bed no.	Thickness in cm. (variation)	Lithology Overlain by "Upper Sands"	Fossils
6	165 (265 - 165)	Dark to brown, compact, homogeneous groundmass coal with pronounced conchoidal fracture. The content of inorganic matter is significant in the uppermost and lowermost part of the seam.	Fossil pollen
5 b	10 (10 - 15)	Yellow-ochreous, fine sand-silt lenses alternating irregularly with lamina or lenses of dark brown (humous) silt. The upper border is sharply cut.	
5 a	90 (50 - 135)	Grey (brownish-greenish), tough, compact silty clay, coarsening upward. So the bed grades upwards into 5 b. Fossil plant remains (leaves) common.	Fossil leaves
3+4	15 (140 - 15)	Single sand bed of varying grain size, cross-bedded with low westerly dip (l'order); these beds again are 2'order cross-bedded with steeper westerly dip. Some of the l'order beds as well as single 2' order lamina, have a varying content of brown clay (silt). The clay-silt beds/lamina leave a humous brown colouring in the overlying sand (ground-water precipitation). Around profile F4 fruits, cones and twigs are found in concentration:	Fossil fruits, seeds, cones and twigs (scattered). *Fasterholt Flora.*
2	30 (70 - 25)	Black brown coal with a high content of wood structures (branch- and stem fragments). The lower part is a tissue-groundmass coal, the uppermost a tissue coal (crowded stream-oriented compressed stems), generally with a a distinct content of plant fragments.	Fossil pollen and wood
1	180 (150 - 190)	Homogeneous browncoal – coaly clay. The lower 3/5 of the seam is a compact homogeneous groundmass coal with a bedding, often with a powder of fine sand on percurrent bedding planes. Towards the top the content of inorganic matter is increasing, leading to a coaly clay in the upper part. Owing to this a distinct change in colour upwards is characteristical.	Fossil pollen
0 b	35 (30 - 35)	A composite bed of sand in small crowded lenticular structures interwoven in a meshwork of lamina of dark brown organic detritus.	
0 a	20 (15 - 25)	Homogeneous bed of light brown fine sand-silt with incoaled plant roots penetrating from the top of the bed. The upper surface undulating and sharply cut.	
-1	45 (55 - 45)	Grey (greenish-brownish), tough, homogeneous fine clay. The upper boundary is sharply cut.	
-2	65	A composite bed of indistinct layers or lenses and lamina of sand and clay upwards grading into the pure clay of bed no. -1.	
(-3	10	Sporadic occurring thin bed of alternating lamina of coal detritus and yellow brown fine sand. The upper and lower boundary is sharply cut.).	
(-4	5	Sporadic occurring band of medium grained greenish sand. Well defined lower and upper boundary.).	
-5	130	A dense, dark brown coal; lowermost a xylitic (tissue-) coal changing upwards into a homogeneous groundmass coal. Uppermost again the coal is rich in xylitic tissues. The upper part of the seam is rather earthy.	
-6	40	A bed consisting preferably of coarse-medium grained sand with coal particles, arranged in small lenses, which are interwoven in a meshwork of detritic sandy browncoal lamina. The lower surface is undulating but rather sharply cut. Upwards this bed grades into the browncoal bed no. -5.	

underlain by the "Middle Sands" ("B-Member"): Deltaic sands.

III. The Klynholt Vest Tongue (of the Odderup Formation)

Locus typicus: The section EM at the Klynholt Vest front (ref. Text-Fig. 34 and Atlas-Fig. 70).

Age: Middle Miocene.

Upper boundary: Laminated sand and silt (Quaternary) resting upon a stone pavement with ventifacts, marking the very boundary.

The type section:

	Thickness in meters	Lithology	Paleontology
Quaternary (laminated silt and sand)			
Upper boundary		*stone pavement with ventifacts*	
	1.5 m	*fine, nearly white, cross-bedded sand at the bottom rich in pebbles*	
--------	*erosion:*	*current-ripples in the surface of sapropelitic detrital brown coal--------*	
	0.15 m	*small sand lenses enclosed on top Black, sapropelitic detrital brown coal.*	*Fossil pollen spores and algae*
	0.65 m	*Black, xylitic brown coal (lignite) with a compact brittle homogeneous matrix containing fragments of lignitic wood, especially concentrating in the lower part of the bed (ref. Thomsen, 4 B.2.2.1a), where dissolved remnants of stumps have been recognized (ref. Atlas-Fig. 70, 71).*	*Fossil pollen, spores and wood*
Lower boundary			

Lower boundary: A root horizon being the remains of a stump horizon, the relicts of the dissolved stumps (Wagner & Koch 1974) reaching into the overlying coal bed of the Klynholt Vest Tongue. The roots penetrate an underlying 75 cm thick cross bedded fine sand continuing into 45 cm laminated fine sand with lamina of brown silt-clay (ref. Atlas-Fig. 71).

4.B.2.2.1. Detailed Description of the components of the Browncoal Bearing Sequence 1: The Southern part of the Søby-Fasterholt area

I. *The Brown Coal Seams*

I.a. *Description and Facies Interpretation*

by E. Thomsen

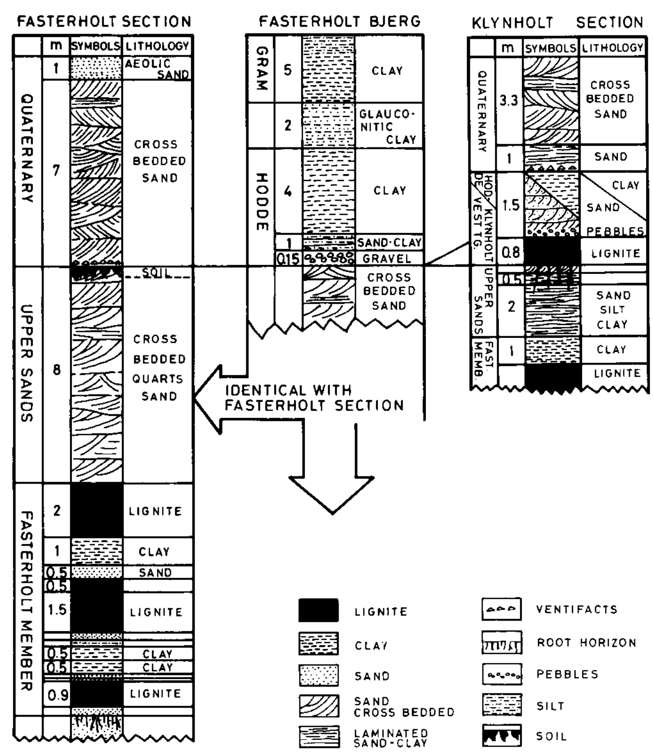
Introduction

In order to determine the coal forming environments, samples from the brown coal seams of the Fasterholt Member in the Carl Nielsen Ltd. open-pit mine and the Klynholt Vest section have been subjected to coal petrographical and chemical investigations.

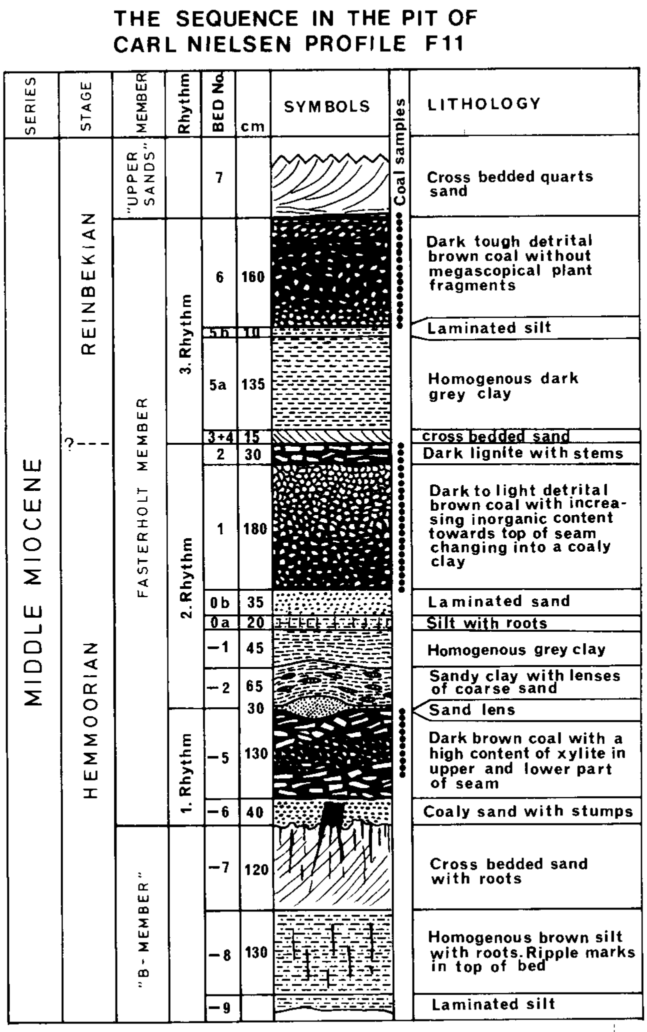
The Brown Coal Bearing Sequence from the two pits are presented in Text-Figs. 23, 25 and 33.

Methods

The chemical analyses comprise proximate and ultimate analyses. In order to investigate potential differences in the content of extractable bitumen, samples from the lower, middle and upper parts of each seam have been extracted 24 hours with a 1:1 mixture of



Text-Fig. 23. Stratigraphical correlation of the Fasterholt section (represented as a simplified version from the Carl Nielsen Ltd. browncoal quarry with the overlying marine sequence from Fasterholt Bjerg) compared with the Klynholt section (from a generalized summary of outcrops, probes and browncoal prospecting drillings). E.F.C. & E.K. comp.



Text-Fig. 24. Lithological log of the Fasterholt Member (type section) based on profile F 11 (ref. description of type section, table 3) and additional stratigraphical information. E.K. & E.T. del.

benzene and alcohol. Since no colour determinations were made during the field work, remission determinations have been carried out with an Elrepho remission photometer, using the filter 1 and BaSO4 as standard.

The macropetrographic analyses were carried out in the laboratory according to a modified classification system suggested by Vogt (1970). The micropetrographic analyses comprise maceral analyses and qualitative investigations. In order to control the rank determinations obtained by the chemical analyses, vitrinite reflectance measurements were made on huminite B in a sample for each seam. Nomenclature and analytical procedures are in accordance with the suggestions in the International Handbook of Coal Petrography (1963, 1971, 1975). A classification scheme has been included (table 4) to demonstrate the maceral classification of brown coal and their definitions.

Results

The results of the remission measurements, macropetrographic and micropetrographic analyses are presented in the section on petrography. The results of the chemical analyses and reflectance measurements are given in the section on chemistry.

Petrography

Carl Nielsen Ltd. Brown Coal Pit (CN), Type section F11

1st Brown Coal Seam (bed no. -5)

The seam is 1.30 m thick, but only samples from the upper 1.00 m are available. The lowermost 0.30 m is xylitic but no further details are available. The results of the remission measurements and the macropetrographic and micropetrographic analyses are presented in Text-Fig. 26.

Macropetrography

The seam consists of a compact dark brown coal without significant colour variation (β diff., 0 (abs) 4.9-5.7). It is characterized by a low, varying content of small compressed unoriented xylitic and humified fragments of stems and branches in the groundmass. In the lower part cuticular fragments are frequent. The coal is a tissue groundmass coal except for an interval near the middle of the seam, that lacks megascopical plant fragments, which represents a groundmass coal. The content of xylite is highest in the upper and lowermost parts of the seam. The cleavage is rough except for the groundmass coal, where the cleavage is conchoidal.

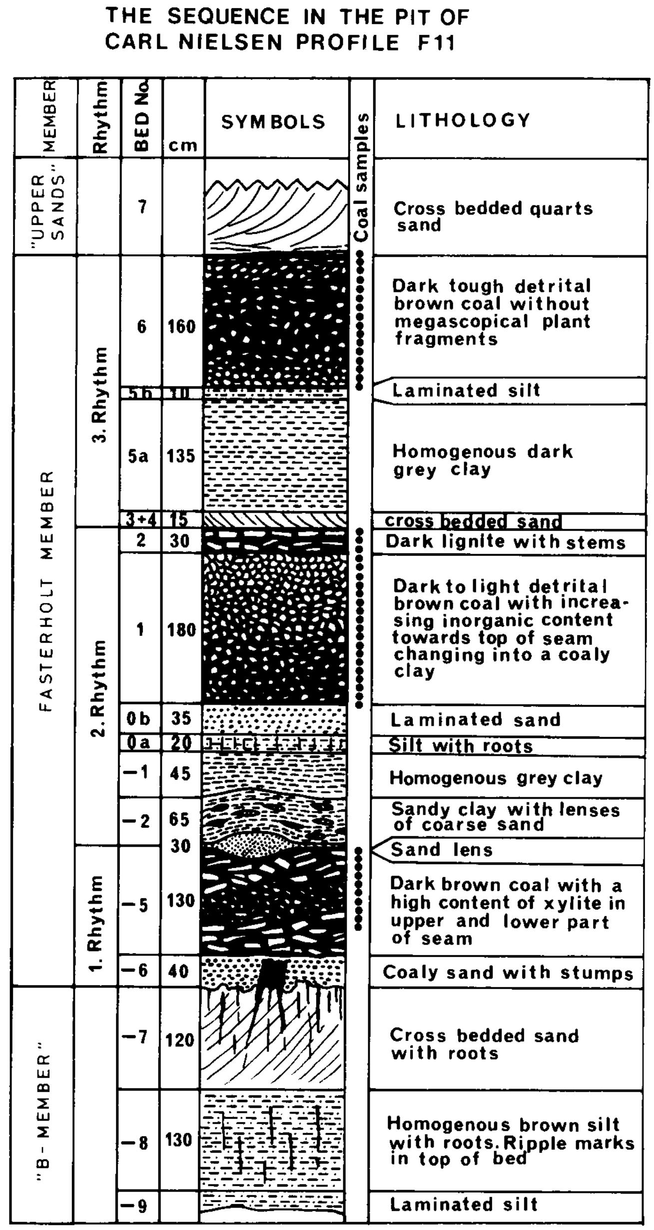
Micropetrography

The maceral analysis shows a distinct variation in the content of humotelinite and humodetrinite through the seam. From more than 20% in sample 1, the humotelinite content gradually decreases to a minimum of less than 5% in sample 4. In the upper part of the seam, the content of humotelinite increases to a maximum of more than 30% in sample 10. This development is accompanied by a more or less corresponding increase/decrease in the content of humodetrinite (maximum in sample 4). The contents of gelinite and corpohuminite are characterized by a weak increase towards the top of the seam except for a pronounced maximum for corpohuminite in sample 5. The liptinites are mainly represented by liptodetrinite and sporinite in the lower half of the seam, while the quantity of resinite and suberinite is high in the upper part of the seam, with two pronounced peaks for resinite in samples 4 and 8. The content of inertinite shows minor variations except for macrinite and fusinite, which have been encountered only in the lower half of the seam.

The lower part of the seam (samples 1-2) is characterized by many fragments of *Marcoduria inopinata* (Weyland 1957), occasionally arranged in a laminated manner (plate 1, fig. 1-2). Another characteristic is the

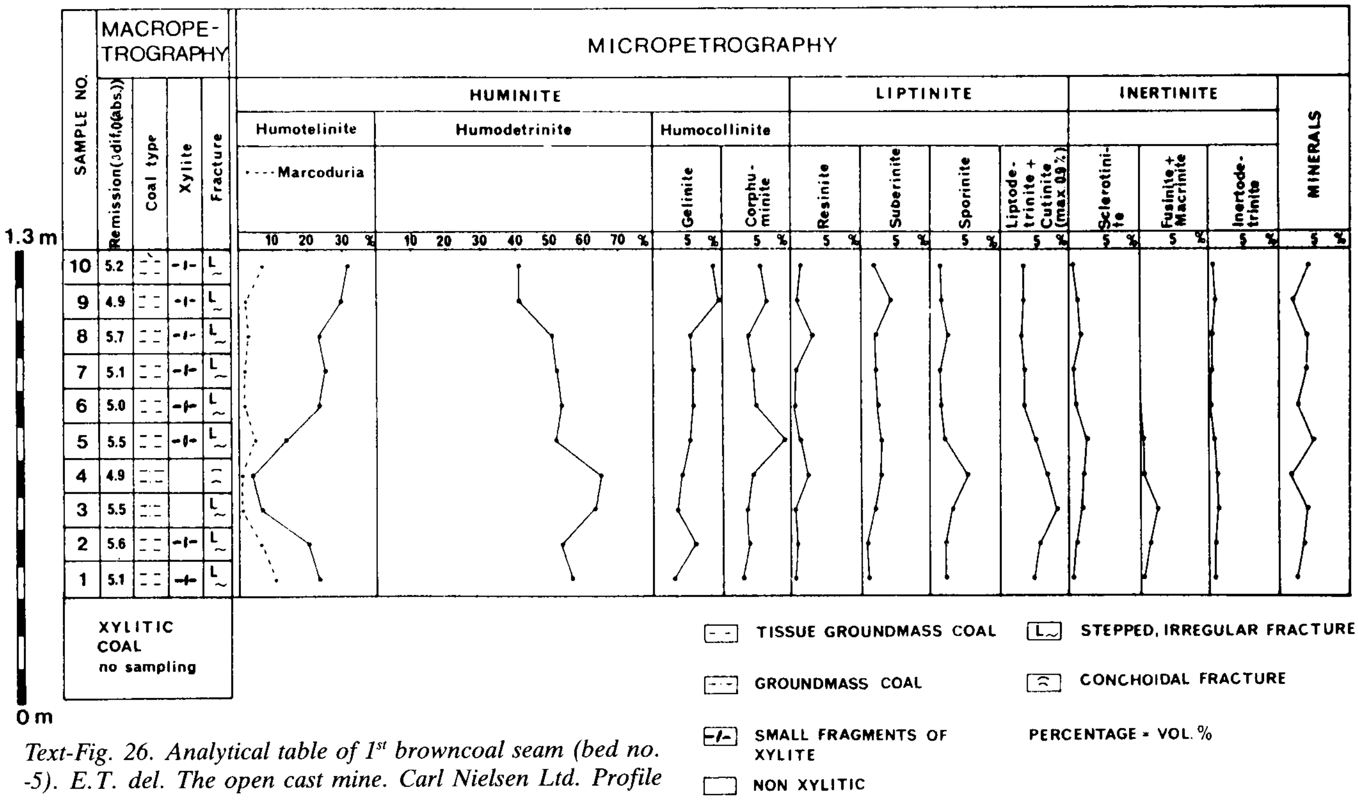
Maceral Group	Maceral	Maceral	Description
Huminite	Humotelinite	Textinite	Ungelified tissues
		Ulminite	Gelified tissues
	Humodetrinite	Attrinite	Ungelified humic detritus
		Densinite	Partly gelified humic detritus
	Humocollinite	Gelinite	Humic gels
		Corpohuminite	Humic cell infillings
Liptinite		Sporinite	Remnants of sporopollenin, suberin, cutin, resins, waxes, balsams, latex, fats and oils; as well as bacterial degradation products of proteins, cellulose and other carbohydrates
		Suberinite	
		Resinite	
		Cutinite	
		Bituminite	
		Alginite	
		Chlorophyllinite	
		Liptodetrinite	
Inertinite		Fusinite	Mainly charcoals
		Semifusinite	
		Inertodetrinite	Detritic inertinite
		Sclerotinite	Fungal remains
		Macrinite	high reflecting gels

Tabel 4. Maceral classification of brown coals.



Text-Fig. 25. Lithostratigraphical log, demonstrating the 3 main seams of the Fasterholt Member. Xylitic browncoal is marked by white chips in a black coal signature (beds no. -5 and 2), clay content by irregular white spots with density varying according to clay content. E.T. del.

presence of thick-walled wood fragments with a high content of phlobaphinite (?Taxodiaceae) (plate 1, fig. 3). A few cork tissues and minor roots are present. The groundmass varies between pronounced attrinitic to densinitic parts with isolated resistant macerals (plate 1, fig. 4). The isolated resistant macerals and the tissues often exhibit a distinct lamination. Allochtonous "stream placers", containing isolated corroded resistant macerals, is another characteristic element in this interval. Towards the middle of the seam (sample 3-4) the amount of preserved tissues apart from cork tissues and a few small roots is markedly reduced. The attrinitic groundmass is characterized by high contents of sporinite and liptodetrinite (maximum for the seam). The content of inertinite likewise attains its maximum in this interval and is mainly represented by inertodetrinite and fungal remains. Allochtonous "stream placers", often with macrinite and semifusinite and a high content of inorganic matter, are rather frequent in sample 3 but markedly reduced in sample 4 (plate 1, fig. 5). A distinct bedding and a high degree of sorting of the groundmass are frequently observed in sample 3 but only occasionally in sample 4. Sample 5 i characterized by a high content of cork tissues (high content of suberinite and maximum for corpohuminite). Humotelinite is mainly represented by remnants of *Marcoduria* and conifer wood. Roots are frequent in the mainly attrinitic groundmass, which has a high content of isolated resistant macerals, especially sclerotinite. The upper part of the seam is characterized by a high content of cork tissues, phloem sclereids and small degraded more or less gelified wood fragments, mainly angiosperms (plate 1, fig. 6). The remnants of conifers are represented by thick-walled tissues often with a high content of resinite and phlobaphinite. The content of conifer wood is especially high in samples 6, 7 and 10. The groundmass is mainly attrinitic, but densinitic parts and gelinite are often common. A gradual transition between tissues and groundmass is rather frequent, and an original wood structure is often visible in the groundmass, especially in situ Pholobaphinites are



Text-Fig. 26. Analytical table of 1st browncoal seam (bed no. -5). E.T. del. The open cast mine. Carl Nielsen Ltd. Profile F11.

common. The tissues and groundmass are often highly attacked by fungi, as evidenced by the frequent occurrence of hyphae, mycelia, spores and sclerotia.

Remnants of *Marcoduria* are well represented in sample 10, but they are markedly reduced in the other samples in the upper part of the seam. In contrast to the lower part of the seam, no distinct lamination has been observed. The pyrite content is varying but high in sample 10.

2nd Brown Coal Seam (bed no. 1 and no. 2)

This seam consists of two distinct beds, a lower 1.80 m detritic coal and coaly clay (1) and an upper 0.30 m xylitic coal (2). The results of the remission measurements and the macropetrographic and micropetrographic analyses are presented in Text-Fig. 27.

Macropetrography

Bed no. 1. This bed is characterized by a distinct colour change from base to top (β diff., 0 (abs) 5.8-17.5), which is related to an increase in inorganic matter. In the lower 1.10 m, the layer is a compact, homogeneous groundmass coal with a distinct bedding, often with a powder of silt-fine sand on the bedding planes. Towards the top, the content of inorganic matter increases, leading to a coaly clay in the upper part of the bed.

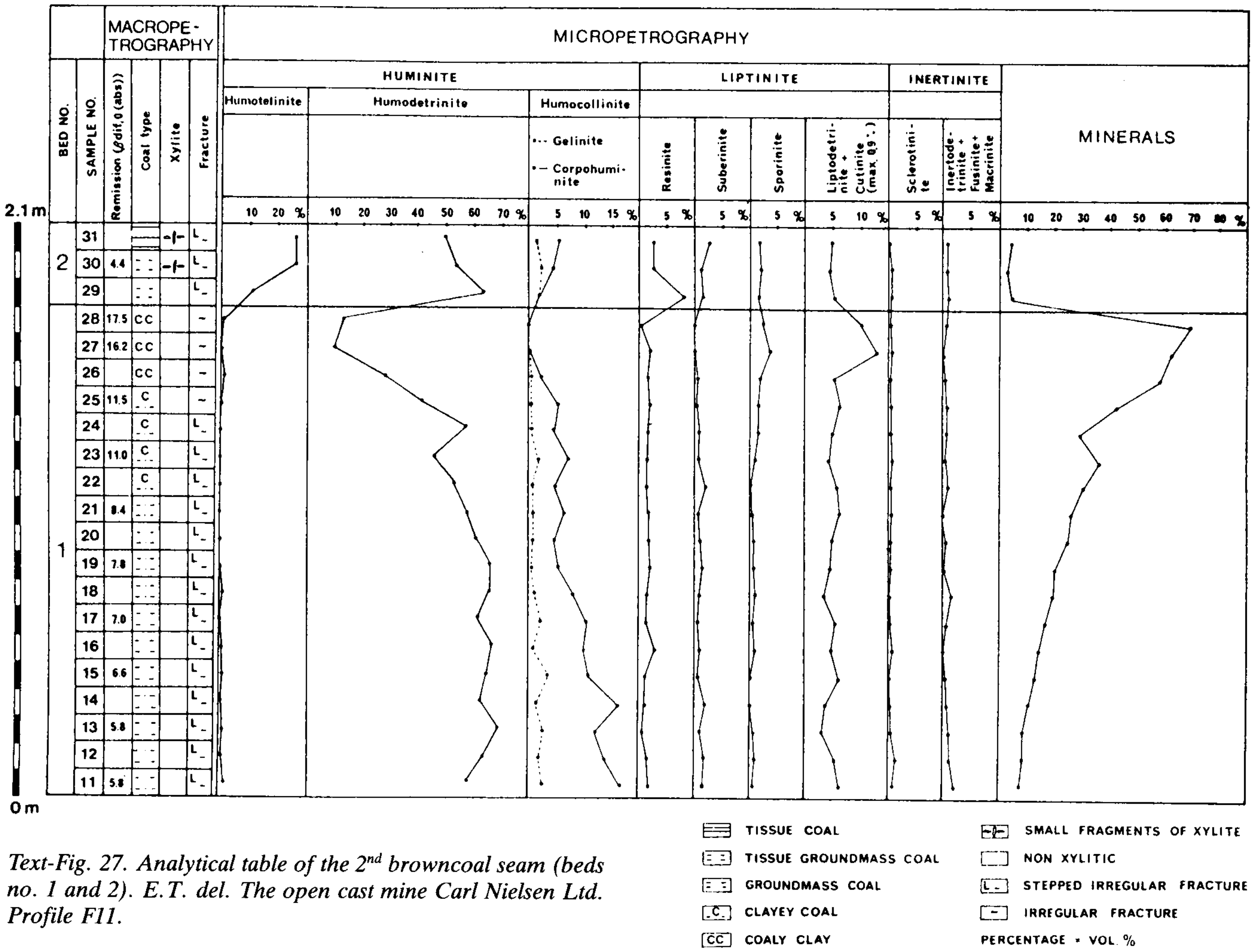
Bed no. 2. This bed is a black brown coal (β diff., 0 (abs) 4.4) containing abundant plant fragments, mainly xylite and humified compressed branch and stem fragments. The lower 0.20 m is a tissue-groundmass coal, while the upper 0,10 m is a tissue coal, with a distinct orientation of the megascopical plant fragments.

Micropetrography

Bed no. 1. The maceral analysis only shows major variations in the content of humodetrinite, corpohuminite, liptodetrinite and inorganic matter. Generally the bed is characterized by a high content of humodetrinite, corpohuminite and inorganic matter. The content of corpohuminite shows a marked decrease from base to top of the bed, while the content of inorganic matter exhibits a drastic increase in the upper part of the bed accompanied by a distinct decrease in the content of humodetrinite. Humotelinite, liptinite and inertinite contents are generally lower than 2%, while liptodetrinite attains high values in the upper part of the bed.

The lower 1.10 m of the bed is characterized by a mainly attrinitic groundmass with a relatively uniform grain size. The groundmass has a high content of isolated, resistant, often corroded macerals, especially phlobaphinite (plate 2, figs. 1-2). The resistant macerals are often concentrated with a distinct orientation, especially in the upper part of the bed. The resistant macerals demonstrate an increase in degree of corrosion up through the bed, accompanied by a marked reduction in their absolute content, especially for phlobaphinite. The inorganic matter is mainly clay, but in places pyrite is rather frequent.

The upper 0.70 m of the bed is characterized by a



Text-Fig. 27. Analytical table of the 2nd browncoal seam (beds no. 1 and 2). E.T. del. The open cast mine Carl Nielsen Ltd. Profile F11.

marked increase in clay content. The organic matter is mainly represented by strongly corroded liptinite, small attrinitic parts and highly degraded humotelinites (plate 2, figs. 3-4). In the mainly inorganic groundmass local occurrences of bituminite are present.

General characteristics for the upper and lower parts of bed no. 1 are a distinct lamination (microbedding), scattered occurrences of alginite of *Botryococcus* type and sponge spicules. In a few samples chlorophyllinite has been observed, identified by its characteristic red fluorescence.

Bed no. 2. The maceral analysis shows a distinct increase in humotelinite and corpohuminite contents towards the top of the bed, accompanied by a corresponding decrease in the content of humodetrinite. The content of liptinite and inertinite is low, except for liptodetrinite and resinite, the latter has high values at the base of the bed. The content of inorganic matter is highly reduced compared to the upper part of bed no. 1, and is mainly represented by coarse quartz grains, while the content of clay is insignificant. The often highly gelified groundmass is characterized by a rather uniform grain size. Concentrations of resistant corroded macerals like resinite, phlobaphinite and sclerotinite are frequent. These, together with the humotelinites, are often consequently orientated, especially in the upper part of the bed. The humotelinites are mainly represented by resin-rich tissues in the lower part of the bed, while tissues rich in tannins dominate the upper part.

3rd Brown Coal Seam (bed no. 6)

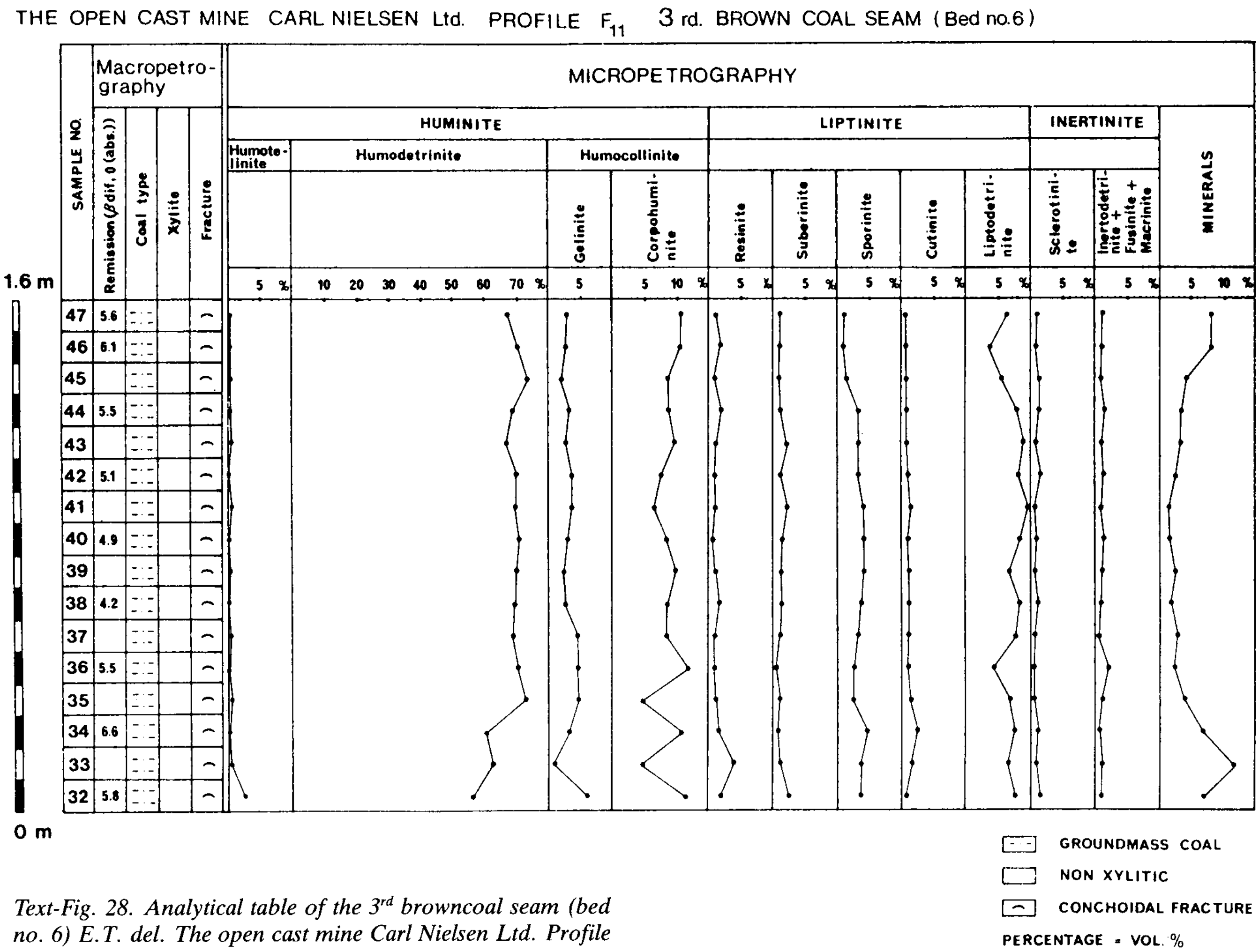
The results of the remission measurements and the macropetrographic and micropetrographic analyses are presented in Text-Fig. 28.

Macropetrography

The seam is a dark to brown (β diff., 0 (abs) 4.2-6.6), compact homogeneous groundmass coal with a pronounced conchoidal fracture. The content of inorganic matter is significant in the upper and lower part of the seam.

Micropetrography

The maceral analysis displays only minor variations in the maceral content through out the seam. A general characteristic is a high content of humodetrinite, spori-



Text-Fig. 28. Analytical table of the 3rd browncoal seam (bed no. 6) E.T. del. The open cast mine Carl Nielsen Ltd. Profile F11.

nite and liptodetrinite. The content of humotelinite is very low. Another characteristic is the very constant content of cutinite.

The samples are characterized by an unsorted attrinitic groundmass in which mainly uncorroded isolated phlobaphinites, resinites and sclerotinites are common. The contents of sporinite and liptodetrinite are very high, often demonstrating a distinct bedding with other macerals (plate 2, figs. 5-6). Tissues are strongly attacked by fungi and are mainly represented by degraded cork tissues, scattered occurrences of small roots and *Marcoduria.* Often an original woody structure is recognizable in the attrinitic groundmass. The content of inorganic matter is significant in the upper and lower parts of the seam and is mainly represented by clay.

Klynholt Vest section (KL)
5th Brown Coal Seam.

The seam is 0.80 m thick (cf. Text-Figs. 23 and 33). No continuous sampling was undertaken in this seam and thus it has not been possible to make a detailed macropetrographic and micropetrographic analyses. The investigated samples comprise one from the upper detritic part of the seam (0.15 m thick) and one sample from the lower, mainly xylitic part (0.65 m thick).

Macropetrography

The seam is developed as a xylitic coal in the lower part of the seam; towards the top the seam changes into a detritic coal. The sample from the lower xylitic part is a dark (β diff., 0 (abs) 5.7) tissue-groundmass coal; the sample is highly degraded and represents a powdered mass with small megascopical xylitic and humified plant fragments. The upper sample is a dark (β diff., 0 (abs) 5.3), highly degraded groundmass coal and like the lower sample, it is powderous.

Micropetrography

The lower sample (48) is characterized by a high content of humotelinite, mainly conifers. The groundmass is mainly attrinitic and is characterized by a very low degree of gelification. The content of liptinite is significant and bituminite has been observed in microlaminae.

The content of inorganic matter is very low.

			Proximate analysis			Ultimate analysis				Bitumen d.a.f.	Refl. R_0
			H_2O %a.f.	Ash %w.f.	Vol.M. %d.a.f.	C %d.a.f.	H %d.a.f.	O+N %d.a.f.	S %d.a.f.		
		49	13.1	7.8	59.1	61.0	6.1	29.3	3.6	21.1	
		48	18.4	8.1	57.7	64.8	6.5	24.5	4.2	23.4	0.25
		47	14.1	21.7	58.4	55.4	6.5	32.3	5.8	17.3	
		44	13.3	10.8	56.4	61.6	4.6	30.3	3.5		
	6	40	14.3	10.4	57.7	63.1	6.8	27.2	2.9	10.0	
		36	14.8	18.7	58.2	64.0	5.0	28.0	3.0		
		32	13.4	23.8	59.6	63.9	6.8	26.3	3.0	10.4	0.28
	2	30	13.0	16.3	60.6	62.2	6.7	25.6	5.5	8.6	0.28
		28	11.4	80.2	74.7	55.1	9.3	32.2	3.4	17.5	
		23	12.9	66.5	63.7	61.1	5.5	29.1	4.3		
	1	19	13.3	37.8	60.5	60.8	6.8	28.3	4.1	9.6	
		15	13.1	31.3	60.2	60.8	4.9	30.0	4.3		
		11	14.0	28.0	58.6	63.9	7.1	25.3	3.7	10.2	0.28
		10	13.2	14.3	61.1	60.1	6.3	27.7	5.9	11.8	
		8	13.0	10.5	61.1	63.5	4.9	27.3	4.3		
	-5	6	13.1	9.6	59.0	63.4	6.3	26.5	3.8	9.3	
		3	12.3	11.6	61.0	64.5	5.1	26.2	4.2		
		1	11.4	9.4	59.8	63.3	6.5	27.0	3.2	10.0	0.29

Tabel 5A. Chemical analyses and vitrinite reflectance measurements.

The upper sample (49) is characterized by a high content of humodetrinite and liptinite. Like the lower sample bituminite is found in microlaminae. The content of humotelinite is very low and mainly represented by highly degraded remnants of conifers. In both samples cork tissues and small roots have been observed.

Chemistry

The results of the chemical analyses and reflectance measurements are presented in table 5a.

Except for the content of ash and bitumen the chemical analyses reveal no significant difference between the seams. Since high ash percentages will influence the values determined for water-ash free material, only samples with less than 20% ash (w.f.) are comparable (Teichmüller 1968). Volatile matter and carbon contents vary respectively between 56.4-61.1%, 60.1-64.8% in samples with less than 20% ash. According to the German (DIN) coal classification (cf. Stach et al. 1982), the seams represent relatively low coalified soft brown coals, a fact which also is reflected by the reflectance measurements, i.e. 0.25-0.29% Ro (cf. table 4, Stach et al. 1975). A comparison with the results of chemical analyses of German soft brown coals (Teichmüller & Thomson 1958; Milde-Darmer 1964; Koch 1970), shows that all seams are characterized by a high content of hydrogen and a very high content of sulphur. Since it is well established that liptinite macerals are richer in hydrogen (Stach et al. 1975), the high hydrogen content is attributed mainly to the significant content of liptinite encountered in all seams. The sulphur content may be related to a high content of organic sulphur and pyrite. This is probably due to severe bacterial activity and an abundant supply of protein-rich organic matter. It is interesting to note that the sulphur content is highest in the upper part of the seams. The microscopical investigations show that this is due to a high content of pyrite, probably related to an ample supply of Fe-ions. Except for the upper part of the seams, the content of pyrite is generally found to be low, hence the high content of sulphur is attributed mainly to organic sulphur.

The ash content is directly related to the amount of inorganic matter present in coal. The values for the inorganic matter content obtained by microscopy are lower than those obtained by chemical analysis. This can in part be related to the respective methods applied, i.e. the determination of volume and weight percentages, but it is also due to difficulties in distinguishing between pore spaces and inorganic material by microscopical analysis. In general all seams are characterized by a high ash content, the variation of which in the second and third seam supports the results obtained by microscopical analysis.

The content of extractable bitumen is high in the upper part of the second and third seams (samples (28 and 47). This is related to the high content of liptodetrinite and local occurrences of bituminite. The high extract yield in the 5th seam (samples 48 and 49), can only be partly explained by the microscopic observations. The bituminous matter must be highly degraded, perhaps it is represented by fine bacterial degradation products. The high extract yield in the upper part of the second and third seams indicates the evolution towards the deposition of subaquatic muds under stagnant conditions (Stach et al. 1975). The high values in the 5th seam is probably related to a marine influence indicated by palynological investigations, the relatively high Mg:Ca ratio and the transgressive succession of facies in which the 5th brown coal seam is the basal unit (ref. chapt. 4.B.4.1. (pag. 92 cont.): The Hodde Formation and 4.B.6., Summary on Lithostratigraphy and Depositional History (pag. 100: Summary) and 4.B.7.6: Environmental Indications from the Microflora (pag. 149)).

Discussion

In any discussion of the genetic problems in coal petrology, the study of peats from recent analogous areas is very important. The river swamps on the Atlantic Coastal Plain contain a remarkable number of the floristic elements represented in the Fasterholt-Flora (Koch et al. 1973; Friis 1975). In certain environments in the Okefenokee Swamp, the peat appears remarkably similar to many European Tertiary brown coals with respect to colour, texture and maceral content (Spackmann et al. 1966). The geological setting associated with the Okefenokee area and with the deltaic river swamps and their vegetation, makes these comparable with the swamps that contributed to the development of the Søby-Fasterholt brown coal area in the Miocene. Cohen (1973, 1974) investigated the petrology of the peats in the Okefenokee area, and related them to original depositional and vegetational environments. Using coal petrographic analysis, Cohen (1973) found that the herbaceous peats showed low percentages of cell fillings and secretions, fungal remains and charcoal, and high percentages of fine granular debris; the peats derived from tree and shrub vegetation showed the opposite tendency (table 5b). Cohen stressed that the peats derived from shrub or tree vegetation have invariably a higher percentage of leaf and twig litter than the open marsh or glades peats. On the other hand the herbaceous types have a higher percentage of roots and rhizomes compared with the forest peats.

Using Cohen's quantitative data on the facies interpretation of Tertiary brown coals, one must bear in mind that coal macerals are in part coalified plant remains with shape and/or structure still preserved and in part degradation products, the plant origins of which are no longer recognizable. For the origin of brown coals, the macerals of the huminite group are of interest, especially the relation between tissues (humotelinite) and humic groundmass (humodetrinite). The data published by Cohen demonstrate marked differences in the quantitative composition between herbaceous peats, and peats derived from tree and shrub vegetation. In this context it must be stressed that the fine granular debris described by Cohen, will subsequently become mainly humodetrinite, eventually gelinite, and not micrinite as in fact suggested by Cohen (1973). Micrinite does not usually occur in peats or brown coals (Teichmüller 1968; Koch 1970), and it seems that it must be regarded mainly as a secondary maceral, that forms during coalification (Teichmüller 1974).

During humification of dead plant material, cellulose is decomposed more rapidly than lignin (Flaig 1968). The relatively stable lignins become concentrated in the peat, which occurs also in plant remains impregnated with tannins, resin, wax, pigments and suberin, e.g. woods and barks. Cellulose-rich plant remains from herbaceous plants and woods of certain angiosperms are less stable, and largely decompose to a humic detritus of cell wall remains; in part they decom-

Quantitative petrographic data applicable to the origin of coal types

	Peat type	Average percent* cell fillings and secretions (pre-resinites and pre-phlobophenites)	Average percent cell wall materials (pre-vitrinites)	Average percent fine granular debris (predominantly premicrinites with some pre-citrinites and mineral matter)	Average percent fungal remains (presclerotinites)	Average percent charcoal (fusinites and semifusinites)
Herbaceous types	Nymphaea	1	49	49	0.3	1
	Carex	1	65	32	0.3	2
	Panicum	1	62	35	0.3	2
	Woodwardia	2	46	49	0.3	3
Arboreous types	Cyrilla	15	56	25	1	4
	Taxodium	10	60	24	1	5

* Data based on point counts of 5 vertically oriented microtome sections of each peat type (1,000 pts. at 125×; pore space disregarded).

Table 5B. A. D. Cohen (1973).

pose further to generate humic gels between the detritus (Stach et al. 1975). Since Cohen's samples only represent surface peats, it can be assumed that the herbaceous and angiospermous peat types will on further decomposition, and under suitable conditions, yield high percentages of humodetrinite.

By comparison with the data published by Cohen (cf. table 5 b), it appears that due to a high content of cell fillings and tissues, *the 1st brown coal seam* represent mainly a forest swamp. The decreasing content of humotelinite upwards through the lower half of the seam, reflects an evolution towards a more open water environment due to the increasing content of resistant corroded macerals. This is supported by the allochthonous "stream placers", the sorting of the material and the bedding observed in sample 3.

In this context the occurrence of *Marcoduria*-like tissues is interesting. The original interpretation of Weyland (1957) that *Marcoduria* represents the remnants of a submerse water plant, has been disputed by Juchniewics (1975). She regards the remnants as representatives of rhizomes of monocotyledones, probably Phragmites, and thus the seam may contain a significant content of reed plants.

The presence of this reed element together with resistant gymnospermous woods, allochtonous "stream placers" and the distinct bedding, indicates a wet forest swamp with areas of open water with reed plants analogous to the more open part of the Nyssa-Taxodium swamp described by Teichmüller (1958), or the limnotelmatic facies described by Schneider (1969) and Hiltmann (1976). Towards the middle of the seam, the content of *Marcoduria* is highly reduced, which could infer an open water environment with water too deep for *Marcoduria* to survive. The upper part of the seam is characterized by a high content of highly degraded wood fragments and large pieces of cork tissues, which indicates an appreciable input of angiosperms. The angiospermous wood remains are accompanied by a significant content of coniferous woods, which indicates a drier forest swamp analogous to the drier forest swamps described by Teichmüller (1958), Schneider (1969) and Hiltmann (1976), perhaps with a mixed forest vegetation as described by Burgh v.d. (1973) and Brelie and Wolf (1981). The upper part of the seam (sample 10) is characterized by a high content of *Marcoduria* and conifers and could represent a passage to a more wet forest swamp, while sample 5 could represent a transitional facies to a drier forest swamp. Thus, the petrographic variations indicate that the 1st brown coal seam in CN represents several peat-forming environments, that have replaced each other in response to variations in groundwater level.

The 2nd brown coal seam in CN consists of two beds. The analysis of bed no. 1 indicates deposition in an open water environment (bedding, orientation of macerals, presence of fresh water algae and sponges). The mainly degraded nature of the organic matter, the lack of roots and the high content of inorganic matter, show that the deposit is allochtonous. The differences between the upper and lower parts of the bed indicate a gradual change in the environmental conditions. The lower part, dominated by humic organic matter, represents a transition from a humic detrital coal to a humic gytja. The upper 0.70 m of the bed is characterized by a high content of inorganic matter, mainly clay, and a high content of liptinite, representing a coaly (bituminous) clay. The increasingly selective character of the organic matter and the high degree of corrosion in the upper part of the bed, indicate a widening distance between the source area of the organic matter and the depositional site. This development is interpreted as representing a gradual infilling of a lake basin. The situation starts with a high input of organic matter, perhaps parautochtonous. A rise in the groundwater level leads to the formation of an open water area with an increasing distance to the areas of major organic production. The presence of silt-fine sand on the bedding planes could represent local washouts from nearby rivers or aeolian deposits.

Bed no. 2 of the 2nd brown coal seam in CN represents a parautochtonous-allochtonous deposit because of the constant orientation of coarser particles, the concentration of greater fragments of humotelinite in the uppermost part of the bed (driftwood), the coarse grain size and the presence of corroded macerals. The close relation to bed no. 1 indicates a shift of the environmental conditions starting with a major contribution of mainly detritic, often corroded material, changing into coarser material represented by resistant corroded macerals, coarse quartz grains and great fragments of humotelinite (driftwood) in the upper part of the bed. This situation represents a shift from a rather quiet depositional environment towards an agitated environment, possibly a stormy situation or a rapid shift of a river arm from a nearby drainage system.

The 3rd brown coal seam of CN is characterized by a high content of humodetrinite and liptodetrinite, scattered occurrences of roots and *Marcoduria.* The mainly unsorted groundmass often exhibits a pronounced bedding. The unsorted character of the detritic groundmass and the frequent bedding, indicate that the peat originated in a calm depositional environment mainly dominated by a less resistant herbaceous vegetation. The petrographic data of Cohen (1973) (cf. table 5B) sustains this interpretation but with the modification that the high content of cell fillings (autochthonous) could point to a significant contribution of woody tissues, probably analogous to the shallow "glades" dotted with tree islands in the Okefenokee area.

When compared with the petrographic data of Teichmüller (1950, 1958) and Teichmüller & Thomson (1958), the seam bears close similarity to the reed coals of the Rhenish brown coal area. However, a marked difference from the German material is the colour of the seam, which is nearly the same as the first forest coal seam in CN. The well-known banding structure of many coal deposits with alternating dark and light layers, was interpreted by Thomson (1950) and Teichmüller & Thomson (1958) as a result of alternating forest swamps and reed moors environments. Benda (1960) and Kilpper (1960) using cuticular analysis have demonstrated that the reed facies was to be found mainly in dark coal lithotypes, while the light reed facies of Teichmüller and Thomson seldom carried reed elements; a fact also noted by Schneider (1966). Milde-Darmer (1964) noted no significant difference in the composition of dark and light layers, while Jacob (1966) suggested an aerobic origin of the light layers in the sense of Wölk (1935). Hence, the dark colour does not necessarily prevent the 3rd seam from being interpreted as a reed coal, a situation which also is encountered in the 1st brown coal seam (samples 3 and 4).

Cuticular analysis by Schneider (1966, 1969, 1978) in the Niederlausitz brown coal area, led to a detailed reconstruction of the coal forming plant associations seen in relation to the macropetrographic composition of the coal. Schneider (1969) points to certain tendencies concerning the facies dependency on the distribution of the main lithotypes, but emphasizes that one particular lithotype does not necessarily represent one particular facies type. The tissue coals ("Geschichtete Kohle") are preferably attached to the border zone between forest coal swamps and the limnic areas, while the stronger decomposed textural types represent the drier forest swamps. Palynological studies by Hiltmann (1976) in the Rhenish brown coal area points to the same tendency in his reconstruction of the coal forming environments seen in relation to the macropetrographic composition of the coal.

A comparison with the data published by Cohen (1973) and the results of the present investigation only partly supports the results of Schneider and Hiltmann. Cohen demonstrates that the peats derived from shrub or tree vegetation invariably have higher percentages of leaf and twig litter than the open-marsh or glades peats. During humification this will lead to a higher concentration of humotelinite in the resulting coal.

The macropetrographic composition of the 3rd brown coal seam of CN suggests an evolution in a dry forest swamp according to the interpretations of Schneider and Hiltmann. The micropetrographic composition and the texture of the seam indicate a calm depositional environment dominated by less resistant plants. Bedding, frequently present in this seam would not be expected to occur in a dry forest swamp due to the high biological activity. This contrast to the interpretations of Schneider and Hiltmann can in part be explained by the presence of highly degraded tissues in the 3rd brown coal seam, which is only indicated by the high concentration of cell fillings. This suggests that woody tissues can probably contribute to the formation of peats without having a significant bearing on the macropetrographic composition of the resulting coal. Furthermore, the presence of resistant remnants of herbaceous plants like *Marcoduria* will have a significant bearing on the macropetrographic composition of the resulting coal. Cohen notes that reed peats are characterized by a high content of roots and rhizomes. The high concentration of such elements is clearly illustrated in the *Marcoduria*-rich horizons in the 1st brown coal seam. On the other hand, *Marcoduria* reeds occur associated with woody debris, which according to Cohen is rarely the case in recent reed peats. Whether this represents a specific relation to forest swamps or a high input of allochtonous material during the deposition of the *Marcoduria*-rich peat types, is difficult to determine. The 3rd brown coal seam of CN represents a reed/bush moor and carries only a limited amount of *Marcoduria* and *Marcoduria*-like tissues (less than 1%). This could suggest a specific facies relation. The facies succession in the 1st brown coal seam demonstrates, that *Marcoduria* is associated with the limnotelmatic areas. This is in good accordance with the interpretations of Schneider and Hiltmann.

The 5th brown coal seam from Klynholt Vest (cf. page 59, 60, 70, 140-142, 164) is represented only by two samples which represent two different environments. The lower sample (sample 48) has a high content of humotelinite and represents a forest swamp. The high content of liptinite, especially bituminite, points to wet, rather stagnant, conditions, probably analogous to the Nyssa-Taxodium swamp described by Teichmüller (1950, 1958) from the Rhenish brown coal area; an environment that is in marked contrast to the original *Sequoia* forest indicated by the basal root horizon (Wagner & Koch 1974). The upper sample (sample 49), because of the lack of humotelinite and a low content of cell fillings, points to an environment analogous to a reed moor. In both samples no distinct orientation and sorting has been observed. This, together with the presence of roots, points to an autochthonous deposition.

The results of the chemical analyses reveal only major variations in the ash and bitumen content that is in good accordance with the facies interpretations. Major chemical differences are not to be expected between the main coal facies (Teichmüller & Thomson 1958) and this is reflected by the investigated seams. The unusual high sulphur content, mainly attributed to organic sulphur, reflects dominance of rather wet peat-forming environments in the Søby-Fasterholt area that are favourable for the preservation of protein-rich, less resistant material.

PLATE 1

Microphotographies of browncoal samples from the Carl Nielsen browncoal pit (CN) at Fasterholt. E.T. Photo.

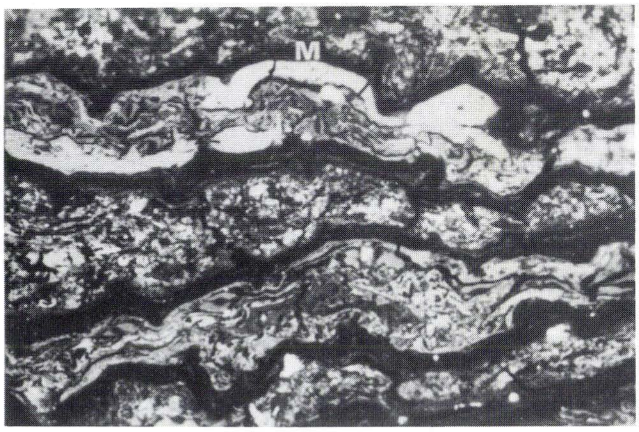


Fig. 1. Marcoduria (M) arranged in a laminated manner. Sample 1, 1st brown coal seam (bed no. -5) CN. Polished block, reflected light.

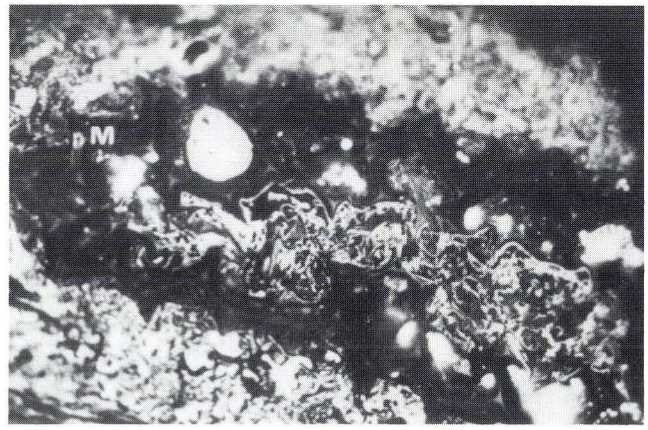


Fig. 2. Well preserved tissue of Marcoduria (M). Sample 2, 1st brown coal seam (bed no. -5) CN. Polished block, reflected light.

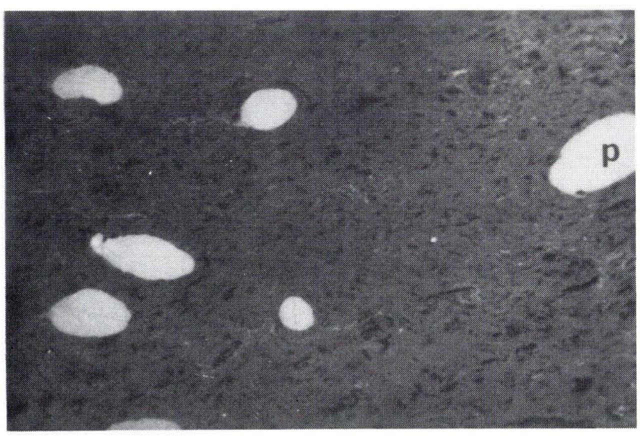


Fig. 3. Thick walled wood fragment with phlobaphinite (p), Taxodiaceae? Sample 1, 1st brown coal seam (bed no. -5) CN. Polished block, reflected light.

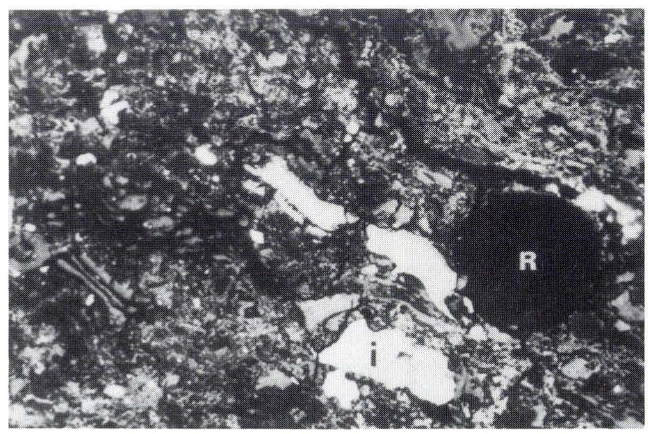


Fig. 4. Attrinitic groundmass with isolated resistant macerals, inertinite (i) and resinite (R). Sample 2, 1st brown coal seam (bed no. -5) CN. Polished block, reflected light.

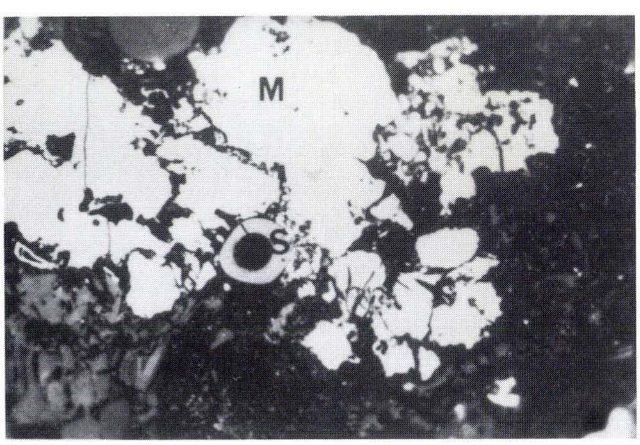


Fig. 5. Macrinite (M) and sclerotinite (S) associated with a mainly inorganic groundmass. Sample 3, 1st brown coal seam (bed no. -5) CN. Polished block, reflected light.

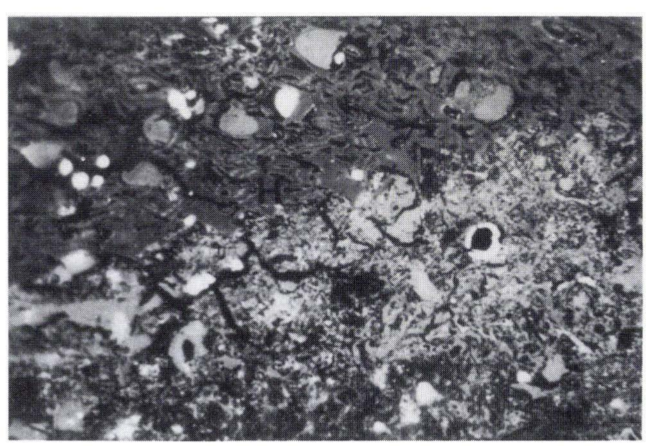


Fig. 6. Gelified degraded wood fragment (H). Sample 8, lst brown coal seam (bed no. -5) CN. Polished block, reflected light.

PLATE 2

Microphotographies of browncoal samples from the Carl Nielsen browncoal pit (CN) at Fasterholt. E.T. Photo.

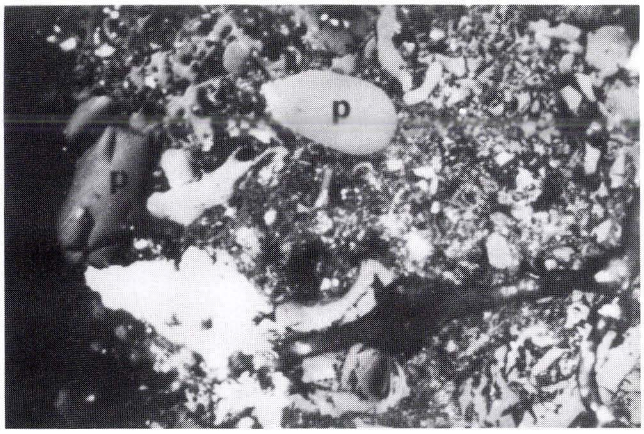


Fig. 1. A mainly attrinitic groundmass with isolated phlobaphinite (p). Sample 12, 2nd brown coal seam (bed no. 1) CN. Polished block, reflected light.

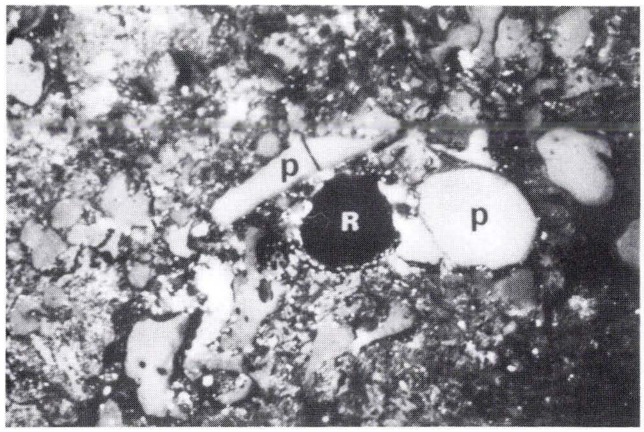
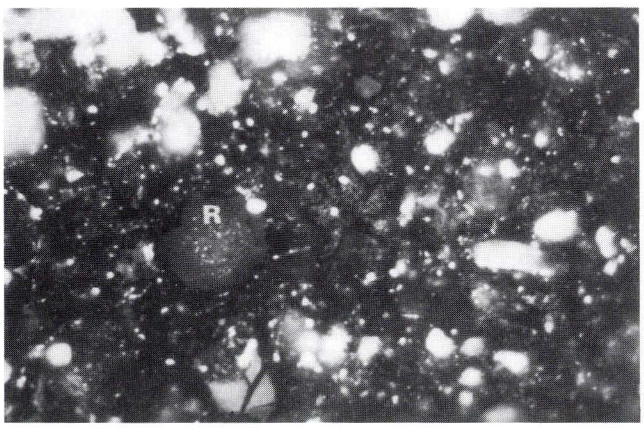


Fig. 2. A mainly attrinitic groundmass with corroded resinite (R) and phlobaphinite (p). Sample 13, 2nd brown coal seam (bed no. 1) CN. Polished block, reflected light.



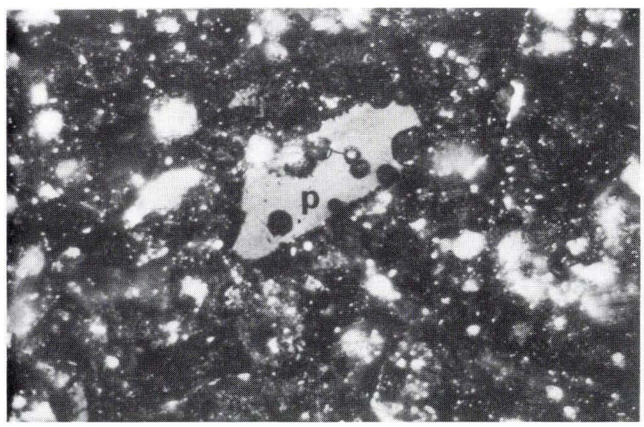


Fig. 3-4. Inorganic groundmass with isolated corroded resinite (R) (fig. 3) and phlobaphinite (p) (fig. 4). Sample 27, 2nd brown coal seam (bed no. 1) CN. Polished block, reflected light.

Fig. 5-6. Distinctly bedded atrinitic groundmass. Sample 39, 3rd brown coal seam (bed no. 6) CN). Polished block, reflected light.

Conclusions

This investigation shows that the four brown coal seams in the Søby-Fasterholt area represent different coal-forming environments. In the Carl Nielsen pit (CN) the *1st brown coal seam* represents the evolution from a moist forest swamp, dominated by gymnosperms, towards an open water environment, that gradually changes into a drier forest swamp with a mixed vegetation.

The 2nd brown coal seam in CN represents the gradual development and infilling of a lake basin that terminates with the deposition of a driftwood horizon.

The 3rd brown coal seam in CN represents a reed/bush moor.

The 5th brown coal seam in Klynholt Vest probably represents the gradual development from a forest swamp to a reed moor.

The chemical analyses reveal no significant differences between the investigated seams, apart from the ash and bitumen contents. The proximate and ultimate analyses, together with the reflectance measurements, indicate that the brown coals of the Søby-Fasterholt area are relatively low coalified soft brown coals. The high sulphur content and the local high ash percentages, make the brown coal deposits highly unfavourable for commercial use.

The results of this investigation show that a proper facies interpretation must incorporate detailed micropetrographic analyses, especially the texture, the content of woody debris (humotelinite) and cell fillings. The occurrence of *Marcoduria* seems to be restricted to limno-telmatic environments.

Acknowledgments

For helpful suggestions and discussions the author wishes to thank associate professor B.E. Koch, Dr. M. Teichmüller and professor M. Wolf. The work was supported by the Danish Natural Science Research Council.

References

Benda, L., 1960: Beiträge zur Stratigraphie und Fazies der rheinischen Hauptbraunkohlenflözes aufgrund einer Kutikularanalytischen Untersuchung der Tagebaue Vereinigte Ville, Berrenrath, Liblar, Lucretia, Sybilla, Fischbach und Fortuna. – N. Jb. Geol. Paläont., Abh. 109, 225-260.

Brelie, v.d., G. & Wolf, M., 1981: Zur Petrographie und Palynologie heller und dunkler Schichten in rheinischen Bucht. – Fortschr. Geol. Rheinld. u. Westf. 19, 95-163.

Burgh, J.v.d., 1973: Hölzer der niederrheinischen Braunkohlenformation. 2. Holzer der Braunkohlengruben Maria-Theresia zu Herzogenrath, Zukunft West zu Eschweiler und Victor (Zülpich Mitte) zu Zülpich. – Rev. Paleobot. Palynol., 15, 73-275.

Christensen, E. F., 1975; The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. – Geol. Surv. Denmark, II Ser. 103.

Christensen, E. F., 1976: The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. – Geol. Surv. Denmark, II. Ser. 108.

Cohen, A.D., 1973: Petrology of some Holocene peat sediments from the Okefenokee swamp-marsh complex of southern Georgia. Bull., Geol. Soc. Amer., v. 84, 3867-3878.

Cohen, A.D., 1974: Petrology and paleoecology of Holocene peats from the Okefenokee swamp-marsh complex of Georgia. – Jour. Sed. Petrol. v. 44, no. 3, 716-726.

Flaig, W., 1968: Biochemical factors in coal formation. – Coal and Coal-bearing strata. Edinburgh, London.

Friis, E.M., 1975: Climatic implications of microcarpological analysis of the Miocene Fasterholt flora, Denmark. – Bull. geol. Soc. Denmark, 24, 179-191.

Friis, E.M., 1976: Ascomycete svampe fra den miocæne Fasterholt flora, Danmark. – Dansk geol. Foren., Årsskrift for 1975, 5-9.

Friis, E.M., 1977a: Leaf whorls of Cupressaceae from the Miocene Fasterholt flora, Denmark. – Bull. geol. Soc. Denmark, 26, 103-113.

Friis, E.M., 1977b: EM-studies on Salviniaceae Megaspores from the Middle Miocene Fasterholt flora, Denmark. – Grana 16, 113-128.

Friis, E.M. 1979. The Damgaard flora: a new Middle Miocene flora from Denmark. – Bull. geol. Soc. Denmark, 27, 117-142.

Hiltmann, W., 1976. Pollenanalytische Untersuchungen im Rheinischen Kohlenflöz der Tagebau Frechen und Fortuna unter besonderer Berücksichtigung der makropetrographischen Ausbildung der Kohle. – Thesis, Technischen Hochschule Aachen.

International Handbook of Coal Petrography, 1963: – 2nd ed., edited by Int. Comm. Coal Petrol. Centre National Recherche Scientifique, Paris.

International Handbook of Coal Petrography, 1971, 1975: – Suppl. to 2nd ed., edited by Int. Comm. Coal Petrol., Centre National Recherche Scientifique, Paris.

Jacob, H., 1966: Petrologische, physikalische und chemische Untersuchungen zur Frage der Bildung heller Schichten in Braunkohlenflöze. – Braunkohle, 6, 206-209, 253-259.

Juchniewics, K., 1975: The fossil flora from near Bogatynia studied by cuticular analysis. – Prace Muzeum Ziemi, 24, 116-132.

Kilpper, K., 1960: Planzenführung, Fazies und Bildungsverhaltnisse im "Hauptflöz der Ville", eine Kutikularanalytische Untersuchung in den Tagebauen Neurath und Frimmersdorf-Süd des rheinischen Braunkohlenreviers. – N.Jb. Geol. Paläont. Abh. 109, 261-308.

Koch, B.E., 1975: Træk af brunkulsbrydningens historie i Danmark. – MIV 5, 10-19.

Koch, B.E., 1977: Stand der geologisch-paläontologischen Untersuchung miozäner Ablagerungen des zentralen Jütlands, Dänemark. – Cour. Forsch. -Inst. Senckenberg, 24, 77-82.

Koch, B.E. & Christensen, E.F., 1979: Introduction to the symposium: The continental Miocene of central Jutland (Denmark) – Geology – Brown Coal Facies – Stratigraphy – Paleontology. – Aarhus University, June the 11-16th, 1979.

Koch, B.E. & Friedrich, W.L., 1970: Geologisch-Paläobotanische Untersuchung der Miozänen Braunkohlen bei Fasterholt in Jutland, Dänemark. – Bull. geol. Soc. Denmark, 20, 169-191.

Koch, B.E. & Friedrich, W.L., 1971: Früchte und Samen von Spirematospermum aus der miozänen Fasterholt-Flora in Dänemark. Palaeontographica 136 B.

Koch, B.E. et al., 1973: Den miocæne brunkulsflora og dens geologiske miljø i Søby-Fasterholt området sydøst for Herning. – Dansk geol. Foren., Årsskrift for 1972, 1-57.

Koch, J., 1970: Petrologische Untersuchungen an niedersächsischen Torfen und Weichbraunkohlen. – Geol. Mitt., 10, 113-150.

Milde-Darmer, K., 1964: Kohlengeologiske Komplexuntersuchungen des Berzdorfer und Zittauer Flözes unter besonderer Berucksichtigung flözgenetischer Probleme. – Freib. Forsch. H., C. 154.

Rasmussen, L.B., 1961: De miocæne Formationer i Danmark. – Geol. Surv. Denmark, IV Ser., 4, no. 5.

Schneider, W. 1966: Beziehungen zwischen Pflanzeninhalt und petrographischer Beschaffenheit von Weichbraunkohlen am Beispiel der miozänen Braunkohlen der Oberlausitz. – Ber. Deutsch. Ges. geol. Wiss., A 11, 615-633.

Schneider, W., 1969: Cuticulae dispersae aus dem 2. Lausitzer Flöz (Miozän) und ihre fazielle Aussage. – Freib. Forsch. H., C. 222.

Schneider, W., 1978: Zu einigen Gesetzmässigkeiten der faziellen Entwicklung im 2. Lausitzer Flöz. – Z. Angew. Geol., Bd. 24, 3, 125-130.

Spackmann, W. et al., 1966: Phytogenic organic sediments and sedimentary environments in the Everglades-Mangrove Complex. Paleontolographica B., 117, 135-152.
Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D. & Teichmüller, R. 1975: Stach's textbook of Coal Petrology. - Borntraeger, Stuttgart.
Teichmüller, M., 1950: Zum petrographischen Aufbau und Werdegang der Weichbraunkohle. - Geol. Jb. 64, 429-488.
Teichmüller, M., 1958: Rekonstruktion verschiedener Moortypen des Hauptflözes der niederrheinischen Braunkohle. - Fortschr. Geol. Rheinld. u. Westf. 2, 599-612.
Teichmüller, M., 1968: Zur Petrographie und Diagenese eines fast 200 m mächtigen Torfprofils (mit Übergängen zur Weichbraun kohle?) im Quartär von Philippi (Mazedonien). Geol. Mitt., 8, 65-110.
Teichmüller, M., 1974: Über neue Macerale der Liptinit-Gruppe und die Entstehung des Micrinits. - Fortschr. Geol. Reinld. u. Westf. 24, 37-64.
Teichmüller, M. & Thomson, P.W., 1958: Vergleichende mikroskopische und chemische Untersuchungen der wichtigsten Fazies-Typen im Hauptflöz der niederrheinischen Braunkohle. - Fortschr. Geol. Rheinld. u. Westf. 2, 573-598.
Thomson, P. W., 1950: Die Entstehung von Kohlenflözen auf Grund paläontologischen Untersuchungen des Hauptflözes des rheinischen Braunkohle. - Braunkohle 2, 39-43.
Vogt, W., 1970: Der makropetrographische Flözaufbau in den Tagebauen Frechen, Fortuna und Inden des niederrheinischen Braunkohlenreviers unter besonderer Berücksichtigung der Brikettiereigenschaften der Lithotypen. - Thesis, Technischen Hochschule Aachen.
Wagner, P. & Koch, B.E., 1974: Fossil roots of Sequoia type from two localities of the Miocene delta deposits of the Søby-area, Denmark. - Bull. Geol. Soc. Denmark, 23, 134-158.
Weyland, H., 1957: Kritische Untersuchungen zur Kutikularanalyse tertiärer Blättern III. Monokotyledonen der rheinischen Braunkohle. - Palaeontographica B., 103, 34-74.
Wölk, E., 1935: Mächtigkeit, Gliederung und Entstehung des Niederrheinischen Hauptbraunkohlenflözes. - Ber. Vers. niederrh. geol. Ver. 28, 81-163.

(4.B.2.2.1.)

I.b. Depositional Structures of the Brown Coal Seams.

By B. Eske Koch.

The brown coal seams of the Fasterholt Member are in principle lenticular beds. The thickness of the individual seam is accordingly variable. Isopach maps have not been constructed for the area, but some initial experiments have been made (E. Heller (DGU) and E. Koch) from which some general trends can be suggested. During our investigations we found the two middle seams (2nd and 3rd seam) exposed over a sufficient distance (optimal extension of outcrop: 1 km in the Carl Nielsen Ltd. pit) to allow for observation of major depositional structures reproduced by these two seams.

From the working fronts of the Carl Nielsen Ltd. pit during the whole period of observations (1968-1970) the variation of thickness from the 2nd and 3rd seams and some intercalated clastic beds were measured and the depositional structures reconstructed in isopach-models seen on Text-Figs. 29, 30, 31.

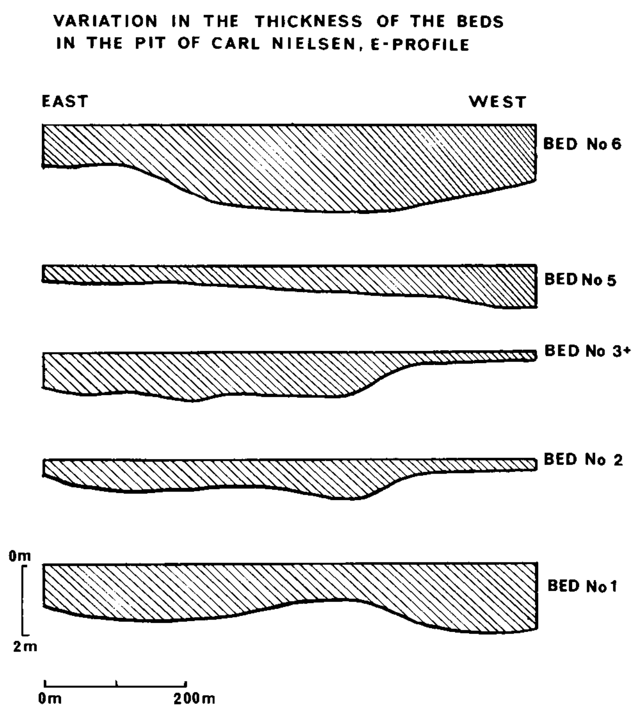
The lowermost seam has been exposed termporarly over a short distance in the western end of the pit and giving no evidence to suggest the overall type of structure. The measure was 1.2 m (bed no. - 5) and the basal sandy bed (no. -6): 0.5 m (sum 1.7 m).

A borehole was drilled at the extreme east end of the pit (at the working front, line K, autumn 1970, DGU drilling no. 95.1942) recording the lowest seam (bed - 5 and - 6). The accuracy of the drilling record does not allow comparison with the records from the pit, but the total thickness of the coal seam (bed no.- 5) and the underlying sandy coal (bed no.- 6) probably does not exceed 1 m. This measure implies a slow decrease in thickness eastwards. This is in accordance with personal information from the mining engineer Mr. Solgaard that the prospecting made by Carl Nielsen Ltd. shows a slowly decreasing thickness in the area to the east of the railway (which runs N-S just to the east of the pit) as well as in the eastern end of the pit.

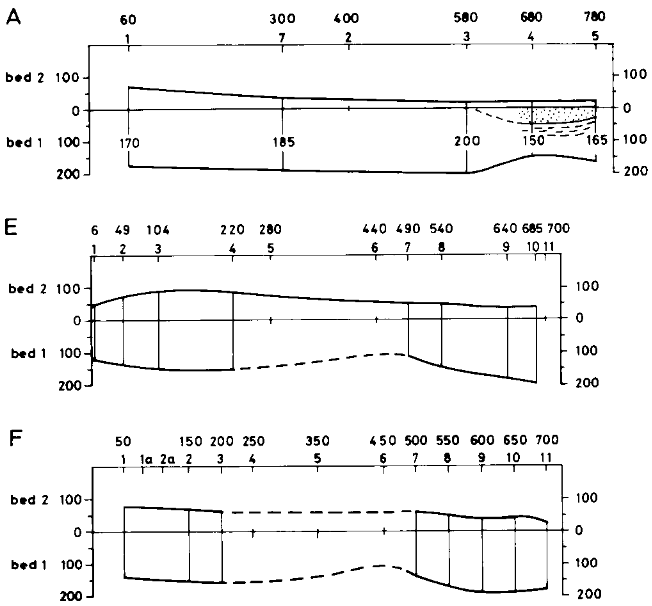
The E-W reconstructed profile through the southern part of the Søby-Fasterholt area gives some general trends (ref. page 75 ff., Text-Fig. 38 and table 10). The 1st brown coal seam has its optimal thickness in the Carl Nielsen Ltd. pit and decreasing generally towards the west into a very thin bed along the the west side of Klynholt.

The 2nd brown coal seam is divided into two parts, a thicker, lower bed (bed no. 1) consisting of compact detritus-coal deposited as a normal clastic sediment (deposition of particles). The deposit generally reproduces the shape of the depositional basin. The upper, thinner part of the coal seam consists of logs of driftwood which does not follow the normal sedimentary depositional pattern, but aligned parallel to the beach or banks on shallow water.

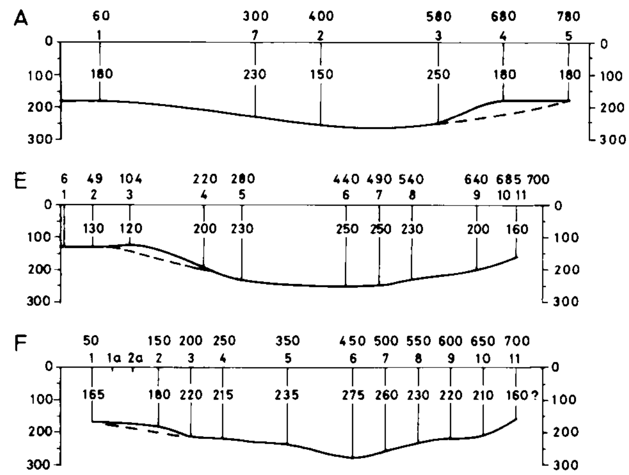
Hence, only the lower bed (no. 1), has been analyzed concerning variation in thickness. This bed wedges out



Text-Fig. 29. Generalized E-W sections showing the external structure of the browncoal beds (no. 1, 2 and 6) and the fossiliferous sand and clay beds (no. 3+4 and 5). E.F.C. del.



Text-Fig. 30. Diagrams showing the external structure of the 2nd browncoal seam (bed no. 1 and 2) in E-W direction through the Carl Nielsen Ltd. pit at Fasterholt. The sections were measured in the mining front A, E and F. The reference plane is the bedding plane between bed no. 1 and 2. Legend: Dotted=sand; Hatched=clay. Horizontal distances in meters, vertical in centimeters. E.K. comp.



Text-Fig. 31. Diagram (see Text-Fig. 30) of the 3rd browncoal seam (bed no. 6) in E-W-direction through the Carl Nielsen Ltd. pit at Fasterholt. The sections were measured on the mining front A, E and F. The reference plane is the upper surface of the 3rd browncoal seam overlain by the "Upper Sands". Horizontal distances in meters, vertical in centimeters. E.K. comp.

slowly eastwards except for an irregularity in the westernmost end of the pit, where a bank or bar occurs with a NW-SE orientation (Text-Fig. 30). This is not only a question of a geometrical structure but (ref. front A on Text-Fig. 30) also of coarser grain size and changing mineralogical composition of the sediment of this structure, first into clay and finally culminating in a sand lens enclosed in the uppermost level of the bed (no. 1). This is covered by bed no. 2, a thin sheet of driftwood coal.

The thickness of the upper driftwood coal (in bed no. 2) varies reciprocally to the detrital coal (bed no. 1), showing an optimal thickness towards the east and clearly wedging out towards the west into a thin "blanket". These observations support a model with low water, perhaps a coastal zone, somewhere to the east of the exposure of the Carl Nielsen Ltd. pit. The 2nd seam constitutes a lateral part of a large basin with its deeper part to the west of the pit.

The 3rd seam represents a more restricted basin or subbasin wedging out in the eastern and the western end of the pit (thickness 1.3 and 1.6 m respectively) with a maximum thickness of 2.5 m in the central part. While the western bar-structure locally constricts the basin of the 2nd seam towards west, (ref. front A, Text-Fig. 30), and clearly is a minor structure with NW SE orientation within a larger basin, the 3rd seam is restricted in wedging out in the western end of the brown coal pit of Carl Nielsen Ltd.

The geometrical analysis is in general accordance with the petrographical facies analysis of the brown coal presented in the former chapter, and with the isopach analysis of the clastic beds involved in this sequence.

These data are included in the analysis of the brown coal bearing sequence for the entire southern part of the Søby-Fasterholt area (ref. chapt. 4.B.2.2.2.B and Text-Fig. 38).

II. The Clastic Sediments intercalated between the Brown Coal Seams. (table 2 and Text-Fig. 24)

a. The clastic sediments between the 1st and 2nd brown coal seams.

These sediments comprise the beds no. 0 to -4. Of these beds no. -3 and -4 only occur sporadically and have been observed in the middle of the working front of the Carl Nielsen Ltd. pit. They wedge out westwards with bed no. -3 first to disappear followed by bed no. -4. The lenses of white sand that fills shallow erosional channels in the upper surface of brown coal bed no. -5 are discontinuous deposits with varying dimensions. The following description begins with these lenses and proceeds upwards.

Clastic sediments between the 1st and 2nd brown coal seams were recorded in the drilling logs without any detailed description (ref. chapter 4B.2.2.2).

The surface of 1st brown coal seam (bed no. -5) is irregularly eroded leaving space for small (a few cm deep and less than one meter wide) to large (1 meter thick and 50 meters wide) lenses. They consist of preferably white, fine grained to coarse sand with muscovite, similar to the larger sand structures of the "Upper Sands" (bed no. 7) but without the secondary Paleozoic marine fossils. Within or on top of the lenses is a thin bed or lamina of earthy brown coal (Text-Fig. 32.4). The larger lenses contain trunks of driftwood and plant detritus (twigs) (Atlas Figs. 31, 32, 33). In profile lines G-H-I (ref. Text-Fig. 3) a large number of similarly orientated, worn, well rounded, thick trunks devoid of the bark were found at the west end of the Carl Nielsen Ltd. pit (Larsen & Friis, 1973). Sieving the sand for fossil seeds and fruits etc. has been in vain.

Bed no -4 occurs sporadically and was deposited directly upon the lst brown coal seam or upon the lenses mentioned above. It is a thin bed (about 5 cm) of greenish-grey, medium-grained sand and is sometimes overlain by a similar thickness of light grey sand to silt.

Bed no. -3 is of sporadical occurrence and is presumably an approximately 10 cm thick extended lenticular structure consisting of an aggregate of lenses or lamellae of light yellow to brown fine-grained sand interwoven into a network of dark brown lamellae of browncoal detritus.

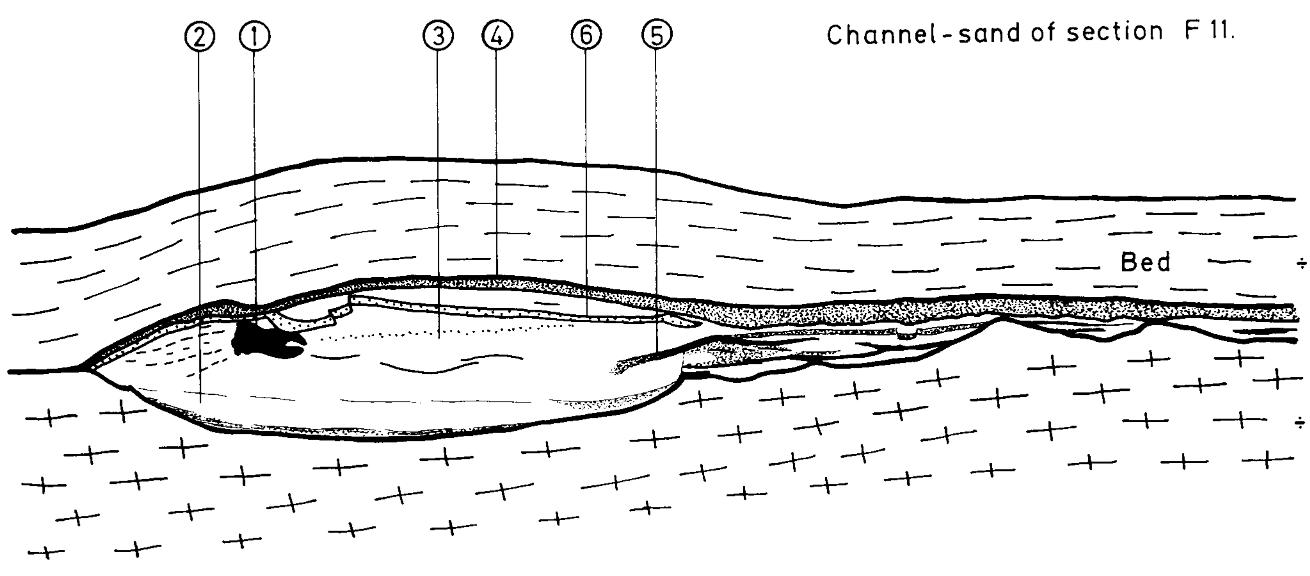
Beds number -4 and -3 seem to be local sandy variations that occur in the lower part of bed -2.

The pure inorganic sedimentary bed no -2 has a well defined lower boundary by following upon brown coal or beds containing coaly debris. Lowermost in bed no -2 there is a thin zone of silt grading into a composite sediment of clay and sand. This has a composite sedimentary structure consisting of small lenses of coarse sand, that vary between light and dark grey colour, interbedded (interwoven) in a matrix of grey clay. In the middle is a thin more continuous bed of coarse to medium grained sand. The clay component increases upwards more and more dominant and in the same time the clay and sand becomes more irregularly changing vertically as horizontally; and the bed finally grades into bed no. -1. The latter is a massive, homogeneous bed of fine, grey clay with a sharp, abrupt upper boundary when overlain by bed no. 0.

Bed no. 0 consists of fine-grained sand to silt of medium brown colour (turns into grey colour by exposal to the air similar to dy). In the upper part (Ob) sand to silt alternates with lamellae of brown coal detritus (organic matter 11%, ash 89%). In a lower subunit (Oa) and separated from the composite upper subunit by a well marked undulating surface we find a homogeneous brown silt similar to dy (Organic matter max. 12%, ash 88%). This lower part of the bed (Oa) is penetrated from its upper boundary by closely spaced vertical, incoaled thin roots. No stumps or tree roots have been found connected with this root bed. Probably it is referable to a herbaceous aquatic or semi-aquatic vegetation.

Bed no. 0 is overlain by the 2nd brown coal seam (bed no.1).

b. The clastic sediments between the 2nd and 3rd brown coal seams.



Text-Fig. 32. Lenticular channel sand deposited in a channel, eroded into the surface of the 1st browncoal seam (bed no. -5). The west end of the Carl Nielsen Ltd. browncoal pit at Fasterholt. E.F.C. del. The outcrop of fig. 32 was exposed in mining front F (E-W section) just to the west of profile F 11. The fluviatile sand lens is 6 metres wide with a maximum thickness of 80 cm. This structure is intercalated between beds no. -5 and-2. The latter bed (few cm. thick) arches up over the sand lens. For reference numbers in the figure see below. 1. The basal part of a trunk, transitional to the primary root branches, that is apparently redeposited as worn driftwood. 2. Dark grey fine sand located in the bottom of the lenticular structure. Its upper limit towards (3) is horizontally bedded. 3. The main component of the channel sand is light yellow-white fine sand containing numerous redeposited pieces of coal and a few lamina of dark earthy bituminous ooze. 4. The uppermost sheet of the channel sand is a earthy black unstructured browncoal overlain by bed no. -2. 5. Lignite embedded in the light channel sand (3) the lens. 6. Olive-green-grey fine sand situated just below (4) and separated from (4) by white fine sand. Near (1) it is broken up by vertical fractures.

This sequence consists of two well defined beds numbered (3+4) and 5, which have been exposed throughout the entire outcrops of the open cast mine of Carl Nielsen Ltd. Clastic sediments were also recorded in the drilling logs but without any detailed description (ref. chapter 4.B.2.2.2).

Bed no. (3+4) consists of fine to medium grained sand and silt, the latter has a significant clay content in some lamina. The bed is one single cross-bedded structure, presumably derived in one single depositional episode. The cross-bedding dips towards the west. The apparent cross-bedding dip in east-west sections of the Carl Nielsen Ltd. pit is very low (approximately 5°) appearing as faintly oblique bedding. Cross-bedding of the 1st order is also cross-bedded with steep westerly dip (2nd order cross bedding).

The thickness of bed no. (3+4) decreases continuously from 1.3 m at the east end to 0.1 m at the west end of the Carl Nielsen Ltd. pit. (ref. Text-Fig. 29).

A certain 20-30 m wide zone (measured along the mining fronts) of the sequence mined between the working fronts A to I and obliquely crossing the mining trenches in NW-SE direction at a distance of 350 m (A-front) – 150 m (I-front) from the east end of the pit, the sand bed no. (3+4) was rich in fossil cones, fruits, seeds, twigs, driftwood and coaly detritus (the *Fasterholt Flora*).

Obscure vertical structures originating in the upper boundary of the bed have been observed. These may be trace fossils of burrowing animals and traces of roots. The finding of a cylindrical pyritic concretion enclosing a root-like structure supports the latter interpretation. Other wider vertical tubes, but indistinct and badly preserved may represent burrowing animals. This may indicate a lacustrine depositional environment.

The basal max. 40 cm as well as some cross-beds are dark brown secondary coloured by humic compounds always occurring above an impermeable clay-rich bed or lamina (Larsen & Kuyp, 1971).

The lower boundary of the overlying bed no. 5 is abrupt. Bed no. 5 consists of a homogeneous, silty micaceous clay (5a). It is compact and well jointed, usually with two sets of vertical jointing perpendicular to each other: N1°-11° and N100°-107°; another system was also represented: vertical joints in direction N66° and N156°). This clay bed is relatively thin (0,45 m) in the east end of the pit (CN) and increases continuously towards west (1.35 m in the west end of the pit). (ref. Text-Fig. 29).

The bed number 5 is divided into two smaller units 5a and 5b. Unit no 5a is fossiliferous containing many scattered well preserved leaf compressions (The *Fasterholt leaf flora*) which have not been determined and analyzed. This clay is abruptly overlain by a maximum of 10 cm of white, very fine micaceous sand (unit no. 5b) with black lamina of coaly detritus.

The upper boundary with the 3rd brown coal seam is abrupt and distinct.

c. The clastic sediments between the 3rd and 5th brown coal seam: The "Upper Sands" of the Odderup Formation.

Above the 3rd brown coal seam follows these clastic sediments represented by a considerable thickness in the Fasterholt area that are dominantly sand with tabular cross-bedding (the "Upper Sands"). In the Carl Nielsen Ltd. pit this sequence is cut off by a Quaternary unconformity. The exact thickness is not known here but it reaches 7-10 meters (profile K6: 8 m, working front E: 10 m, the same measure also recorded in the drilling of Fasterholt Bjerge, DGU No. 95.894). At the drill site Bjerregaard, DGU no. 95.2166 this sand sequence is overlain by Hodde Clay and is 10 m thick. A similar thickness can be suggested from the drilling Fb 1, 1979 (Fasterholt Bjerg (ref. page 74, Text-Fig. 46). The thickness of this sand sequence decreases westwards. Hence, at the drill site in Munkballegaard. (Lavsbjerg Øst DGU no. 95.1995) where it is overlain by the Hodde Clay the "Upper Sands" is 7 metres thick. Further to the west at the west front of the Klynholt mining area the clastic sediments between the 3rd and 5th brown coal seams are 3.5 metres in thickness. Here is found above the 3rd coal seam 1 m of micaceous clay overlain by 2.5 m sands containing lamina and minor beds of brown clay.

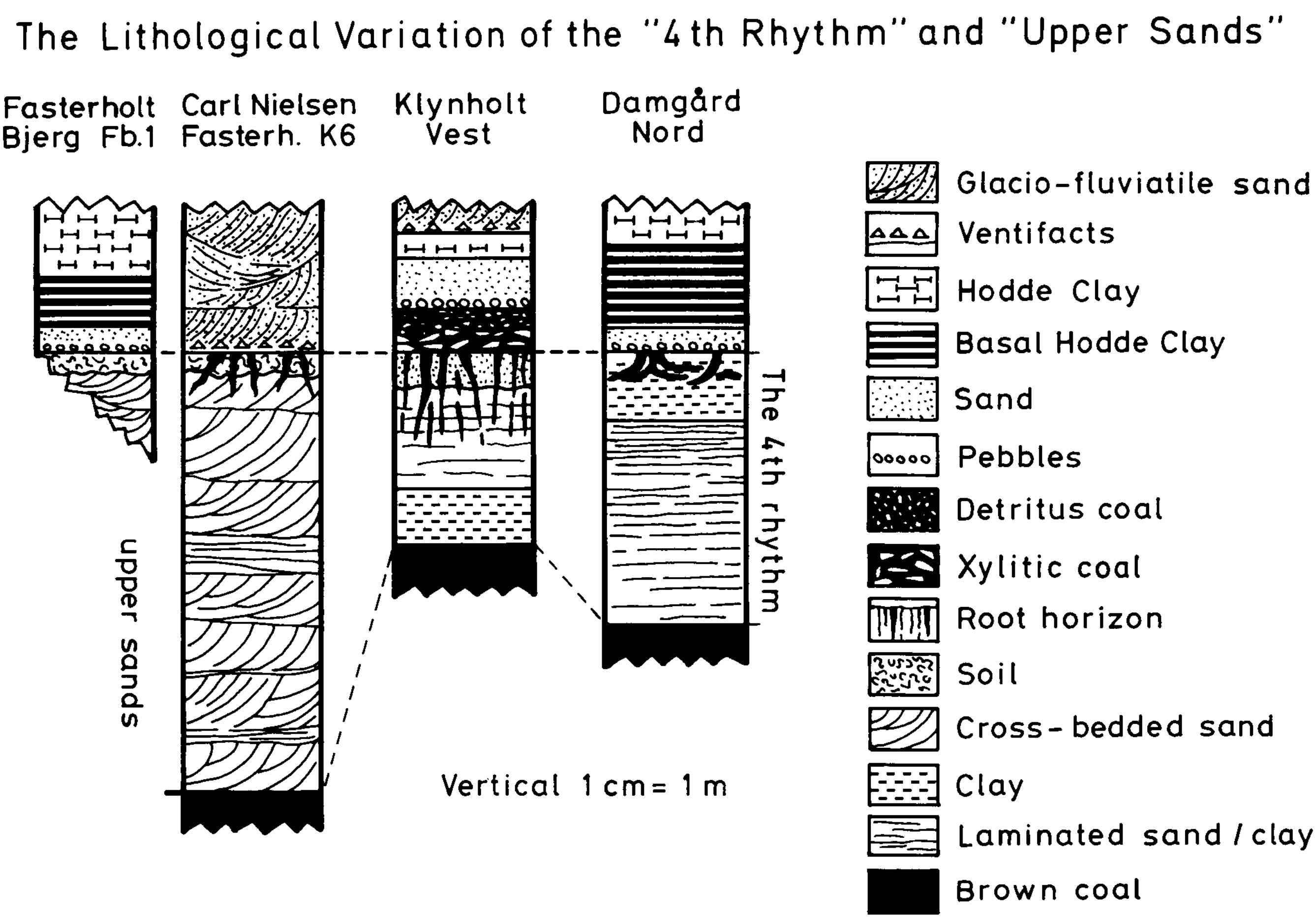
In the eastern part of the Søby-Fasterholt area the Hodde Clay seems to rest directly upon the white cross-bedded sand (ref. to drillings Fasterholt Bjerg 1, 1979, Bjerregaard and Lavsbjerg Øst (Munkballegaard)) and is valid for the north-front of the Klynholt mining area as well as its continuation in the pit of Søren Pedersen (to the N of Munkballegaard)). One exception is found in the middle of the working front K of the Carl Nielsen Ltd. pit where a black soil with roots of *Taxodioxylon gypsaceum* (related to *Sequoia sempervirens* (Wagner & Koch 1974) occurs at the culmination of the disconformity Tertiary/Quaternary (i.e. an erosional relict). Here the sands within a 50 m interval reaches an optimum of 8 metres in thickness, terminating in a fossil partially disrupted soil. According to the well "Fasterholt Bjerg 1" (Fb 1) this level of the paleosoil must be very near to the lower boundary of the Hodde Clay.

In the western and northwestern part of the Søby-Fasterholt area, the upper part of the sequence between the 3rd and the 5th local seam is modified, containing clay lamina or clay beds as described from the different localities: One or more thin clay lamina just below the Hodde Formation in the central part of the north front of the Klynholt mining area; a 2-2.5 m sequence of brown (humic) clay beds (-lamina) alternating with white sand (the amount of clay increases upwards as the sand decreases) below the boundary of the Hodde Formation in the Damgaard N pit where a 0.7-1.3 m thick clay bed terminates the sequence and is overlain by the Hodde Formation. Fossil roots from the boundary contact with the Hodde Clay penetrate the upper part of this clay which is rich in well preserved fossil leaves, coniferous twigs and compressed fruit (the *Søby Flora*). A similar sequence terminates the "Upper Sands" of the Odderup Formation in the NW corner of the Klynholt mining area but here it contains only thin clay beds and ends with a sand bed containing a root – and stump horizon overlain by the 5th brown coal seam. On this coal seam rest the basal transgressional gravel of the Hodde formation.

This modified representation of the "Upper Sands" of the Odderup Formation in the western and north-western part of the Søby-Fasterholt area is a restricted local facies. In the Damgaard S east front the "Upper Sands" yielded scattered fossil seeds. described as the *Damgaard Flora* (Friis 1979). The sands have been investigated by professor G. Larsen and his pupils 1971-72 (unpublished). The transitional sequence ending the succession of "Upper Sands" is treated below in special sections. The present data derives in a principally palaeontological and coal petrographical investigation so this extended sand deposit was only given minor attention and no detailed sedimentological description will be presented. For supplementary information the reader can be referred to Larsen & Friis (1973), Friis et al (1980). The "Upper Sands" is a white sand deposit of varying grain size and appears in regular cross bedded tabular structures. The dip of the cross-bedding is generally in NE direction but changes between SE to NE (see also Larsen & Friis 1973). Beds with undoubted westerly dip were exposed for a time during 1970 in the westerly part of the Carl Nielsen Ltd. pit. The "Upper Sands" contain pebbles of silicified Ordovician limestone containing fossils or isolated worn fossils well-known from the Baltic region to the NE of Bornholm and extending to the south of the Åland islands (Spjeldnæs 1975 and Spjeldnæs in Koch et al 1973).

c.a) The "Upper Sands" of the Carl Nielsen Ltd. pit at Fasterholt.

The "Upper Sands" is a pure sand deposit (with subordinate gravel) found between the 3rd brown-coal seam and the Hodde Formation. During the present investigation it was exposed in its entire extent in the Carl Nielsen Ltd. pit at Fasterholt. At this locality it



Text-Fig. 33. Facies variation in the sequence above the Fasterholt Member (3rd and 4th browncoal seams), from the main localities in the southern and western Søby-Fasterholt area. In the locality next to the village of Fasterholt, the deltaic facies ("Upper Sands") is typical. In the western-northwestern localities continuation of this facies is represented by a lacustrine 4th rhythm (a "coarsening upwards" succession). E.F.C. & E.K. del. et comp.

rests on the 3rd brown coal seam with a sharp and distinct boundary between these two contrasting deposits. There are no distinct signs of an erosion in the surface of the coal bed. There is no evidence of any gradation in grain size of the sands just above the boundary. A thin zone (max. 10 cm) of sand, brown in colour from secondary pigmentation, can be found where the sand is in contact with the coal (groundwater precipitation of humic compounds).

The sand is arranged in cross-bedded tabular structures (beds) (Atlas-Fig. 51) with a high content of quartz, hence its pure white appearance. Current ripples have been observed between tabulate beds. It is well-sorted within a single lamina of the cross bedding but the lamina vary from fine to coarse-grained. Mica is the most important accessory mineral. The "Upper Sands" appears as a homogeneous deposit concerning position and depositional structure throughout the 7-10 m thick section. The cross-bedded units are thin, generally 1/2 m thick but usually thinner in the uppermost part of the unit. The cross-bedding generally dips towards NE but deviates into E to SE. During a period in 1970 an exposure at the western end of the pit showed a westerly dip for cross beds in the middle part of the sequence. In a few cases small lenses of a serpentine-green clay were found in this western part of the pit, but the mineralogy could not be optically determined.

The sand is devoid of primary fossils but generally contains pebbles of secondary Ordovician fossils isolated or in silicified grey-bluish limestone well known from the Baltic region between Bornholm and Åland-island. A collection from this locality was determined by N. Spjeldnæs (in Koch & Friedrich, 1970, Spjeldnæs, 1975) who found the following species:

Corals: 1 fragment of a heliolithidean coral
Bryozoans:
Diplotrypa petropolitana Nich.
Mesotrypa sp.
Dianulites cf. *fastigatus* Eichw.
Hallopora sp.
Nemantotrypa sp.
Ceramoporoide sp.

In the Carl Nielsen Ltd. pit the "Upper Sands" are overlain by the Quaternary glacio-fluviatile deposits. The boundary is a disconformity. The overlying Hodde Formation is not exposed. It is found in the outcrops in the Lavsbjerg Hill (Klynholt and the Damgaard mining area).

In working front K at profile K6, Carl Nielsen Ltd. mining pit a culmination of the disconformity exposes an optimal thickness of the "Upper Sand".

Here, uppermost a black soil horizon was exposed, only undisturbed for a short distance (10 m), elsewhere the cryoturbation had deformed it and left a dark grey core of this soil in each "pocket". The soil was penetrated by remains of almost vertical tree-roots, which had often resisted the cryoturbation and preserved small relicts of the soil around them. This soil will be treated in detail in a separate chapter (ref. page 129) because of its implication on environmental and stratigraphical discussions.

At about the level of the unconformity, as found above the black soil horizon of profile K6, the Hodde Formation was seen to rest on grey sand in the hill of Fasterholt Bjerg (drilling Fb 1, 1979) (ref. the drilling log at page 74 ff. and Text-Fig. 46). Obviously this soil- and root horizon is overlain by the Hodde Formation analogous to the situation recorded from the western localities of the Søby-Fasterholt area and is evident from the probe set on the nearby hill, Fasterholt Bjerg. The eastern end of this hill is situated just to the south of the western end of the Carl Nielsen Ltd. pit where a N-S auxiliary trench at this place gives access for a road leading down into the pit. This extension of the pit reaches just into the foot of the hill and continuously exposes the brown coal bearing sequence and the "Upper Sands" all the way.

The Fasterholt Bjerg (hill) is made up of the clays of the Hodde- and Gram Formations. About 150 m WSW from the nearest exposure of the "Upper Sands" in the southern appendix of the Carl Nielsen Ltd. pit (and 625 m from profile K6) a probe Fb. 1, 1979 (surface elevation 57.5 m) penetrated the Gram Clay, glauconite clay and Hodde Clay which was seen to end in gravel and grey sand at 14.5 m below the surface. The base of this sequence is at a level corresponding approximately to the level of the soil and root horizon overlying the "Upper Sands" mentioned as occurring in profile K6. The gravel may correlate with the basal gravel of the Hodde Formation, and the "grey sand" might be identical with the soil. We cannot exclude the possible presence of the impermeable 5th brown coal seam, but the technical circumstances under which the probing was stopped (a high artetic hydrostratic pressure) exclude the existence of an impermeable coal or clay bed within a meter beneath the end of the probing.

c.b. The soil and root horizon of front K at the brown coal pit of Carl Nielsen Ltd.

The boundary between the Tertiary and the Quaternary in the Carl Nielsen Ltd. pit at Fasterholt is marked by a disconformity with shallow undulations and a pavement of stones, among which many are ventifacts (Atlas-Fig. 63). In the working front K (1970) at profile K6 (Table 6, Wagner & Koch, 1974), the disconformity is a flat culmination stretching over a distance of about 50 m with an amplitude of 1-2 metres. Within the culmination is a remnant of black soil, 20-30 cm thick (Wagner & Koch, 1974, Fig. 2) (Atlas Fig. 64), which has mostly been removed by erosion responsible for the disconformity. This paleosoil originated on a cross bedded quartz sand (bed no. 7) and contains 5% "organic matter" (black, organic debris). (After separation of the sand from the paleosoil the remaining black fraction contains 37% ash respectively 63% organic matter. The organic matter consists of small particles of plant debris, of wood, isolated tracheids, vessel, sievetubes, sieve plates, bordered pit, pieces of cuticles, epidermal fragments, amorphous humic substances, resin, and a great quantity well preserved pollen and spores.

The soil presumably has been eroded considerably before the Quaternary erosion because it contains three roots only as thick as a finger and never thicker. The trunks to which they belonged are not preserved at all and must have been placed further up in the soil. The roots have been determined by Wagner to *Taxodioxylon gypsaceum* (affinis *Sequoia sempervirens*) (Wagner & Koch 1974). The roots pass at a steep angle (more than 60°) through the soil. This information points to a well-drained soil, and the determination of the roots of *Sequoia* sp. indicates the soil to be Tertiary.

It is obvious that these soil remnants represent only a lower part of the original soil that supported the Sequoia trees. It cannot be proven at this moment whether this soil was the basis from which a 5th brown coal seam evolved similar to what has been described from the west front of the Klynholt mine at a near (if not the same) stratigraphical level. The nearest drilling DGU no. 95.2166 Bjerregaard and DGU no. 95.1942, Fasterholt Bjerge (and the probe Fasterholt Bjerg 1, 1979) have not added sufficient detailed information to contribute to the solution of this problem.

The disconformity represents a surface that has been exposed to an arctic climate during the Quaternary ice ages, presumably early Weichselian (Würmian). The zone below the disconformity is more or less overprinted by periglacial soil structures (Atlas Fig. 67). Hence, most of the original black soil has been disturbed while remains are preserved as a grey core in cryoturbation pockets (Koch et al. 1973, Fig. 6), except for the sites containing roots. The roots have been resistant to the cryoturbation and have kept a surrounding cap of black soil (Wagner & Koch, 1974, Fig. 3) (Atlas-Fig 65). The roots are rather miserable the central wood being highly dissolved and often replaced by sand, especially in the upper part of the roots where they are wider and near to the disconformably overlying Quaternary surface. Some roots are better preserved in the deeper part of the fossil soil to allow a determination (see above). The fossil pollen and spores are corroded to a different degree and often physically deformed but a significant percentage is well preserved (see below).

Regarding the interpretation of the observations of this stratigraphical level, ref. chapter 4.B.2.3.

Mr. P. Ingwersen (Geological Survey of Denmark) in 1970 made a preliminary inspection of the fossil pollen of this soil and found the following genera represented (personal communication):

Pinus silvestris type	*Taxodium* sp.
Pinus haploxylon type	*Sequoia* (?)
Betula	*Rhus* type (?)
Alnus	*Ulmus* type
Corylus-Myrica	*Picea* type
cf. *Cyrilla* type	*Castanea* type
Tilia (2 types)	*Tsuga*

Later the senior author during a bio-stratigraphical investigation found the following fossil species (generally

Table 6: The sequence above the upper browncoal searn of the productive member at Fasterholt. Record of section K6, the Carl Nielsen Ltd. browncoal pit (after Wagner & Koch, 1974).

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

in terms of Thomson and Pflug, 1953 and Brelie, 1967, 1968. See pag. 135 and table 20):

	Number of specimens	%
Pinuspol labdacus Potonié	25	13
Abietinaepol. microalatus Potonié	9	5
Tsugapol. igniculus Potonié	2	1
Sequoiapol. polyformosus Thiergart	5	3
Taxodiaceaepol hiatus Potonié	3	2
Sciadopityspol. serratus (Pot. & Ven.) Raatz	5	3
Inaperturopol. dubius (Pot. & Ven.). Potonié	8	4
Platanoidites gertrudae Pot., Thoms. & Thiergart	1	½
Quercoidites henrici Potonié	3	2
Quercoidites microhenrici Potonié	7	4
Tricolpopol. quisqualis Potenié	1	½
Tricolpopol. fallax Potonié	2	1
Tricolpopol. parmularius Potonié	1	½
Cupuliferoidaepol. fusus Potonié	2	1
Cupuliferoidaepol. pusillus Potonié	2	1
Cyrillaceaepol. megaexactus Potonié	9	5
Cyrillaceaepol. exactus Potonié	5	3
Rhoipites pseudocingulum Potonié	9	5
Nyssapol. sp. sp.	7	4
Momipites punctatus Potonié	13	7
Platycaryapol. microcoryphaeus Potonié	1	½
Trivestibulopol. betuloides (Pflug) Potonié	10	5
Triporopol. robustus (Pflug) Potonié	1	½
Triporopol. coryloides (Pflug) Potonié	37	2
Intratriporopol. instructus (Pot. & Ven.) Potonié	12	6
Alnipol. verus Potonié	2	1
Pterocaryapol. stellatus (Pot.) Raatz	2	1
Liquidambarpol. stigmosus (Pot.) Raatz	2	1
Total	186	100

Besides a normal Middle Miocene representation of species there is a remarkably high representation of betuloide (*Trivestibulopol. betuloides* (Pflug) Potonié), coryloide (*Triporopol. coryloides* (Pflug) Potonié) and tilioide (*Intratriporopol. instructus* (Pot. & Ven.) Potonié) pollen which might refer to the understore of the *Sequoia* forest to which the root remains in the soil bears witness (Wagner & Koch, 1974), or to a mixed forest association including *Sequoia,* on relatively dry land.

c.c. The succession of the NW-corner of the Klynholt mining area.

A short account of the transitional succession between the brown coal bearing succession and the Hodde Clay in the NW-corner of the mining area of Klynholt was published by Wagner & Koch 1974. Observations from the west wall of the open cast-mine of Klynholt (section EM) were undertaken at its final stage when the mine had been abandoned and before the recent stage of total submersion (Atlas-Fig. 70). The observations have been made by the senior author in 1970 when nearly the whole sequence above the 3rd brown coal seam was exposed and a detailed survey was made by E.M. Friis in 1971. These observations are substantiated by the drilling DGU no. 95.2163, Fasterholtgaard no. 1 and by two probes made by the Department of Stratigraphy and Paleontology, Aarhus University 1978 (BI-BII). This latter probe is situated in line with the west wall of the pit and at its north end. The DGU borehole no. 95.2163 is less than 50 m to NW of the latter (ref. Text-Fig. 21, point 5; 39). So a length section of 70 meters in N-S direction can be described as follows below (ref. Text-Fig. 34). This section can be correlated with the exposures to the north in the Damgaard mining area by means of several small probes which were set in the intervening area in 1972 (ref. Text Figs. 39, 40).

E.M. Friis' survey is based upon the records of two profiles, EM I-II, one in each end of the section. There is a high degree of similarity between the two profiles, the only important deviation is that the erosional boundary between the 5th brown coal bed and the overlying sand (with pebbles at the basis) has been only recorded in the northern profile. A generalized description is presented below in Table 8:
The uppermost 1.20 m consist of aeolic sand with the recent soil and a debris horizon above and a heather soil below. Further an iron pan (podsol) occurs at the bottom of the heather soil.

The underlying Quaternary deposits consists of 3 meters of sand lamellated with silt and gytja at the top and in the bottom of the unit. This sandy sequence presumably represents the eastern flank of the Quaternary fluviatile depositional structure which follows the stroke of the Fasterholtgaard-Søby road mentioned

Table 7. The sequence above the upper browncoal seam of the Fasterholt Member. Record of section EM, NE-corner of Klynholt mining area. (after Wagner & Koch, 1974).

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
Tertiary	1.6 m	Fluviatile sands Pebbles
		erosion (current-ripples)
	0.8 m	black, sapropelitic, detrital brown coal Browncoal (Xylite)
	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 secondary 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

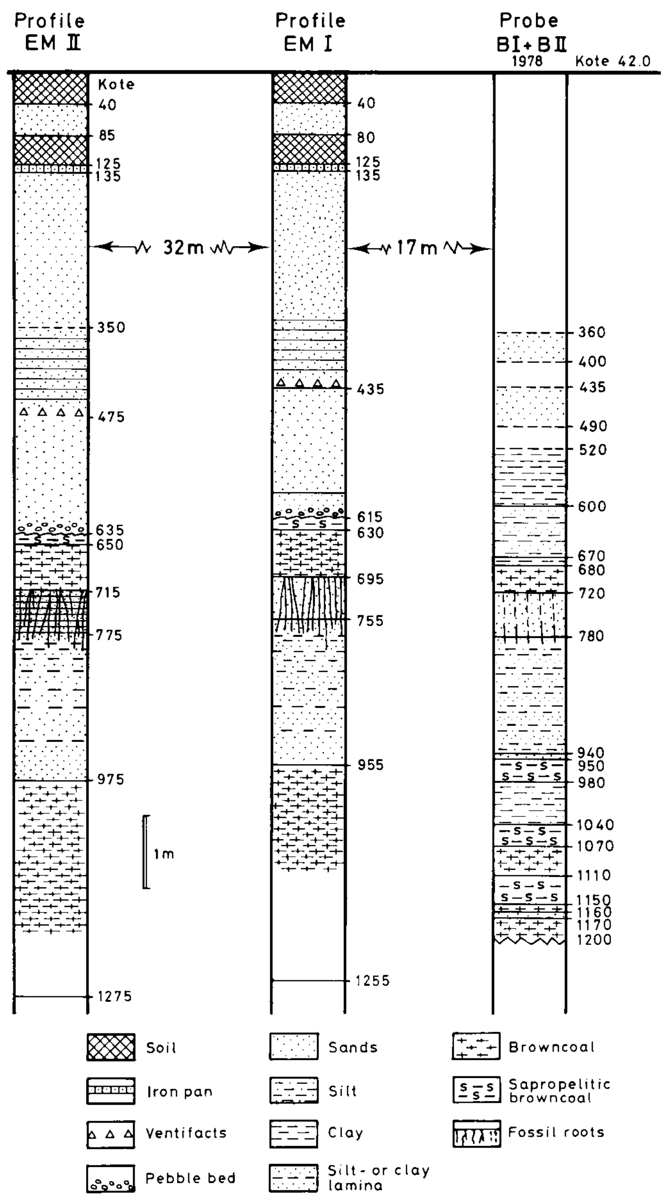
in the chapter 4A: The Quaternary (page 41). The Quaternary/Tertiary boundary is marked by a stone pavement with ventifacts, a common feature in this region.

At this locality the Tertiary sequence has been recorded down to the top of the local 4th and respectively 3rd brown coal seam, expressing a total thickness of about 3 m. The upper surface of the brown coal was found in about 11 meters below the surface. It is overlain by approximately 1 m of brown micaceous clay which is followed by 2.0 metres of alternating fine-grained sand and brown humic clay; the amount of clay increasing upwards. This is again overlain by 0.6 m of lamellated fine-grained sand. Deriving in the 5th brown coal seam tree roots (Sequoia sp., ref. Wagner & Koch 1974) in nearly vertical position penetrate the entire sand clay bed, i.e. to a depth of more than 2 meters. They apparently derive from the strongly dissolved trunks of which only scanty remains are left in the bottom of the coal seam.

The (5th) brown coal seam is about 0.8 m thick, mostly consisting of xylitic black brown coal, but the uppermost 15 cm is a highly bituminous black detrital coal (groundmass-coal), enclosing small sandy lenses in its uppermost part. Its upper surface is ripple marked from erosion and overlain by a thin bed (few cm) of sand with pebbles. The coal bed consists of a black brittle matrix that contains plenty of wood fragments in highly dissolved stage, a groundmass-tissue coal (for detailed description ref. page 43 and E. Thomsen 1979).

Above the 5th brown coal seam is an erosional boundary (paraconformity; on a regional term: disconformity. ref. page 117,126) followed by 1.60 m of light (white) cross-bedded sand with a basal gravel (pebble) bed. The basal 35 cm of the sand is brown from secondary colouring due to humic compounds in a water saturated zone above the impermeable clay-coal bed below . The cross-bedding is rather steep and appears to dip towards S-SE. In the section in question this sand bed is cut off by an abrupt boundary marked by the ventifact pavement (Quaternary-Tertiary boundary) mentioned above.

The assumed correlation of this bed and its basal pebble bed (gravel) is demonstrated in the profile dia-



Text-Fig. 34. Diagram of logs from the EM outcrop (2 logs), and probes BI-BII (1978) of Klynholt Vest. E.K. comp.

gram (Text-Fig. 23, 33). It seems reasonable based only on lithostratigraphical criteria to correlate it with the basal littoral facies, i.e. the basal transgressional gravel of the Hodde Formation from the pit of Damgaard N and the north front of the Klynholt area. Ref. the probes no. BI-BII, 1978, and the drilling Fasterholt-, gaard no. 1 (DGU file no. 95.1995).

In the probes no. BI-BII, 1978, at the north end of section EM we find the same sequence of beds as in the outcrop of this section except for the occurrence of a black and brown clay, probably the basal part of the Hodde Clay, substituting partly for the light sand (1.60 m thick) which occurs in the outcrops of the section EM both of which are above the 5th seam. The drilling record of these probes are referred to below:

File of probe BII 1978 (combined with probe BI 1978; situated 20 m to the south) (Text-Fig. 34).

Level: 42.5 m
Probe BII 1978

0– 3.60 m	*No record (presumably Quaternary).*
3.60– 4.90 m	*Fine (light) ochreous, micaceous, fine-medium grained sand (Quaternary). (No record 4.00-4.40).*
4.90– 5.20 m	*No record.*
5.20– 5.45 m	*Homogeneous darkbrown, micaceous clay (Hodde Clay, continuing downwards).*
5.45– 5.55 m	*Black, silty micaceous clay.*
5.55– 5.70 m	*Fine clay in fine lamella of alternating darkbrown clay, and black clay.*
5.70– 5.80 m	*Fine, homogeneous black clay.*
5.80– 5.95 m	*Brown, homogeneous fine clay (Hodde Clay, lowermost bed).*
5.95– 6.40 m	*Coarse, grey sand with thin beds of black clay.*
6.40– 6.70 m	*Coarse sand, in the lowermost part an about 5 cm thick fine grey clay.*
6.70– 6.90 m	*Homogeneous, brown, earthy brown coal (5th brown coal seam).*
6.90– 7.60 m	*Light grey-brown micaceous fine sand. In the lowermost part fragments of lignite (fossil roots?).*
7.60– 8.50 m	*Micaceous silt, uppermost with fossil plant detritus. The lowermost part dark and light coloured fine micro-lamella of clay and silt.*

Level: 42 m
Probe BI 1978

0– 2.0 m	*No record.*
2.00– 4.70 m	*Sand-gravel (Quaternary).*
4.70– 6.50 m	*No record except for a bed of gravel with pebbles at 5.50 m*
6.50– 7.40 m	*Fine sand.*
7.40– 9.20 m	*Alternating lamina of yellow-brown micaceous silt and dark grey-black silt-clay with coal detritus.*
9.20– 9.30 m	*Dark grey, micaceous coarse sand.*
9.30– 9.50 m	*Brown micaceous gytja (clay-silt).*
9.50–10.10 m	*Succession of lamella of silt and brown coal gytja. The gytja-brown coal gradually becomes dominant downwards.*
10.10–10.60 m	*Alternating lamella of earthy black brown coal and brown gytja-homogeneous brown coal. The earthy brown coal dominates on top gradually changing into gytja-brown coal down wards.*
10.60–10.90 m	*Homogeneous detrital brown coal.*
10.90–11.00 m	*Dark grey coarse sand.*
11.00–11.35 m	*Homogeneous detrital brown coal continues down wards (3rd brown coal seam, Fasterholt Member).*

11.35 (level: 31.1 m) End of probe.

The interval 5.20 – 5.95 m in the probe B II can be correlated with the Hodde Clay, and the interval 5.95-6.70 m with the basal (transgressional) bed of clay lamina alternating with sand and gravel beds of the Hodde Formation.

c.d. The succession of the Damgaard N pit, including the Søby Flora bed.

The outcrops of this locality has been described in details by Christensen (1975) in his introduction to the description of the Søby-Flora. An abstract follows below (see also chapt. 4.B.7.6).

Later, a probe penetrating the beds in question down to 12 m below the surface was set at the NW-corner of the former Damgaard N pit (table 8). Some brown coal prospecting drillings at this locality by private companies also are used for an account of this sequence (with permission of the Geological Survey of Denmark) (ref. the map of Text-Figs. 62, 63).

Christensen (1975) illustrates the geology of the Damgaard N pit with a generalized profile at the fossil plant locality of the west wall (Christensen 1975, table 2) and of the west- and north fronts (Christensen 1975, table 3) (ref. Text-Figs. 37, 44, and 45); Adding drilling DGU, file no. G5-Søby 568 (surface elevation 51.6 m) and file no. 6-Søby 575 (surface elevation 52.5 m) the following description can be presented.

Drilling 568 records the 2nd brown coal seam between the 16.6 m– 20.0 m (thickness 3.4 m) and 3rd seam at 13.7– 15.3 m (thickness 1.6 m). Above the 3rd brown coal seam follows 1– 1.15 m of sand that grades into approximately 2m of sand alternating with thin beds and lamina of brown clay (gytja) which increases in frequency upwards. These beds are overlain by a varying thickness (0.7– 1.3 m) of brown micaceous clay (oxidizes quickly into grey colour by exposure). The lower half of this clay is compact and the upper half contains 6 lamina of fine sand. The thickness is optimal at loc. 8 (ref. Text-Figs. 37, 45). Just to the east of this locality of the North front the bed is laterally cut off unconformably by cross-bedded white coarse-medium grained quartz sand (described in detail by Christensen 1975, Fig. 4) (Text-Fig. 37). The brown micaceous clay (gytja) contains a rich fossil flora of leaves, coniferous twigs and compressed fructifications, named the *Søby Flora* (Christensen 1975, 1976, 1978) (ref. chapt. 4.B.7.6.).

Deposited on (and to the east of) the steeply eastwards dipping unconformity (erosional escarpment) is an erosional debris wedge of alternating sand and micaceous clay, the same facies as the fossiliferous clay of the Søby flora and the underlying bed of sand and clay.

The basal beds nearest to the unconformity contain cobbles of the fossiliferous clay.

Laterally overlapping this debris cone as a westwards pointing wedge follows at the same level a white coarse-medium grained sand in thick flat lying (horizontal) structures (beds) with westerly dipping (!) cross-bedding. This sand represents the normal condition of the "Upper Sands" (bed no. 7) in the area (ref. the Carl Nielsen Ltd. pit, the Klynholt north front and Damgaard S east front) but here is probably a channel sand on top.

The fossiliferous clay of the Søby flora as well as the overlapping "Channel Sand" is overlain by the basal gravel of the Hodde Formation which is followed by Hodde Clay. Christensen (1975, p. 13) notes "Occasional plant root 0.2 to 5.0 cm thick, penetrate the plant bed from the top, often branching and forming a horizontal network." The sedimentation seems to have

TABLE 8. Log of probe "DAMGAARD N. 1978" (Compiled by E. Fjeldsø Christensen).

Pipe No.	m. b.s.	Description		Lithological units	Formation
		rubbish			
	1.80	Uppermost: Pale, grey (weathered) clay			
I		grading downwards into		Gram Clay	
	2.70	brown silty clay		(Gram Ler)	Gram
			3.00		
II		Green-grey glauconitic, silty clay		Glauconite Clay	Formation
	3.60			(Glaukonit ler)	
			3.80		
III		Black fine clay			
			4.20		
	4.50	Black sandy clay			
IV		Black silty clay			
	5.40	grading into			
V					
	6.30	Black fine clay			
VI					
	7.20	Very fine black clay		Hodde	Hodde
			7.35	Clay	
		Brown clay			
VII			7.70		
		Black, silty clay		(Hodde Ler)	Formation
	8.10		8.10		
		Brown, micaceous clay			
VIII			8.35		
		Brown, silty clay			
			8.65		
		Minor lacuna in sampling			
	8.80				
		Black, fine, micaceous clay			
			9.35		
IX		Brown, silty micaceous clay	9.55	Basal	
	9.70	Lamella of fine sand	9.79-9.80	Transgressional	
		Brown, coarse, micaceous clay	9.84	Bed	
		Brown, fine clay			
X			9.95		
		Lamella of fine sand			
			9.96		
		Brown, fine clay with		Søby-Flora	
		plant fossils		Bed	
	10.60		10.60		
		Micaceous silt			
		Alternating light, micaceous			Odderup
XI		fine sand and			
		Brown, micaceous clay			
	11.50		11.50		Formation
		Alternating medium grained			
		micaceous sand and			
XII		Brown coarse clay			
	12.20		12.20		

been interrupted by a rather sudden draining of the swamp (lacustrine) basin. The type of unconformity and the neighbouring fluviatile facies may be causally related to this draining.

III. The Lower Boundary of the Fasterholt Member

By B. Eske Koch and E. Fjeldsø Christensen

The lower boundary of the Fasterholt Member has only been observed at the western end of the Carl Nielsen Ltd. pit near Fasterholt bjerg (elevation 68 m – 223 ft.).

The boundary may best be classified as a paraconformity owing to the concordance between the under- and overlying sequence and the lack of marked traces of erosion or relief of the surface (boundary). Nevertheless, the boundary shows small scale irregularities, of two orders. The larger undulations are rather irregular with an amplitude of a few decimetres and one to a few meters wide. The second order irregularities look like "load casts", i.e. downwards projecting pockets, less than 10 cm deep and wide.

The Fasterholt Member rests concordantly upon a nearly continuous succession of light (white), sand, about 40 m in thickness. This sequence has been penetrated by two drillings in this region (DGU borehole no. 95.1942, Fasterholt Bjerge at Fasterholt railway station and DGU borehole no. 95.1995, Lavsbjerg Øst, at Munkballegaard) and only the uppermost few meters have been exposed. This happened in the western end of the Carl Nielsen Ltd. pit (at Fasterholt Bjerg).

This sand has been recorded underlying the Fasterholt Member in 3 boreholes in the southern part of the Søby-Fasterholt area (the drillings Bjerregaard, Fasterholtgaard 1 and -2). These boreholes penetrated this member and reached 2–8 metres down into the underlying sand, without marked deviations being recognized.

The following description may therefore be representative for the area in question on general terms.

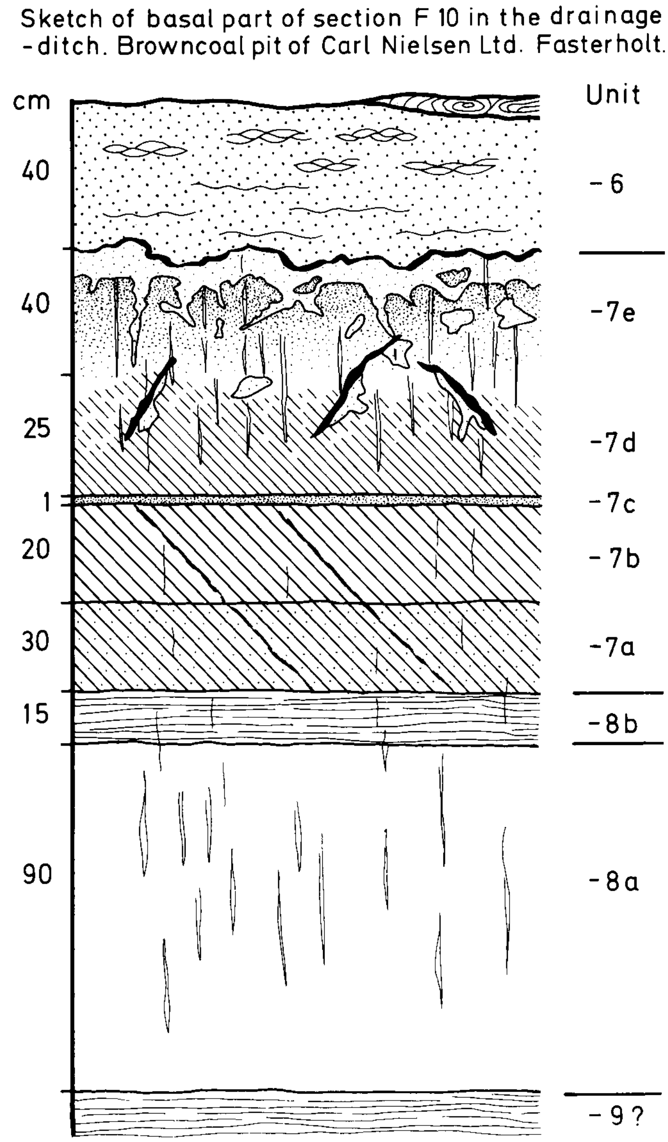
The relatively short time in which this lowermost part of the outcrops of the Carl Nielsen Ltd. pit was exposed did not permit a detailed sedimentological investigation and was also outside the plans of the present project. Therefore, we have to our disposal only the field observations with detailed pictures and sketches and general sedimentary samples of the different units.

The description is based upon the appearance of the beds in vertical section and at right angle to the bedding plane. In some cases vertical sections at right angles have been studied (Atlas Fig. 51, 52).

The different units (beds) of the sequence referred to by the letters, are found on the supplementary sketch Text-Fig. 35.

The bed above the boundary (the lowermost bed of the Fasterholt Member) is a very characteristical basal bed (no. -6) below the 1st browncoal seam. It is 0.3-0.5 m thick and has a black to dark grey appearance in the field. It is a composite bed of coarse sand and brown coal detritus. It seems to be a stream deposit with a composite structure consisting of two main elements:

1. Small lenses of light grey, coarse sand, 2-3 cm



Text-Fig. 35. The substratum and lower boundary of the Fasterholt Member from profile F 11. Composite bed no.-6 rests on a weathered surface of disintegrated soil ("intraformational breccia") containing fossil roots. The following units are involved: -6. Composite fluviatile bed of coarse sand-microlenses, interwoven in a meshwork of brown-coal detritus. An incoaled and compressed trunk of overlying coal seam (-5) is indicated on top. < Unconformity (fossil ground surface)>. -7e. "Intraformational breccia": Angular pieces of fossil soil (root bed) in a ground of fine sand ("quicksand"?).-7d. White cross-bedded sand with fossil roots penetrating from bed -7e. -7c. Brown-black laminated sand. -7b. White coarse-grained cross-bedded sand containing fossil roots penetrating from the overlying beds. < Fossil groundwater level (top of brown humus precipitate)>. -7a. Petrographically resembles bed no. -7b but coloured by secondary precipitated brown humous compounds. Also contains fossil roots. -8b. Brown laminated humous silt. -8a. White coarse to medium-grained sand with fossil roots. -9. Brown laminated silt.

thick and about 3 times as wide. These lenses contain undulating black microlamellae.

2. The sand lenses are interwoven with black to dark brown coal detritus which appears lamellated owing to a content of very flat microlenses of sand containing only scattered black particles. These microlenses are parallel (concordantly) arranged, i.e. the apparent long axis of the lenses (in cross section) is parallel with the orientation of the undulating bedding of the brown coal lamallae.

This bed contains fragments of wood and driftwood in concordant position. The content of inorganic matter has been measured by combustion at a mean of 98%. The remaining 2% represents organic matter (brown coal detritus).The lower boundary of this bed is the subject of this chapter and its configuration has been briefly mentioned above. It shall here be considered in detail as follows.

The substratum consists of the white cross-bedded sands of which only the upper few beds (2.5 metres) have been exposed during mining. Only the uppermost two beds, from our field record together referred to as no. -7, are interesting in this connection (1.2 metres thick). The uppermost part of this bed has the character of a fossil, transformed soil (unit – 7e) (0.4 metres thick) with a rather complicated structure. This soil grades irregularly through a thin zone into a cross-bedded, untransformed lower part of the bed (unit -7d). This cross bedding dips ENE. Below unit -7d is a few cm of dark brown-black sandy clay (unit no. – 7c). The underlying bed (unit -7b and -7a) consists of coarse to medium grained white sand, cross-bedded with dips (stream orientation) towards NE. This bed is characteristical because its lowermost part is brown and sharply delimited upwards at a concordant horizontal level. Nevertheless the cross-bedding is uninterrupted by this sharp boundary of the brown colouring (i.e. secondary colouring, ref. Larsen & Kuyp 1971) proving the origin in one sedimentary bed.

The fossil soil (unit no. -7e) has a dark grey to black matrix of sand with organic detritus. This soil matrix is part of a composite structure grading between: 1) A dominant grey to black matrix containing angular or steeply dipping irregular structures (tubes and blocks) of light (white) very fine grained sand (to silt), and 2) a soil matrix occurring in isolated angular enclaves (blocks) in a ground of white very fine grained sand (to silt) (ref. Atlas-Figs. 51, 52, 53, etc.). In this latter alternative the matrix is not always black to grey but a lighter grey. There seems to exist a correlation between this latter extreme and the depressions of the 1st order undulations of the boundary between the beds -7e/-6. Sometimes an incoaled tree-root makes up the longer side of the angular soil matrix-enclave, which is then elongated in the direction of the tree-root.

The black to grey soil enclaves are usually separated from the overlying bed no. -6 by a narrow irregular zone of white fine- grained sand. This sand has a poorly defined tendency to horizontal bedding, rather ghostly, but as a rule the intervening sand of this bed is very fine and has no structural orientation. The overall structural impression is a structure similar to an "intraformational breccia", but there are also features that look like leaching and bleaching of a soil in transformation leaving the light unstructured sand etc. just below the unconformity.

Throughout bed no. -7 are black incoaled thin roots, the majority of which in unit -7e are vertical and very crowded (Atlas-Fig. 55, 56). They are extremely well exposed in unit -7d, black roots on a white matrix, (Koch et al. 1973, Fig. 9). Also, in the underlying brown humic silt (bed no. -8) there are similar roots and predominantly vertical as in the growth habit. The fossil roots are crowded in the black to grey soil matrix, (Atlas-Figs. 51, 52, 53), but are rare (few) and occasionally preserved as very thin threads, sometimes horizontal, in the intervening fine sand. Generally the thin roots are cut off at the borders between soil and the white, unstructured sand. In this sand they seem strongly disintegrated when preserved at all.

Generally, the thicker tree roots are badly preserved anatomically, and it has not been possible to make a better taxonomical determination than to the Conifers (personal communication with P. Wagner). But unlike the fine roots the thicker tree roots continue unbroken through the different components of the beds of this outcrop.

Besides this continuous content of crowded thin roots, clusters of tree roots of varying thickness (5-10 cm diam.) are found, sometimes with remarkably thicker specimens and sometimes uniting into what may be a 1st order root branch or a fragment of a stump (Atlas-Fig. 59, 60). These roots are often seen to converge upwards, presumably towards a common disintegrated stump. The tree roots are found in the sand, bed no. -7. The thicker roots end and the stump fragments rest in the paleosoil of the uppermost unit of this bed (no. -7e) and are sometimes seen to end upwards in an irregular dissolved state into the overlying black sandy bed no. -6 (Atlas-Fig. 59, 60) . Within the restricted exposure, a few very large stumps are seen to reach into the 1st brown coal seam (Atlas-Fig. 27) and a single individual passes upwards through this seam (Atlas-Fig. 33). The roots and stumps are rather disintegrated, and the wood anatomy is poorly preserved. At present it has only been possible to determine the affinity of any root- or stump-samples as belonging to Conifers (personal communication with P. Wagner).

The thick tree roots penetrate steeply into the substratum, into the lowermost directly observed bed no. -8 at the basis of the outcrop (depth below the boundary max. 2.5 metres). Also, the thin roots penetrate vertically into the substratum through bed no. -7 (more than one metre) and seem to continue more scattered through the sand bed -8 (2-2.5 metres below the unconformity).

These deep roots indicate that the vegetation standing on the paleosoil, has grown under relatively well-drained conditions and the groundwater level was constantly well below 2.20 m. The dimensions of the roots and the trunks show that this forest had big trees, and from the closeness of the stumps it can be inferred that several generations of large trees are represented. The original soil must have been a part of a stable surface. The upper boundary of this soil-bed is also the base of the sand with brown coal detritus (bed no. -6) which is the lower boundary of the Fasterholt Member. This surface is a boundary in a concordant sequence and does not strictly show any marked erosional relief, but just does show small deviations. These deviations include small scale irregular undulations with an amplitude of a few decimetres and a width of a few metres. Further, this boundary has small equidimensional "pockets" less than 10 cm deep and wide projecting downwards. These "pockets" (as seen in a vertical section) represent long, narrow troughs and containing incoaled remains of tree branches or stems in the shape of half cylindrical shells representing remains of the woody cylinder or the bark of strongly dissolved specimens (Atlas-Fig. 54). These wood shells line the small troughs or pockets and are seen to be broken in the manner that the shell lining the distal part of the pocket has its continuation at the basal (proximal) level of the pocket, indicating that the "pocket" (trough) was established by a pressure and a displacement of material. The "bedding" (orientation of small sand-lenses) of the composite bed no. -6, is normally parallel without deviations. However at the bottom of the bed and in connection with these "pockets" the structure (sand-lenses) of bed -6 adjusts itself to the bedding and shape of the "pockets". Also the white very fine grained sand of the soil bed shows, in cases when a sorting of the sand material allows it, a conformity with the curve of the pocket's periphery. Along the top of sand bed (-7) are places where the sand was injected into the basal or lateral part of the pocket in agreement with the breaking and displacement of correlated parts of a wood shell (Atlas-Figs. 24, 54). Also plastic deformation after deposition is responsible for some features of the sediments at this boundary.

Bed no. -6 has proved to contain driftwood and some of the undulations of the boundary seems to be the result of driftwood displaced (sunk) into the water-saturated substratum like load casts.

The undulating bedding at the bottom of bed no. -6 is caused by the larger undulations of the boundary but these deviations are adjusted within the lower half of the bed.

So far the rather short front on which we have been able to study these phenomena allows a general statement, the dark-grey angular soil blocks appear to occur more scattered in a (dominant) very fine grained white sand ("matrix") occurring in correlation with the depressions of the 1st order undulations of this boundary.

IIIa. Interpretation of the "Intraformational Breccia" by B. Eske Koch

The interpretation of the sequence below the lower boundary of the Fasterholt Member may involve also the history in its widest sense of the following 1st brown coal seam. It will, therefore, in some cases be necessary to involve some of the conclusions from descriptions and interpretations not yet presented. In such cases reference is made to the appropriate pages.

From what has been described above it must be assumed that after the approximately 40 metres of light grey to white sands which occur below the brown coal bearing sequence had been deposited, a stage of epeirogenic stability was reached in which a soil and arborescent vegetation was established and developed. The root- and stump horizon infers a certain amount of ground water retreat after a long period of delta building (see chapter 4.B.3. page 89).

The complicated structure of the soil-bed may be explained as follows:

The black-grey soil material may represent an originally unbroken soil established in the surface of the sands by high forest. Later this continuous soil was broken up due to changing conditions (rising groundwater and renewal of sedimentation). The fine grained sand and silt was transformed into a mobile state (quicksand) and became "intruded" into the bed, under the forming of a structure like a so-called "intraformational breccia".

This theory is supported by the following observations:

The base of the soil-structure is not conformable with its upper surface (the fossil ground = the boundary), but rather concordant with the bedding of the underlying sediments and especially parallel to the fossil ground water surface of unit no. -8b (secondary groundwater colouring that may indicate the horizontal level at that moment). Hence, the soil is thin at the places with depressions of the 1st order undulations, and thick at the culminations (Atlas-Fig. 51, 52). In the places where the soil bed is thin, i.e. under the depressions of the boundary, the white fine-grained "intrusive" sand is the dominant component of the composite soil structure and the dark, polygonal soil enclaves are subordinates in the sand matrix. Here, the groundwater pressure would the easiest have broken through the soil and consequently the quicksand would have penetrated. The sand is also dominant where larger stumps penetrate the soil, often lining the sides of the stump (Atlas-Figs. 58, 60), or filling the interior of disintegrated stumps or stem bases (Atlas-Figs. 57, 58).

The fine, light coloured, "intrusive" sand seems to have been mobile because this pure sand is found in extreme thickness below culminations (crests) of the boundary (= culminations of bed no. -6) (Atlas-Figs. 51, 52) and along the sides of the pockets of bed no. -6 that protrude downwards into the soil. The pure sand has even been seen to be folded into the black "pocket" (Atlas Fig. 54). The concentrations of sand at the flanks of the pocket has also been observed to be folded up into the basis of bed no. -6 (Atlas-Figs. 23. 54).

Hence, the deformations are younger or simultaneous with bed no. -6.

The "pockets" that protrude from bed no. -6 into the soil seem to be the results of deformations because the cylindrical wood shells of these "pockets" can be seen to be broken. One part of the woody shell is found to coat the distal part of the pocket and is displaced from the rest of this woody structure occurring at the basis of the "pocket". The above mentioned infolding of the white sand into the "pocket" points to the same activity. Also, the orientation of the material of bed no. -6, normally parallel with the bedding, is depressed (i.e. sunk) into the pocket and adjusted to the convexity of its circumference.

The orientation of the internal structure of the overlying bed no. -6 follows to a certain degree the undulations of the boundary with bed no. -7 (Atlas-Figs. 23, 24).

These deformations and the break up of the soil and intrusion of quicksand could be the result of the rising groundwater (from a level below 2.20 m) that made possible the deposition of 1st brown coal seam. This initial groundwater rise must be an inevitable factor in the geological history of the succession in question (the lowest part of the Fasterholt Member). The rising groundwater level mobilized the fine underlying sands and silt (quicksand) and raised the groundwater pressure from below to break through the relative impermeable soil.

In causal connection with groundwater rise, surface water (from the delta) made its way through the dying or ruined forest leaving a mixed deposit of sand and debris from the forest soil (bed -6). The load of this sediment and trees (stumps) (the larger more intact tree stumps are normally situated in a depression of the undulation of the boundary) may have caused the penetration of the quicksand to create the mixed soil structure ("intraformational breccia"). Perhaps also the load of the following brown coal deposits may have continued and terminated this process. From the deep open cast mines the authors have become well acquainted with the mobility of this kind of fine sands and silts that became reworked, transported and displaced in the wet bottom of the mining trench, causing severe troubles to the miners in earlier days.

In the intruding areas, the quicksand partly disintegrated the finer subfossil roots of the intrusive areas. The finer roots are generally interrupted at the borders between the soil-blocks and the fine interveining sand. This indicate some mechanical action responsible for the emplacement of the fine sands. The "intrusive" sand is naturally devoid of cross-bedding and other original sedimentary structures of the original bed. This sand is in fact very fine and homogenous and devoid of cross-bedding, contrary to the sands below the soil.

The late weak folding (mentioned in the chapter on Tectonics page 155) might be an alternative reason for the deformations found along the lower boundary of the Fasterholt Member. However, this is a geological event much later in time. Folding of the tectonical incompetent beds (sands) should result in small faults (ref. page 156 and Atlas-Fig.s 41, 42, 110, 111) that would have also interrupted the root-structures. However, we find to the contrary a plastic deformation of supposedly tectonical incompetent sediments (the "intruding" sands).

IV. The Upper Boundary of the Fasterholt Member

The Fasterholt Member, as defined in chapter 4B 2, pag. 56 is overlain concordantly by the white quartz sands of the Odderup Formation, provisionally named in this paper "the Upper Sands". During the period of the field investigations (1968-1970) this boundary was accessible in the browncoal open cast mines of Carl Nielsen Ltd. at Fasterholt and of Hoffmann & Sons at Søbylund and Kølkær. Also, the boundary in question was recorded in the boreholes Fasterholt Bjerge (Dan. Geol. Surv., file no. 95.1942), Lavsbjerg Øst (Dan. Geol. Surv., file no. 95.1995), Bjerregaard (Dan. Geol. Surv., file no. 95.2166), Fasterholtgaard no. 1 (Dan. Geol. Surv., file no. 95.2163) and Fasterholtgaard no. 2 (Dan. Geol. Surv., file no. 95.2164) (Text-Fig. 38).

In the outcrops of the open cast mines this boundary is easy to recognize because of the contrast between the white quartz sand and the darkbrown browncoal. Generally the boundary is regular, and flat lying, but in the region in question affected in places by irregular but week folding (ref. chapter 4 C: Tectonics, pag. 155). The browncoal surface is not obviously affected by weathering or by erosion and has not been exposed enough to support a vegetation or burrowing animal life. It seems likely that this boundary is the results of a relatively abrupt change in sedimentation but represents normal superposition, probably at a stage of advanced infilling of the swamp (lake) with browncoal ooze. A narrow zone of no more than 10 cm of fine-grained sand follows directly upon the browncoal. This sand is brown coloured, presumably from secondary precipitation of humic colloids from local groundwater pooling on the impermeable surface of browncoal and browncoal-clay.

In the southwestern to western part of the Søby-

Fasterholt mining area the 3rd browncoal seam is succeeded by clay and by the 4th seam. The surface of the 4th seam which is overlain by the "Upper Sands" (of restricted thickness) represents the upper boundary of the Fasterholt Member.

In Klynholt Vest area, incl. the Fasterholtgaard no. 2 borehole, the 3rd browncoal seam is overlain by one meter of brown micaceous clay which tentatively is regarded as part of the Fasterholt Member. This is owing to the fact that the (equivalent) 4th seam is found locally above this clay in the western Klynholt area (Lavsbjerg Øst borehole).

The deltaic sequence ("Upper Sands") in the Klynholt Vest area is substituted by a lacustrine sequence of sands alternating with clay/silt. The "Upper Sands" are of an optimal thickness in the synclinoria (Browncoal pit of Carl Nielsen Ltd., Fasterholt), thin in the anticlinoria (Klynholt Vest, the Damgaard mines, the Hoffmann & Sons' mines) and extremely thin in the browncoal pit of Søbylund (Hofffmann & Sons) on the very top of an anticlinorium (ref. Text-Fig. 63, 66, Atlas-Figs. 85, 86). This thinning and thickening is due to a later erosional period than the tectonics influence.

V. The Upper Boundary of the Odderup Formation

The upper boundary of the Odderup Formation is marked by a break in the sedimentary sequence due to either a paraconformity or a disconformity between the Odderup Formation and the Hodde Formation.

Below the Quaternary outwash plain (e.g. at Fasterholt) the "Upper Sands" are generally not entirely preserved due to Quaternary erosion that has removed the uppermost few metres of it leaving a low shallowly undulating disconformity (ref. the Carl Nielsen Ltd. pit at Fasterholt). Hence, the Odderup Formation is overlain at Fasterholt by a Weichselian (Würmian) glaciofluviatile sequence of sands and gravels with a basal stone pavement containing many ventifacts (Atlas-Figs. 10, 11, 61). The Quaternary sands, deposited in narrow lenticular structures, have an ochreous colour from weathering and easily distinguishes this sequence from the nearly white underlying Tertiary fluviatile quartz sands deposited in tabular cross-bedded structures (Atlas Fig. 50, 62,109, 119).

The Tertiary sequence has been subject to a weak folding, and the Quaternary sequence is unaffected. The boundary between the two units becomes more obvious because of the angular unconformity found at the flanks of the folds (Atlas-Figs. 109, 110, 111).

These geological features have been exposed in the Carl Nielsen Ltd. mining area during the entire period of active mining as well as in the more northerly pits of Hoffmann & Sønner at Søbylund and Kølkær (Atlas-Figs. 85, 86, 87, 89, 90, 91). The unconformity and related phenomena have been described or discussed on page 29.

At the Lavsbjerg Hill the "Upper Sands" (4th rhythm) are more completely preserved. The boundary here is a paraconformity, indicated locally in the western localities by a root horizon. Normally, where the "Upper Sands" of the Odderup Formation is overlain by the marine, transgressive Hodde Formation, the paraconformity grades into an unconformity, with weak erosional structures.

Generally, the Odderup Formation is overlain by the Hodde Formation. This is best demonstrated by the excellent exposures of the north front of the Klynholt mining area and the east front of the Damgaard S pit. In these exposures the "Upper Sands" are in thick cross-bedded tabular-lenticular structures that are, in general, concordantly overlain by a sequence of alternating black bituminous and brown humous clays.

The upper boundary of the Odderup Formation, between Klynholt (section EM) and the pit of Damgaard N in the west front of the Søby-Fasterholt area deviates from the general conditions. Here, a lacustrine facies of alternating humous clay and white sand is the stratigraphical equivalent of the "Upper Sands"; this version can be regarded a 4th rhythm and is terminated by a root (and stump-) horizon; this is directly overlain in the Damgaard N pit by the Hodde Formation. In Klynholt Vest a 5th brown coal seam is found between this root horizon and the Hodde Formation (ref. the "Klynholt Vest tongue", page 37). A paleosoil with a root horizon also is capping the "Upper Sands" in profile K6 from the brown coal pit of Carl Nielsen at Fasterholt. In profile K6 the "Upper Sands" are exceptionally thick due to an erosional crest of the disconformity between the Tertiary sand sequence and the Quaternary outwash sands.

The following detailed descriptions of the upper boundary of the Odderup Formation concerns the following localities:

1. The North front of the Klynholt mining area.
2. The East front of the Damgaard S. pit.
3. The exposures of the Damgaard N. pit.
4. The SW-corner of the Damgaard mining area.
5. The NW-corner of the Klynholt mining area.
6. The K-front of the Carl Nielsen Ltd. pit at Fasterholt.

1. The North front of the Klynholt mining area.

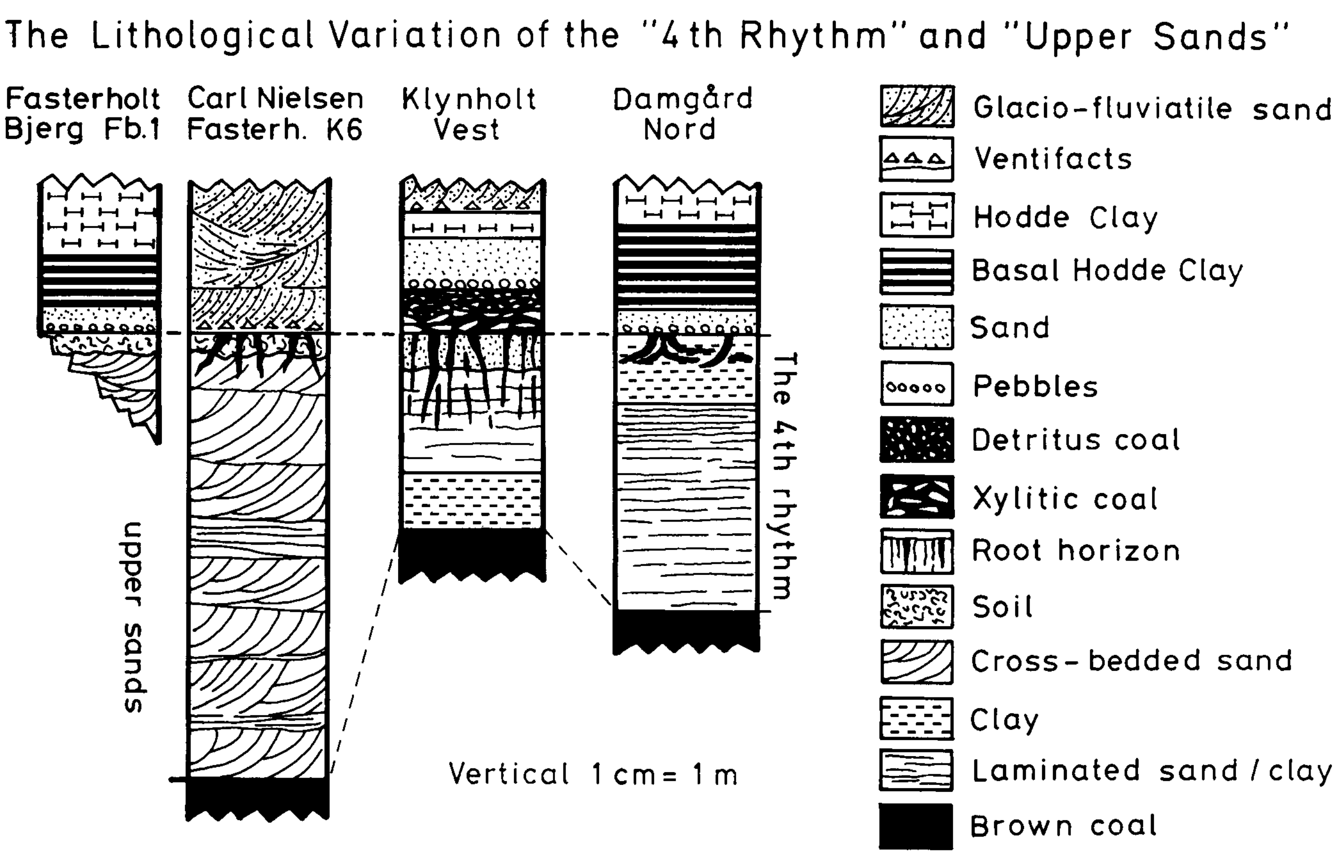
The north front of the Klynholt mining area is a combination of 3 (sub) fronts, (in total more than 1 km long) displaced northwards by small west facing fronts creating a zigzag structure, with good exposures in the 3 E-W striking subfronts. Hence, the exposure of this front is discontinuous, i.e. divided in 3 sectors which are a little out of line (Text-Figs. 21 and 62) and with some deviation from the general E-W orientation. In this north front excellent exposures of the boundary between the "Upper Sands" of the Odderup Formation and the overlying Hodde Clay as well as the sequence of the Hodde Clay is seen in a max. 10 m high cliff rising from the pond of the submerged brown coal pit. This section cuts the deposits in a manner to expose a flat synclinal structure flanked by low anticlines towards west and presumably also towards the east. The idea of these sediments represented in folded features is the most probable explanation at the moment (ref. the chapter on tectonics page 155). A competing idea of a sedimentary basin bounded by synsedimentary ridges (bars) favoured before the structures of the underlying brown coal sequence of the Fasterholt Member was detected (ref. Koch et al. 1973) is less likely.

The stratification of the lower part of the Hodde Clay seems concordant with the upper boundary of the Odderup Formation. The upper part of the Odderup Formation in most exposure consists of a several meters thick sand bed with easterly dipping cross bedding (Atlas-Fig. 67). It consists of a chain of lenticular structures interdigitating with one another. A similar but narrower and obviously lenticular bed is continuous in the easternmost part of the exposure of the North-front. Although concordance is difficult to state in this case there seems to be a general concordance between the upper boundary of the Odderup Formation and this chain of lenticular "beds". The boundary of the Odderup Formation is extraordinarily regular without marked undulations, but some diminutive erosion seems to have preceded the deposition of the Hodde Formation or have taken place at its onset. The cross-beds of the medium to coarse grained sand is often completely preserved to the top with the cross-bedding converging into the original upper surface of the bed, i.e. uneroded. So, this uppermost zone has experienced some erosion in places, but only up to a degree leaving undulations similar to coarse ripples or shallow pools. We never observed the underlying bed of sand to be transsected by this unconformity nor to be truncated even to a fourth of its thickness. Hence, the "Upper Sands" are overlain by the basal gravel of the lowermost bed of the Hodde Formation (the transitional bed between psammitic and pelitic sediments).

Only in the easterly part of the exposure a finer thin bed or lamina of brown silt and silty clay is included as the last fluviatile deposits of the "Upper Sands". Apart from this single case the uppermost part of the Odderup Formation entirely consists of white sand.

The lowermost bed of the Hodde Formation consists of coarse sand and gravel varying in thickness (5-20 cm) followed by an alternation of brown to grey sand-silt and black clay in lenses or in thin beds.

Scattered trace-fossils of branching tubular structures in the sands below the boundary have been observed along the north front, but is more abundant in



Text-Fig. 36. Correlation of logs from localities in the southern and western Søby-Fasterholt area demonstrating the upper boundary of the Odderup Formation with the transgressional Miocene sequence (Hodde Clay resp. Klynholt Vest Tongue with the 5th browncoal seam), and in part with the Quaternary (Carl Nielsen Ltd. quarry). Generally, a fossil root horizon marks the border zone. E.F.C. & E.K. del. et comp.

the sand-silt and a dominant and characteristical feature in the sand to silt and the black clay of the basal bed of the Hodde Formation. They have been investigated by Asgaard & Bromley (1974) (ref. page 68 and 93), and E. Fuglsang Nielsen (1984).

The boundary along the North front is a weak erosional unconformity leaving a flat surface, with indistinct structural indications of erosion.

2. The East front of the Damgaard S pit.

The east front of the Damgaard S pit is a 500 m long cliff oriented in NNE-SSE direction and rising from the water of the submerged pit. Analogous with the north front of the Klynholt mining area it presents an excellent exposure of the Hodde Clay and the boundary to the underlying "Upper Sands" of the Odderup Formation. Also, the section cuts a shallow syncline merging southwards into an anticline and presumably even northwards into another anticline (ref. chapter 4 C. on tectonics, page 155). Also here the well-bedded lower part of the Hodde Clay is concordant with the bending of the boundary with the underlying "Upper Sands". This boundary is well exposed as a result of the contrast between the dark clay and the white underlying sands.

The "Upper Sands" are medium to coarse grained, white and rich in quartz. Also here it occurs in long, thick, cross-bedded, mutually interdigitating (lenticular) structures.

In the "Upper Sands" we have observed traces of erosion and presumably some redeposition at the upper boundary. In the central part of the outcrop very well preserved branched *Ophiomorpha* (Asgaard & Bromley 1974) have been found penetrating to a depth of more than 2 metres into the sand (Koch et al 1973 Fig. 16) (Atlas-Fig. 83, 84). They are common here, but not continuous throughout the exposure. These occasional trace fossil have generic affinity to the crustacean genus *Callianassa* (Asgaard & Bromley 1974) and may represent a single rather short episode or a series of sporadical episodes. The sum of information indicates that the upper boundary was a tidal flat at the time of the burrowing with a tidal amplitude of more than 2.5 m (depth of the burrows min. 2.5 m).

In the east front the base of the Hodde Formation starts with a thin bed of coarse sand and gravel of varying thickness (5-10 cm) grading rather abruptly into the Hodde Clay.

The boundary is here a weak erosional unconformity involving a tidal flat and weak indications of erosion that were never seen to cut completely through the entire uppermost bed of "Upper Sands". Shallow pools less than half a meter deep changing into a surface of large ripples are the largest erosional structures observed. In some cases the uppermost sand bed has not been eroded at all because the convergent upper part of the cross bedding is preserved.

This description is valid for the southern 2/3 of the outcrop, however some irregularity was seen in the northern part. Due to the relatively high level of submergence of the pit at the time we did our first thorough observations of this outcrop (1972) the rest of the front was not studied at this level. Photographs from 1958 by P. Ingwersen (D.G.U.) and from late in 1970 suggest that a cross section through an occurrence of "channel sand" was exposed in the outcrop (ref. Atlas-Fig. 81 and Friis, 1979, fig. 2) earlier during the browncoal mining.

3. The South Front and SW-corner of the Damgaard mining area.

The boundary between the "Upper Sands" of the Odderup Formation and the Hodde Clay raises continuously southwards along the southern end of the extended outcrop of the east front of the Damgaard S mining area. This character is somewhat obscured by erosion and replacement of the Hodde Clay by a Quaternary solifluction deposit. At the east end of the south front (the SE corner) of Damgård S the Hodde Clay has disappeared, and in the outcrop the "Upper Sands" are exposed in ENE-NE dipping tabular (-lenticular) beds. These beds are cross-bedded with easterly dips (NE-E-ESE). During the early spring of 1979 a large slide from the southern end of the tip of the Damgård S mine into the submerged pit, presumably induced heavy waves (breakers) that cleared the south front from its nearly continuous cover of talus sand and herbaceous vegetation and cleaned the entire outcrop of the east front. As a result good exposures of the "Upper Sands" along the south front were available (ref. the Atlas-Figs. 119-121). The tabular and long lenticular beds describe an anticlinal structure with eastward dip in the east end of the south front, horizontal bedding in the central part of the front and westward dip in the west end, where the boundary Hodde Clay/ "Upper Sands" again appears, the Hodde Clay becoming continuously thicker towards west. At the west front (in the SW corner of the Damgaard mine) the Hodde Clay attains a thickness of 3-4 metres with the "Upper Sands" just appearing underneath. In the exposure of the west-front the border between the two units dips to the north. Consequently the Hodde Clay occupies a major part of the outcrop towards north (max. 4 m) when disappearing into the tip. The Hodde Clay rests on a thin gravel bed, like at the east front, is bedded in 7 rather thin units of alternating lighter and darker colours. The variation in colour is due to different permeability/water content, and is similar to other exposures of the lowermost Hodde Clay at the Lavsbjerg Hill, where we have found an alternation of brown, humous and black bituminous clays (ref. the chapter about the Hodde Formation, page 92, and the Hodde Clay, page 93-94).

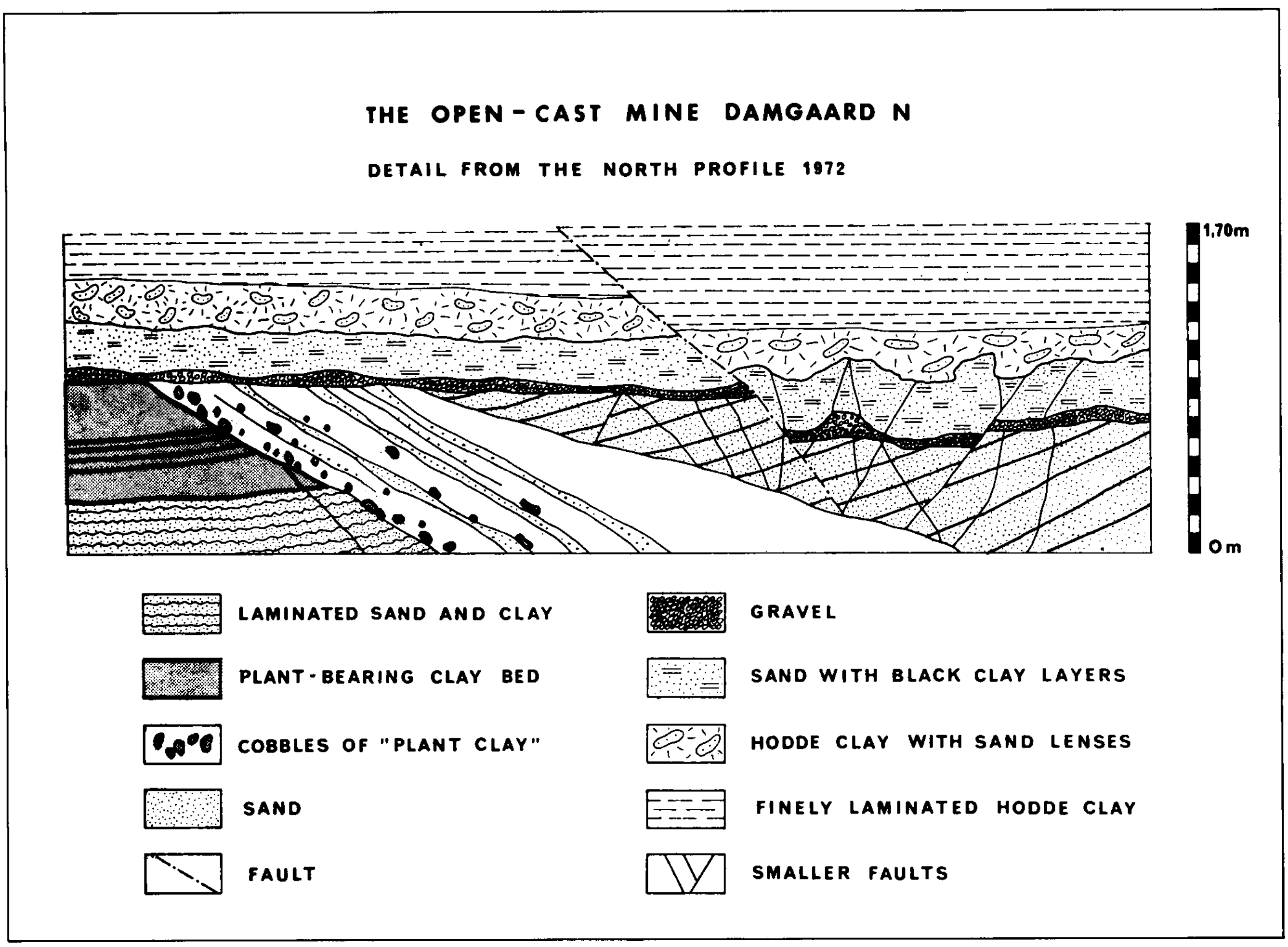
The boundary between the "Upper Sands" and the Hodde Clay at the south front shows only weak indications of erosion. The boundary is approximately concordant, never cuts entirely through the uppermost sand bed, and only insignificantly affects the cross bedding structure. In the westernmost outcrop a superficial lenticular bed was seen to wedge out against the boundary but was obviously part of an original lenticular sedimentary structure.

Hence, the character of the limit between the "Upper Sands" and the Hodde Formation in the south front of Damgaard S agrees with the Klynholt north front and in general with the localities of Damgaard S. The question of the anticlinal structure exposed in cross-section in the south-front, will be discussed in the chapters on tectonics (4 C.) (page 155).

4. The Pit of Damgaard N.

The exposures of the west and north fronts of the Damgaard N pit have been thoroughly investigated during the collection of the *Søby Flora* (E.F. Christensen 1975). Christensen (1975) has given information regarding the outcrops and his figures are reproduced here as Text-Figs. 44, 45. See also Atlas-Figs. 72-79.

The Hodde Formation is exposed through the whole outcrop (the West and North fronts). In the north front the Hodde Formation has a basal transitional bed of sand and black clay including a basal gravel bed of 5-10 cm. The sand to black clay bed wedges out towards the W and has disappeared at the site of the west front, where only the thin basal gravel is left, directly overlain by the Hodde Clay. Below the Hodde Formation are two different situations: 1) In the eastern end of the North front the "Upper Sands" is found; 2) In the western end is a lacustrine succession of brown humic clay and sand lamina containing the *Søby Flora.* This sequence is overlain by the basal gravel of the Hodde Formation but contains scattered roots penetrating into the brown clay from its upper boundary. This indicates a depositional lacuna between the brown clay and the basal gravel of the Hodde Formation. The indication of a hiatus is supported by a lateral border-zone of the lacustrine succession towards the white fluviatile sand. Here a steeply east-dipping erosional front cuts off the lacustrine succession and shows that the lacustrine suc-



Text-Fig. 37. The uppermost part of the Odderup Formation (below the Hodde Formation) from the north profile of the submerged Damgaard Nord quarry. To the right (east) are cross-bedded channel sands with westerly dips that are more or less faulted. East of the channel sand, are the silt and clays of the 4th rhythm in the browncoal bearing sequence, the Søby-Flora bed inclusive. E.F.C. comp. et del.

cession has been eroded along its eastern edge. On this erosional escarpment we find a residual deposit of brown clay and sand, the lowermost beds containing cobbles of the fossiliferous clay from the lacustrine beds. Obviously the lacustrine basin was drained, and a vegetation had settled over the surface of the lacustrine deposits (fossil roots!); and later the beds were subjected to river erosion, obviously the same river branch which deposited the uppermost white fluviatile sand bed of the east end of the north wall of the pit. This is probably the same event which has been recorded as a pocket of "channel sand" from the northern end of the east-front of the Damgaard S pit (ref. page 68, 80, 88, 102 and Atlas-Figs. 78, 79, 81, 101; see also Friis 1979, fig. 2).

Hence, we have found here some details of the latest history of the area before the transgression of the sea depositing the Hodde Clay, changed the conditions radically.

Supplementary information of this stratigraphical level is found in the NW corner of the Klynholt mining area (page 70-71). Further information about the remaining upper part of the Odderup Formation is available from drillings and probings (ref. page 71-74).

The border between the Odderup Formation and the Hodde Formation varies at this locality from a paraconformity (hiatus), with a root horizon and without obvious indications of erosion, into an erosional unconformity without any erosional relief. This unconformity exists due to different age indicated by the deposits underlying the Hodde Formation, involving an interval with erosion and (ore) deposition after the root-horizon was established and before the Hodde Clay-transgression took over.

Table 9. The sequence above the upper browncoal seam of the Fasterholt Member. Record of section EM, NE-corner of Klynholt mining area (after Wagner & Koch (1974), Tab. 2).

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

5. The NW-corner of the Klynholt mining area.

In the west front of the Klynholt mining area about 150 metres south of the point where this front meets the north front, there is an 80 m long outcrop rising from the submerged pit (section EM). This outcrop was briefly described by Wagner & Koch (1974), and detailed information is found in page 58 ff. Here we are concerned only with the problem of the boundary of the Odderup Formation and its relation to the Hodde Formation.

Less than 1 m of Hodde Clay has been described from drillings in the vicinity (to the NW and N of this outcrop) but without definite indication of the stratigraphical level in relation to the succession of Hodde Clay known from the sections of Klynholt N, Damgaard S and Damgaard N. The probe BII, 1978, set at the very northern end of section EM, has also recorded about 3/4 meter of Hodde Clay, that was here retrieved in a complete core sampling (ref. the file of probe BII 1978, page 60). It shows a succession characteristical for the lowermost part of the Hodde Clay of this region of thin beds of black bituminous clay and brown clay. An underlying transitional bed of alternating sand and clay was also found in the core. Beneath this is a 10 cm thick clay bed followed by a 1/2 m thick coal bed. This coal bed correlates well with that of the exposure of section EM observed in 1971-72, and the same lacustrine sequence follows below in the probe and in section EM and allows us to correlate this section with the W front of Damgaard N. The first metre below the coal bed in section EM and probe BII 1978 is a fine sand containing a remarkable deep-reaching root horizon. (In section EM the roots were determined to have a near affinity to the genus Sequoia by P. Wagner in Wagner & Koch, 1974). This correlates with the root horizon of Damgaard N. Consequently the Søby-Flora clay of the latter locality is substituted in section EM by fine sand.

Hence, the deposition of the Odderup Formation terminated in the western area (concerning section EM of Klynholt and the North front of Damgaard N) due to subsidence of the ground water (regressive tendency) and to draining of the lake containing the Søby-Flora clay. This was followed by fluviatile erosion of the latter deposit at the Damgaard N. Consequently, the marker of the upper boundary of the Odderup Formation (4th rhythmic unit) here is a root/stump horizon.

In section EM a coal bed, thinning towards N, indicates the succeeding rise of the groundwater level ("transgressive" tendency of the entire region) and the elimination of the Sequoia forest. The change from a xylitic coal into a sapropelitic detrital coal supports the idea of submersion. Ripple marks in the upper surface of this detrital coal and an overlying gravel indicates the introduction of the Hodde Formation. The basal gravel is a regional marker horizon. The basal transgressional sand-clay bed of the Hodde Formation is substituted in section EM by the 1.6 m cross-bedded fine sand deposited above the coal, indicating a facies change towards the south at this stratigraphical level. Hence, the uppermost brown coal bed of Klynholt Vest indicates the onset of changes leading to the transgression and deposition of the Hodde Clay, and should be employed as a separate lithostratigraphical unit, in practice as a tongue of the Odderup Formation terminating this formation. This new unit is named the Klynholt Vest Tongue (ref. the definition, page chapt. 4B.2.1. III).

6. The K-front of the Carl Nielsen Ltd. pit at Fasterholt.

In chapter 4B.2.2.1. II c.c. the boundary between the Quaternary and the Tertiary was described and the conditions of the boundary in the working front K was mentioned on page 93.

In the central part of mining front K this boundary has a low culmination (crest) in which remains of a fossil soil containing fossil tree roots were preserved. The roots have been determined to *Taxodioxylon gypsaceum* (Wagner & Koch 1974) with affinity to the extant *Sequoia sempervirens*. Most of this occurrence is so near to the boundary, which here was an exposed surface during the Weichselian glaciation, that it has been badly disturbed by solifluction. Nevertheless, this remnant proves, that as is the case in the western part of the Søby-Fasterholt area, a root horizon existed uppermost in the "Upper Sands" as well as in the equivalent 4th rhythmic unit of the browncoal bearing sequence. It probably correlates with the occurrences in the Klynholt Vest and Damgaard N to the west. The *Sequoia* roots rule out this soil as Quaternary and the pollen spectrum of the soil rules out a Pliocene age. In the upper Miocene the area was covered by the Gram Clay sea. Hence, the soil probably is older than the Hodde Clay. Consequently, a correlation with the western localities is reasonable. This correlation provided, the section K6-K7 of the Carl Nielsen pit represents the entire "Upper Sands" of the Odderup Formation, except perhaps for an upper part of the soil that may have been eroded during the Quaternary.

Apart from unique occurrence of the K-front, the "Upper Sands" is not complete in this brown coal pit. One to two meters of the soil and root horizon and the "Upper Sands", has generally been removed by Quaternary erosion.

Probe Fb. 1, 1979 on the hill of Fasterholt Bjerg (ref. page 74) situated just to the south at the western end of the Carl Nielsen Ltd. pit (the Midtkraft mining area), indicates that the soil horizon was probably overlain directly by the Hodde Formation before the Quaternary erosion. An auxiliary trench dug in N-S direction from the western end of the Carl Nielsen Ltd. pit into the foot of eastern end of Fasterholt Bjerg, exposed the brown coal bearing sequence of the Odderup Formation. The probe Fb. 1, 1979, (Text-Fig. 46 and page 74) was set on the north slope of Fasterholt Bjerg, 175 m WSW of the southern end of this trench. Beginning at elevation +57.5 m it penetrated Gram Clay, downwards into the glauconitic clay and Hodde Clay and finally a basal bed of alternating lamina of black clay and sand resting upon 15 cm of transgressional coarse gravel at elevation +44 m (13.35-13.55 m below surface). The drilling stopped in a grey sand at 14 m below surface, i.e. elevation +43.5 m. This is close to the same level as measured for the black soil in sections K6-K7 at the K front of the pit. At this level the drill stopped due to the high groundwater pressure. This indicates that no impermeable layer is present underneath within the next meter. Hence, probably no coal- or clay bed corresponding to the 5th brown coal seam of Klynholt Vest is present just below the grey sand in which the probe stopped. The grey sand is probably correlative with the soil horizon of section K6-K7 and consequently, the Hodde Formation rests unconformably upon the soil-root horizon similar to the one found on top of the "Upper Sands" of the K-front of the Carl Nielsen Ltd. pit.

4.B 2.2.2. Detailed Description of the Components of the Browncoal Bearing Sequence 2:

A. The Drilling Records:

The drillings on the East-West correlation line (Text-Fig. 38)

In cooperation with the Geological Survey of Denmark 3 boreholes were drilled down to 120 m below the surface and 4 were drilled down to to 30-40 m below the surface. These holes were made in 1970-1975 and all of them penetrated the entire Odderup Formation incl. Fasterholt Member and went into its substratum. The drillings were made with an electro hydraulic rig (type "Ideal" 105, Celler Maschinen Fabrik) with max. 12" well casing, in the deeper boreholes tapering telescopic downwards. This rig belongs to Geological Survey of Denmark (Operator: I. Spang Nielsen (DGU)). For the geographical location of these wells see the map Text-Figs. 21 and 62.

Drillings to 120 m below the surface:

Drilling Fasterholt Bjerge, (Fasterholt railway station), file no. 95.1942, Aug.-Oct. 1970 (Text-Fig. 21: (1)).

Drilling Fasterholt Plantage I, file no. 95.1941, May 1970.

Drilling Lavsbjerg Øst, file no. 95.1995, Feb.-March 1975, Text-Fig. 21: (3).

Drillings to 30-40 m below the surface:

Drilling Fasterholt Plantage II (farm of O.C. Simonsen), file no. 95.1946, Dec.-March 1970-1971.

Drilling Fasterholtgaard no. 1 (Klynholt Vest), file no. 95.2163 March 1973, (Text-Fig. 21 (5)).

Drilling Fasterholtgaard no. 2 (Lavsbjerg), file no. 95.2164, March 1973, (Text-Fig. 21 (4)).

Drilling Bjerregaard, file no. 95.2166, April-May 1973, (Text-Fig. 21 (2)).

The drilling (probe) Fasterholt Bjerg 1. 1979, (Text-Fig. 21: Fb 1).

Besides the above mentioned boreholes a number of smaller drillings (probes) have been set at different localities as seen in the Text and Text-Figs. 39-40, 46. One of these, the probe Fasterholt Bjerg 1 (Fb. 1), which is an important supplement to the outcrops of the Carl Nielsen Ltd. browncoal pit (ref. Text-Figs. 23 and 46), is mentioned in this chapter. Probing was carried out with a small rig belonging to the Dept. of Paleontology and Stratigraphy, Geol. Inst., Aarhus.

Drilling Fasterholt Bjerge, file no. 95.1942, 1970 (Text-Fig. 21. (1)).

Locality: At the SE-corner of the pit of Carl Nielsen Ltd. in its final stage, 1970; at the northern end of Fasterholt railway station.

Surface level: 51.0 m

0-1.30	Soil and rubbish
1.30-10.70	Sand of changing grain size, and gravel (Quaternary)
10.70-17.40	Light grey, micaceous quartzsand. (Tertiary: "Upper Sands", Miocene).
17.40-18.60	Brown coal (Fasterholt Member, 3rd rhythm).
18.60-19.30	Clay (Fasterholt Member, 3rd rhythm).
19.30-20.70	Sand and silt (Fasterholt Member, 3rd rhythm).
20.70-22.80	Brown coal and gytja (Fasterholt Member, 2nd rhythm).
22.80-23.00	Fine grained sand and silt (F.M., 2nd rhythm).
23.00-24.20	Clay (F.M. 2nd rhythm).
24.20-25.50	Sand and a thin brown coal bed (Fasterholt Member: 1st rhythm).
25.50-27.40	Fine-medium grained sand.
27.40-28.50	Silt-clay (fossil wood, perhaps roots).
28.50-29.00	Fine-medium grained quartzsand.
29.00-29.20	Black clay.
29.20-42.00	Fine-medium grained quartzsand, downwards turning into coarse quartzsand.
42.00-66.80	Preferably fine grained sand with thin clay beds at 46-46.30 m and around 53.50. Scattered sand with browncoal detritus. At 60.00-61.00 coarse quartzsand.
66.80-72.30	Brown, consolidated micaceous clay with sporadic thin beds of sand.
72.30-73.60	Coarse quartzsand.
73.60-74.40	Black-brown strongly consolidated clay, fragments of lignite at the bottom.
74.40-78.30	Fine-medium grained sand.
78.30-78.50	Lignite and black gytja.
78.50-80.60	Medium grained sand.
80.60-80.75	Brown coal and brown clay (?).
80.75-88.10	Medium-coarse quartzsand.
88.10-89.20	Brown clay with a bed of fine sand.
89.20-120.0	Preferably fine grained sand with silt and micaceous clay with changing frequency, from about 110.5-116.0 preferably silt with micaceous clay of changing frequency.

Pollen-statistical stratigraphical analyses (method: G. von der Brelie, 1967) correlate the sequence 10.7-20.7 with microflora zone D. From 20.7 and downwards to 25.5 correlates with microflora zone C without its lower limit being reached. Both zones belong to the Miocene, Hemmoorian (C)-Reinbekian (D).
Abbreviations: F.M. = Fasterholt Member.

Drilling Lavsbjerg Øst, file no. 95.1995, 1975 (Text-Fig. 21 (3)).

Locality: 100 m NE of Munkballe farm a few hundred metres to the east of the point Lavsbjerg (71 m)

Surface level: 55.0 m

0-2.10	Soil and rubbish.
2.10-4.00	Black-brown clay shading into green. The uppermost 0.40 m weathered into brown colour. (Hodde Clay, Reinbekian).
4.00-4.10	Yellow-brown sandy clay.
4.10-5.00	Coarse grained sand ("Upper Sands").
5.00-10.90	Light grey, medium grained sand ("Upper Sands").
10.90-12.60	Brown coal in two beds separated by 0.60 m clay and fine sand (Fasterholt Member, 3b rhythm).
12.60-14.00	Black and brown clays, below with intercalated sand (Fasterholt Member, 3b rhythm).
14.00-16.00	Brown coal, with intercalations of silt and sand 14.50-15.00 (Fasterholt Member, 3a rhythm).
16.00-17.30	Brown clay with sand (F.M. 3a rhythm).
17.30-19.10	Brown coal (partly 17.50-18.00, solid bed 18.50 -19.00), humous clay (17.30-17.50) and mixed (18.00-18.50) (F.M. 2nd rhythm).
19.10-21.20	Silt, brown clay with silt (F.M. 2nd rhythm).
21.20-22.10	Brown silt and sand (F.M. 2nd rhythm).
22.10-22.30	Sand with fossil wood (driftwood?). (F.M. 2nd rhythm).
22.30-23.50	Brownish fine-medium grained sand (F.M. 2nd rhythm).
23.50-24.50	Brown coal and brown sand (F.M. 1st rhythm).
24.50-25.00	Silt and sand.
25.00-26.30	Brown micaceous clay with lamellae of fine sand (Fasterholt Member, 1st rhythm).
	——— Lower limit of Fasterholt Member ———
26.30-27.50	Fine grained sand and silt with clay (soil?)

27.50-47.00	Fine-medium grained quartz sand.
47.00-47.50	Sand with silty clay.
47.50-52.50	Fine grained brown sand.
52.50-53.00	Coarse quartzsand.
53.00-54.00	Fine sand rich in mica alternating with sandy clay and coarse quartzsand.
54.00-57.50	Brown fine grained micaceous sand.
57.50-60.00	Brown fine grained micaceous sand alternating with thin beds of brown clay.
60.00-65.50	Brown fine-grained micaceous sand.
65.50-66.10	Silt and sand (dark grey).
66.10-69.50	Brown, solid micaceous clay, in the middle black-grey. Intercalated are thin beds of fine-grained sand (Arnum Formation?)
69.50-69.80	Coarse sand.
69.80-71.00	Sand and silt (Arnum Formation?)
71.00-75.30	Brown solid micaceous clay, with intercalated thin beds of fine grained sand (Arnum Formation?).
75.30-77.15	Thin beds of clay in silt (Arnum Formation?).
77.15-78.00	Sand and clay (Arnum Formation?).
78.00-78.50	Lignite (78.00-78.20) and brown silt (78.20-78.50).
78.50-79.00	Brown silt and sand with fossil wood (driftwood?).
79.00-80.50	Clay with sand and driftwood(?), at 80.00 a thin bed of brown coal.
80.50-88.00	Fine grained micaceous sand, at 82.20 a thin brown coal bed.
88.00-88.20	Coarse quartz sand.
88.20-88.40	Brown clay and silt.
88.40-89.30	Brown sand and silt.
89.30-89.50	Brown clay and silt.
89.50-89.80	Brown fine-medium grained sand with coarse quartz grains.
89.80-90.00	Brown clay.
90.00-108.00	Brown fine sand with single very thin clay beds, a few pieces of brown coal between 98.50-99.00. A thin bed of brown micaceous clay below 106.00.
108.00-113.00	Sand and silt.
113.00-114.50	Sand.
114.50-117.00	Brown clay with beds of fine sand – silt. Clay predominating between 115.00-116.00.
117.00-120.00	Brown silt and sand.

Abbreviations: F.M. = Fasterholt Member.

Drilling Fasterholtgaard no. 1, file no. 95.2163, 1973 (Text-Fig. 21 (5)).

Locality: 125 m to the north-west of the section EM in the NW corner of the Klynholt mining area.

Surface level: 50.0 m.

0.0-0.10	Soil.
0.10-0.90	Grey-yellow medium grained sand (aeolic-driftsand).
0.90-1.05	Soil with tree roots.
1.05-4.40	Fine-medium grained sand.
4.40-4.90	Sand-gravel with stones (Quaternary).
4.90-5.40	Black-brown and green clay (Hodde Clay, Reinbekian).
5.40-6.40	Grey medium grained sand with thin layers of clay and pebbles (at the basis?) (Hodde Formation, basal transgression bed).
6.40-6.60	Quartzsand with pebbles overlying a thin bed of brown coal (basal gravel of the Hodde Formation).
6.60-7.00	Brown coal (5th brown coal seam).
7.00-7.60	Grey medium grained sand ("Upper Sands" = 4th rhythm).
7.60-9.70	Brown fine sand and silt ("Upper Sands" = 4th rhythm).
9.70-10.80	0.5 m brown coal (4th seam) overlying brown micaceous clay (Fasterholt Member, 3rd rhythm).
10.80-12.55	Brown coal (Fasterholt Member, 3rd rhythm).
12.55-12.60	Sand (Fasterholt Member, 3rd rhythm).
12.60-13.40	(Sandy) brown coal (Fasterholt Member, 3rd rhythm).
13.40-14.20	Brown clay, (Fasterholt Member, 3rd rhythm).
14.20-16.60	Brown coal with subordinate silt. 14.20-15.10 lignite, (Fasterholt Member, 2nd rhythm).
16.60-17.45	Brown clay (Fasterholt Member, 2nd rhythm).
17.45-17.70	Grey fine-medium grained sand (Fasterholt Member, 2nd rhythm).
17.70-19.35	Black brown clay, at the bottom sandy with lignite pieces (Fasterholt Member, 2nd rhythm).
19.35-21.30	Fine-medium grained sand, subordinate silt (Fasterholt Member, 2nd rhythm).
21.30-21.80	Black clay (Fasterholt Member, 2nd rhythm).
21.80-22.40	Sand (Fasterholt Member, 2nd rhythm).
22.40-22.80	Brown coal (max 0.5 m) (Fasterholt Member, 1st rhythm).
22.80-25.00	Sand.

Drilling Fasterholtgaard no. 2, file no. 95.2164, 1973 (Text-Fig. 21 (4)).

Locality: At the south border of the Klynholt mining area to the SW of the point Lavsbjerg.

Surface level: 57.0 m.

0-0.15	Soil.
0.15-0.55	Yellow sand (aeolic driftsand?).
0.55-1.60	Grey, medium grained sand with stones in the bottom (Quaternary).
1.60-3.80	Changing grey and ochreous sandy clay (weathered glauconite clay?).
3.80-4.85	Grey and ochreous fine clay (weathered glauconite clay?).
4.85-5.20	Ochreous sand and clay (weathered glauconite clay?).
5.20-7.40	Grey clay with a few beds of ochreous sand (glauconite clay?).
7.40-7.60	Black (dark grey) clay (Hodde Clay).
7.60-7.80	Green-grey clay and sand (Hodde Clay).
7.80-8.10	Grey clay (Hodde Clay?).
8.10-8.70	Yellow silt, sand and clay (Hodde Clay).
8.70-13.40	Black-grey clay (Hodde Clay).
13.40-16.00	On top grey-green silt-fine sand in a thin zone downward coarser sand with thin consolidated clay-beds. (Basal bed of Hodde Formation and probably the upper part of 4th rhythm/"Upper Sands".
16.00-16.80	Grey fine-medium grained sand.
16.80-18.70	Brown coal with lignite. (Fasterholt Member, 3rd rhythm).
18.70-20.05	Brown clay with silt beds. (Fasterholt Member, 3rd rhythm).
20.05-20.75	Brown coal with a thin sand bed and some silt. (Fasterholt Member, 2nd rhythm).
20.75-21.00	Brown micaceous clay overlying a thin sand bed. (Fasterholt Member, 2nd rhythm).
21.00-21.90	Brown coal. (Fasterholt Member, 2nd rhythm).
21.90-22.50	Brown clay. (Fasterholt Member, 2nd rhythm).
22.50-22.80	Fine-grained sand. (Fasterholt Member, 2nd rhythm).
22.80-23.30	Black-brown clay. (Fasterholt Member, 2nd rhythm).
23.30-25.20	Brown-grey fine sand and silt. (Fasterholt Member, 2nd rhythm).
25.20-25.60	Brown coal. (Fasterholt Member, 1st rhythm).
25.60-28.00	Grey-brown fine quartzsand and silt. (Fasterholt Member, 1st rhythm).
28.00-28.15	Brown coal. (Fasterholt Member, 1st rhythm).

28.15-28.50	Brown micaceous clay. (Fasterholt Member, 1st rhythm).
28.50-36.00	Grey fine-medium grained sand.

Drilling Bjerregaard (Fasterholt), file no. 95.2166, 1973 (Text-Fig. 21 (2)).

Locality: Fasterholt Bjerg, 50 metres to the ENE of the farm Bjerregaard.

Surface level: 58.0 m

0-0.25	Soil.
0.25-0.40	Grey sand (leaching horizon of podsol soil).
0.40-1.10	Ochreous sand (precipitation horizon of podsol soil).
1.10-1.30	Grey-yellow medium grained sand, scattered stones. (Quaternary).
1.30-3.00	Green clay, sporadical changing into ochreous. (Glauconite clay, Gram Formation?).
3.00-4.60	Black brown clay (Hodde Clay).
4.60-4.80(?)	Coarse gravel. (Basal gravel of Hodde Formation).
4.80(?)-15.00	Fine-medium grained sand.("Upper Sands").
15.00-15.60	Coarse sand. ("Upper Sands").
15.60-16.40	Silt ("Upper Sands").
16.40-16.80	Fine-medium grained sand. ("Upper Sands").
16.80-17.50	Brown clay. (Fasterholt Member, 4th rhythm).
17.50-19.90	Black-brown clay and brown coal. (Fasterholt Member, 3rd rhythm).
19.90-20.90	Black and brown clay. (Fasterholt Member, 3rd rhythm).
20.90-21.30	Brown coal with lignite.(Fasterholt Member, 3rd rhythm – bed no. 2).
21.30-21.50	Black-brown clay. (Fasterholt Member, 3rd rhythm – bed no. 1).
21.50-22.20	Brown coal. (Fasterholt Member, 3rd rhythm – bed no. 1).
22.20-23.60	Grey and brown clay. (Fasterholt Member, 3rd rhythm).
23.60-23.80	Grey medium grained sand.
23.80-27.10	Grey clay. (Fasterholt Member, 3rd rhythm).
27.10-27.60	Black clay and brown coal, subordinate sand. (Fasterholt Member, 1st rhythm).
27.60-34.50	Fine-medium grained quartzsand.

Drilling Fasterholt Plantage I, file no. 95.1941, 1970 (chapt. 4B.5, page 99, Text-Fig. 47).

Locality: South-west end of O.C. Simonsens's farm (Skovbjerg) at the west border of Fasterholt Plantage (forest).

Surface level: 45.0 m

0-0,20	Loam.
0.20-0.50	Sand with iron pan.
0.50-3.00	Sand.
3.00-4.70	Gravel and sand with stones (Quaternary).
4.70-9.60	Sandy clay with stones (Quaternary) (Solifluction?).
9.10-10.10	Fine grey solid clay (Quaternary).
10.10-15.60	Coarse sand and gravel with stones (Quaternary).
15.60-32.00	Fine-medium grained grey quartzsand (Tertiary?).
32.00-32.30	Thin beds of silty micaceous clay in fine sand (Tertiary).
32.30-41.40	Grey fine sand, with a few thin beds of silty micaceous clay (Tertiary).
41.40-42.50	Silt, in the lower part with brown coal detritus.
42.50-43.60	Brown coal with intercalated black silt with brown coal detritus.
43.60-47.00	Silt with brown coal detritus with increasing coal content from 45.00 to 46. m, at 46.00 about 5 cm brown coal.
47.00-48.70	Brown coal, 3 beds separated by presumably silt (sample lacking).
48.70-49.60	Black coaly silt and clay.
49.60-50.10	Brown coal (Lower Miocene (?): Aquitanian?).
50.10-52.00	Black clay.
52.00-54.00	Fine grained sand.
54.00-54.40	Silt.
54.40-60.00	Fine grained sand.
60.00-60.70	Fine grained sand with silty clay with mica.
60.70-63.60	Fine-medium grained sand.
63.60-66.60	Fine grained sand with thin clay beds.
66.60-78.00	(Fine-) coarse grained sand with scattered thin beds of brown coarse clay.
78.00-79.00	Alternating brown coarse clay and quartzsand.
79.00-80.50	Brown, silty clay with intercalated fine sand.
80.50-112.30	Preferably silt, alternating with subordinate and sandy clay and beds of fine sand. 98.70-111.00 several thicker beds of brown silty clay.
112.30-112.50	Solid black-brown and green clay with quartz grains.
112.50-113.80	Fine sand and clay with quartz grains downwards changing into coarse quartz sand.
113.80-114.10	Black-brown, solid silty micaceous clay.
114.10-115.40	Fine silty sand with quartz grains.
115.40-115.70	Solid brown silty micaceous clay.
115.70-118.80	Coarse-medium grained quartzsand with thin clay beds.
118.80-120.00	Silt(?).

Drilling Fasterholt Plantage II, file no. 95.1946, 1970 (chapt. 4.B.5, page 99, Text-Fig. 47).

Locality: South-west end of O.C. Simonsen's farm (Skovbjerg) at the west border of Fasterholt Plantage (forest). To the east of the very nearby DGU drilling no. 95.847, 1943.

Surface level: 46.0

0-0.20	Soil.
0.20-0.55	Yellow medium grained sand with pebbles.
0.55-1.40	Grey silt (clay?) and sand beds.
1.40-11.90	Sandy clay, from 3.05 m with pebbles. (Solifluction?), Quaternary.
11.90-13.00	Yellow sand, gravel and stones (glacio-fluviatile sediments?).
13.00-14.15	Brown and black, fine clay (Hodde Clay?).
14.15-14.40	Dark sand and silt with lignite fragments.
14.40-15.40	Brown and black clay.
15.40-19.20	Dark sand and silt, with lignitic fragments (concentrated between 17.70-18.00).
19.20-19.80	Brown clay alternating with thin beds of fine sand.
19.80.20.60	Brown micaceous clay.
20.60-22.10	Black micaceous clay, with brown coal between 21.90-22.10 m.
22.10-22.40	Fine-medium grained sand.
22.40-22.55	Micaceous silt.
22.55-24.50	Brown fine sand-silt with a few pieces of lignite.
24.50-30.00	Fine-medium grained quartzsand, at 26.20 black clay (15 cm).

The drilling (probe) Fasterholt Bjerg 1, 1979 (Text-Fig. 21: Fb 1; 46).

Operator: S. Meldgaard Christiansen, Geological Institute, Aarhus.

Locality: The north hang of the E-W ridge projecting from Lavsbjerg and eastwards towards Fasterholt and ending to the east in the point Fasterholt Bjerg (68 m), 400 m to the ESE of the farm Bjerregaard (ref. the map Text-Fig. 21).

Surface level: 57.5 m.

0-1.2 m	Soil and aeolic sand.
1.2-2.7	Weathered, fine brown-grey clay (presumably Gram Clay).
2.7-3.1	Brown clay with lamina of silt (Gram Clay).
3.1-5.8	Fine brown-grey clay (Gram Clay).
5.8-6.35	No record. (The limit Gram Clay/glauconitic clay in this interval!).
6.35-8.15	Fine, green-greyish glauconitic clay.
8.15-9.10	Brown fine clay (Hodde Clay).
9.10-9.30	Black-brown clay (Hodde Clay).
9.30-9.55	Black-dark brown clay with glauconite grains (Hodde Clay).
9.55-9.80	Light brown clay (Hodde Clay).
9.80-12.30	Fine, black clay with lamina of brown clay (Hodde Clay).
12.30-13.35	Alternating thin beds of black fine clay and brown micaceous clay, in the upper 45 cm the brown clay is coarse and rich in mica. 13.20- 13.35 a bed of fine brown micaceous clay (Hodde Clay).
13.35-13.50	Coarse sand and gravel. (Hodde Formation).
13.50-14.00	Medium grained-coarse sand (transgressive basal bed of Hodde Formation).
14.00-	End of core. The cutting cone ended in an alternation of clay and sand with pebbles, according to the sample which adhered to the terminal cutting unit. This can be interpreted as a part of the transgressive basal bed with its basal gravel (pebbles!) of the Hodde Formation.

The probe could not penetrate deeper owing to high artesian water pressure. This by experience indicates a thick permeable bed below and that no impermeable bed (brown coal or clay) is found within 1-2 metres.

Comments on the Drilling Program.

The drillings are aligned along a general east-west direction from Fasterholt (east end of the Carl Nielsen Ltd. pit) through Klynholt to the outwash-plain west of Fasterholt Plantage. This was to establish a stratigraphical correlation between the main locality (the Carl Nielsen Ltd. pit, at Fasterholt) and the localities on the Lavsbjerg Hill, including DGU drilling no. 95.849 (1943) to the west of Fasterholt Plantage. The latter drill site is where the marine Upper Miocene Gram Clay (fossiliferous), glauconite clay and the Middle Miocene Hodde Clay have been previously recorded (Rasmussen, 1966, page 60). The drilling program and the exposures made possible the construction of a geological east-west section through the southern part of the Søby-Fasterholt mining area (ref. Text-Fig. 38).

It is possible now to trace the productive part of the Fasterholt Member (1st-3rd brown coal seam), the "Upper Sands" and the Hodde Clay, their variation in thickness and general tectonic structure. Correlation between Klynholt Vest (Fasterholtgaard no. 1 borehole) and the 30 m deep Fasterholt Plantage II borehole is somewhat dubious, and no reliable lithostratigraphical correlation can be established with the Fasterholt Plantage I borehole (95.1941). A collection of small seeds obtained for biostratigraphical information from the latter well was done by E.M. Friis, 1985, but were insufficient for a conclusion.

The description of the geological succession below the Fasterholt Member is based upon the 3 boreholes drilled down to 120 m below surface. This will be treated in a separate section, ref. page 89. A special report on the sedimentological analysis of the samples from Lavsbjerg Øst borehole was published by Friis, Nielsen, Friis & Balme, 1980.

B.

The Boreholes of the Southern part of the Søby-Fasterholt area and their Compilation into an East-Western Profile.

A generalized survey of the boreholes of the southern part of the Søby-Fasterholt area arranged on an east-west line is demonstrated on Text-Fig. 38. The Fasterholt Plantage I and II boreholes are omitted, because they are not correlative based entirely on lithostratigraphy (ref. below). This diagram shows that it is possible to correlate the 1st through 3rd major brown coal seams based on lithostratigraphy and to demonstrate that they are continuous from east to west with a minor increase in thickness towards the west and with a subordinate variation in clay (-silt-sand) content. (There is a general coordination between the lithostratigraphical and biostratigraphical correlation, the deviations being subordinate to the level of substages (ref. chapter 4.B 7 page 138, 140, 142)). It is obvious that the "Upper Sands" (equivalent to the 4th rhythm) attains an optimal thickness (10 m) eastwards (between profiles K6 and K7 in the Carl Nielsen Ltd. pit, Fasterholt and in the Bjerregaard borehole) decreasing considerably westwards.

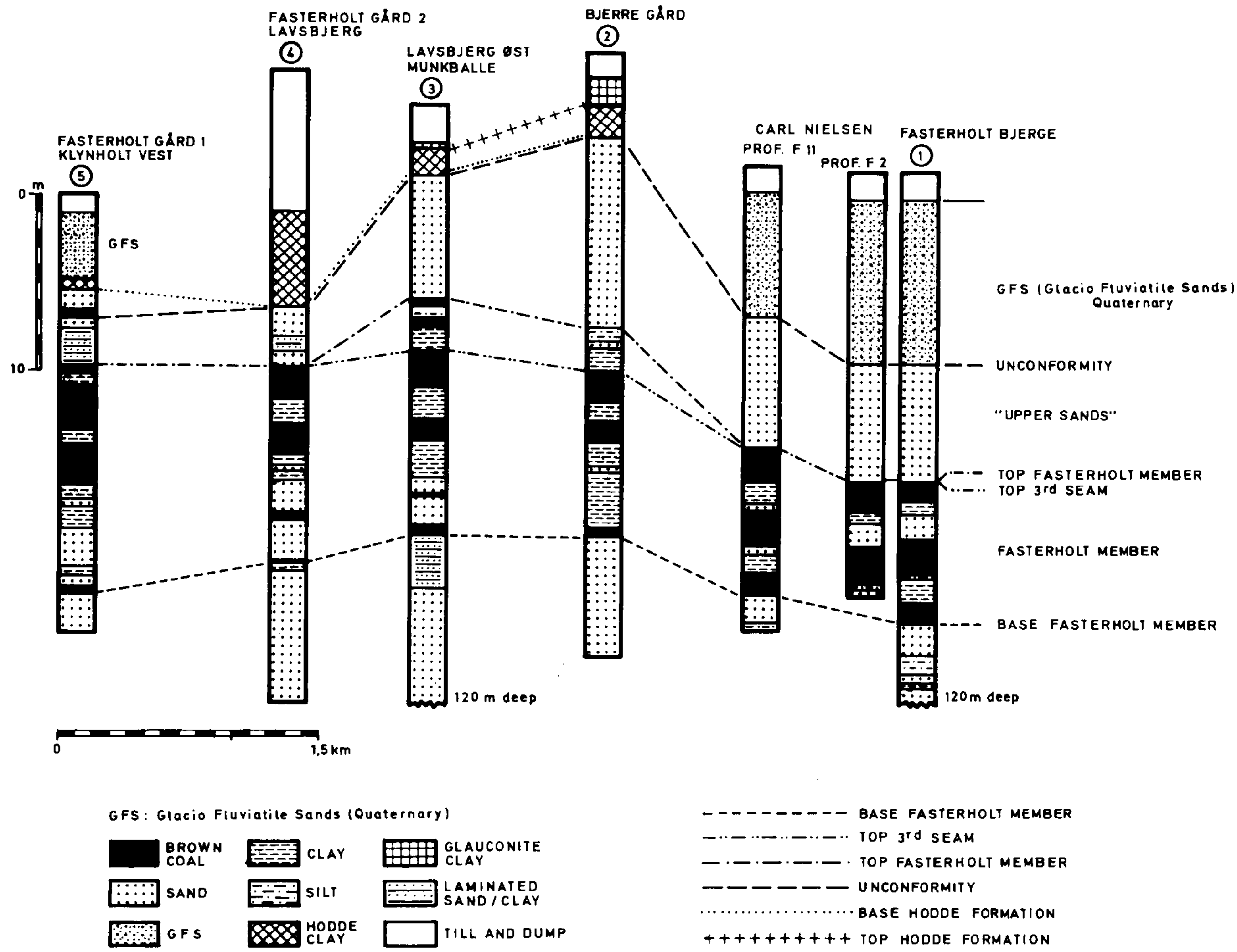
Also, the sequence rises from east (Fasterholt Bjerge – Bjerregaard) towards west (i.e. dips eastwards) into a (tectonical) culmination with high point on Lavsbjerg Hill (Lavsbjerg Øst – Fasterholtgaard no. 2). Consequently the brown coal seams are at a relatively high elevation and nearest to the surface at the west front of the Klynholt and Damgaard mines (Fasterholt: 20-25 m below surface. Section EM and the Fasterholtgaard no. 1 borehole: About 12-14 m below surface). This culmination is a tectonic structure. The available information implies that the Tertiary sequence is folded and that the Lavsbjerg Hill culmination is a shallow anticlinorium (ref. chapter 4.C.3 on Tectonics, page 155).

West of the Fasterholtgaard-Søby road and corresponding approximately to the Fasterholt Plantage (forest) area are no records of the Fasterholt Member or a shallowly occurring brown coal deposit. We have made several attempts to drill wells, but could not without unreasonable costs penetrate the stony Quaternary deposits. As mentioned before, this area is covered by a deposit of stone to coarse gravel in a NNW-SSE strike. This was interpreted by the late State geologist Dr. K. Milthers (personal communication) to be a Pleistocene deep river channel (fossil valley). The drilling technician of DGU, Mr. I. Spang Nielsen, with his experience of hundreds of brown-coal prospecting drillings of this area has confirmed this statement.

The following trends can be gleaned from the information of the E-W cross-section of the southern part of the Søby-Fasterholt area of Text-Fig. 38 and table 10 (pag. 78):

1. Fasterholt Member and the "Upper Sands".

Regarding the eastern part (about 1 km) of the cross-section involving the Fasterholt Bjerge borehole (no. 95.1942) and the two profiles F2 and F11 of the Carl Nielsen Ltd. pit, there is a distinct correlation concerning the 1st, 2nd, and 3rd brown coal seams and the intervening clastic sediments. From Text-Fig. 38 it does not appear that the 2nd seam is biparted (bed no. 1 and 2) at the eastern localities and that the lower detrital coal bed (bed no. 1) here becomes richer in clay upwards, and its uppermost part consists of a humous clay (ref. page 41-42). The lowermost part of the overlying



Text-Fig. 38. East-West litho-stratigraphical profile through the southern part of the Søby-Fasterholt area from Fasterholt railway station (1) to Klynholt Vest (5). E.F.C. & E.K. comp. In accordance with the definition of the Fasterholt Member, the "Base Fasterholt Member" is defined as the base of the lowermost browncoal seam of the Browncoal Bearing Sequence, even in Fasterholtgaard 2 and Lavsbjerg Øst boreholes where two thin seams occur in the lowermost part of the sequence. The evidence of the root-horizon marking the "Base Fasterholt Member" can rarely be recorded from the drilling samples due to the unconsolidated sands. The Top 3rd Seam is a regular lithological level, except for the Fasterholtgaard 1 borehole where an intercalated clay occurs in the upper part of the 3rd seam. This does not interfere with the general bio-stratigraphical evidence provided by the pollen analysis from this level, and may facilitate the definition of the Top 3rd seam in this local variation. The top Fasterholt Member is defined at the top of the uppermost browncoal seam and below the "Upper Sands". The clay-silt succession in equivalent stratigraphical level even devoid of brown-coal, is accepted as part of the Fasterholt Member due to occurrence of similar beds in an equivalent position in the succession of the Lavsbjerg Øst borehole. The upper boundary of the "Upper Sands" is an angular unconformity with the Quaternary glaciofluviatile sands-gravel as the overlying in the eastern localities concerning profile F 11, (ref. Text-Fig. 24, the type section and the overlying sequence of probe Fb 1). At Lavsbjerg Hill, the "Upper Sands" is overlain by the Hodde clay with a transgressional/erosional paraconformity except for the Fasterholtgaard 1 borehole and profile EM of Klynholt Vest where a root horizon underlying 5th seam is synchronous with and marks the paraconformity.

driftwood-coal (bed no. 2) is exceptionally rich in clastic material in these localities. A silt or sand bed sporadically separates the two subseams and this tendency increases westwards in direction of Bjerregaard (no. 95.2166).

In the Bjerregaard borehole the 1st, 2nd and 3rd seams can easily be pointed out, but all three seams contain more clay than in the eastern localities. This appears from the drilling record where the 2nd and 3rd seams (detrital browncoal) are each divided into two by a clay bed. This is also seen occurring with the 2nd seam in the eastern localities and the 3rd seam of the Carl Nielsen Ltd. pit is rich in clay. At Bjerregaard it is remarkable that the 3rd seam is succeeded by a clay bed (black clay and grey brown clay) and a (sand-) silt bed. Above follows the light quartz sand of bed no. 7 ("the Upper Sands"). The latter reaches its max. thickness of the profile line: 10-11 metres at this locality.

In the locality of Bjerregaard borehole the 1st seam is very thin in comparison to the eastern localities and consists of alternating layers of thin clay- and coal. Clay bed no. 5 can easily be recognized, but it is thinner than in section F11 and the clastic beds of the 2nd rhythm are thicker here than in F11.

At the Lavsbjerg Øst borehole (no. 95.1995) we find some deviation in continuing the trend from borehole Bjerregaard but the main succession is like that of the Bjerregaard borehole. The 1st seam is thin and from here it is easy to pick out the 2nd and 3rd seams. The 2nd seam is not clearly divided by a clay layer, and the upper part consists of alternating layers of clay and coal instead of dominantly coal. The 3rd seam is biparted by a thin silty sand bed continuing upwards into a clay bed. Remarkable is a 4th seam (subrhythm 3 b), which is biparted by a silty sand bed similar to the 3rd seam. It seems to be a lateral equivalent to the (sand and) silt bed between 15.0 m and 16.8 m of the Bjerregaard borehole. At least the sequence (15.0) 15.6 m to 19.9 m of the latter may correlate approximately with the sequence of 10.9 m – 16.0 m in Lavsbjerg Øst borehole.

The clastic sequence in the 2nd rhythm is thick, agreeing with the Bjerregaard borehole, but the lower clay bed of the latter is replaced by medium-grained sand.

The next drilling record in westerly direction concerns Fasterholtgaard 2 (Lavsbjerg). It contains three seams correlative to 1st to 3rd seams. The 1st seam is thin and the clastic sequence of 2nd rhythm is similar to that found at the Lavsbjerg Øst borehole beginning with sand and ending in clay. The sand is predominant with the upper clay only of minor thickness. The 2nd rhythm contains a small browncoal seam which may indicate a sub-rhythm, which is also indicated in profile F 11 of the Carl Nielsen Ltd. browncoal pit by a minor root horizon dividing bed no. 0 into an (a) and (b) subunit.

The 2nd seam is separated by clay, with the upper coal layer also biparted but by a thin sandy intercalation.

Bed no. 5 consisting of clay with thin silt layers and therefore composed differently than in other records of this unit. The 3rd seam is massive in thickness and is overlain by sand with a zone containing thin clay intercalations, that has no equivalent in the Lavsbjerg Øst borehole. It may be a marginal deposit corresponding to the upper clay and 4th brown coal bed (sub rhythm 3b). At least the upper part of the sand may correlate with the "Upper Sands" and an uppermost part may enclose the basal, "transgression-bed" of the Hodde Formation. This sand is overlain by Hodde Clay, and consequently the 4th and 5th seams are lacking. Only a thin silt bed below the Hodde Clay may indicate similar changes of sedimentation, or the corresponding deposits were removed by later erosion.

It should be noticed that the clastic sequence of 2nd rhythm is thick, though thinner than in the similar equivalents of the Lavsbjerg Øst and Bjerregaard boreholes which is characteristic for the western boreholes.

In interpreting the Fasterholtgaard 2 (Lavsbjerg) drilling log it should be noted that this borehole is located to the eastern, steeply dipping flank of a fold (ref. Atlas-Fig. 115). This may seriously affect part of the thickness recorded (e.g. the record of a thick Hodde Clay).

The Fasterholtgaard 1 borehole (Klynholt Vest) located at the west border of the Søby-Fasterholt mining area, records 4 -(5) brown coal seams. It seems reasonable to correlate the thin seam at level 22.4 m-22.8 m to the 1st seam (bed no. -5). The following clastic sequence is similar in thickness and succession to the 2nd rhythm at the Lavsbjerg Øst and Fasterholtgaard 2 boreholes, though is thicker than them. The 2nd and 3rd seams are thicker than any other records of this profile. The upper part of the 3rd seam contains a clay bed 60 cm thick. This clay may correlate with the clay overlying the 3rd seam in the Bjerregaard and Lavsbjerg Øst boreholes. In the Fasterholtgaard 1 borehole the overlying 0.5 meter thick coal bed, and perhaps together with the overlying sand-silt bed or part of it, may correlate with the 4th coal bed (sub-rhythm 3b) of Lavsbjerg Øst borehole. This is favoured by the author because of its fit to a wider set of criteria, as will be demonstrated later (page 79-80, 164).

In addition to this survey of the profile-line where main features of the individual records (outcrops and boreholes) were analyzed and compared, the behaviour of the single units known in detail from the Carl Nielsen Ltd. pit shall be considered as part of the profile-line and especially regarding the variation of thickness. These units have only a lithostratigraphical meaning:

The delta sands ("Upper Sands").

Bed no. 7: Increasing in thickness to a maximum to the east, where the total thickness (below the Hodde

Clay) is only known from the Bjerregaard borehole (10-11 m). This thickness may be valid in the Fasterholt area (the Carl Nielsen Ltd. pit where this sand attains a thickness of at least 10 meters somewhere between the profiles K6 and K7). The thickness decreases westwards to 2 m; max. 3.4 m at Lavsbjerg (Fasterholtgaard 2) and 0-2.7 m at Klynholt Vest (Fasterholtgaard 1).

The 3rd brown coal seam, beds 6a-6b (subrhythm 3b): This is a local clay- and coal-bearing sequence extending, according to information from the Bjerregaard-Lavsbjerg Øst boreholes, presumably to the west border of Klynholt (Fasterholtgaard 1 borehole and section EM). The sequence appears to represent the final stages of brown coal deposition in a locally restricted relict of the original extended basin.

The silty clay, bed no. 5: This bed can be traced continuously throughout the profile-line. It is rather thin in the east (0.5 m) increasing from the Carl Nielsen Ltd. pit to Lavsbjerg Øst borehole (except at the Bjerre gaard borehole). From Lavsbjerg Øst it decreases westwards as seen in the Fasterholtgaard 2 borehole and becomes very thin for, perhaps partly to be expressed as brown coal, at Klynholt Vest (Fasterholtgaard 1 borehole).

The 2nd brown coal seam, bed no. 1 + 2: This seam thins eastwards, increases in thickness to a maximum in the middle of the Carl Nielsen Ltd. pit, and again decreasing through the west end of this pit and Bjerregaard to Lavsbjerg Øst where it reaches a minimal thickness. From here it increases westwards (Fasterholtgaard 2 borehole) attaining its absolute optimal thickness at the west border of the Søby-Fasterholt area (Fasterholtgaard 1 borehole).

The clastic sequence of 2nd rhythm, bed no. 0- (-4): This rather well defined sequence is relatively thin (1.5-1.65 m) in the Carl Nielsen Ltd pit, consisting of clay, silt, and sand. It becomes much thicker (4.9 m) as recorded in Bjerregaard borehole, here predominantly consisting of clay. In Lavsbjerg Øst borehole it consists of 2.1 m of clay with sub- ordinate amount of silt overlying 2.8 m. sand, i.e. a total of 4.9 m. At the Fasterholtgaard 2 borehole it amounts 3.3 m with about 1 m of clay overlying the sand. It reaches an optimal thickness of 5.8 m. at Klynholt Vest (Fasterholtgaard 1 borehole). The upper half consists of clay and the lower half is predominately sand with a 0.5 m thick clay bed in the lower part. It is a well defined unit due to its position in the entire sequence, but varies in lithology from predominately clay to clay and sand in varying proportions.

The 1st brown coal seam, bed no. -5: This seam is well defined by its position in the total sequence and in the eastern occurrences by its petrography. It is thickest in the west end of the Carl Nielsen Ltd. pit (1.0-1.2 m) with a tendency to decrease eastwards within the pit. It is thinner (1/2 m) at Bjerregaard and Lavsbjerg Øst borehole (1/2 m), and even thinner as seen in the Fasterholtgaard 1 and 2 boreholes (0.4 m).

From the analytical point of view it is interesting in addition to regard the variation in thickness of different composite units as well as the total thickness of brown coal, clay and brown coal + clay respectively (ref. Table 11).

From the figures of the table 11 is indicated that a minimum of sediment were deposited towards east in the area of the Carl Nielsen Ltd. pit during the period of brown coal production. Optimal deposition took place at Klynholt Vest and at a slightly lesser rate in the area of Munkballe (Lavsbjerg Øst), eastwards in the direction of Bjerre (Bjerregaard). An intervening minimum is located in the area of Lavsbjerg (Fasterholtgaard 2 borehole) i.e. between Munkballe and the west border of Klynholt (Fasterholtgaard 1 borehole).

In the eastern part of the Fasterholt area where a minimal deposition took place, a relatively larger part

Table 10. The variation in thickness of the Browncoal Bearing Sequence, total thickness of Browncoal, Browncoal and Clay, and of Clay, along the E-W profile across the southern part of the Søby-Fasterholt area. Thickness in metres. E.K. comp.

	Fasterholtgaard 1 (Klynholt Vest)	Fasterholtgaard 2 (Lavsbjerg)	Lavsbjerg Øst	Bjerregaard	CN, F11	Fasterholt Bjerge
1	12	8.7	10.5	9.5	8.5	8
2	13 (12)	8.8	14.6	9.5 (10.8)	8.5	8.1
3	5.7 (−5th seam) 6.2 (+5th seam)	3.8	4.2	2.8 (3.3)	5.3	3.2
4	9.8 (−5th seam) 10.3 (+5th seam)	6.6	8.2	10.6	6.7	6.7
5	4.1	2.6 (2.9)	5.1	8.2	1.9	1.9

1 = The coal-bearing sequence (1st + 2nd + 3rd rhythms (ref. type section F11)
2 = The coal-bearing sequence, including subrhythm 3b (beds −5 to +6 in extenso) (−5th seam).
3 = Total thickness of browncoal.
4 = Total thickness of browncoal + clay.
5 = Total thickness of clay in the browncoal bearing sequence.

Letters in metres.

of the sequence consists of brown coal deposits than at other localities. To the extreme west, at Klynholt Vest, there is also a relatively high proportion of brown coal in the sequence. The central area having an optimal total thickness contains a relatively higher proportion of clay and smaller amount of coal.

The thickest part of the sequence was in general attained by an increase in both brown coal and clay deposition. However, the deviation in the amount of clay and productive brown coal in the brown coal-bearing sequence in (Fasterholt Member) is modest.

It is obvious (Text-Fig. 38) that the deposition of brown coal (clay) had an early optimum towards east (1st seam), but continued longer in the area of optimal deposition in the middle of the profile (Munkballe-Bjerre) and partly also at Klynholt Vest.

In conclusion of table 10 we find in general for all (4) factors max. values to the west at the Fasterholtgaard 1 borehole.

A tendency to high values is found for the Lavsbjerg Øst borehole, concerning thickness of the coal-bearing sequence and high value for the amount of brown coal + clay. The optimal value for brown coal + clay is found at Bjerregaard, the neighbouring locality to the east, where the two factors (1 and 2) also show high values. A tendency to concentration of minimal values was found to the east in the Fasterholt Bjerge borehole.

The total amount of brown coal is oscillating along the cross section: An absolute maximum to the west (Fasterholtgaard 1), and a maximum of similar dimensions at section F11 (to the east) and a lesser high value at Lavsbjerg Øst. These optima represent every second locality alternating with low values (Fasterholtgaard 2, Bjerregaard, Fasterholt Bjerge). This may be corroborant with the tendency to subdivision in small basins or subbasins recognized for the 2nd browncoal seam in the Carl Nielsen Ltd. pit. (ref. also A.G. Rasmussen 1982, 1984).

2. The Hodde Clay

The marine Hodde Clay overlies the brown coal bearing sequence (the Fasterholt Member) at Lavsbjerg Hill and the extension to the east (Fasterholt Bjerg), reaching into the mining area of Carl Nielsen Ltd. at Fasterholt. In the latter area the Hodde Clay overlies the Fasterholt Member, according to the drilling (probe) Fasterholt Bjerg 1, (about 170 metres to the SW of the pit).

This black, bituminous Hodde Clay was recorded in probe Fasterholt Bjerg 1, as 3.5 m thick but when the glauconitic zone and the uppermost black clay of this locality are also included it amounts to 5.15 metres thick. From the Bjerregaard borehole the unit was recorded as 1.8 m thick and overlain by glauconitic clay. Whether this corresponds to the glauconitic clay inclusions in the Hodde Formation or of the lower part of the Gram Formation is unknown. So, it is uncertain whether the 1.8 m is the total thickness of the Hodde Clay at this particular locality or if it represents only the lower part of the Hodde Clay.

A similar thickness was recorded in the Lavsbjerg Øst borehole with only a small amount of glauconitic clay found in the uppermost part. Here the total thickness is unknown.

In the Fasterholtgaard 2 borehole the Hodde Clay was measured as considerably thicker (4.7 m). A well-known anticline in this area has a pronounced dip on the east flank which may explain this large value. Also the discrepancies between the thickness of the Hodde Clay in the probe Fasterholt Bjerg 1 and the Bjerregaard Borehole may be explained from the folding of the sequence (ref. chapt. 4 C, Tectonics). The Hodde Clay was found in the Fasterholtgaard 1 borehole as a thin half meter thick bed and resting upon the transgressional basal bed of the Hodde Formation. The basal beds consist of sand, clay and the basal gravel amounting to 1/2 metre in thickness. The Hodde Clay is here overlain by the Quaternary and due to erosion it is presumably not preserved in its original thickness.

The Hodde Clay has been recorded along the whole profile line except for the Fasterholt Bjerge borehole (DGU file no. 95.1942). Its total thickness has been undisputably recorded from probe Fb. 1 (1979). A similar thickness was recorded for the Fasterholtgaard 2 borehole on the northern flank of the Lavsbjerg point. The thickness amounts to about 5 metres in the southern part of the Søby-Fasterholt area. In probe Fb. 1 (1979) it was noticed that the Hodde Clay overlies the Odderup Formation but no coal bed corresponding to the 5th seam of Klynholt Vest was recorded. This infers that the 5th brown coal seam of the Klynholt Vest Tongue is restricted to the western localities, and it is probably a local deposit of the transitional interval from delta to marine environment.

Further information on the Hodde Clay (and the Gram Clay) is found in chapt. 4.B.4. and in chapter 4 C. on Tectonics.

3. Conclusion

The 1st to 2nd and 3rd brown coal seams are found all through the entire profile line across the southern part of the Søby Fasterholt area. The thickness of these seams varies in relative, but inconsiderably in absolute measures. The thickness of the clastic parts of 2nd and 3rd rhythms also are seen to vary.

A complete extra rhythmical unit (subrhythm 3 b) with an associated brown coal seam (the 4th seam) was recorded only in Lavsbjerg Øst borehole, but a clay and a silt-bed above the 3rd seam in the Bjerregaard borehole indicates a similar sedimentary trend. This extra rhythm (subrhythm) may be present to the west (Fasterholtgaard 1 borehole) represented by the clay bed and overlying brown coal bed that ends deposition of the coal-clay successions of the Fasterholt Member.

However, this is not supported in the pollen-stratigraphical investigation (ref. chapt.4.B.7.).

Subrhythm 3b is overlain at Lavsbjerg Øst by the deltaic sands of bed no. 7 ("Upper Sands"). It is present in the western part of the profile but differs in composition enough that correlation cannot be based on lithostratigraphy alone.

It is clear from observations from section EM of Klynholt Vest, (which is identical with the upper section of the Fasterholtgaard 1 borehole) that the sand unit with silt interbeds overlying the coal-bearing sequence and ending in a root- and stump horizon, indicates a retreating groundwater level ("regressive" tendency in regional terms) at this stratigraphic level (Wagner & Koch 1974). Hence an unconformity (paraconformity) exists between this sand-silt sequence and the overlying (uppermost) brown coal bed in Klynholt Vest (5th seam). Therefore these two units cannot be regarded parts of a 4th rhythm. On the contrary the coal bed of section EM, resp. the Fasterholtgaard 1 borehole, is a separate (5th) unit in a historical succession, and the sand-silt sequence below it in Klynholt Vest can be regarded a lithostratigraphical equivalent, synchronous and correlative with the sequence of sand and silty clay containing the *Søby-Flora* at the Damgaard N. pit.

At Damgaard N the root-horizon on top of the Odderup Formation and the river-erosion of the drained Søby-flora sequence indicates a subsidence of groundwater and a regressive tendency in regional terms. This sequence is older and even the regressive situation is earlier (older) than the deposition of the latest (uppermost) delta-sand bed(s) of unit no. 7 (channel sands) found under the Hodde Formation in Damgaard N. The erosion of the Søby flora bed in Damgaard N is a result of the "regressive" situation and is followed by deposition of a "channel sand" at this locality, which is the first succeeding deposit of the area. The root- and stump horizon is a valuable stratigraphical indicator in this region (ref. also section K6 of the Carl Nielsen Ltd. pit) but could not be recorded in any drillings (except for probe BII. 1978), including Lavsbjerg Øst. Therefore the relationship of the 3b subrhythm to the Søby-Flora sequence cannot be determined, mainly because the root-horizon; unfortunately it is difficult in unconsolidated sediment to be recorded by means of drilling.

Presently the 3b subrhythm is considered older than the Søby Flora sequence or partly synchronous with it. The latter possibility is especially valid for the sand-silt bed of the 3b subrhythm.

The Søby-flora sequence is correlative with a part of the "Upper Sands" (unit no. 7). Correlation of the root-stump horizon at the Klynholt Vest with the root horizon of section K6 in the Carl Nielsen Ltd. pit supports this view.

The "Upper Sands" (unit no. 7) is thickest to the east and decreases towards west to a restricted thickness of Klynholt Vest where it is represented by the Søby-flora sequence. The thickness of unit no. 7 and the productive brown coal sequence containing the seams 1, 2, and 3 varies reciprocally.

In general, the brown coal bearing sequence thickens westwards and has the highest absolute content of brown coal here. The deposition of brown coal was concentrated in the east at the beginning (lst seam), but shifted westerly and continued longer, i.e. until the introduction of the changes leading by the "Upper Sands" to the deposition of the Hodde Clay (the transgression of the region) radically changed the geological environment. The final deposition of delta sand before the transgression took place preferably to the east and with a decreasing intensity towards west. This is reflected by the shift of brown coal deposition in the same direction. The brown coal of this deposit can be regarded a deltaic border facies ("delta-rand fazies", according to Ahrens, Lotsch & Tzscoppe, 1968). The Fasterholt Member and the "Upper Sands" represent a continuous depositional history of the region in question containing large-scale features and obvious local variations agreeing with a deltaic environment above sea level, and near to the sea.

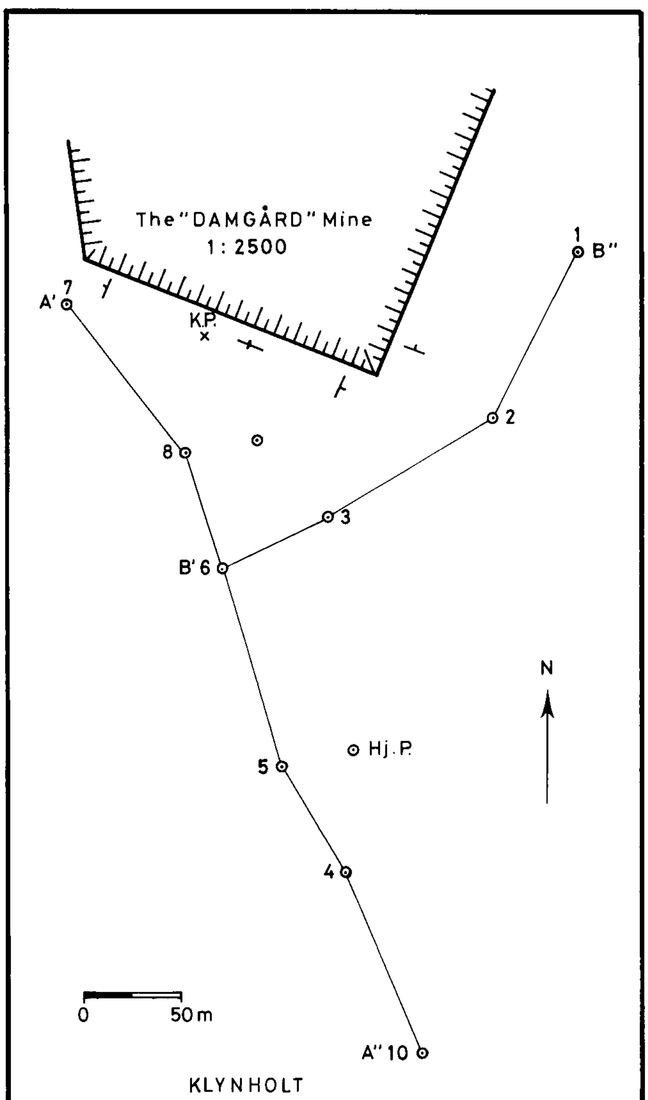
Regarding the biostratigraphical information and the conclusions implied, ref. page 124, 125, 134-135, 149-150, 162, 163-164.

Seen in the diagram (Text-Fig. 38) of the cross-section in E-W direction across the southern part of the Søby-Fasterholt area are distinct lithological changes marking the beginning and the termination of deposition of the Fasterholt Member (the browncoal bearing sequence of the Odderup Formation). This is obvious for the change from the Fasterholt Member into the "Upper Sands" which ought to be nominated a separate member (when sufficient information and detailed sedimentological evidence becomes available). The upper limit of the Fasterholt Member marks the change from a relatively stable situation of the North Sea Basin to a dynamic period. The erosional base level in the eastern border zone of the basin was displaced eastwards and caused mobilization, transport and rapid deltaic sedimentation as an introduction to the succeeding eastward transgressive expansion of the marine Hodde- and Gram Formations. The deposition of the 5th browncoal seam and its basal root/stump horizon represents a local(?), temporary interruption of the lithological, transgressive progression.

4.B.2.2.3. Detailed descriptions of the components of the Browncoal Bearing Sequence 3:

The intervening area between the Damgaard and Klynholt mines.

Between the southern front of the Damgaard mine and the northwest end of Klynholt there is a small area (5 ha. = 0.05 km^2) that has not been mined, so the original geological sequence is preserved. In order to facilitate the correlation between the outcrops and drillings of the Damgaard- and the Klynholt mines, 10 small probes (with core) were set in the intervening area during the summer 1972. The relief of the disconformity between the Fasterholt Member and the Hodde Formation allowing for alternative interpretations complicates the correlation of the geological sequence. Variation in the local sedimentary and paleobotanical sequence in the upper part of the Odderup Formation and the Hodde Formation also complicates interpretation. For placement and general stratigraphical information of these probes, see Text-Figs. 39 and 40. In Text Fig. 40 are recorded only those probes that succeeded to give a satisfactory core. The anticline, that is exposed in cross section in the south front of Damgaard S (ref. page 160 and Atlas-Fig. 119) and the north front of the Klynholt mine is also recorded in Text-Fig. 40 based upon the probes 6, 3, 2 and 1. The Hodde Clay is recorded in probes 6 and 1 and is lacking in 2 and instead the "Upper Sands" is overlain by the Quaternary. The anticlinal axis is oriented with NW-SE direction and is known to occur over a distance of at least 3/4 km. It appears as a superficial sand belt which is seen in the dump of the former Klynholt mine (see further information in chapt. 4.C. page 155 on Tectonics, esp. page 160-161 and Text-Fig. 63). The occurrence of the Hodde Clay (outcrops and probes) is extended over the Lavsbjerg Hill area to the east of the anticlinal crest. From the exposure in the SW-corner of the Damgaard mine, the Hodde Clay is known to occur to the west of the anticlinal crest and is also recorded by probes no. 7, 6, 5 and 4. The probe no. 4 is important for it is the most northerly occurrence of the 5th browncoal seam here found in an earthy modification (weathered?). So far the distribution of the 5th brown coal seam to the south and west, is not known.



Text-Fig. 39. Sketch map with the relative position of the probes 1-10 (1972) in the unmined area between the Damgaard mine and Klynholt Vest area. E.F.C. & S.R.J. comp.

4.B.2.2.4. Detailed Description of the Components of the Browncoal Bearing Sequence 4.

1. The area east of the Søby Sø (lake).

In the northern part of the Søby-Fasterholt mining area two open pit mines to the east of the Søby Sø (lake) were in operation up to 1969. The northern pit was situated directly east of the lake with the approximately E-W orientated working front ending at the railway between Kølkær and Fasterholt. The southern pit also reached near to the railway and was situated just west of the Søbylund settlement. Both of them were worked by the engineering company Hoffmann & Sønner for the "Vestkraft" powerstation, the town of Esbjerg. The east-west distance of the working front was less than 500 m long.

Generalized sections from these pits were published by Koch & Friedrich, (1970) and Koch et al., (1973) (in German and Danish, respectively). They shall be outlined below with additional information from some of the prospecting probes recorded from the area in question.

1. The northern pit of Hoffmann & Sons (near Kølkær (Atlas-Fig. 85,86): Standard section.

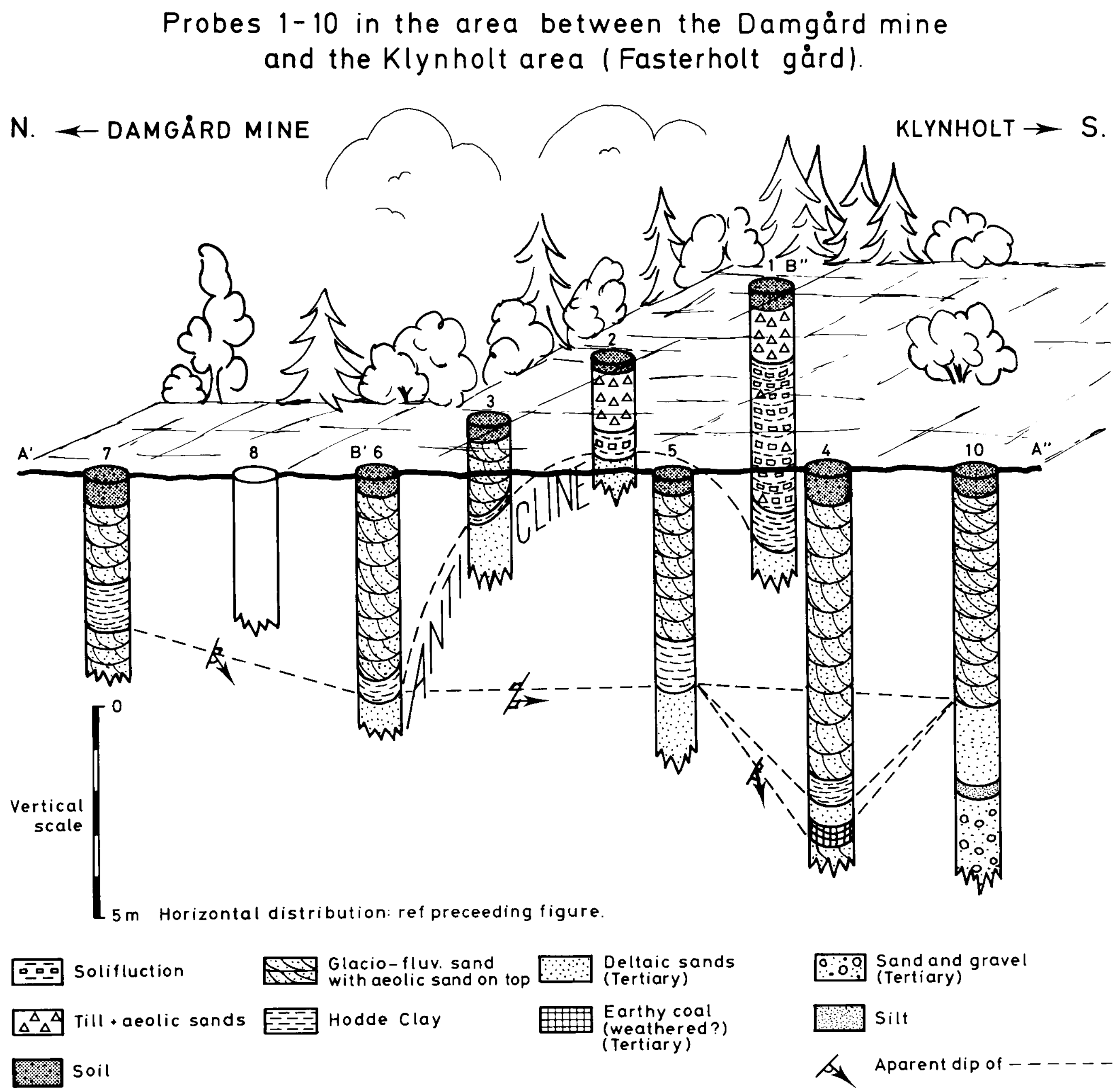
Surface level: 50.0 m

About 10 m	Sands. (Quaternary).
1-3 m	Sand, the uppermost part (about 1 m) is brown with layers of silt and clay. (Tertiary).
4 m	A single cross-bedded (dip NE) bed of white quartz-sand ("Upper Sands", Odderup Formation)
1.3 m	Black lignite: Abundant wood fragments in a black, brittle matrix (Fasterholt Member, continues below).
1.4 m	Brown micaceous sand, grading downwards into silt.
1.9-2.2 m	Homogeneous, well consolidated browncoal.

Below this coal is a grey micaceous clay rich in fossil leaves. The lower limit is unknown but a minimum thickness of 2.5 m has been recorded.

In principle this section is identical with the logs of the nearby prospecting probes Søby no. 1308, 1309, 1310, 1311, 1335, 1336 (Geol.Surv. Denmark, file numbers). They are included in Text-Figs. 62, 63 in the chapter on tectonics, ref. page 323. Unfortunately none of the probes reach deep enough to be sure that the browncoal-bearing sequence (the Fasterholt Member) was penetrated.

Four former probes was placed in a WSW-ENE line



Text-Fig. 40. Sketch demonstrating the system of probes 1-10 (1972) in the area between the Damgaard mine and the Klynholt Vest area. The generalized logs demonstrate the lithostratigraphy and the anticlinal culmination revealed by the boundary "Upper Sands" - Hodde Clay (see text-fig. 39 for relative position and geographical orientation). E.K. & E.F.C. comp.

in the following order with 1311 displaced 25 m to the south of the line 1308, 1309, 1310.

Probes 1335 and 1336 are about 500 m to the south placed on a similarly orientated line.

There seems to be some variation in the thickness of the upper coal seam and the seams below. A trend is not perceptible from the few probes. The variation in thickness may be a result of the folding to which the sequence has been influenced.

2. The southern pit of Hoffmann & Sons (near Søbylund) (Atlas- Fig. 88):

Standard section.

- Surface level: 50.0 m

About 11 m	Sands (Quaternary and Tertiary).
About 1 m	Black lignite (Fasterholt Member; continues below).
About 1 m	Brown coarse sand with black coaly interbeds.
1 m	Clay grading in the lowermost part into brown coal.
2 m	Homogeneous, well consolidated brown coal.
0.5 m	White sand
0.5 m	Grey to black clay
1.5 m	Clay
2 m	Homogeneous well-consolidated browncoal.
Underlying:	Clay of unknown thickness.

No fossils were found in our inspections of this pit in 1968.

This sequence is in accordance with the prospecting probes Søby no. 1401, 1402, 1403, 1404, 1405, 1412, 1413, 1414, 1415. These probes are included in Text-Figs. 62, 63, 66 from the chapter on tectonics, ref. page 323.

Unfortunately, these probes do not penetrate the browncoal bearing sequence (the Fasterholt Member).

Probes 1401-1405 were placed on a WNW-ESE line and parallel to the probes 1412-1415, about 125 metres to the north. Along both cross-sectional lines, the uppermost coal bed has an overall decrease in thickness towards the west. Only the two eastern probes 1405 and 1415 deviate with smaller values. The upper seam appears a little thinner in the southernmost line. The same east west variation in thickness is valid for the seam below.

Similar trend were not found between the two lines, but it seems likely that this variation is due to the structure of the depositional basin(s) as found in the larger exposures of the Carl Nielsen Ltd. pit at Fasterholt. The occurrence of the browncoal-bearing sequence with three seams, as known from Fasterholt, may continue into the area immediately east of the Søby sø lake. This is supported by the known occurrences of the browncoal mining of the area, but not proved by the observations form the pit of Søbylund.

Further information is presented in a paper on the brown coal resources of Central Jutland by A. Grambo-Rasmussen (1984) and the section 4.C. on tectonics of the present paper (page 323).

4.B.2.3. Interpretation of the descriptive Information from the Browncoal Bearing Sequence of the Odderup Formation, including Fasterholt Member.

I. The progressive rhythmic succession

The brown coal bearing sequence of the Søby-Fasterholt area (the Fasterholt Member and the "Upper Sands" etc. of the Odderup Formation) is a well defined sequence based on boundaries, lithology and stratigraphical succession.

The lower boundary (of the Fasterholt Member) is characteristical by its appearance (the complex soil structure with tree stumps and a dense root horizon) and by its stratigraphical inference of an interval of geological and environmental stability between different periods of sedimentation. This limit is best classified as a paraconformity because of the lack of any erosional relief and due to the general concordance of the older and younger beds.

The upper limit is just as distinguishable, marked by a disconformity or paraconformity, the result of an Upper Middle Miocene transgression continuing throughout the Upper Miocene Gram Clay. In the Søby-Fasterholt area, the upper boundary is similar to the lower one, being defined by a root horizon just below the basal gravel of Hodde Formation.

The former descriptive chapters (4.B.2.2.2, 4.B.2.2.3, 4.B.2.2.4) have treated the different subunits of the browncoal bearing sequence from a descriptive point of view.

The present chapter deals with the characteristical lithostratigraphical succession of the browncoal bearing sequence, esp. the Fasterholt Member.

A survey of the entire descriptive information of the browncoal bearing sequence of the Odderup Formation (Text-Figs. 24, 25, 36) reveals a progressive rhythmic succession. This is not the cyclic succession of cyclothemes with nearly identical cyclic units, but a progressive rhythmical development of the 4 units making up a depositional cyclus. The rhythmical units become thicker, the initial psammitic bed of the rhythm becomes thicker and of wider horizontal extension. The boundaries between the rhythmical units become less distinct, the element of erosion declining to insignificance between the 3rd and 4th units. Of these the lowermost 3 units constitute the Fasterholt Member, the 4th final unit the "Upper Sands" and the equivalent lacustrine facies may constitute a 4th rhythm.

In the Lavsbjerg Øst borehole (D.G.U. file no. 95.1995) it was necessary to distinguish between two subunits, 3a and 3b, including a 3rd and a 4th browncoal seam.

Each rhythmic unit begins with either sand lenses distributed along an erosional surface or with a continuous bed of sand. Each unit ends with a brown coal bed, homogeneous or compound structure, and topped by a thin clay bed or with an increasing percentage of brown humic clay in the coal bed (a "fining upwards sequence"). A composite clay-silt-fine sand succession or a silty clay bed, is intercalated between the basal sand and the browncoal bed, except for the 1st rhythmic unit. The 4th unit is atypical and is either a continuous succession of sand (to the east) or a sand bed ends to the west in a lacustrine sand-clay sequence devoid of browncoal. In both cases they are topped by a root-horizon. These rhythmic units have been named "Rhythms".

The following account of the rhythmic units 1-3 is based upon the Carl Nielsen Ltd. pit at Fasterholt.

The 1st rhythm is only 1.5 m thick and consists of a composite basal bed of sand lenses or laminae interwoven with laminae of sandy organic detritus. The rhythm gradually changes upwards into a black lignite, which according to E. Thomsen (ref. chapt. 4.B.2.2.1.Ia) consists of a succession of different facies (beds) in the sense of Teichmüller and Thomson 1958 (modified by Brelie & Wolf, 1981b) (ref. page 802). The lignite has a distinct upper boundary obviously marked by erosion.

The 2nd rhythm (Text-Fig. 24) is 6 m thick and rests on a grooved erosional surface on which separate lenses of sand (channel-sand) have been deposited (in erosional channels). This basal sand is rich in worn trunks of driftwood (ref. page 53). Above the erosional surface or lenses follows a series of silt to fine sand and clay (gytja) in composite beds divided by a bed of pure bluish-grey fine clay. On top of the 2nd rhythm is a composite brown coal unit, that begins as a homogeneous detrital brown coal bed ("groundmass coal") changing upwards into a humic clay, locally into silt and sand. This again changes into xylitic brown coal (lignite) consisting of crowded, compressed and incoaled driftwood, often with an obvious orientation ("Schwemmkohle" = driftwood coal). Horizontal differentiation from a bushmoor facies entering from east into a detritus coal-gytja facies to the west has been recognized through the 1 km long Carl Nielsen Ltd. pit (Thomsen 1979). This rhythm abruptly ends with the above following 3rd rhythm. The boundary is concordant and does not contain any obvious signs of erosion in the brown coal bed so it appears as a paraconformity. A marked lithologic change indicates an abrupt difference in depositional conditions from lake to delta or river environment. Therefore, the boundary was established near to the regional erosional base level at that time.

The 3rd rhythm (Atlas-Figs. 39, 40, Text-Fig. 24) is 5-6 m thick and begins in the east with a max. 1.5 m thick delta bed with flat westerly dipping cross-bedding of 1st order. Second order cross-bedding also dip towards the west. This delta wedges out over a distance of 3/4 km westwards into a 5-10 cm thick sand cover. The overlying silty clay is sharply limited up-and downwards and its thickness varies reciprocally to that of the underlying delta deposits (1/2 m thick to the east, 2 m in the west). From its lower boundary, trace fossils dominantly penetrate in vertical direction at least 1/2 m into the underlying sand. Upwards,the clay grades into 10-20 cm of alternating fine sand and silty brown coal detritus, followed by 2 – 2 1/2 m thick homogeneous, detrital brown coal. The brown coal lowermost begins and upwards ends in a brown, coaly clay. Its upper surface is flat without marked traces of erosion. Small shallow basins, max. 10 cm deep, with coarse to very coarse sand, may indicate a depositional lacuna.

Information about "the 4th rhythm" ("Upper Sands" and the equivalent lacustrine facies) is based upon a combination of observations from the Carl Nielsen Ltd. pit at Fasterholt (Text Figs. 23, 33, 36) and from the Klynholt mining area. The maximum thickness found in the eastern areas is 10 m (Bjerregaard borehole) and at Klynholt Vest it is 2.5-3.5 m thick. In the east the main component of this rhythm is white cross-bedded sand in tabular structures. The sand is seen to terminate in a fossil soil and root horizon in profile K6, about 8 m above the base. In the west (Klynholt Vest-Damgaard N) a lacustrine succession of sand, silt and clay dominates the profile.

Quaternary erosion has removed any other deposits below the outwash plain and our drillings do not give detailed information on any continuation of the sequence (the Bjerregaard borehole has not recorded brown coal at this level, but recorded the Hodde Clay at about 10 m above the basis of this rhythm). The probe F.b. 1, 1979 has penetrated the Hodde Clay and its basal gravel and reached into grey sand to almost the level as the soil in K6. In the west front of Klynholt the 3rd brown coal seam is seen to continue upwards into one meter of silty clay. The overlying sand ("4th rhythm") contains thin beds of humic clay (gytja) increasing in thickness upwards and penetrated by vertical tree roots from tree stumps in the overlying 0.8 m brown coal (lignite). This brown coal bed seems to be a local event belonging to the following transgressive sedimentary episode of the Hodde Clay. The root-horizon indicates a lowering of the ground water level accompanied locally by erosion, which terminates "the 4th rhythm".

This sedimentary sequence allows for a number of general conclusions regarding the geological environment based upon the sediments and their structure (i.e. the minerogene sediments and the brown coal seams and related sediment with organic content). The brown coal deposits allows us to distinguish between a number of coal facies related to different types of geological and biological environmental conditions. The depositional structures, the unconformities, and the fossils (especially the fossil floras including the stump and root horizons, and trace fossils) allow us to interpret the entire geological succession into a succession of environmental situations, tending towards a historical account of the evolution of the area during Upper Middle Miocene. A concentrate of basic information for this account is found in Text-Fig. 48. See also Text-Fig. 68.

The detailed criteria was to an extent, already presented in the descriptive part of this book (the brown coal petrographical facies interpretation and the corresponding conclusions, ref. section 4.B.2.2.1.Ia (E. Thomsen) and 4.B.2.2.1. II. A number of special problems and criteria supporting this interpretation well be discussed below.

II. Interpretation of the Sedimentary Rhythms of the Fasterholt Member, the "Upper Sands" and Equivalent Lacustrine Facies of Klynholt Vest.

General information can be deduced regarding the depositional environment from the beds of Fasterholt Member.

For the brown coal beds this information has already been presented for the reader on page 39 ff. This knowledge is provided in the statements of this chapter, and especially in the conclusion. But an interpretation of the clastic sediments must be made in order to obtain their content of environmental information.

The information from the clastic sediments preferably derives from the field observations. No systematical sedimentary laboratory analyses have been undertaken except for the Lavsbjerg Ø borehole (Friis, Nielsen, Friis & Balme 1981). Therefore information from the clastic deposits is supplementary to the facies interpretation of the brown coal seams analyzed by E. Thomsen (ref. chapter 4.B.2.2.1.Ia) and which is a major tool in the present investigation.

IIa. Interpretation of the Basal Bed of 1st Rhythm (bed no. -6).

The basal bed of the Fasterholt member, bed no. -6, represents the initiation of swamp conditions producing the 1st brown coal seam. It is situated above a paraconformity which appears to have been a surface well above ground water level and supporting a forest vegetation dominated by Conifers (ref. page 63). Bed no. -6 is situated below a brown coal bed that indicates swamp conditions. Open water conditions were already in existence by the time of the deposition of the lower parts of the brown coal bed according to the brown coal petrographical facies-analysis (E. Thomsen, ref. chapt. 4.B.2.2.1.Ia).

The sedimentary structures (inclusive a lenticular arrangement of the sand, the undulating structure of the detrital lamina and the content of driftwood) indicate this bed was deposited in current water, and its stratigraphical position between the paraconformity and the swamp deposits would indicate the possibility for flooding by shallow current water. More specifically, similar to fluctuating streams flowing through a possibly ruined forest land, moving and re-depositing the organical debris of the forest soil and carrying sand into and through this devastated environment. The preceding rise in groundwater may be the cause of the reorganization of the soil material and the underlying water-absorbing silt to fine sand (ref. below).

After the groundwater level rise above the ground surface an open water swamp occasionally as a lake, covered the area (ref. 1st seam, page 39, 46).

The initial rise of groundwater level deteriorated the forest and leading to deposition of bed no. -6, resulted in an unstable water-saturated substratum. The fine sand-silt of underlying bed no. -7 changed to quicksand and breaking up and intruding the soil to create an "Intraformational "Breccia" (described page 62-64, interpreted page 64-65). After this period the history of the swamp recorded by the 1st brown coal seam began and evolved according to the model which was reported by Thomsen (page 80.2, 80.8).

IIb. Interpretation of the Clastic Sequence of the 2nd Rhythm.

The 1st brown coal seam shows indications of erosion in its upper surface. When deposition was brought to an end, the surface of the deposit was left open to erosion by current water to a varying extent (brooks, small streams, river branches). The erosional channels vary in dimensions (sections varying from less than one meter to 100 metres). They are filled with fluviatile sands, driftwood, and plant-detritus to a thickness varying from one decimeter to one meter. No traces of a stump or root horizon have been left at this level. The exposures of channel sands in question were a few hundred meters long and over this distance only a few vertical trunks are seen to penetrate from the unit below into the overlying fluviatile lenses. The kind of vegetation that grew at this level during these changing conditions remains an open question, but a stabilization to an extent similar to those which established before the 1st rhythm is not in question. The river derived sand (lenses) contained an abundance of worn trunks (driftwood) devoid of the bark. The rivers (river-branches) gradually filled their channels and temporarily flooded their surroundings as seen in beds -3 and -4 containing sand and with thin lamina of organic detritus. This situation changed to a permanent flooding, at first with shallow water at a rather high energy-level (bed -2: Silt, rich in clay, enclosing small coarse sand lenses with growing content of clay). Depositional environment gradually changed (transition between bed -1 and -2) to deeper water and a low energy-environment rather poor in oxygen (bed -1: Bluish-grey clay or dy). In this way a lake became established.

During the first part of this evolution the fluviatile sand lenses and beds -3 and -4 occurred sporadically and were interchanging. These were followed by lake beds of continuous and wider distribution (beds: -2, -1, 0, 1, and 2).

Lacustrine sedimentation continued upsection with deposition of humic clay, a sand-silt bed, followed by sand and silt lenses interwoven with lamina of brown coal detritus (bed 0) sedimentation ended with an allochtonous detrital brown coal that finally turned into humic clay, locally into sand. After this, the lake underwent constriction from the periphery, the bushmoor facies moved into the basin from the east (ref. coal-petrographic facies interpretation, page 80.4). Later, probably after a violent period of flooding enormous amount of drift logs were stranding on shallow limnetic littoral flats and the neighbouring bush-moor (bed +2: "Schwemmkohle", i.e. driftwood coal). In the lower part of the 2nd brown coal seam there is a low content of inorganic matter, the brown coal consisting entirely of very fine-grained plant detritus (allochtonous). This part of the bed cleaves along bedding planes where there is a fine sand-silt powder. These criteria together with the driftwood of bed no. 2 point to an extensive and at least periodical fluviatile and/or aeolic influx into the lake.

Thus the 2nd rhythm ended with constriction or elimination of the open water cover. The local basin had filled up in the region of the Carl Nielsen pit at Fasterholt and the groundwater level had sunk accordingly.

IIc. Interpretation of the Clastic Sequence of the 3rd Rhythm.

The environmental history of the underlying 2nd rhythm ends with constriction of the sedimentary basin, and the limnetic littoral zone moving westwards according to the information of the outcrops of the Carl Nielsen Ltd. pit at Fasterholt. The next bed, sand bed 3 + 4, continues without marked interruption from the underlying browncoal of the 2nd rhythm. It represents a small delta spreading from east towards west into a basin (lake). The cross-bedded sand bed is max 1,6 m thick at the eastern end of the pit and wedges out towards west over a distance of about 500 m into a 10 cm thin bed that continues westwards. This sand shows a flat lying, westerly dipping cross-bedding of 1st order with the cross-beds westerly dipping (second order cross-bedding). This agrees with the final events found in the 2nd rhythm. There are no obvious signs of erosion to be found on the surface of the 2nd brown coal seam, but indications of surface weathering and a single case of a fossil tree stump has been observed at this level. The surface was at least raised up to groundwater level, as evidenced by the occurrence of the delta sediment (ref. page 53 ff.) and the stump may support this opinion or infer a local surface above groundwater level. The physical energy of the stream was moderate to low, the fine-grained sand was dominant and even silt and sporadically clay sedimentation were involved. Large amounts of small to medium-sized fossil seeds, fruits, cones, and small twigs were deposited in a certain zone of the sections throughout this small delta. This is the *Fasterholt (diaspore) flora* (ref. page 106) which indicates the important role of the aquatic and swamp-vegetation played in the surrounding landscape. An important part of these fossil seeds and fruits are so physically well-preserved that we may assume that they were transported over short-distances. The river of the delta must have picked up these plant remains while passing through a neighbouring area. The rich flora is divided into different associations like forest swamp, bush moor, and the better drained levees (ref. chapter 4.B.7.2: The Fasterholt Flora, page 106 ff.) and extended areas (e.g. on the Ringkøbing Fyn High?), inhabited by a mixed mesophytic forest (Friis 1975, 1976, 1977a,c, 1985; Koch & Friedrich 1971; Koch et al. 1974; Koch & Christensen 1979; Koch 1977, 1979, 1984).

The overlying bed of micaceous coarse silty clay (bed no. 5) from east towards west increases its thickness reciprocally to the underlying delta sand bed (bed 3 + 4). The bed indicates the synchronous existence of deeper water in the westerly part of the basin and a general rise of water level, due to a change from delta to shallow lake conditions. Trace fossils in the east part of the lake (near Fasterholt) reach from the lower surface of the clay down into the underlying delta sand. The coast of the lake was not far away because the silty clay also contains well preserved and often entire fossil leaves.

This micaceous clay (bed no. 5) and the underlying delta sand may, at least partly, represent synchronous facies i.e. neighbouring sedimentary environments in the same lake expanding towards east (in relation to the E-W profile-line of the southern Søby-Fasterholt area).

This clay changes upwards to a thin layer of fine sand-silt with lamina of coal detritus into a detrital brown coal (bed no. 6 = 3rd seam). The brown coal bed reproduces the shape of the central parts of the local depositional basin (the lake) by its variation of thickness. In relation to the underlying this brown coal bed represents a restriction of the basin (lake) and perhaps is one of the sub-basins of the lake (compare I.b. Depositional Structure of the browncoal seams, page 51). The 3rd seam has a significant amount of clay at the bottom and at the top of the sequence. It begins with a detrital humic clay, changes upwards into a detrital brown coal and ending with a detrital, humic clay.

From petrographical analysis the bulk of the sediment appears as a "Reed-bushmoor" facies. The very fine-grained detrital coal with insignificant inorganic content and lack of inorganic lamina indicate a protected depositional environment. The facies analysis implies to a "reed-bushmoor" existing during most of the deposition the seam, i.e. a deposit from a protected low-energy environment with shallow water and characterized by dense growth of reed and rushes. This facies interpretation is supported by the fact that the coal bed rests upon a sand-silt layer on which the reed growth could originally have established itself. At the beginning and the end of the brown coal deposition for the 3rd rhythm, a remote tributary may have acted as the source of the clay and sand content. At the western end of the Carl Nielsen Ltd. pit at Fasterholt, a sand bed is also intercalated in the uppermost part of the 3rd seam.

IId. Interpretation of the Sedimentary Sequence of the "Upper Sands" (incl. 4th Rhythm)

From the drillings it is known that an additional rhythm or subrhythm that may be part of the 3rd rhythm, occur locally and ends browncoal deposition in the Lavsbjerg Hill area, before the browncoal bearing sequence were accomplished with the deposition of the "Upper Sands" (coarse, deltaic sands grading into limnetic sand-silt towards NW, i.e. Klynholt Vest). The latter may be interpreted as a final (4th) rhythm in relation to the underlying sequence.

From the drillings and exposures it is known that the "4th rhythm" predominantly consists of light coloured (white) medium to coarse grained quartz sand in cross-bedded tabular structures ("Upper Sands"). Its maximal thickness is in the southeastern part of the Søby-Fasterholt area where the Carl Nielsen Ltd. pit is situated. The optimal thickness (10 m) was discovered in the Bjerregaard borehole (DGU file no. 95.2166). From the E-W drilling profile of Fasterholt to Klynholt Vest (ref. page 76) this sequence was noted to decrease rapidly in thickness towards the west in this profile (e.g. Fasterholtgaard 1 borehole) to about a third of the optimal thickness seen in the Bjerregaard borehole. Also to the northwest it grades into a lake deposit containing the *Søby-Flora* (Christensen, 1975, 1976 and section 4.B.7.6 of this paper).

These "Upper Sands" contain fossils from the Ordovician silicified limestones and rock fragments from the Baltic, east of Bornholm and south of Åland Islands (Spjeldnæs in Koch et al. 1973) (ref. page 56), and small pieces of flint and silicified remains of the Danian bryozoan limestone. The lacustrine clays in the Klynholt region has revealed well preserved redeposited Oligocene-Eocene species of Dinoflagellate cysts (personal communication with C. Heilmann Clausen). This indicates a general transport route from the east. Contrary to this information the local dip of the cross-bedding of the Søby-Fasterholt area generally is NE-NNE. Only at the Carl Nielsen Ltd. pit was recorded a single case of a westerly dip. This may only reflect a sporadical and local direction of transport, the former is the general direction of the area.

A regional knowledge about the "Upper Sands" is not established at the moment and our information obviously is only a detail of a complex paleogeography that needs investigation on a regional scale.

Spjeldnæs (1975) proposed that the "Upper Sands" is a littoral marine deposit and was under influence of a current passing from SW and W into the embayment to the north of a peninsula derived in the Jutland-Funen high. This paleogeographical model was highly relevant at the time of deposition of the Hodde Clay, but the interrelation between the "Upper Sands" and the lacustrine facies in the western part of the Søby-Fasterholt area and the conditions during deposition of the 1st-3rd rhythm are not in accordance with this idea. Also, no proof of a marine environment have ever been found in the "Upper Sands". This theory may be modified to involve a delta spreading from the north flank of the "Jutland-Funen peninsula" into its northern embayment. The Grindsted Graben structure may have acted as a guiding structure for the drainage system. Along the western side of the Søby Fasterholt area the "Upper Sands" wedges out and is replaced by a lake-deposit which terminates the final (4th) rhythm. This is the only part of the succession that reveals some detail about the existence of different environments at the final stage of its monotonous history. We shall now turn to this information.

III. Discussion of the Environmental Conditions at the final Stage of the Browncoal Bearing Sequence as illustrated by the Sequence in the South-Western part of the Søby-Fasterholt area (Lavsbjerg Hill).

In the previous descriptive sections, exposures, drillings and probes from the northwestern end of the Klynholt mining area and the Damgaard mining area and also the conditions of the upper boundary of the Browncoal Bearing Sequence have been reviewed. Other information for the understanding of the environmental conditions at the final stage of deposition of the Browncoal Bearing Sequence and the establishment of the disconformity at the initial stage of the following transgression and especially about the basal transgressional bed of the Hodde Formation can be found in the chapter on this formation (page 92 ff.).

In the western part of the Søby-Fasterholt area the last (4th) rhythm of the Browncoal Bearing Sequence indicates that the swamp and lake environment of the 3rd rhythm continued to exist while delta sands were deposited to the east in the Fasterholt area. At a late stage some stabilization of sea level or "regression" with subsidence of the groundwater level (an alternative explanation as due to establishment of higher hummocks, islands or bars has not found support) allowed a forest to become established in which *Sequoia* sp. aff. *sempervirens (Taxodioxylon gypsaceum* (Goeppert) Kräusel)) thrived. The root horizon has been recognized in an outcrop at the NW corner of the Klynholt mining area as well as in the Carl Nielsen Ltd. pit at Fasterholt. In the Damgaard N pit a root horizon devoid of thick tree roots occurs at the same stratigraphical level, but here the botanical systematical affinity of roots have not been determined. We have no means to determine whether these three occurrences are exactly synchronous but that they indicate a period of stabilization, are situated in the uppermost end of the sequence of the last (4th) rhythm, and are at the stratigraphic level of micro-flora zone D (ref. page 143, Text-Figs. 58-59) supports their correlation. In the region of the Damgaard N mine the aquatic environment (lake) existed continuously through the 4th rhythm but after deposition and consolidation of the Søby-flora clay bed it was completely drained and covered by a vegetation. "Occasional plant roots, 0.2 to 0.5 cm thick, penetrate the plant bed from the top, often branching and forming a horizontal network" (cit. Christensen 1975, page 13). This root horizon contains no thicker tree roots. This indicates a relatively higher groundwater at the Damgaard N locality than in Klynholt Vest even during this "dryer" episode suggesting a variation of environment and biotopes of the area under consideration. Prior to the deposition of the uppermost delta sand bed ("Upper Sands") of the north front of the Damgaard N pit the Søby-flora bed and its underlying sand-clay sequence was eroded by an active river branch. The Søby-Flora bed and associated erosional debris cone and root horizon are cut off by this latest fluviatile sands of the area. Both sequences are unconformably overlain by the basal transgressional gravel bed of the Hodde Formation. This active erosion of the Søby-Flora bed with its upper root horizon demonstrates at this locality some sinking of the erosional basis level with draining of the lake of the Søby-Flora clay (ref. Text-Figs. 37, 45, Atlas-Figs. 73-75).

The stabilization (or "regressive" tendency) resulting in falling ground water level seems to have involved the whole region of our investigation. Neither in the Damgaard N pit nor in the Carl Nielsen pit are there sediments present to indicate a continued deposition. Only is there in section EM in Klynholt a depositional sequence including stumps that are almost totally disintegrated followed by a 0.6 m xylitic brown coal and 0.2 m highly sapropelitic detrital brown coal (in total the 5th seam) i.e. deposition due to raising groundwater. The original distribution of this thin brown coal bed towards the S and W is not known.

Close to the upwards limit of the sapropelitic coal are small sand lenses and its upper surface is ripple-marked. A thin bed of coarse sand with pebbles at the base follows directly above. This pebble layer probably equivalents the basal gravel of the Hodde Formation, the basal transgressional sand-clay bed of which are at Klynholt Vest substituted by 1.5 m of cross-bedded sand including the pebble layer at the base. The basal sand-clay bed of the Hodde Formation is rather thick in the western part of the Søby-Fasterholt area (1 m) and the sand in question represents most likely an equivalent marginal outwash (delta?) facies overlying the 5th brown coal seam at Klynholt. Here this sand deposit and the sequence below indicates a gradual continuation of deposition beginning with the 5th brown coal seam and continues into the Hodde Formation. The deposition of the 5th brown coal seam was an early introductory episode of the (local?) history of the transgression before the tidal zone entered the area. The cross-bedded sand with its content of pebbles at the base may be a terminal tongue of a small southerly delta of the littoral zone overriding the local marginal moor (peat deposit) at the border of the tidal flat (see the information on trace fossils page 68, 93). The ripple marks of the surface of the sapropelitic coal proves this to have been unconsolidated or only weakly consolidated when it was flooded (transgressed) and underline the continuity of the transitional sequence between the non-marine and the marine facies. Hence, no marked interruption of the the depositional history appears between these two facies in the southwestern Søby-Fasterholt area (Klynholt Vest), though some tidal erosion may have interfered.

A pollen-stratigraphical analysis based on the principles of G. von der Brelie has shown that the 5th browncoal seam presumably belongs to the microflora zone D (of the Lower Rhenian Area) which is also partly the case for the Hodde Formation, also correlated with the (Early) Rheinbekian. This correlation supports the idea of a continuous transition of deposits between the Browncoal Bearing Sequence (non-marine environment) and the Hodde Formation (marine facies), because it does not leave time for a marked interruption of deposition.

No convincing information as to the existence of any topographical relief at this stage of the geological history of the Søby-Fasterholt area has been found. The possibilities for a higher topography of the region of Central Jutland are connected to the tectonical structure of the Ringkøbing-Funen High and the salt diapirs. The concentration of xylitic browncoal occurrences on this high (contrary to detrital browncoal poor in wood outside e.g. of the Søby-Fasterholt area) mentioned by K. Milthers (1941a) must be considered.

4.B.3 The Sequence below the Fasterholt Member

The sequence below the Fasterholt Member is known mostly from drillings, especially the Fasterholt Bjerge borehole, no. 95.1942 and Lavsbjerg Øst borehole, no. 95.1995 (see chapter 4.B.2.2.2.) Only the uppermost few meters of this sequence was temporarily exposed during the brown coal mining (see chapter 4.B.2.2.III and Text-Fig. 41) in the western half of the Carl Nielsen Ltd. pit at Fasterholt, during the early autumn 1969. The samples from Lavsbjerg Øst borehole (no. 95.1995) have undergone a special sedimentological and paleobotanical analysis by Friis, et al. (1980). The sequence that was penetrated by the two boreholes (95.1942 and 95.1995) can be divided in an upper sand member followed below by a silt-clay member and a sand-sequence the base of which is unknown, and so the thickness of this sand sequence. The two mentioned boreholes penetrate to 120 m below surface, that is about 95 m below the basis of Fasterholt Member and the total Miocene can be expected to be considerably thicker. In the oil prospecting drilling Nøvling no. 1, situated 8 km NW of the town of Herning, the Miocene was determined to be 201 m thick (Kristoffersen 1973, page 63-67).

Because the stratigraphy is not well known for this sequence only brief descriptions can be presented, using provisional descriptive names such as Middle Sands ("B-Member"); The black clay and silt ("C-Member) and Lower Sands ("D-Member"). For supplementary analytical information refer to Friis et al. 1980

4.B. 3.1. The Middle Sands ("B-Member")

This sequence consists dominantly of light-grey to white sands and is situated between 25.5. m and 66.0 m levels below the surface in the Fasterholt Bjerge borehole, D.G.U. file no. 95.1942 and between 24.5 and 66.0 m in the Lavsbjerg Øst borehole, no. 95.1995.

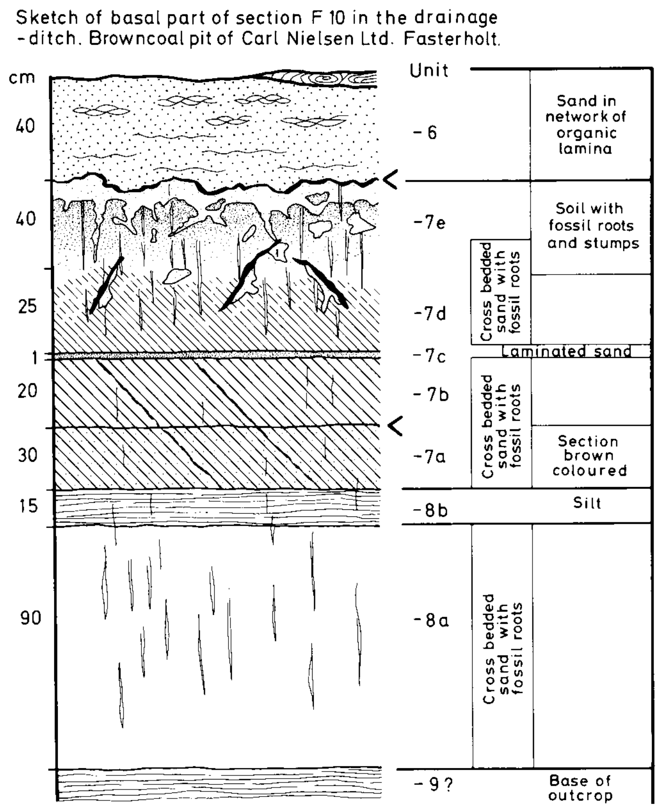
The upper boundary with the Fasterholt Member is 26 m below the surface at profile F10 in the Carl Nielsen Ltd. pit (type section) (Text-Figs. 24, 41-43).

The uppermost bed is a cross-bedded sand of which the upper part has been transformed into a fossil soil with a complicated structure comparable to a "intraformational breccia". This has already been described on page 105, 111 concerning the lower boundary of the Fasterholt Member. The sequence exposed in profile F10 is reproduced Text-Fig. 41. The major characteristics of the single units reported here are in supplementum to the field report.

The uppermost bed (-7) is mainly a white cross-bedded coarse to medium grained-sand with the steeply ENE dipping units of the cross-bedding differing in grain size. The upper part of the bed appears as a tabular structure resting on lenticular units below. The uppermost part of bed no -7 is developed as the paleosoil on the top (unit: -7e).

Below the paleosoil is unit -7d with the original sedimentary structures preserved. Unit no. -7d overlies a few centimeters of horizontally bedded grey sand (unit no. -7c) (Text-Fig. 41). The total thickness of units -7d and -7c is 1.0-1.5 meter.

Two different coloured units (-7a and -7b), one white and the other a brown, sand follow below. It is obviously one sedimentary bed, consisting of a cross-bedded sand with the single units of the cross-bedding changing from fine to coarse sand. The cross- bedding dips steeply towards the ENE. The upper white sand is



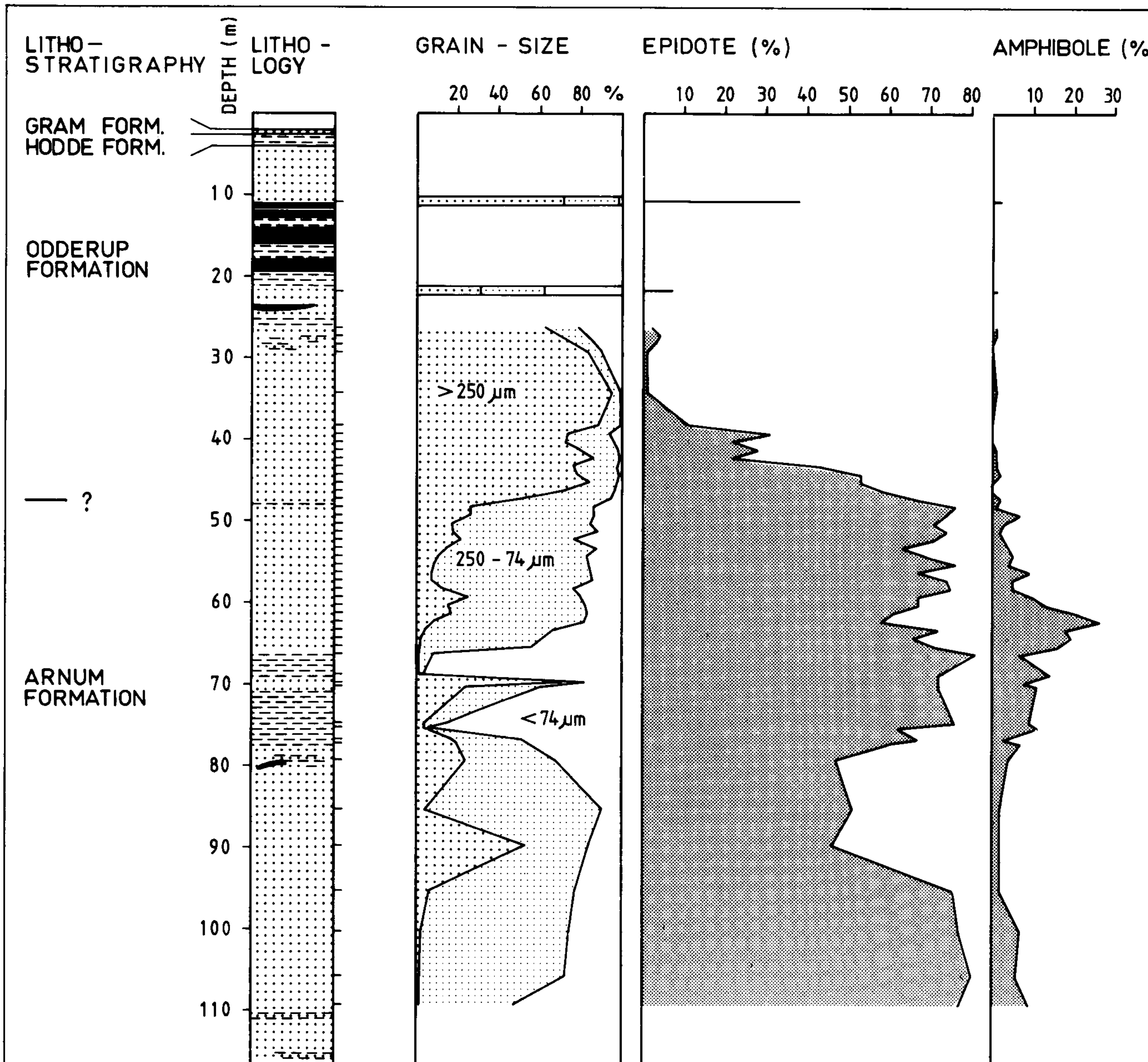
Text-Fig. 41. The upper part of the sequence ("B-Member") below Fasterholt Member at profile F. 11. The lower boundary of the Fasterholt Member is at the corroded surface underneath bed no. -6. The uppermost bed of the "B-Member" has been transformed during an interval of the Miocene into a soil with fossil roots and stumps, and later into an "intraformational breccia" with more or less disintegrated fossil roots. The following lithological units are involved: -6. Composite fluviatile bed of coarse sand-microlenses, interwoven in a meshwork of browncoal detritus. An incoaled and compressed trunk of the overlying coal seam (-5) is indicated on top. < Unconformity (fossil ground surface)>. -7e. "Intraformational breccia": Fossil soil (root bed) broken into pieces by intruding fine sand ("quicksand" ?). -7d. White cross-bedded sand with fossil roots, penetrating from bed -7e. -7c. Brown to black laminated sand. -7b. White coarse-grained cross-bedded sand containing fossil roots penetrating from the overlying beds. < Fossil groundwater level (top of brown humus precipitate)>. -7a. Petrographically resembles bed no. -7b but coloured by secondary precipitated brown humous compounds. Also contains fossil roots. -8b. Brown laminated humous silt. -8a. White coarse to medium-grained sand with fossil roots. -9. Brown laminated silt.

about 45 cm thick in profile F11 and 20 cm thick in profile F10, the lower brown to dark brown sand is 30 cm thick in profile F11, 30 cm thick in profile F10. The boundary between the two units is horizontal and flat, but exists only due to secondary colouring from humic compounds (oxidize quickly when exposed to the air into grey coloured compounds). The cross-bedding passes the boundary undisturbed. The total thickness is near 50 cm (ref. Atlas-Figs. 92, 93). The brown colouring with its distinct upper limit is due to groundwater action (fossil groundwater level). (Larsen & Kuyp, 1971).

The unit below, no. -8b is a 15-20 cm laminar bed of changing light sand and humic silt-clay, also with a brown colouring underlain by a 0.9 m thick bed of brown silt (unit no. -8a). It is, like bed no. 7, traversed by many vertical roots. The roots are rather thick, presumably owing to a better preservation than the roots in the units just above.

Unit no. 9 was the deepest situated bed exposed during our field studies in the Carl Nielsen Ltd. pit. This bed is a laminated succession of light coloured sand and black sand lamina – with fine brown coal detritus. The base was not exposed but presumably the coarse to medium grained sand well known from the drillings (ref. below) continue the sequence just below.

From the drilling reports the following description of the Middle Sands ("B-Member") can be presented:



Text-Fig. 42. Grain-size and concentration of epidote and amphibole of the sand fraction. The Lavsbjerg Øst borehole (1975) (see also Text-Fig. 43). From H. Friis, Bjørslev Nielsen, E.M. Friis & C. Balme, 1981.

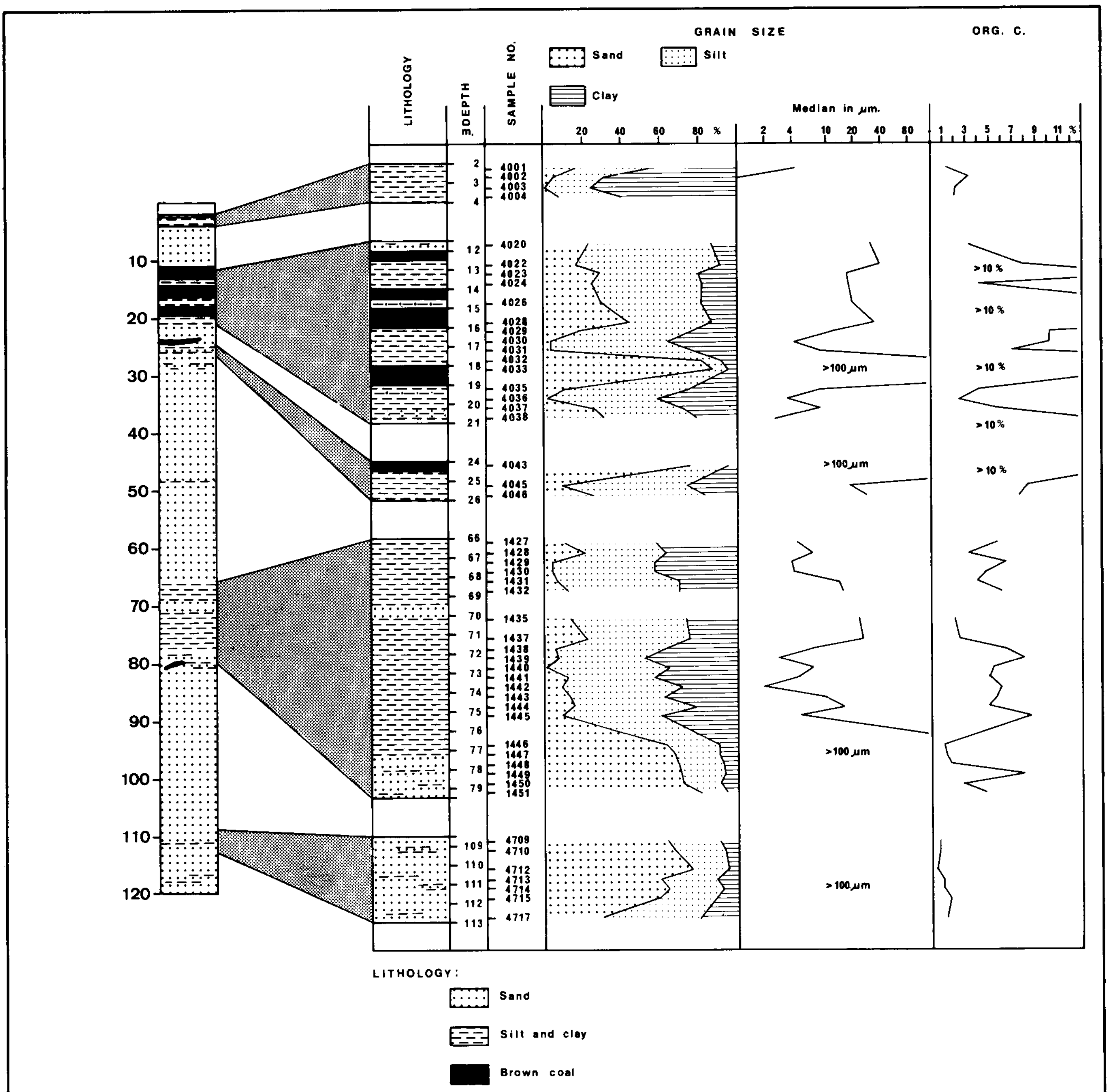
The upper part of the member is about 21 m thick and consists preferably of coarser sands and a bed of silt and clay in the uppermost part similar to what has been described from the Carl Nielsen Ltd. pit. In the Lavsbjerg Øst borehole (no. 95.1995) the uppermost 3 meters is an alternating succession of sand and beds of silt and clay. In the central part of the "B-member" is a concentration of clay beds. It seems lithologically similar to the sequence below the upper root horizon in Klynholt Vest and Damgaard N, at the level of the *Søby-Flora*. The basal 20 m is a sequence of medium-grained sand and partly fine sand with a few thin clay beds found in the middle.

There is good agreement between the two boreholes (Fasterholt Bjerge, D.G.U. file no.95.1942 and Lavsbjerg Øst, D.G.U., file no. 95.1995) regarding this interval.

4.B 3.2. The Black Clay and Silt ("C-Member")

The "C-member" is found between 66.0 and 74.5 m levels below the surface in the Fasterholt Bjerge borehole, no. 95.1942 and between 66.0 m and 79.0 m in the Lavsbjerg Øst borehole no. 95.1995. The member consists predominately of clay with some silt and minor sand intercalations.

The drilling record of the two boreholes differs slightly. No. 95.1942 has a few metres of silt on top and the clay is black. At the bottom is an intercalation of



Text-Fig. 43. A generalized log showing grain size and amount of organic carbon of the clay fraction. The Lavsbjerg Øst borehole (see also Text-Fig. 42). From H. Friis, Bjørslev Nielsen, E.M. Friis & C. Balme, 1981.

very coarse sand with rollers (?) of clay. The lowermost meter of the member (clay) contains some lignite pieces. Borehole no. 95.1995 has a thin silt layer on top of this member and it consists mainly of brown clay with 1/2 meter of coarse sand and 1/2 m of silt between 69.5 m and 70.5 m. The bottom is 1.5 m consisting downwards of 3 beds: sand, black to brown clay and silt with some driftwood. The black to brown clay at this level was the subject of a pollen stratigraphical analysis and though the fossil pollen are to a degree corroded and often deformed countings were possible. The analysis indicates a correlation to the border between microflora zone C and microflora zone B of Brelie (1968) and most probably below this border i.e. in zone B. Microflora zone B is correlated with the Aquitanian in the Lower Rhine province, and may then be synchronous with the Vierlandian of Southern Jutland and Schleswig-Holstein. Microflora zone C is in general correlative with the Hemmoorian.

One interesting observation on the pollen-slides was the occurrence of Dinoflagellate cysts, which may indicate brackish or marine influence. Their low frequency and poor preservation allows for a reservation in indicating environmental conditions (personal communication by S. Piasecki).

4.B 3.3. The Lower Sands ("D-Member")

This member is found between the 74.5 m – 120 m levels in the Fasterholt Bjerge borehole, no. 95.1942 and between 79.0 m to 120 m in the Lavsbjerg Øst borehole, no. 95.1995.

There is agreement between the two drilling records concerning the upper part consisting of sand with variation in grain size. This interval has been recorded as 14 m and 9 m thick. Between 80.5 and 82.5 m a thin brown coal bed (15-20 cm thick) and between 88.5 m and 90.5 m a few thin clay beds alternating with sand and silt have been recorded.

Between 90.5 m and 107-108 m occurs predominately sand with subordinate silt and scattered thin clay layers or lamina. From about 108 m to 117 m clay and silt beds become more abundant in the sand.

Below follows sand to the level 120 m at which level the borehole was completed.

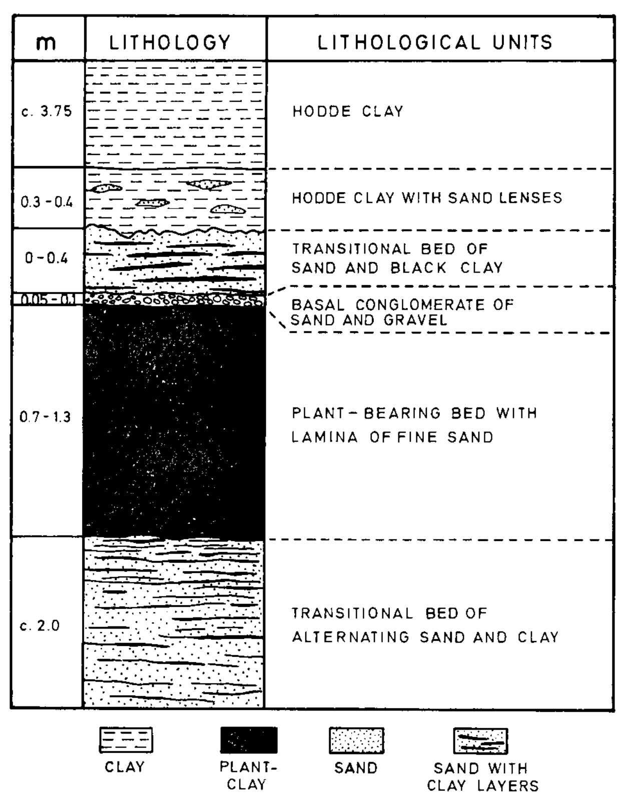
4.B.4. The Hodde- and Gram Formations

4.B.4.1. The Hodde Formation (Rasmussen, 1961)

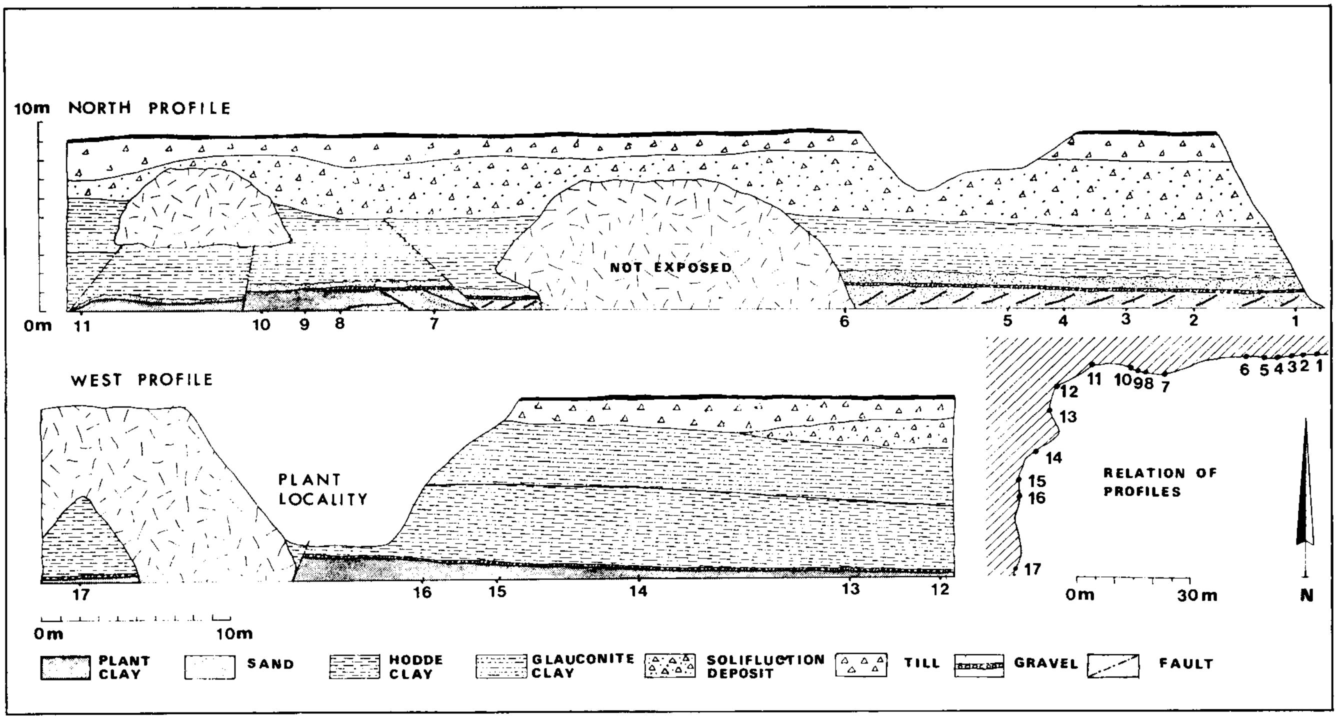
The Hodde Formation is accessible in a number of good exposures in the southern and western part of the Søby-Fasterholt mining area, even though a decennium has past since active mining closed down. Some of these exposures are large enough to reveal the outline of large scale depositional and the tectonic structures. The principal exposures are in the north front of the Klynholt mining area (Atlas-Figs. 16, 67, 95, 97), the east front of the Damgaard S pit (Atlas-Figs. 82, 98, 99) and the north- and west front of the Damgaard N pit (Atlas-Figs. 73, 79, 101, 108). These exposures stand as 10-15 m high cliffs above the waters of the submerged pits and are still swept clean by wave action. The west front of the Søby-Fasterholt area, from the former coal stock of the Damgaard mining company and northwards till near the brook of Søndre Søby Bæk in the vicinity of Sønder Søbygaard, is mostly cut into the Hodde Clay. This section is mostly covered by a thin talus and vegetation. Smaller but useful exposures are found in the SW corner of the Damgaard S pit (the west front) (Atlas-Fig. 100), at the south front of the Klynholt area, at Lavsbjerg (Atlas-Figs. 115, 116), where also the Gram Formation is exposed over a long distance; further in the north front of the submerged Søren Pedersen pit to the N of Munkballe farm (ref. the map Text Figs. 20, 21 and Atlas-Figs. 17, 18).

The information regarding the Hodde Formation from the drillings, see page 79 ff and Text-Fig. 38.

The Hodde Formation consists of a basal transgressional gravel, eventually composite of gravel and black clay. Above follows the Hodde Clay consisting lowermost of a distinctly bedded unit overlain by homogeneous clay. These stratigraphical units will be described below as follows.:



Text-Fig. 44. Generalized profile at the plant locality Damgaard N E.F.C. del. (ref. pag. 126 cont.).



Text-Fig. 45. The abandoned open-cast mine Damgaard N ... E.F.C. del. (ref. also pag. 126 cont.).

I. The Basal Transgressional Bed.

The basal transgressional deposit consists of a gravel of varying thickness (about 20 cm), sometimes (e.g. Damgaard N, the north front) it contains scattered big rollers of flint (several cm in diameter). This gravel has a regional distribution and is recorded with the Hodde Clay e.g. to the N of the Jutland-Funen High at Hjortsballe and to the S of this high at Hodde (type locality) and Odderup (Rasmussen 1961 (Fig. 3), 1966). The gravel was used in the standard section of the late state-geologist Dr. K. Milthers and is based on the experience from the 1941-1949 drilling program of the Geological Survey of Denmark (Heller, 1961a).

In the Søby-Fasterholt area, this basal gravel is often extended to a basal unit of a compound bed consisting of sand alternating with layers or lenses of black, micaceous clay. This basal unit also can be a black, micaceous clay containing lenses of coarse to fine grey to white sand. This bed varies in thickness up to a max. of 2 m (Atlas-Fig. 78) and locally may be overlain by another gravel bed on top. These variations may also follow each other in stratigraphical order ref. Text-Figs. 37, 44, 46; Atlas Figs. 76, 77, 78, 80, 94).

This basal bed is seen in most of the Klynholt north front, and in an isolated outcrop the composite type of basal bed was exposed in 1974 in the Klynholt south front along the eastern flank of the anticline at Lavsbjerg (Atlas-Fig. 116).The gravel bed occurs in the N-S section of the Damgaard S pit, but the transitional sand-clay bed leading into the continuous sequence of the Hodde Clay is thin or lacking. The gravel and the sand clay bed is well developed in the north front of the Damgaard N pit (Atlas-Fig. 78)

At the base of this transgressional bed funnel shaped entrances to burrows filled with the basal gravel and sometimes irregularly mixed with sand are found. The burrows extend downwards into the underlying "Upper Sands" of the Odderup Formation. These steeply dipping to vertical tubes have black linings and penetrate at least 2 m down into the sand. The tubes are filled with sand and are swollen into a spherical chamber at the points of braching. These trace fossils have been described by Asgaard & Bromley 1974 (Atlas-Figs. 83, 84). They belong to *Ophiomorpha* which based on the burrows are close to the extant *Callianassa major.* The *Ophiomorpha* are concentrated in the "Upper Sands" below the Hodde Clay (syncline) of Damgaard S, generally occurs more scattered in the Klynholt north front (ref. Asgaard & Bromley 1974).

In the sand and silt of the transgressional bed above the basal gravel, meniscus back-filled tunnels burrowed by a particular group of *Spatangids* were found besides the *Ophiomorpha.* Also the black or silty clay involved in the basal transgressional bed is intensely bioturbated *(Ophiomorpha* and *Spatangids)* (Atlas-Fig. 94). This has been demonstrated by stereoscopic X-ray photography by E.F. Nielsen (1985).

II. The Hodde Clay.

The Hodde Clay is a sequence of micaceous, well consolidated humic and bituminous clays, the latter being the dominant. The stratigraphical sequence consists of two units: 1) Lowermost a succession of distinctly bedded clays, 2) overlain by a thick, homogeneous black clay (the Hodde Clay proper).

In the Søby-Fasterholt area these clays are poor in fossils and devoid of calcareous tests. Marine molluscs are known from the Brande brickwork pit and the Hundehøj pit about 5 km to the south (Rasmussen 1966, 1970). Dinoflagellate cysts are common in the Hodde Clay (Piasecki, 1980).

In the Søby-Fasterholt area the Hodde Clay is confined to the Lavsbjerg Hill and occurs here, according to well exposed sections in different geographical directions, in a manner which reproduces general features of the original depositional basin and, or alternatively, shallow folding (see chapter 4 C, Tectonics, page 155) which has given rise to the Lavsbjerg Hill structure and its superficial occurrence of the Hodde Clay.

A.) Lithology and Lithostratigraphy.

The Hodde Clay of the Søby-Fasterholt area (Atlas-Figs. 95-101) varies lithologically from brown humic clay or a fine laminar succession of dark brown and light brown clay to a micaceous, black bituminous clay. It varies from pure to silty. A greyish green glauconitic clay is found locally in the uppermost thick, homogeneous part of the sequence. The Hodde Clay is solid, well consolidated due to low pH, containing mica in varying proportions and is rich in pyrite. The brown clays rich in humic compounds are similar to the clays that often grade petrographically into the detrital brown coal of the Fasterholt Member (beds no. 1 and 6).

The stratigraphical sequence consists of two parts. Lowermost 1) a distinctly bedded sequence of alternating brown humous (silty) clay (4 beds) and black bituminous fine clay (3 beds), overlain by 2) a homogeneous thick sequence of black bituminous fine clay (the Hodde Clay proper) (Atlas-Fig. 96). Glauconitic clay occurs as inclusions uppermost in this thick black clay in the transitional zone to the overlying green glauconite clay of the Gram Formation.

An example of this succession is given by the log of probe F.B.1. (1980) (Text-Fig. 46). In the Søby-Fasterholt area it is exposed in the west front of the Damgaard N pit (table 8, Atlas-Fig. 73), in the central part of the N-S section in the Damgaard S pit and in the Klynholt north front (the easterly section). At these localities the Hodde Clay reaches the maximal thickness for the area (Damgaard N: 4.8 m) It is found overlain by the Gram Clay in the Klynholt south front at Lavsbjerg point (Atlas-Figs. 103, 115, 116).

The stratigraphical distribution of the different types of clays follows a general pattern, but not consequent. The clay layers that are interbedded with sand (and gravel) in the basal transgressional bed are generally black and bituminous. Lowermost in the sequence of the Hodde clay, 4 beds of brown humic clay are alternating with 3 beds of black clay. Sometimes the two clays are seen to occur microlamellate within the bed (Text-Figs. 36, 48; Atlas-Figs. 16, 82, 96, 117).

Within the general pattern of alternating beds some petrographical variation may occur between the brown humous beds regarding silt content or fine structure. Also in the black bituminous beds variations occur in structure e.g. homogeneous contra lamellate.

This bedding is sometimes difficult to distinguish exactly, especially in fresh outcrops i.e. the number of beds may appear to vary between 6-7. The basal bedding of the Hodde Clay is continuous through the exposures of Klynholt N and Damgaard S and has been recorded in several probes, e.g. F.b.1 (1979) (Fasterholt Bjerg). The lowermost 5 beds are each about 20 cm thick and the upper two beds are each 40-50 cm. Hence, the total thickness of this basal sequence of the Hodde Clay amounts 1.50-2.00 meters.

The black bituminous homogeneous clay represents the uppermost 2/3 of the sequence. It includes a zone in top of the sequence with inclusions of or more continuous greyish-green glauconitic clay which may be silty to sandy due to the crystallinity of the glauconite.

Brown beds may occur in the middle of the homogeneous clay sequence, and here black and silty clay and silt may often occur.

Concerning the petrography and bioturbation of the Hodde Clay, ref. E. Fuglsang Nielsen (1985).

B). Geochemistry and Facies.

The relative Ca/Mg ratio (after Pitzner, 1968) of the Hodde Clay and the small brown coal bed (5th seam) just below the Hodde Clay has been measured by x-ray fluorescence analysis (S. Grundvig, Geol. Inst., Aarhus University) in relation to the underlying non-marine brown coal beds of the Fasterholt Member. The following Ca/Mg ratios were found:

Hodde Clay:		
Damgaard S. mine	0.2 – 0.6	mean 0.32
Hundehøj near Brande	0.2 – 0.6	mean 0.4
5th brown coal seam:		
Klynholt	0.3	
3rd brown coal seam:		
Carl Nielsen pit		
Fasterholt		
Upper part	3.6 – 4.7	mean 4.0
Lower part	5.4 – 7.1	mean 6.0
2nd brown coal seam:		
Carl Nielsen pit		
Fasterholt		
Upper part (bed no. 2)	9.5	
Lower part (bed no. 1)	5.0	

These mean values, derived from a number of localities arranged in stratigraphical order, show a distinct difference in the values from the two facies/stratigraphical levels, indicating a considerably higher (relative) Mg content for the Hodde Clay (and the small 5th brown coal seam on which the marine Hodde Clay is resting) in relation to the lower (relative) Mg content of the underlying non-marine deposits at a lower level.

These results are in agreement with the conclusion of Pietzner, (1968) that marine, bituminous clays and similar non-marine (bituminous or coaly) clays which for a time have been situated below, but near to the sea bottom (i.e. by superposition of marine deposits as a consequence of a succeeding transgression) are enriched in Mg relative to Ca. The colloidal organic matter and clays in this way have been exposed to infiltration of Mg^{++} ions from migrating sea water resulting in the well known Mg to Ca exchange.

This is in contrary to the limnetic clays situated deeper in the sections and protected by impermeable clay beds. They are unaffected by marine influence and so relatively rich in Ca relative to Mg.

A geochemical study on the occurrences of Hodde Clay of the southern Jutland was published by B. Dinesen (1976).

C) Biostratigraphy.

The localities of Lavsbjerg Hill have not yielded macroscopic marine fossils. The nearest fossiliferous Hodde Clay locality is at the clay pit of Hundehøj west of Brande (the Brickwork Co., Brande) and 6.5 km SW of Lavsbjerg Hill. A number of boreholes at Høggild (e.g. D.G.U. file no. 95.1510 b) (Rasmussen 1966), about 6.5 km to the NW were seen also to contain fossils. The fossil fauna of the Hodde Clay has been described by Rasmussen (1966, 1968).

Pyrite casts of foraminifera have been found (personal com. L. Banke Rasmussen) and Hystricomorpha (Dinoflagellate cysts) are common (Piasecki 1980). They occur (according to this author) in the Hodde Clay as well as in the clay of the basal transgressional bed. The paleontology of the molluscs and the regional stratigraphy have been treated thoroughly by Rasmussen (1961, 1966, 1968).

The fossil fauna of the Hodde Clay of Jutland according to Rasmussen (1966) is correlative to the Reinbekian (Upper Middle Miocene) and agrees with the conclusion of Piasecki (1980).

Fossil pollen are common in the Hodde Clay and varies from extremely well preserved to an extremely corroded condition. Gymnospermous bisaccate pollen are the dominant which is the general trend for Tertiary coastal marine deposits rich in organic matter (Brelie, 1958, 1963). The well preserved fraction was analyzed stratigraphically (Koch, 1984) (ref. page 140-143).

The pollen-stratigraphical study of Koch, (1984), and this paper page 135 correlates the Hodde Clay of the Søby-Fasterholt area and the underlying 5th brown coal seam to the microflora zone D. of Brelie (1967) in the Lower Rhenian area. This is correlative with the Reinbekian (central part of the Lower Rheinian Main Seam (Hauptflöz).

III. The Hodde Formation: Regional Geology.
The facies of the Hodde Formation is widely distributed in the North Sea region attaining considerable thickness in the central part of the basin (Rasmussen 1974 estimates the total Neogene sequence at about 1000 m). It gradually decreases in thickness to the east and does not exceed 10 m onshore in Jutland. In the present survey, only an outline of the regional distribution to the North of the Jutland-Funen High will be presented. The map of Text-Fig. 12 demonstrates the distribution and the boundary of the furthest eastern occurrence. This boundary is obviously influenced by the Jutland-Funen high and leaves a digitate basin to the north of the high. In the narrow "embayment" stretching towards SE from the Videbæk – Herning region (enclosing the Søby Fasterholt area) the Hodde Clay decreases in thickness towards E (on the line Nørre Høggild – Fasterholt Plantage – Lavsbjerg Hill).: Nørre Høggild, max. 5.5 – 6.5 m, Fasterholt Plantage, 5 m, Lavsbjerg Hill, (5.15-) 3.75 m; and towards SE (on the line Brande Brickwork – Skjerris gaard and Store Langkjær – Hjortsballe): Fasterholt Bjerg (probe F.b.1. (1979)), about 5 m, Brande, about 4 m, Hjortsballe, 2.7 m

In the NW-end of Lavsbjerg Hill the Hodde Clay obtains a maximum thickness of 4.9 m and 1.5 km to the SE it is 3.5 m thick in Klynholt N.

IV. Discussion of the depositional structure of the Hodde Formation and tectonics.
In the Søby-Fasterholt area the Hodde Formation is only exposed on Lavsbjerg Hill, a tectonic structure modelled by erosion (ref. Text-Fig. 22). Nevertheless, the good exposures of the fronts left after the browncoal mining have a sufficient extension to demonstrate the general structure of the formation in question. The principal exposures are demonstrated on Atlas-Figs. 95-101, 115-117.

It appears that the long exposures of Klynholt and Damgaard S cut across what may be a local basin of deposition of the Hodde Formation with the maximum thickness in the middle, and gradually wedging out laterally. But the distinctly bedded lower Hodde Clay continues through the entire outcrop without a similar variation in thickness, and without any signs of lateral onlap at the margins of the "basin". This opens for the alternative interpretation of the structure as being due to shallow folding, i.e. a syncline. Its length axis is oriented in NW-SE direction which is parallel to the Jutland-Funen High situated to the south of the localities in question.

The eastern edge of the Hodde Clay occurrence of Lavsbjerg Hill is not well exposed due to the Quaternary erosion. At the western edge of the depositional area of the Hodde Clay is a SSE-NNW stretching "ridge" consisting of the "Upper Sands" (white quartzsand) of the Odderup Formation. To the west of the "ridge" the Hodde Clay is not well represented due to river erosion during the Quaternary. But in the southwest corner of the Damgaard mining area and in probes no. 4, 5, 6 and 7, about 100 m to the south (ref. page 163), the Hodde Clay appears at the west flank of the "ridge". This "ridge" is seen in an entire cross section in the south front of the Damgaard mining area (Atlas Figs. 119-121). The continuation in SSE direction of this sandy structure is even reproduced by the waste from mining of the Klynholt area. The "ridge" was originally considered a primary sedimentary structure (a bar, see Koch et al. 1973) and in coordination with the shallow "basin" of the Klynholt north front. On the contrary the tectonic interpretation (see chapter 4 C) considers these structures a shallow syncline merging into a westerly flat anticline. A survey of the entire Søby-Fasterholt area gives a general support to a tectonical influence of the Tertiary sequence for which is argued in chapter 4. C.on Tectonics.

This does not exclude the existence of synsedimentary structural elements of (a) local sedimentary basin (s), but if such structure(s) is (are) involved here it is rather accurately overprinted by the tectonic structures. Or it needs a more thorough structural and sedimentological analysis involving clearing of more outcrops and involving a wider region for its reconstruction. It has been difficult to distinguish the shallow syncline respectively anticline from a shallow basin of clay deposition and sandy bar in the present outcrops.

The existence of (a) particular local sedimentary basin(s) of the Hodde Formation is not proved by the present field investigations.

The sequence of the Hodde Formation is the product of a transgression beginning from its initial stage when this area was invaded by tidal flooding and onwards. Already during the deposition of the basal sand-clay bed the Spantangidean meniscus backfilled structures seem to indicate constant flooding over the entire area of distribution of the Hodde Formation.

We have found no distinct criteria for a local "basin-structure" of the Hodde Clay to have been established before or during the transgression by means of extended erosion. The lower boundary of the Hodde Formation (disconformity or paraconformity?) only cuts secondary sedimentary structures such as cross-beddings in the uppermost bed of the substratum (the "Upper Sands"). It does not cut through the gross sedimentary bedding (not to confuse with the gross cross-beddings) which appears generally, to be conform to the bottom of the "basin". This is especially clear for the western limiting "ridge". The Hodde Clay cuts what seems to be "channel sands" in restricted troughs of the Damgaard mine outcrops (north- and east fronts of 1969-74), i.e. the youngest cross-bedded sand (river sand) in the area the channel of which has been eroded also into the "Søby-flora-clay" and which forecasts the depositional cyclus of the Hodde Formation as also the 5th brown coal seam does. The continuity of the deposits from the 4th rhythm of the underlying sequence (of Klynholt) does not agree with geological processes needed for the establishment of a fundamental structure like the Hodde Clay "basin" of the Damgaard S- and Klynholt areas.

The "Upper Sands" beneath the thickest central part of the Hodde Clay structure are exposed in the Damgaard S section and is the site of a concentration of trace fossil (*Ophiomorpha* mentioned page 68. 93). Koch et al. (1973) assumed this coordination between trace fossils and the deepest part of the Hodde Clay "basin" to be primary. This phenomenon is not repeated in the Klynholt north front and this correlation in Damgaard S may be at random and not conclusive. Spjeldnæs (1975) held the idea that the ridge(s) is (are) coastal bar(s) and he regards the "Upper Sands" a littoral marine deposit. This seemed to find support in the fact that the cross-bedding of these sands in tabular units in general dip in easterly direction which is in disagreement with the normally held idea of a delta in a river system coming from the east (the East Sea basin). With only detailed information from this restricted area it seems too early to construct a local model for the littoral paleoenvironment of the "Upper Sands" and the Hodde Formation.

V. Depositional Environment of the Hodde Formation. The high content of terrestrial material (plant detritus and humic compounds (compare B. Dinesen 1976) in a transgressive sequence (ref. above) indicates the evolution of a coastal sedimentary environment during this depositional episode. The high content of terrestrial organic material and humic compounds may through its high oxygen consumption during degradation have produced euxinic conditions with the sapropelic type of sediment, though a (well aerated) shallow water environment might be expected from a coastal locality. The high content of organic matter and pyrite (H^2S production) may also correlate with a rather low pH value of the deposit adding to the toxic effect of the environment. The low pH points to a reason for the lack of calcareous fossil tests and the compaction and toughness of the clay. The silty horizons and the high content of mica may indicate a near by river outlet and/or a periodical influence of higher wave- or stream energy.

The marine influence cannot be doubted due to the high content of Dinoflagellate cysts, a Mg/Ca ratio higher than the non-marine organic sediments of the region (the brown coal) and the sporadic occurrence of glauconite in the top of the Hodde Clay.

It is reasonable on this basis to regard the Hodde Formation of the Søby-Fasterholt area as a succession of lagunal, estuarine and protected shallow marine facies onlapping the deltaic facies. Piasecki (1980) in his environmental considerations about the fossil Dinoflagellate cysts of the Hodde Clay regards the depositional environment as neritic to estuarine.

After this paper was finished E. Fuglsang Nielsen has produced a M.Sc.- dissertation (E.F. Nielsen, 1983) and published an abstract (E.F. Nielsen 1985). This sedimentological, geochemical and paleontological (trace fossil structures) investigation must be consulted for detailed information.

VI. Summary of the Hodde Formation.
The more obvious characteristics of the Hodde Formation in the Søby-Fasterholt area are:

1) The basal transgressional bed of gravel, sand, and clay.

The coarse grained sediment is evidence of an environment of high physical energy at the beginning, which decreased and changed the sedimentation as time went on.

At first from the high energy phase trace fossils are found indicating the tidal zone (*Callianassa* sp.), the overlying sand silt deposits with burrows from the *Spatangids* indicate a later phase with constant water cover. Dinoflagellates (*Hystricomorphs*) in the clay layers also indicate marine influence.

2) Hodde Clay.

1) Dinoflagellate cysts (*Hystricomorphs*) are common, indicating marine estuarine environment.
2) In the brown clay a content of fine grained plant detritus and humic compounds (responsible for the beds of brown colour).
3) In the black clay a content of bituminous matter (responsible for the black colour) is characteristical.
4) High content of muscovite, especially in the coarse and silty clays and is in common with the sediments (sands and silt) of the underlying delta deposits.
5) Calcareous tests of Foraminifera and of the benthic fossil fauna element (Molluscs) are lacking in the area in question. Pyrite casts of foraminifers have been observed.
6) Pyrite is abundant.
7) High Mg/Ca ratio in contrary to the underlying non-marine brown coals.
8) Glauconite is not a characteristics of the Hodde Clay but inclusions of glauconite occur in the uppermost part as a transition to the overlying glauconitic clay of the Gram Formation.

4.B.4.2. The Gram Formation

(Text-Figs. 46, 48; Atlas-Figs. 103, 115)
The Gram Formation has been described by Rasmussen 1956, 1961, and 1966. This formation consists of two units:

2) The Gram Clay
(Atlas-Figs. 103, 115)

1) The Glauconite Clay
(Atlas-Fig. 102)

Both of these two units (members) can be seen in the Søby-Fasterholt area on the Lavsbjerg Hill and its easterly continuation, named Fasterholt Bjerg.

The largest outcrop with the most complete succession is found where the south front of the Klynholt mining area cuts across the northern flank of the point Lavsbjerg (71 m).

Here along a distance of about 100 meters, the front was cleared of talus and vegetation in 1974 and opened for observation from the eastern flank of the Lavsbjerg anticline and eastwards (Atlas-Fig. 103). In the central part of the anticline, the "Upper Sands" of the Fasterholt Member is exposed at the foot of the section. Above follows the 2,9 m thick Hodde Formation with a basal gravel bed overlain by a bed of alternating black clay and sand. Above follows the Hodde Clay including the basal succession of alternating black and brown clay. The black bituminous Hodde clay is exceptionally hard and brittle with glossy fracture.

Along the east flank of the anticline follows the Glauconite Clay (2,2 m thick). Above is the Gram Clay, dipping a little to the east in the approximately 100 m long exposure. The Gram Clay in this exposure is more than 9 m thick. In its lower part it is a hard and tough brown clay with scattered calcareous concretions. In this lower part we have observed a row of concretions indicating the bedding with a low easterly dip.

The Gram Clay is fine in the lower part, and becoming coarser upwards to where it is silty at the top of the section.

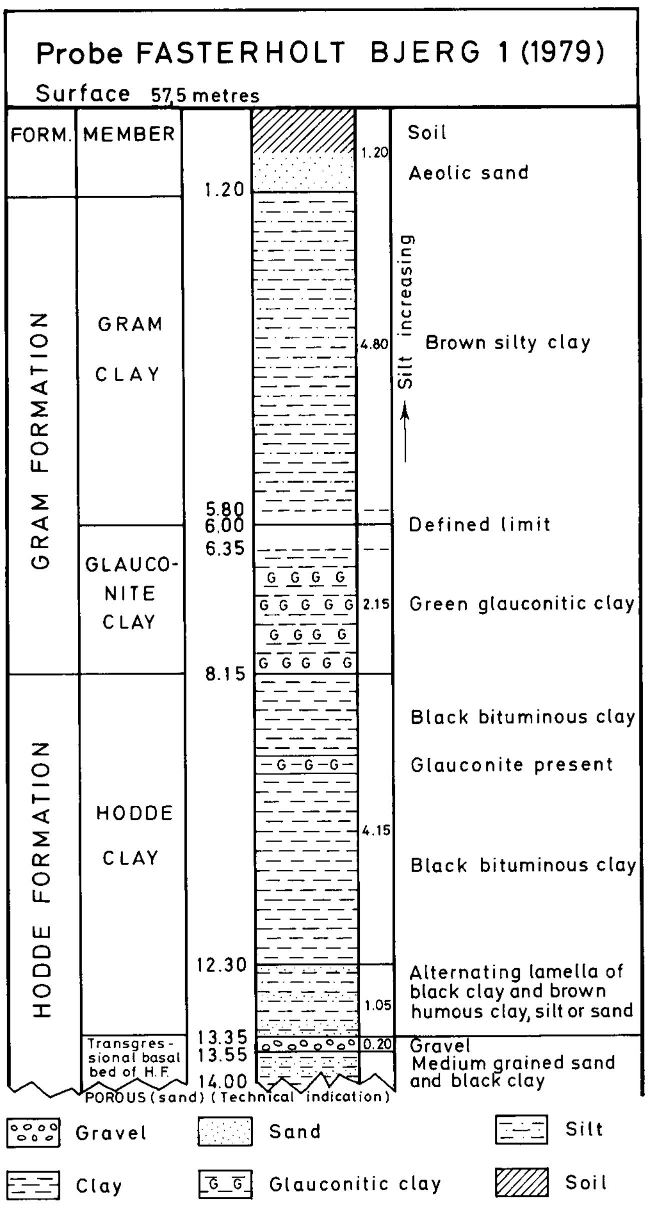
In the lower part of the section (Atlas-Fig. 103), there are numerous impressions of molluscs coated with the incoaled periostracum. These fossils are determinable, and Rasmussen (1979) gives an account of the fossil fauna. Rasmussen (1979, page 20) writes as follows:

"The following species have been identified: *Astarte reimersi* (Semper in Ravn 1907), *Cardita orbicularis* (Sowerby, 1825), *Galeodea echinophora* (Linne 1758), *Sipho distinctus* (Beyrich, 1956), *Gemmula badensis* (Hoernes, 1875) *Conus antediluvianus* (Bruguière, 1792), *Bathytoma cataphracta* (Brocchi, 1814) and *Brachytoma obtusangula* (Brocchi, 1814). All the species mentioned are typical for the Danish Upper Miocene Gram fauna, and the presence of *Cardita orbicularis* means affinity to the *Astarte reimersi-Goodallia esbjergensis* zone (ref. Rasmussen, 1966)".

Hence, the fossils correlate with the lower part of the brown Gram Clay of the type locality (Gram Brickwork, Southern Jutland).

In the F.b.1 (1979) probe in Fasterholt Bjerg (Atlas-Figs. 22 (1), 47) the Gram Clay was penetrated from 1.2 m.b.s.l. – about 6.0 m.b.s.l. (a thickness of 4.8 m) and was found to overlay a green-grey glauconitic clay, 2.15 m thick, it again resting on the black Hodde Clay. The uppermost 1.5 m (1.2-2.7 m.b.s.l.) is weathered into a grey clay and below this at 2.7-3.1 m.b.s.l. is a brown Gram Clay with lamina of silt; the remaining of the Gram Clay (3.1-about 6 m) is a grey-brown pure clay.

The west wall of the Damgaard N pit shows the Glauconite Clay of the Gram Formation to be a max. of 3.5 m thick. The glauconite occurs as visible grains, giving this clay a silty-sandy quality. The Glauconite Clay at this locality overlies a complete Hodde Clay



Text-Fig. 46. Log of Fasterholt Bjerg 1 probe (1979). The position of this probe, a few hundred meters SW of the Carl Nielsen Ltd. browncoal pit, the Fasterholt Bjerg hill, is important to complete the regional profile at Fasterholt linking from the "Upper Sands" to the Hodde and Gram Formation. So, the Miocene sequence is represented without interruption. E.K. comp.

sequence resting on the basal gravel of the Hodde Formation (ref. Text-Fig. 46, Atlas-Fig. 108). A probe set in the NW-corner of the Damgaard N pit (probe Damgaard N, 1978, surface level: 55.0 m) revealed the presence of the Gram Clay (see table 8, page 61). Hence, the Gram Clay is well represented on the Lavsbjerg Hill and especially in the southern-southeastern part including Fasterholt Bjerg.

The occurrence of the Gram Formation is important as it supplies the local stratigraphy with a well-dated marine mollusc fauna (Upper Miocene). This fauna and the presence of the dinoflagellate cysts of the Hodde Clay described by Piasecki (1980) correlate the marine sequence above the Odderup Formation with the Miocene marine deposits well known from elsewhere in Jutland.

As a part of an experimental *radiometric dating* program of the Miocene and Oligocene glauconitic deposits of Jutland, Dr. Ole Larsen, from the Geological Institute, Copenhagen University, calculated the following values for the Glauconite Clay of the Gram Formation of the Lavsbjerg Hill:

1) Green glauconitic clay (Gram Formation) about 1 m above the lower boundary towards the Hodde Clay, located at the south front of Klynholt at the point Lavsbjerg	8.8 ± 1.1.m.y.
2) Green glauconitic fine sand, about 3 m above the lower boundary towards the Hodde Clay, located at the west wall, the Damgaard N pit	10,0 ± 0.5 m.y.
3) Green glauconitic, fine sand about 2 m above the lower boundary towards the Hodde Clay, located in the Damgaard N. pit	13.2 ± 0.5 m.y.

Dr. Ole Larsen reports that the conditions of the crystals were not ideal for dating of these samples due to a relatively low K content and small size of the crystals. Hence, the ages are not exact but reliable when a margin of 2-3 m.y. is considered.

4.B.4.3. The Sequence Overlying the Type Section at the western end of the Carl Nielsen Ltd. browncoal pit at the Fasterholt Bjerg.

At the west end of the Carl Nielsen Ltd. browncoal pit with the main trench in E-W direction, an additional southerly trench was excavated to lead a road into the pit. This auxiliary trench was dug into the foot of the Fasterholt Bjerg hill, rising 10-15 metres above the outwash plain in which the main trench was excavated. This hill is a Pleistocene erosional relict, and here the browncoal bearing sequence (the Fasterholt Member) is overlain by the marine Hodde Formation (Upper Middle Miocene) followed by the marine Gram Formation (Upper Miocene) (Text-Fig. 46). This was recorded in a probe that was drilled on Fasterholt Bjerg in 1979 (ref. the drilling record, page 74).

At a level approximately the same as the boundary that occurs between the fossil soil with tree-roots on top of the Tertiary "Upper Sands" and the Quaternary in the section between the profiles K6 and K7 of the main trench at Fasterholt, the base of the Hodde Formation is recorded in probe Fasterholt Bjerg 1 (1979). At this level, below the Hodde Clay, is a basal bed of gravel underlying a coarse to medium grained sand (Tertiary). This means that in the section between the profiles K6 and K7 nearly the entire Fasterholt Member is represented similarly as the case in Fasterholt Bjerg.

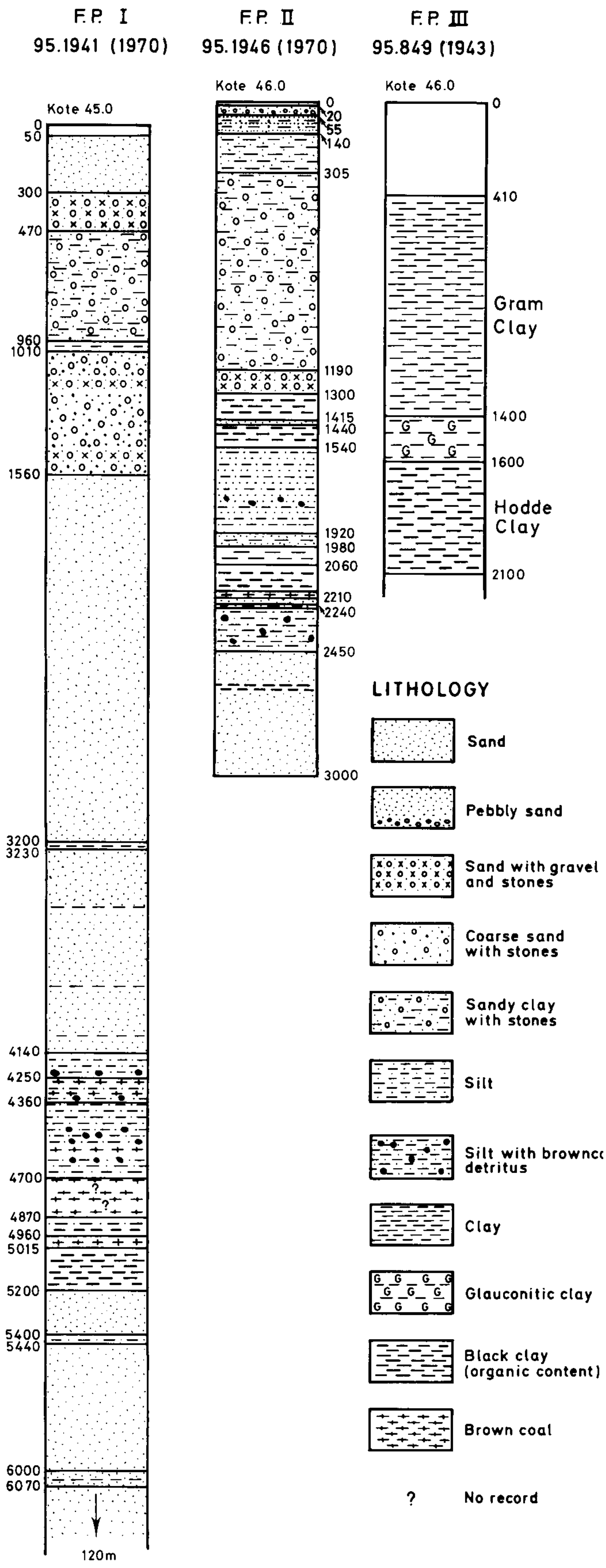
4.B.5. The Drillings West of the Søby-Fasterholt area: Fasterholt Plantage.

On the plain to the west of Fasterholt forest three boreholes were drilled at O.C. Simonsen's farm. One was an older brown coal-prospecting boring (D.G.U. file no. 95.849, 1943) and the other two drilled in 1970, both were described in the file (chapter 4.B.2.2.2. page 74) . They were located near to each other along an approximately east-west line stretching 150 metres. Based on lithostratigraphy alone none of these can be correlated with certainty to the boreholes and exposures to the east of Fasterholt forest.

The easternmost borehole no. 95.849 (1943) is spaced about 100 metres to the east of the Fasterholt Plantage II borehole, no. 95.1946, and only 50 m to the west of the latter is the Fasterholt Plantage I borehole, no. 95.1941.

According to our general knowledge of the geology of the area in question, the borehole no. 95.849 penetrated an entirely marine pelitic sequence (the Hodde Clay, Glauconite Clay and Gram Clay (ref. Rasmussen 1966, page 60-61) of Upper Middle Miocene and Upper Miocene age) representing the normal situation of the Lavsbjerg Hill where the Tertiary deposits lie a few metres below the surface, probably overlain by Quaternary deposits but this is not specified in the log.

The other two boreholes have penetrated a rather thick sequence of presumably Quaternary deposits, which can be tentatively determined in the terms of the local geology. Hence, borehole no. 95.1946, after passing through the normal soil and drift sand on top, penetrated a thick sequence of solifluction-deposits and borehole no. 95.1941 drilled through a similar but much thinner solifluction bed overlain by a glacio-fluviatile bed of coarse gravel and sand. From the relative position of the three borings and the type of sediment recorded, it is indicated that borehole no. 95.1946 is situated on a rather steep flank (thick solifluction) of a "fossil" Lavsbjerg Hill, that is presently totally levelled, and that borehole no. 95.1941 is in a more ex-



Text-Fig. 47. Logs from 3 boreholes west of Fasterholt Plantage (the fields of O.C. Simonsen's farm): Fasterholt Plantage I (file no. 95.1941) (1970); Fasterholt Plantage II (file no. 95.1946) (1971) and D.G.U. browncoal prospecting well, file no. 95.849 (1943) (F.P. III). With permission from D.G.U. (Geol. Surv. Denmark). E.K. del.

treme position on this flank (thinner solifluction) where a cover of glacio-fluviatile sand was deposited later upon the solifluction deposit.

The Tertiary sequence recorded from the boreholes Fasterholt Plantage I and II (resp. no. 95.1941 and no. 95.1946) cannot be correlated together or correlated lithostratigraphically to the browncoal-bearing sequence from the Søby-Fasterholt mining area to the east.

Below the Quaternary in borehole no. 95.1946 is found 2.4 m of beds similar to the Hodde Formation overlying a sand-silt sequence that could correlate to the similar deposit of "the 4th rhythm" of Fasterholtgaard 1 borehole and the *Søby Flora* sequence of Damgaard N.

The base level of the Hodde Clay in borehole no. 95.1946 is about 5 metres above the basal level of the Hodde Clay in borehole no. 95.849 possibly indicating a minor relative upwards displacement of the sequence of the westerly of the two drillings.

There is no possibility for precise correlation of the boreholes no. 95.1946 and no. 95.1941 or any lithostratigraphical indication of the relative displacement. But they are definitely relatively displaced due to the fundamental difference, and it indicates that the 3 boreholes are situated in a fault zone.

The total lack of Hodde Clay below the Quaternary in borehole no. 95.1941 may indicate another relative upwards displacement which is relative to borehole no. 95.1946. This is supported by the analysis of the fossil pollen from borehole no. 95.1941 (ref. below). In conclusion it appears that along the western flank of the erosional Lavsbjerg Hill structure there is a fault along which the east side is displaced downwards relative to the west side. Presently, the amplitude and strike/dip of this fault is not known. It seems to be a fault zone with multiple faults.

The relative displacement opens for the possibility that the sequence between 41.4 m – 52.00 m is relatively uplifted and may correlate with the clay-silt sequence between 66.5 m and 74.5 m in the borehole Fasterholt Bjerge no. 95.1942.

A preliminary palynological analysis of the brown coal at a level about 50 m.b.s.l. in the Fasterholt Plantage I borehole is representative of a typical Miocene association. There is a notable frequency of *Inaperturopollenites emmaensis* Muriger & Pflug and some Paleogene relicts occur that are not found in any notable amounts in the Browncoal Bearing Sequence of the Søby-Fasterholt area. This indicates an occurrence of older deposits (Aquitanian or older) at this level than is the case in the boreholes of the Søby-Fasterholt area to the east of Fasterholt Plantage.

4.B.6. Summary of the Lithostratigraphy and Depositional history in the Browncoal Bearing Sequence of the Søby-Fasterholt area.

The Fasterholt Member and the "Upper Sands" together are a succession of browncoal beds and clastic sediments including transitional sediments (e.g. organic clays, sands with browncoal detritus). Generally the individual beds are distinctly limited by diastems, paraconformities-weak disconformities (Text-Fig. 23, 24). In accordance with the marginal position of the Søby-Fasterholt area, in relation to the entire Miocene depositional basin, the Browncoal Bearing Sequence is relatively thin (15-22 m.) as are generally the Miocene Series of the Central Jutland.

The sedimentary sequence of the Fasterholt Member is characterized by its rhythmic succession with well-defined sub units. These sub-units are not identical but show an obvious similarity in the sedimentary succession expressed by a consequent change (evolution) within the sub-unit. They show a rhythmic, progressive succession from bottom to top reflecting an evolution in the sedimentary conditions (environment). This is expressed in the grain-size and internal sedimentary structures of the beds, which reflects a changing energy level of the sedimentary agents. There is a general tendency of these sub units to reflect an evolution from high-energy conditions into low-energy conditions. From below, the sub-units generally begin with coarse and poorly sorted sediments, sometimes combined with composite sedimentary structures, referring to current water. This basal sediment has a sharp lower boundary, resulting from a preceding interval of erosion or non-sedimentation. This is a gradual change upwards through the sub-units leading towards finer and more homogeneous sediments (pure silt, pure clay, detrital brown coal). (Ref. Text-Fig. 48). Occasionally a retrogressive succession is intercalated (a sub-sub-unit). So each browncoal seam ends a sub-unit. In consequence of the rhythmic succession that reflects a "transgressive" evolution leading into a terminal "regressive" situation for each sub-unit, these sub-units may be termed *rhythms* because they are different successive units in a progression, and not identical cycles.

The Fasterholt Member could tentatively be divided into 3 rhythms and the overlying "Upper Sands" could be regarded as a 4th one being atypical in the Fasterholt area, but grading into a typical 4th unit in Klynholt Vest.

The Lower Boundary of the Fasterholt Member:

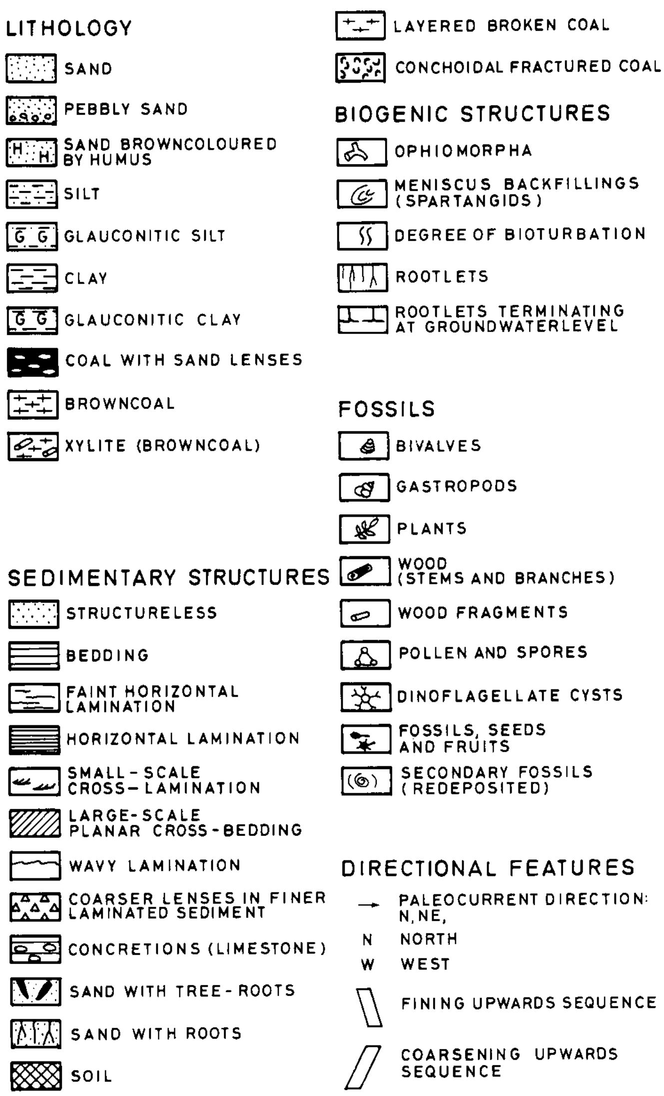
The Fasterholt Member rests on a psammitic sequence of cross bedded coarse to fine-grained sand ("B" Member). Developed from its uppermost bed of coarse to medium grained white sand of the "B Member" is a fossil soil with crowded thin vertical fossil rootlets, remains of tree stumps, and individual tree roots all in vertical or steeply dipping position. The stumps are normally deeply eroded or disintegrated. The boundary between this bed and the basal bed of the Fasterholt Member is the original ground surface and in principle is concordant and erosion has not been pronounced. The frequency and dimensions of its stumps and roots indicate that a forest was established upon this surface for a long time. Unfortunately, the stumps and roots are strongly disintegrated, and it has been possible only to determine them to the taxodiaceous gymnosperms (personal communication by P. Wagner).

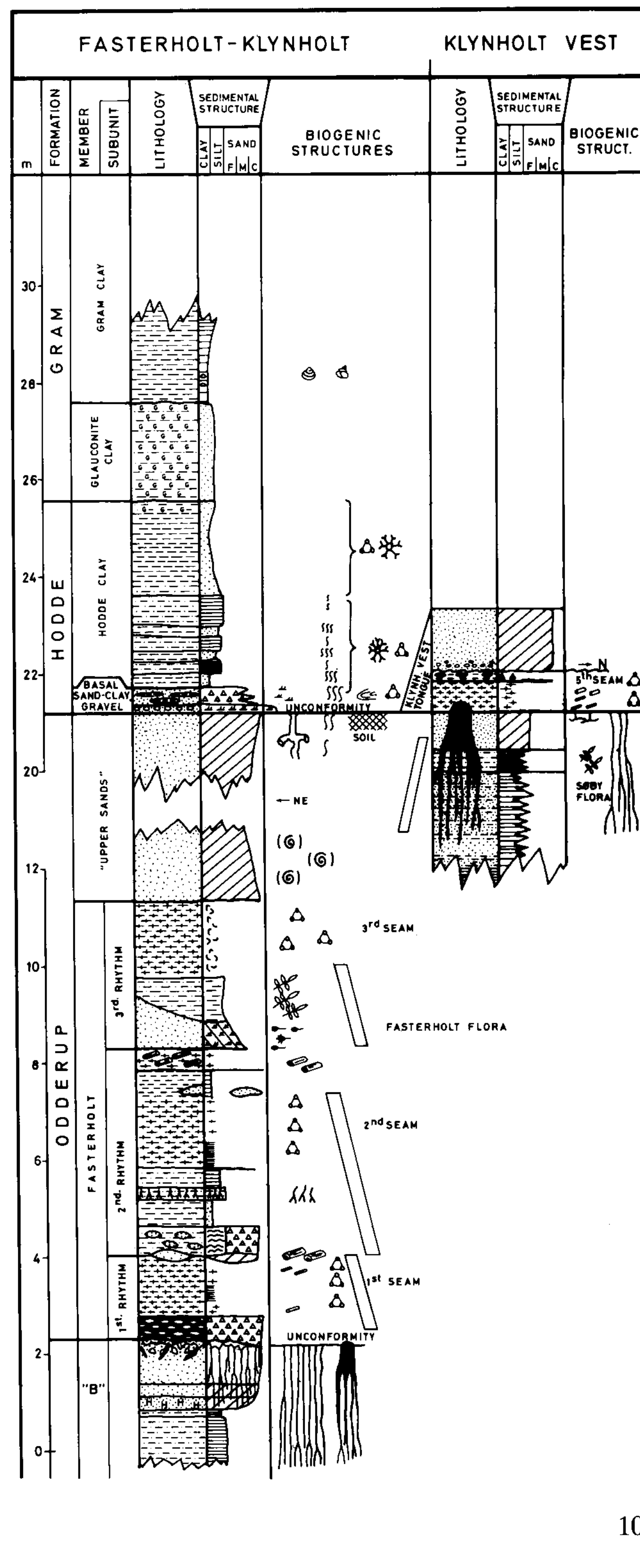
The roots penetrate through the substratum below the soil more than 2 metres indicating low groundwater level, i.e. a consequence of a "regressive" situation of this coastal region.

The lower boundary of the Fasterholt Member is a paraconformity involving a marked period of non-deposition and soil development. Hence, a distinct "regressive" period preceded deposition of the Fasterholt Member.

The Upper Boundary of the Upper Sands:

Our detailed insight in the uppermost part of the Fasterholt Member and its overlying formations allows a more complicated model for the geological evolution to be constructed for the interval around the upper boundary of this rhythmic succession. Generally the Hodde Formation overlies the Odderup Formation in Central and Western Jutland. The Hodde Formation





Text-Fig. 48. *Lithostratigraphical diagram of the southern (Fasterholt-Klynholt area) and western (Klynholt Vest) parts of the Søby-Fasterholt area, summing up all the available information of sedimentary materials, structures and fossils. E.K. comp.*

also overlies the browncoal bearing succession of the Fasterholt region and these conditions have been recognized only on the Lavsbjerg Hill and its extensions towards SE (Bjerre) and NW.

The thick sequence of cross-bedded (generally NE dipping) white sands (preliminarily named the "Upper Sands"), found between the 3rd brown coal seam (inclusively the local 4th) and the root horizon at the base of the 5th seam, in the Carl Nielsen Ltd. pit at Fasterholt, appears to be the widest extended facies at this level. Towards west-northwest it becomes gradually replaced by clay alternating with the white sand (Klynholt Vest) and then into a dominance of the brown clay in the Damgaard N pit (including the *Søby Flora* bed) (Text-Fig. 37). In spite of high frequency of observations it is not possible to prove whether we are doing with exactly synchronous intergrading (fluviatile lacustrine) facies. Hence, the 4th rhythm is not well-defined and is a provisional term.

Regardless of the intergrading facies these deposits along the west side of the Søby-Fasterholt area end near to the boundary of the Browncoal Bearing Sequence (with the overlying Hodde Formation) in a soil horizon with fossil tree stumps and/or a root horizon. The tree roots are sequoide (det. P. Wagner: Wagner & Koch 1974) and penetrate directly and steeply more than 2 metres into the substratum. In general this indicates that after deposition of 4-10 m of lacustrine-fluviatile sediments and before the deposition of the Hodde Formation, a period of non deposition (a "regressive" situation) dominated the area. In the Damgaard N pit the lacustrine sequence ending with a root-horizon was even eroded by a river and replaced later or simultaneously with westerly dipping fluviatile white sands. This supports the idea of a final "regressive" event with (tendency to) non deposition and/or erosion.

In the Søby-Fasterholt area the Hodde Formation generally overlies the white cross-bedded sand ("Upper Sands" and the equivalent "4th rhythm"). In the eastern part of the Damgaard N pit it overlies the youngest fluviatile beds of this "Upper Sands" (channel-sand), i.e. the beds deposited by a river which eroded the *Søby-Flora* clay and its intruding root-horizon. In the western end of this pit, the *Søby-Flora* bed and the root horizon is overlain by the Hodde Formation with a paraconformity, implying a lacuna (?) of differing length. About 1 km to the south, in Klynholt Vest, a small coal seam (the 5th seam) is situated above the stump-root horizon and is overlain by a sandy version of the basal bed of the Hodde Formation. This coal seam consists of about 65 cm of lignite (deposited in a forest swamp) changing upwards into a 15-20 cm thick sapropelitic detritus browncoal (open water facies) with small sand lenses in the upper part. The sand lenses are transitional to the overlying basal sand of the Hodde Formation. The coal bed is ripple marked (current ripples) in its upper surface indicating that the deposit was unconsolidated when the overlying cross-bedded sand was deposited. The ripples and cross-bedding of the 5th seam indicate the same stream direction as that of the overlying cross-bedded sand. Traces of weathering, oxydation or severe erosion were not found in the surface of this 5th seam in Klynholt Vest. Close observations in Klynholt Vest prove the overlying sand is synchronous with the basal transgressional bed of the Hodde Formation. The spatangidean burrows of the basal transgressional bed (Asgaard & Bromley 1974, Damgaard N pit) proves this to be a marine deposit under continuous water cover. Hence, the 5th coal seam with its inclusion of small sand lenses in the top grades into the overlying sand (equivalent with the basal bed of the Hodde Formation), a gradual transition in Klynholt Vest, while a short lacuna with diminutive erosion is found on other localities where the "Upper Sands" is overlain by the Hodde Formation.

Hence, in the western part of the Søby-Fasterholt area (Klynholt Vest, Damgaard N etc.) the root and stump horizon is overlain by a succession of beds indicating a gradual transgressive evolution ending with the Hodde Clay transgression represented by the basal transitional bed of the Hodde Formation succeeded by the Hodde Clay; and presumably locally (in Klynholt Vest) even preceded by (initial) peat sedimentation on the foreland (5th seam).

Generally, where the Hodde Formation overlies the Fasterholt Member (Odderup Formation) there is a para- or indistinct disconformity. This involves a lacuna which presumably includes a "regressive" period, with a forest on the delta, and weak erosion. To the south in the Klynholt area this includes a final period of rising groundwater allowing deposition of forest peat followed by open water bog conditions, before the marine transgression conquered the region. The general lacuna of the Hodde Formation/Odderup Formation continues locally as a paraconformity between the "Upper Sands" (the 4th rhythm) and the 5th seam. This lacuna includes the time of formation for the 5th seam found only locally and also a short lacuna between the 5th seam and the Hodde Formation the latter evidenced by the tidal zone conditions causing light erosion and redeposition.

Summary:

The Fasterholt Member rests upon a fossil soil with degraded fossil stumps and densely crowded and deeply penetrating vertical roots/rootlets. This indicates that a non-depositional interval (a "regressive" situation) interrupted the deposition of the sedimentary sequence and preceded the deposition of the Fasterholt Member. This level is well suited for subdividing the Miocene sequence in the Søby-Fasterholt area.

The sequence of the Fasterholt Member indicates that deposition was initiated by a rising ground water level (aquatic sediments), the initial stage of which may be traced in the secondary structures of this soil-horizon ("intraformational breccia"). The beds of this sequence were deposited subaquatic under changing conditions: Deposition by current water (high energy sedimentary agents) in the initial stage and with a marked tendency for a continuing deposition under decreasing in energy, leading into a terminal stage with deposition under low-energy conditions. This succession (evolution) repeats itself rhythmically throughout this member.

This rhythmic succession represents a history of an accelerating deposition. It starts with a low amount of inorganic and total sedimentation (the 1st rhythm): Forest swamp-brown coal and related facies of lesser thickness but of a wider geographical extent, followed by acceleration in deposition of anorganic, and total sedimentation including impure detrital browncoal (2nd and 3rd rhythms) terminating with a thick deposit (about 10 m.) of coarse-fine quartzsands ("Upper Sands"/4th rhythm), and ending in an episode of non-deposition (root/stump horizon). This indicates a depositional history under the influence of a rising erosional/ depositional base-level which is overtaken by sedimentation (influenced by stagnation in the subsidence of the depositional basin and/or interference of the main factors controlling the sedimentation).

This type of succession reflects the way in which the mechanism of the subsidence of the entire large basin (the North Sea basin) was transformed into the marginal local environment giving rise to a discontinuous depositional process. The Fasterholt Member represents the continuous competition between sedimentation and subsidence (rise of water level) in which sedimentation repeatedly overtook the effect of subsidence. Therefore, the overall situation during the deposition of the sequence Fasterholt Member – "Upper Sands" is (discontinuous) "transgressive".

The browncoal bearing sequence ends with a stump and root horizon with steeply and deeply penetrating roots/rootlets. The stumps have been strongly disintegrated and deeply weathered. This youngest part of the Odderup Formation, including the root horizon, has been submitted to river erosion before the deposition of the basal layers of the Hodde Formation. This last non-depositional interval ("regressive" situation) interrupted the sedimentation after the widespread and extensive deposition of cross-bedded white sands and lacustrine sediments ("Upper Sands"/ The "4th rhythm"); and before the deposition of the 5th brown coal seam and the Hodde Formation.

The deposition of the browncoal bearing sequence was succeeded by the transgressive Hodde Formation, representing a succession of deposits from the following stages of the rapidly expanding transgression: 1) Stagnation and establishment of a forest swamp onshore, grading into open water swamp (5th browncoal seam), 2) tidal zone with *Callianassa* burrows, 3) littoral zone with Spatangids (transitional basal bed of the Hodde Formation), 4) open stagnating sea with heavy inflow of organic debris (Hodde Clay).

The exposures in the Søby-Fasterholt area represent a geological history beginning with a relative "regressive" situation (delta ending with the lower root-stump horizon and soil), after a period of non-deposition continuing with a (discontinuous) "transgressive" situation with deposition of the Fasterholt Member and the "Upper Sands" (excl. the 5th seam) and ending in a "regressive" situation (upper root-stump horizon and river erosion). Finally a marine transgression leading to deposition of the Hodde Formation and further continuing into the Gram Formation ends this historical-geological episode. This entire history may be the onshore expression of accelerating subsidence of the North-Sea Basin leading to a climax during the transgression of the Hodde- and Gram Formations.

4.B.7. Stratigraphy.

The previous descriptive and interpretative chapters have demonstrated the facies- and lithostratigraphical pattern of the Browncoal Bearing Sequence of the Søby-Fasterholt area and has outlined some main features of its depositional history (ref. the summary page 212). This must be supplemented by bio- or chronostratigraphical information to obtain a reliable chronostratigraphical succession of units and a reliable perspective of historical events. Hence, this chapter will discuss the stratigraphical tools which are available.

A provision for a stratigraphical study of the Browncoal Bearing Sequence of Central Jutland is to recognize that the area in question occupies a peripheral position of the Neogene North Sea basin. The subsidence of the basin must have influenced the marginal areas to a lesser extent and with some retardation of the depositional reactions, strengthening the discontinuity of the depositional process in relation to the central regions.

The depositional succession of beds recorded from the Søby-Fasterholt area is a good example because of the presence of a gross rhythmic depositional structure with many paraconformities and weak disconformities. The subunits and single beds in the area are bounded by sharp diastematic boundaries and characterized by a rapid change of sediments (facies).

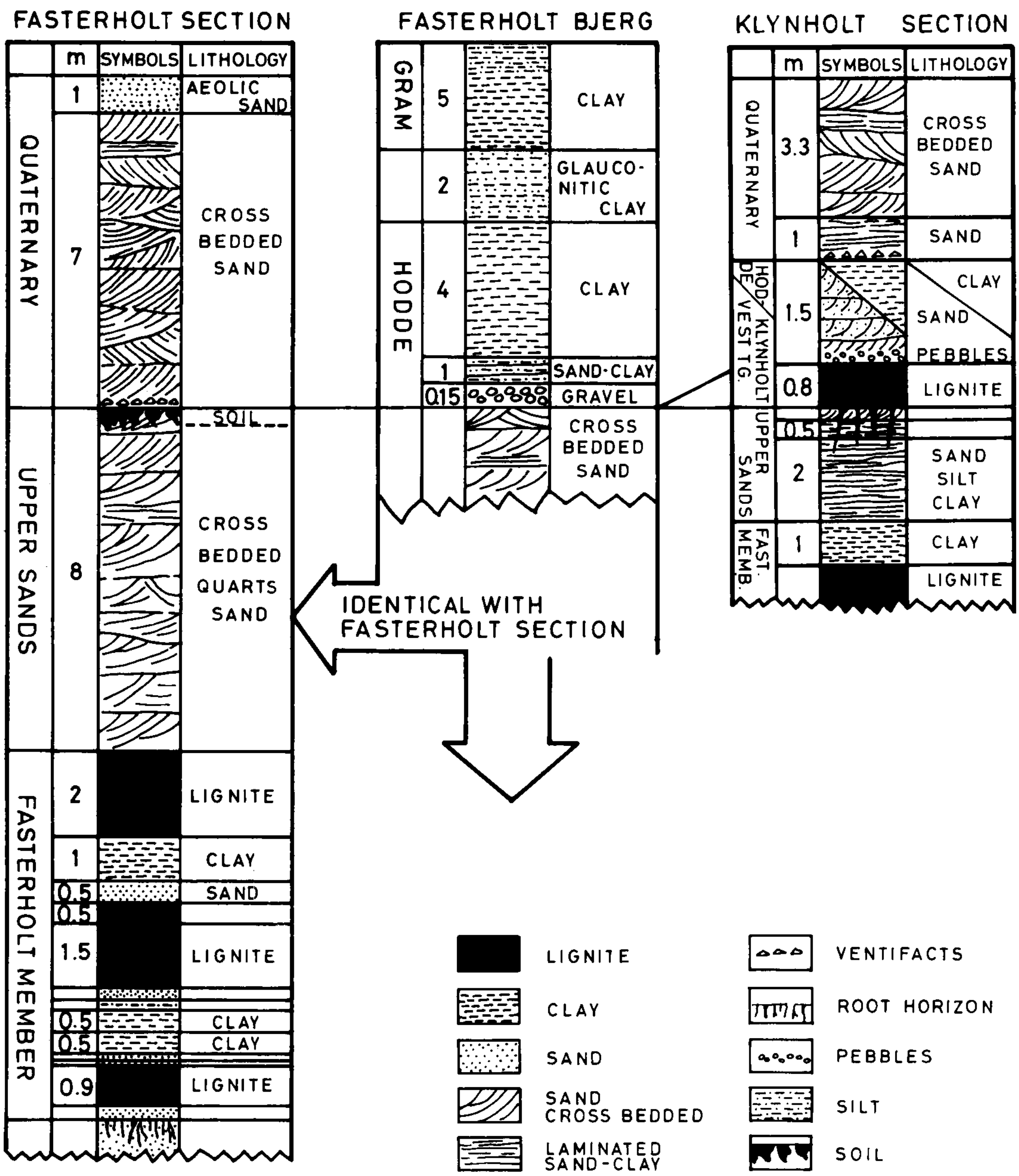
The depositional history of the Browncoal Bearing Sequence consists of 3 general episodes terminating by a final 4th episode of transgression.

1) A period of non-deposition and/or erosion (unconformity, soil combined with deep root-horizon and stumps (forest-trees), evidence of subsiding ground-

water level, traces of erosion) related to a regressive situation in the marine realm of the North Sea basin.

2) A period of discontinuous, rhythmical deposition (of subaquatic sediments, partly from open water environments (swamps, lakes, rivers and deltas) due to rising groundwater), which may be related to a general transgressive tendency in the North Sea basin.
3) A period of non-deposition and/or erosion (unconformity, soil combined with deep root-horizon and stumps (forest-trees), evidence of subsiding groundwater level, traces of erosion) related to a regressive situation in the marine realm of the North Sea basin or at least a situation where the sedimentation overtook the rate of subsidence definitively for a while. Indications suggest that (3) may be an inferior episode within a general transgressive period which is introduced by (2) and culminates with (4).
4) The marine transgression of the Hodde Formation.

It is also important to observe that before this succession of events (based on a succession of stratigraphical units), a preceding depositional episode took place according to the Fasterholt Bjerge (1970) and Lavsbjerg Øst (1975) boreholes. In the former the argillaceous sequence ("C Member") (66-74 m.b.s.l.) is found and supposed to be marine due to its content of dinoflagellate cysts (Koch 1979). This has been substantiated by Piasecki (personal communication). In the latter borehole an argillaceous sequence occurs at a similar elevation (66-76 m. b.s.l.). This sequence together with



Text-Fig. 49. Stratigraphical correlation of the Fasterholt section (represented as a simplified version from the Carl Nielsen Ltd. browncoal pit with the overlying marine sequence from Fasterholt Bjerg compared with the Klynholt section (from a generalized summary of outcrops, probes and browncoal prospecting drillings). E.F.C. & E.K. comp.

overlying arenaceous deposits were inferred as marine based on sedimentological criteria and sharks teeth (Friis et al. 1980). So, a marine transgression is indicated at its climax (clay deposition) under shallow, marine conditions (dinoflagellate cysts – Piasecki pers. comm.) (Friis et al. 1980). This transgression was followed by the filling up with psammitic deposits, and later by a delta prograding over the region in question and introducing coarser psammitic deposits. The sequence ends with non-deposition (ref. the 1st episode mentioned above).

The Hodde- and Gram Formations overlying the browncoal bearing sequence are, at the moment, the most important stratigraphical markers available in the region (ref. page 95, 97). The Hodde Clay is enclosed within the Reinbekian Stage (Upper Middle Miocene) (Rasmussen 1966, 1970, 1979, Piasecki, 1980, the latter study based upon samples from the Søby-Fasterholt area). The Gram Clay in the overlying Gram Formation is generally referred to the Upper Miocene (Gramian Stage) (Rasmussen 1966). Based on fossils from Lavsbjerg Hill the *Astarte reimersi-Goodalia esbjergensis* Assemblage-zone (lower Gramian) was recorded in the Søby Fasterholt area (Rasmussen 1979). These marine deposits are generally younger than the Fasterholt Member.

The succession of the Hodde and Gram Formations in the Lavsbjerg Hill area fits exactly with the standard description of Rasmussen 1966 (pag. 10-11).

Experimental radiometrical dating of the Glauconite clay of the Gram Formation has been undertaken by Dr. Ole Larsen (personal comm. 1979) on samples from Lavsbjerg (8.8 ± 1.1 m.y.) and from the Damgaard N browncoal pit (10.0 ± 0.5 m.y. and 13.2 ± 0.5 m.y.). Because the glauconite material was not ideal for dating the values are not exact but can be taken as estimations which are reliable with a 2-3 m.y margin (see page 98).

The Browncoal Bearing Sequence approximately 15-22 m thick, represents a considerably thicker original succession of unconsolidated sediment, especially because of the large amount of water contained in original peat, browncoal ooze and clay. The above cited thickness could be enlarged to about 30-40 metres of original sediment. So we must calculate with a minimum subsidence factor of 35-45 metres in the local area in question. Due to the marginal location of the Søby-Fasterholt area within the structure of the North Sea basin this thickness must reflect a considerably larger correlated subsidence of the central part of the basin. Hence, the browncoal bearing sequence must be supposed stratigraphically correlative with one of the general transgressions of the history of the Neogene North Sea basin (initial or final stage). This must be an important provision for the present stratigraphical correlation analysis.

In comparing our descriptive information with the stratigraphical diagram of Rasmussen (1961 and 1966) under these provisions, we will find the following theoretical possibilities for correlation of the Browncoal Bearing Sequence:

1) with the transgression of the Reinbekian/Upper Middle Miocene (Hodde Formation)
2) with the transgression of the Hemmoorian/Middle Miocene (Arnum Formation)
3) with theoretical discontinuities of either of the two transgressions mentioned under (1) and (2).

4.B.7.1. The Browncoal Bearing Sequence.

The occurrence of overlying marine formations determines the stratigraphical upper limit of the Browncoal Bearing Sequence. The directly overlying deposit i.e. the marine Hodde Formation, is separated from the brown coal bearing sequence by a paraconformity (or an indistinct disconformity) representing a very short lacuna (locally near to a gradual transition). The Hodde Formation is chrono-stratigraphically enclosed within the Reinbekian Stage (Rasmussen, 1966).

Comparing the stratigraphical model proposed by Rasmussen (1961, 1966) and the relatively peripheral location of the Søby-Fasterholt area in the area of distribution of the Hodde Clay infers that the transgression which covered the Browncoal Bearing Sequence (subsidence of the basin) had expanded eastwards some geologic time before it reached this peripheral area and here started deposition of the local Hodde Clay sequence. Hence, the overlying Hodde Clay determine a theoretical upper stratigraphical (age) limit for the Browncoal Bearing Sequence somewhere within the range of the Reinbekian Stage. There are no known discontinuities within the Reinbekian transgression allowing for an alternative depositional period ending in a situation of non-deposition (a "regressive" episode). A detailed history of this kind is known for the Hemmoorian of Slesvig-Holstein (Hinsch, 1973, a, b, ref. Text-Figs. 16-19). Concerning the Hodde Clay-transgression discontinuities were as an open theoretical possibility, foreseen in the symbolism for facies boundaries in the diagram of Rasmussen (1961, 1966).

The main tool for determination of the stratigraphical correlation and determination of the geological age is the fossils of the Browncoal Bearing Sequence. The deposits of the 3rd and 4th rhythmical units contain a number of fossil floras, which have been investigated: The *Fasterholt (diaspore) Flora,* the *Damgaard Flora* and the *Søby Flora*. The large collections of the *Fasterholt Flora* were obtained from the basal delta bed of the 3rd rhythmic unit (bed 3+4). A leaf flora was collected from the overlying silty clay bed (no. 5) (not yet described).

The *Damgaard Flora* has been found in the uppermost "Upper Sands" (equivalent to the 4th rhythmical unit) of the Damgaard S pit just below the Hodde Clay.

The *Søby Flora* occurs in the uppermost clay-bed of a lacustrine sequence of the 4th rhythm at a stratigraphical level comparable to the *Damgaard Flora* and also just below the Hodde Clay.

Besides, an undescribed leaf flora was collected in the brown coal pit of Hoffmann & Sønner, Kølkær in a claybed below what is the 2nd browncoal seam of the three main seams.

The brown coal seams contain a rich fossil microflora of well preserved gymnospermous and angiospermous pollen, and less abundant, fossil cryptogamic spores.

Hence, the stratigraphical analysis of the Browncoal Bearing Sequence must at this moment treat the following problems:

1) The stratigraphical information of the *Fasterholt Flora*
2) The stratigraphical information of the *Damgaard Flora*
3) The stratigraphical information of the *Søby Flora*
4) The stratigraphical information from pollen analysis of the browncoal seams.

4.B.7.2. The Fasterholt Flora.

4.B.7.2.1.

The Fasterholt Flora predominantly consists of fossil diaspores (cones, fruits, seeds) and twigs. It has been collected in the Carl Nielsen Ltd. browncoal pit at Fasterholt during the years 1968-1970. The fossils occurred in the fluviatile sands between the 2nd and 3rd browncoal seams (bed no. 3+4). These sands occur locally in a single cross-bedded wedge-shaped sand bed some hundred metres wide. This bed represents a small, local and sporadical (short lived) occurring delta of only one single bed spreading from east towards west as indicated by the cross bedding. The fossils occurred at a 50-100 metres interval in the mining fronts, representing east-west sections through the Browncoal Bearing Sequence. These fossiliferous intervals of the small delta (sand bed no. 3+4) make up a SE-NW trending zone that was seen to cross in the eastern half of the mining trench during the field work (1968-70).

The delicate incoaled fossils were difficult to handle during collecting, the organic matter (Huminite) being in a colloid gel state. Hence, they were the best collected by sieving away the sand portion in the slowly flowing water of the drainage ditches. Afterwards they were stored in tightly closed water-filled buckets and sent to the laboratory for preparation and fixation (the procedure described in Koch & Friedrich 1971). Different procedures were used for sieving out the larger (>2 mm) and the smaller fossil seeds and fruits (<2 mm) respectively. The former were collected in normal sedimentological sieves except for bulk collecting where the sieves consisted of wooden boxes with a bottom of a similar meshwork were used.

The smaller fraction was collected by flotation in pans or buckets, a procedure introduced by dr. F. Holý, Praha, during his visit as a guest lecturer in Geological Institute, Aarhus University in 1970. During the field work season of 1968-1970, 70 buckets (2.5 litre) of fossils were collected from the mining fronts A-D-E-F- and H and passed through a fixation process with Canadabalsam after dehydration.

The larger fraction of fossil seeds and fruits has been studied by B. Eske Koch and W.L. Friedrich and is still under consideration (see the list of literature). The smaller fraction was studied by E.M. Friis (lit.cit.).

Detailed information on the *Fasterholt Flora* has been published by Friedrich & Koch (1970, 1972); Friis (1974, 1975, 1976, 1977 a,b, c, 1979, 1985); Koch (1973, 1975, 1977 a, b, 1979, 1984); Koch & Christensen (1979); Koch & Friedrich (1971, 1972); Koch, Friedrich, Christensen & Friis (1973).

The plant megafossils of the *Fasterholt-Flora* obtained from the C. Nielsen Ltd. browncoal pit, represent the most diverse fossil assemblage in the Fasterholt area. The flora comprises more than 150 species of three-dimensionally preserved reproductive and vegetative organs including fruits, seeds, anthers and twigs of angiosperms, cones seeds and twigs of conifers, fern sporangia, megaspores of water ferns, and spore-bearing organs of fungi.

The following systematical list of the genera and species of the *Fasterholt (diaspore) Flora* has been compiled by B. Eske Koch exclusively from information in Friis (1985) (the microfraction of seeds and fruits), Koch (1984), Koch & Friedrich (1971) and unpublished determinations by Koch (the megafraction).

4.B.7.2.2. Fasterholt Flora:

List of identified species:

PTERIDOPHYTA.
- *Lycopsida.*
  - *Selaginella pliocenica* Dorofeev
- Pteropsida.
  - *Salvinia cerebrata* Nikitin ex Dorofeev
  - *Salivinia* sp.
  - *Azolla nikitinii* Dorofeev
  - *Azolla ventricosa* Nikitin
  - *Azolla tuganensis* Dorofeev

GYMNOSPERMAE
- Coniferopsida.
  - *Abietaceae:*
  - *Pinus* sp.
  - Taxodiaceae:
  - *Sequoia couttsiae* Heer

Sequoia langsdorfii (Brongniart) Heer
Taxodium dubium (Sternberg) Heer
Glyptostrobus europaeus (Brongniart) Heer
Cupressaceae:
Hellia salicornioides Unger
Tetraclinis wandae Zablocki

DICOTYLEDONES.
Magnoliaceae:
Magnolia lignita (Unger) Mai
Liriodendron sp.
Saururaceae:
Saururus bilobatus (Nikitin ex. Dorofeev) Mai
Cambombaceae:
Brasenia cf. *tenuicostata* Nikitin
Nymphaeaceae:
Nuphar sp.
Nymphaea sp. 1 and 2
Hamamelidaceae:
Liquidambar sp.
Liquidambar aff. *magniloculata* Czeczott & Skirgiello
Plantanaceae:
Plantanus neptuni (Ettingshausen) Buzek, Holy & Kvacek
Ulmaceae:
Planera sp.
Fagaceae:
Quercus sp.
Betulaceae:
Alnus sp.
Tubela cf. *baltica* (Dorofeev) Dorofeev
Myricaceae:
Comptonia srodoniowae Friis
Myrica kirchheimeri Friis
Myrica stoppii Kirchheimer
Myrica wiesaensis Kirchheimer
Myrica sp.
Juglandaceae:
Cyclocarya crassa (Dorofeev) Dorofeev
Cyclocarya nucifera (Ludwig) Mai
Pterocarya limburgensis C & E.M. Reid
Polygonaceae:
Rumex sp.
Theaceae:
Eurya stigmosa (Ludwig) Mai
Hypericaceae:
Hypericum danicum Friis
Hypericum holyi Friis
Flacourtiaceae:
Poliothyrsis eurorimosa Mai
Clethraceae:
Clethra cimbrica Friis
Ericaceae:
Lyonia danica Friis
Zenobia fasterholtensis Friis
Eubotrys sp.
?*Enkianthus* sp.
Epacridicarpum chandlerae Friis
Arctostaphyloides globula (Menzel) Kirchheimer
Arctostaphyloides menzelli Kirchheimer
Symplocaceae:
Symplocos cf. *durenensis* Mai
Symplocos gothani Kirchheimer
Symplocos lignitarum (Quenst.) Kirchheimer
Symplocos minutula (Sternberg) Kirchheimer
Symplocos salzhausenensis (Ludwig) Kirchheimer
Symplocos schereri Kirchheimer
?*Sphenotheca incurva* Kirchheimer
Primulaceae:
Lysimachia sp.
Rosaceae:
Prunus cf. *langsdorfii* Kirchheimer
Prunus cf. *spinosa* Linné
Potentilla pliocenica E.M. Reid
Potentilla sp.
Rubus sp. 1 and 2.
Pyracantha acuticarpa (C. & E.M. Reid) Szafer
Droseraceae:
Aldrovanda praevesciculosa Kirchheimer
Lythraceae:
Decodon gibbosus (E.M. Reid) E.M. Reid
Decodon vectensis Chandler
Decodon sp.
Microdiptera parva Chandler
Microdiptera sp.
Mneme menzelii (E.M. Reid) Eyde
Onagraceae:
Ludwigia corneri Friis
Ludwigia collinsoniae Friis
Myrtaceae:
Myrtus palaeocommunis Friies
Trapaceae:
Trapa sp.
Cornaceae:
Swida gorbunovii (Dorofeev) Negru
Swida sp.
Nyssaceae:
Nyssa disseminata (Ludwig) Kirchheimer
Nyssa ornithobroma Unger
Mastixiaceae:
Eomastixia menzelii Kirchheimer
Mastixia menzelii Kirchheimer
Araliaceae:
Aralia pusilla Dorofeev
Aquifoliaceae:
Ilex saxonica Mai
Rhamnaceae:
Paliurus sp. aff. *spina-Christi Miller*
Paliurus sp.
Vitaceae:
Tetrastigma chandleri Kirchheimer
Vitis globosa Mai
Vitis parasilvestris Kirchheimer

Vitis teutonica A. Braun
Caprifoliaceae:
Weigela srodoniowae Friis
Rubliaceae:
Cephalanthus pusillus Friis
Lamiaceae:
Teucrium sp.

MONOCOTYLEDONES.
Alismataceae:
Caldesia sp. 1 and 2
Hydrocharitaceae:
Stratiotes kaltennordheimensis (Zenker) Keilhack
Potamogetonaceae:
Potamogeton heinkei Mai
Potamogeton sp.
Najadaceae:
Najas sp.
Juncaceae:
Juncus sp.
Zingiberaceae:
Spirematospermum wetzleri (Heer) Chandler
Cyperaceae:
Scirpus ragozinii Dorofeev
Dulichium marginatum (C. & E.M. Reid) Dorofeev
Cyperus sp.
Cladium reidiorum Nikitin ex Dorofeev
Cladium bicorne (Saporta) Friis
Cladium sp.
Carex sp. 1 and 2
?Eriophorum sp. 1 and 2
Caricoidea jugata (Nikitin ex Dorofeev Mai
Cladiocarya europaea Mai
Cladiocarya trebovensis (Buzek) Mai
Araceae:
Pistia sibirica Dorofeev
?Epipremnum crassum C. & E.M. Reid
Lemnaceae:
Lemna sp.
Typhaceae:
Typha sp. 1, 2 and 3.
Sparganiaceae:
Sparganium pusilliodea Mai
Sparganium multiloculare E.M. Reid & Chandler
Sparganium cf. *simplex* Huds.
Sparganium ramosum

INCERTAE SEDIS
Aracispermum canaliculatum Nikitin ex Dorofeev
Carpolithes natans Nikitin ex Dorofeev
Carpolithes dorofeevii Friis
Carpolithes nikitini Friis
Carpolithes tiffneyi Friis
Rhamnospermum bilobatum Chandler
Spondiaecarpum turbinatum Menzel

The fossils described by Friis (1985), and included in the present floral list are based on investigation of more than 14.000 specimens, most of which are angiosperms. About one third of the taxa were referred to fossil species previously described from other Tertiary floras of Europe. The remaining fossils could not be accommodated in any known species, either due to inadequate material or because they had not previously been described. The fossil fruits and seeds of *Rubus, Alismataceae, Carex* and *Typha* may be identical to material described from other fossil floras. However, difficulties in distinguishing between modern species in each of these genera on the basis of fruit and seed characters have prevented an exact determination of these taxa. Fruits and seeds of *Clethra, Lyonia, Zenobia, Eubotrys, Myrtus,* and *Pistia* have for the first time been described from the fossil floras of Europe, and 15 new species have been established:

Myrica kirchheimeri,
Hypericum danicum,
H. holyi,
Clethra cimbrica,
Lyonia danica,
Zenobia fasterholtensis,
Epacridicarpum chandlerae,
Ludwigia corneri,
L. collinsoniae,
Myrtus palaeocommunis,
Weigela srodoniowae,
Cephalanthus pusillus,
Carpolithes dorofeevii,
C. nikitinii,
C. tiffneyi.

The most abundant fossils are fruits of *Epacridicarpum chandlerae* which constitute more than 20 per cent of the smaller angiosperm fossils from the Fasterholt Flora. Various species of *Myrica* make up about 20 per cent of the specimens, and the Rosaceae, primarily represented by *Pyracantha acuticarpa,* constitute 14 per cent of the fossils. *Betulaceae* and *Cyperaceae* each contributes about nine per cent of the angiosperm specimens. Each of the remaining taxa makes up less than three per cent of the fossils.

4.B.7.2.3. General Analytical Information of the Fasterholt Flora based on genera

The following factors are discussed concerning 76 genera of the Fasterholt Flora included in table 11:

1) Frequency of individuals,
2) Kinds of Organs in question,
3) Phytogeography (Arcto-Tertiary and Paleotropical elements), and

4) Ecology (habitats),
5) Climate, and
6) Growth Habitat of the closest recent relatives.

1) Frequency: About half the genera (53%) are rare i.e. represented by few or single specimens (less than 10). 30% are common species (10-1000 specimens) and 17% are dominants (bulk occurrence).

The frequency of the fossils is determined by an interaction of processes: Frequency of the plant (in the depositional environment or along a natural road of transport), distance from the deposition site and/ or the agent of transport, resistance against disintegration (chemical, biological, physical), and the natural equipment for facilitating dissemination of seeds and fruits.

2) Plant organs found: The bulk of the Fasterholt Flora (92%) is carpological material (seeds and fruits, cones and infloresenses). Other lignified organs such as twigs, some with small leaves (e.g. conifers) or thorns occur. Leaves are in general not available in the Fasterholt Flora, the vegetative thallus of Azolla (Water Fern) is the only example.

3) Phytogeography: The ratio between the Paleotropical elements (33%) to the Arcto-Tertiary elements (66%) is useful for the history of the vegetation and has especially been utilized by Mai (1965, 1967) et al.) in defining the floral zones and climatic evolution through the Oligo-Miocene. In the present paper the P:A ratio has been used in the stratigraphical synthesis (page 263). Koch & Christensen (1979) determined the ratio P:A as 36:64 based on a smaller number of genera. Friis (1985) determined the ratio P:A = 39:61.

4) Ecology: The vegetational habitats are important as a support to the geological interpretation of the depositional environment. This factor also influences the frequency factor of the fossil species. The percentage of ecological habitats of the Fasterholt Flora are (see table 12, pag. 113):

Aquatic plants: 19%; Wetland plants: 41%; Dryland plants: 40%.

5) Climate: This factor is based upon comparison with the closest recent relatives to the fossil species. The ratios of the Fasterholt Flora area:

Species with tropical affinity 21.5%
Species with subtropical affinity 42%
Species with temperate affinity 36.5%

Friis (1985) has estimated the ratio of exclusively tropical/subtropical species of the Fasterholt Flora to 10-17% and reports on the climatic implications.

6) Growth Habitats: About half of the fossil diaspores of the Fasterholt Flora are derived from trees and shrubs, the other half from herbs and small pseudoshrubs.

The following numerical information can be extracted from the table 11:

The Arcto-Tertiary genera generally dominate over the Paleotropical genera (calculated for the total number and 3 frequency-groups):

	Number	Percent	Domin.	Interm.	Rare
Arcto-Tertiary	38	66.6%	82.5%	73%	73%
Paleotropical	19	33.3%	17.5%	27%	27%

Frequency of the climatic groupings (of the 3 frequency-groups):

	Dominants	Intermediate	Rare
Tropical genera:	4 (10%)	14 (35.5%)	20.5 (54.5%)
Subtropical genera:	10 (17%)	21 (35.5%)	28.5 (47,5%)
Temperate genera:	9 (20%)	16.5 (30.5%)	26.5 (49.5%)

4.B.7.2.4. Environmental Indications of the Fasterholt Flora

A list of the species of the Fasterholt Flora derived from the combined studies of the larger and the smaller sieve-fractions (the latter from Friis, 1975) indicates about 150 species.

About 75% of these species after comparison with modern relatives on species or genus level can be referred to one of three general types of habitat: dryland-, wetland- and aquatic habitat.

The remaining fossil species belong to modern genera with species occupying a variety of habitats, covering more than one of the above mentioned general habitats. Hence, they generally are omitted in this study.

The genera of the Fasterholt Flora are listed in *table 11* and the species in *table 12* according to these generalized habitats.

We find 32 (37.5%) species in dryland habitats, 38 (45%) species under wetland habitats and 15 (17.5%) species with aquatic habitat. Hence by number the aquatic-wetland species are in majority in relation to species of dryland habitats (about information concerning analysis on genus-level, see chapter 4.B.7.2.3.).

If we investigate the type of habitats in regard to the frequency of a species, the wetland habitat includes 28 of the dominant and common species; the dryland habitat 22 species. This small number of species is not conclusive, but high ratio of dryland species may indicate a considerable input from long distance transported plant remains into the sand facies like what is shown for the *Søby Flora* (table 19) by Christensen (1978).

Among the wetland plants with high frequency in the Fasterholt Flora is *Taxodium dubium,* probably a near relative of the extant *Taxodium distichum,* which can temporarily survive in open water habitats up to 2 metres in depth. *Taxodium distichum,* like the fossil species, has relatively few seeds in a cone; the cones disintegrates upon maturing. The pèltate cone scales

TABLE 11 (+ = extinct genera)	Fasterholt Flora									Closest extant relatives							
	Frequency																
	dominant	common	rare	Diaspores	Cones/Infructescences	Twigs/Thorns	Leaves	Paleotropical	Arcto-Tertiary	Aquatic species	Wet-land species	Dry-land species	Tropical	Subtropical	Temperate	Trees/Shrubs	Herbs/Shrublets
Sphenopsida																	
Equisetum			—			—					—		—	—	—		—
Pteridophyta																	
Azolla		—		—			—	—		—			—	—			—
Salvinia		—		—				—		—			—	—			—
Gymnospermae																	
Glyptostrobus	—			—	—	—			—		—			—	—	—	
Pinus		—		—	—				—			—		—	—	—	
Sequoia	—			—	—	—			—			—		—	—	—	
Taxodium	—			—	—	—			—		—	—		—	—	—	
Tetraclinis			—		—							—		—		—	
Angiospermae																	
Dicotyledones																	
Aldrovanda			—	—				—		—			—	—			—
Aralia			—	—					—			—			—	—	
Brasenia		—		—				—		—			—	—			—
Cephalanthus			—	—					—		—		—	—		—	
Clethra			—	—							—	—	—	—	—	—	
Comptonia			—	—					—		—	—		—	—	—	
Cyclocarya+	—			—					—								
Decodon		—		—					—		—			—	—		—
Eomastixia+			—	—				—									
Epacridicarpum	—			—				—									
Eurya			—	—				—					—	—		—	
Hypericum		—		—							—	—	—	—	—	—	—
Ilex			—	—				—				—	—	—	—	—	
Liquidambar	—			—	—				—			—		—	—	—	
Liriodendron		—		—					—			—		—	—	—	
Ludwigia		—		—						—	—		—	—	—	—	—
Lyonia			—	—	—				—		—			—	—	—	—
Lysimachia			—	—					—		—	—		—	—		—
Magnolia		—		—								—		—	—	—	
Mastixia			—	—				—			—	—	—	—		—	
Microdiptera+			—	—				—									
Mneme+			—	—					—								
Myrica	—			—							—	—	—	—	—	—	
Myrtus		—		—								—		—	—	—	
Nuphar			—	—					—	—				—	—		—
Nymphaea			—	—						—			—	—	—		—
Nyssa	—			—					—		—	—	—	—	—	—	
Paliurus	—			—		—			—			—		—		—	
Planera			—	—					—		—			—	—	—	
Platanus		—		—	—				—			—		—	—	—	
Poliothyrsis			—	—					—			—		—	—	—	

TABLE 11 (continued) (+ = extinct genera)	Fasterholt Flora									Closest extant relatives							
	Frequency																
	dominant	common	rare	Diaspores	Cones/Infructescences	Twigs/Thorns	Leaves	Paleotropical	Arcto-Tertiary	Aquatic species	Wet-land species	Dry-land species	Tropical	Subtropical	Temperate	Trees/Shrubs	Herbs/Shrublets
Potentilla			—	—					—		—	—			—		—
Prunus			—	—					—			—		—	—	—	
Pterocarya	—			—					—		—	—		—	—	—	
Pyracantha	—			—					—			—		—	—	—	
Quercus			—		—				—			—		—	—	—	
Rubus		—		—					—		—	—	—	—	—	—	
Rumex			—	—					—					—	—		—
Saururus			—	—					—		—			—	—		—
Sphenotheca+			—	—				—									
Spondiaecarpum+		—		—	—			—									
Swida		—		—					—		—	—		—	—	—	
Symplocos		—		—				—				—	—	—		—	
Tetrastigma+			—	—				—									
Teucrium			—	—							—				—		—
Tubela+ (Alnus)	—			—	—				—		—	—		—	—	—	
Vitis		—		—		—			—			—	—	—	—	—	
Weigela			—	—					—		—	—		—	—	—	
Zenobia			—	—					—		—				—	—	—
Monocotyledones																	
Aracispermum+			—	—				—									
Caldesia			—	—				—		—	—		—	—			—
Carex			—	—							—		—	—	—		—
Cladium			—	—				—			—		—	—	—		—
Cyperus		—		—							—		—	—	—		—
Dulichium			—	—					—	—	—			—	—		—
Epipremnum			—	—				—			—		—	—			—
Juncus			—	—						—	—			—	—		—
Lemna			—	—						—			—	—	—		—
Najas			—	—						—			—	—	—		—
Pistia		—		—						—			—				—
Potamogeton			—	—					—	—			—	—	—		—
Scirpus		—		—							—		—	—	—		—
Sparganium		—		—					—		—		—	—	—		—
Spiramatospermum+	—			—	—			—									
Stratiotes		—		—					—	—				—	—		—
Typha		—		—							—		—	—	—		—
%	17	30	53	79	13	6>	1	33>	66>	19	41>	39>	21>	42	36>	52>	47>
Number of genera (n=76)	13	23	40	73	12	6	1	19	38	15	32>	31	30>	59>	52	36>	33
	76			92				57		78>			142			69>	

Table 11. Analytical information concerning the genera occurring in the Fasterholt Flora and the biology of the closest recent relatives. E.K. comp. 1986 (Koch et al. 1973)

dehiscing from the axis to liberate the seeds is a factor strongly working against frequent fossil representation of the cones.

In the Fasterholt Flora only juvenile cones are found. The relatively common occurrence of these cones and the immense quantity of well preserved seeds and cone scales of *Taxodium dubium* indicates a habitat near to the site of deposition and a high frequency of individuals (in relation to e.g. *Sequoia langsdorfii*, ref. cit.). In a similar manner the common and well preserved cones of *Glyptostrobus* points to a biotope near the site of deposition and the species as playing an important role in the wetland-aquatic environment. Another example of a swamp dweller represented by single specimens is the fruit of *Planera* sp. (Ulmaceae). The modern representatives of *Planera* grow in open water associated with species of *Nyssa* in southeastern USA (*Nyssa* species are dominant in the Fasterholt Flora) and may be very rare (scattered occurrence).

These fossil species are in accordance with the facies interpretation of the brown coal beds they are found in. The existence of wetland environments occurred several times during the deposition of the browncoal bearing sequence.

The many well known aquatic plants of the floral list are strong arguments for the existence of open waters but it is not possible using their individual frequencies (no dominants!) to indicate whether they lived near to the site of deposition. Their growth habit gives a high chance for transport away from the habitat and their seeds and fruits are adapted to easy dispersal by water.

The dryland floral element may indicate the existence also of well-drained or temporarily dry habitats. This type of habitat is found in large modern deltas (e.g. Mississippi), but long distance transport is also a plausible reason for the high frequency and representation.

Clear indications of long distance transport occur. One of the dominant species of the dryland habitats is *Paliurus* sp. aff. *spina-christi* (det. Koch). The vast majority of the thousands of specimens in the Fasterholt Flora collection are heavily worn, rolled into ideal spheres from the original half-spherical, winged shape adapting them to wind-dispersal. They must have undergone a long transport, especially because they contain 3-4 loculi that, when air-filled, must have kept them floating for a time during river transport.

To the contrary the wetland species *Pterocarya limburgensis* (with river-bank habitat) has delicately ribbed fruits which are generally well preserved in the fossiliferous bed. The angular seeds of *Taxodium* are, as mentioned above, intact also presumably being local habitants.

Among the dryland species listed above is also *Sequoia langsdorfii.* The seeds of this species are dominant in the collections from Fasterholt, but these are usually produced in vast quantities, many in each cone. Hence, there are natural conditions favouring a high frequency of these fossil seeds. The cones are resistant and they occur with about the same frequency as the weak, juvenile cones of *Taxodium dubium* (ref. above). The relative low frequency for the *Sequoia* cones must indicate a markedly lower frequency of individuals of the species on possible scattered local habitats in the vicinity of the depositional environment, or a long distance between habitat and depositional site. In general it appears to indicate a dryland ecological habitat like the extant relative *Sequoia sempervirens*.

The relatively rare occurrence of fossil leafy twigs underlines this conclusion, like the rare occurrence of stump horizons of *Sequoia* sp. aff. *sempervirens* in connection with paraconformities of the upper and lower boundaries on the browncoal bearing sequence, and with supplementary indication of low ground-water level.

This means that the fossil *Taxodium* and *Sequoia* species of the Søby-Fasterholt region represent opposite ecological requirements regarding environments (in a region of relatively high precipitation).

A few fossil species or genera of *Table 12* have been recorded in two or more different habitats due to comparison with the recent relatives showing this tolerance. A few of them have been admitted to the species/habitats list in question, because of their importance (dominants) in the fossil flora. Among them is *Nyssa* with two fossil species in our floral lists. The "stone" of the Nyssa-fruits have been sieved out in the thousands and are under paleontological analysis. The "stones" are of a varying preservation ranging from heavily worn specimens devoid of their ribs to well-preserved specimens with the ribs and even the stylar base remaining. They may indicate local as well as a more remote origin. These fruits are loculate and have been buoyant for a while during water transport. A morphological variation of species because of gradual transitions may indicate more natural species than indicated in the floral lists.

A preliminary analysis of the small sieve fraction seeds and fruits is presented by Friis, 1975 (chapter: Vegetational analysis, pp. 181-182).

The information which can be obtained from the Fasterholt Flora regarding the vegetational environment agrees in general with the conclusions based upon the geological and brown coal petrographical observations pointing to a deltaic environment. In this landscape, the erosional base level and (the combined factor) groundwater level, is near to the surface and reflecting local as well as regional changes. Hence, deposition and erosion easily changed, allowing for the characteristical variability in textures and structures with many diastematic breaks and many unconformities and lacuna seen in the sedimentary record. This also permits a variety of ecological environments and plant associations from aquatic to xeric all within an area of low topography. Xeric environments were often promoted by common occurrences of raw soils.

Table 12. Species of the Fasterholt Flora arranged according to their assumed habitats. E.K. comp. (Koch & Christensen, 1979).

Symbols: d: dominant c: common r: rare

Wetland species:

Equisetum	r	*Nyssa disseminata*	r
Glyptostrobus europaeus	c	*Pterocarya limburgensis*	c
Taxodium dubium	d	*Planera* sp.	r
		Teucrium sp.	r
Cleathra sp.	c	(*Vitis* div. sp.)	
(*Comptonia srodoniowae*)	(c)		
Decodon gibbosa	c	*Carex* div. sp.	c
Decodon vectensis	r	*Caldesie proventita*	r
Hypericum div. sp.	c	*Claudium* div. sp.	r
Liquidambar magnilocu-lata	d	*Cyperus* sp.	c
Lyonia danica	c	*Dulichium marginatum*	r
Ludwigia div. sp.	c	*?Epipremnum* sp.	r
Lysimachia sp.	r	*Juncus* sp.	r
Myrica kirchheimeri	c	*Scirpus ragozinii*	c
Myrica stoppei	r	*Sparganium multiloculare*	r
Myrica wiesaensis	c	*Sparganium pusilloides*	c
Myrica sp.	d	*Sparganium* cfr. *simplex*	c
Nyssa ornithobroma	d	*Spirematospermum wetzleri*	d
		Typha sp.	c

Aquatic species:

		Lemna sp.	r
Azolla nikitini	c	*Nuphar* sp.	r
Azolla tuganensis	r	*Nymphaea sp.*	r
Azolla vectensis	c	*Trapa* sp.	r
Salvinia cerebrata	c	*Najas* sp.	r
Salvinia sp.	r	*Pistia sibirica*	c
		Potamogeton cfr. *heinkei*	r
Aldrovanda praevescicu-losa	r	*Stratiotes kaltennordhei-mensis*	c
Brasenia cf. *tenuicostata*	c		

Dryland species:

		Magnolia lignita	c
		(*Myrica* div. sp.)	(d-c-r)
Cupressoide cones	c	*Myrtus paleocommunis*	c
Hellia salicornioides	c	(*Nyssa* div. sp.)	(d)
Pinus sp.	r	*Paliurus* sp.	d
Sequoia langsdorfii, seeds	d	*Platanus neptuni*	c
Sequoia langsdorfii, cones	c	*Prunus* cfr. *spinosa*	c
Sequoia langsdorfii, twigs	r	*Prunus* cfr. *langsdorfii*	r
Tetraclinis wandae	r	*Pyracantha acuticarpa*	d
		Quercus sp.	r
Aralia pusilla	c	*Swida gorbunovii*	c
Comptonia srodoniowae	c	*Symplocos gothani/udwigi*	c
Eurya stigmosa	c	*Symplocos lignitarum*	r
Hypericum div. sp.	c	*Symplocos minutula*	r
Ilex saxonica	r	*Symplocos salzhausenensis*	c
(*Liquidambar* sp.)	(d)	*Symplocos scheereri*	r
Liriodendron sp.	c	*Vitis* div. sp.	c-r

4.B.7.3. Stratigraphical information of the Fasterholt Flora

4.B.7.3.1. General Information:

Friis (1985) presents an analysis of the 40 species in the Fasterholt Flora that has been recorded from European Late Tertiary fossil floras (ref. table 13). Of these species 38 occur in the Miocene, 20 in the Oligocene, 19 in the Pliocene, 9 in the Eocene and 1 in the Paleocene. Obviously the Miocene species are predominant in the Fasterholt Flora. Some genera studied from a systematical and evolutionary point of view include *Stratiotes* Linné surveyed by Holý and Bůžek (1966) (ref. Text-Fig. 50). *Stratiotes kaltennordheimensis* (Zenker) Keilhack found in the Fasterholt Flora ranges from the uppermost Oligocene to the end of the Miocene.

Table 13. Stratigraphical distribution of genera in the Fasterholt Flora (Friis, 1985, table 1).

Fossil species	Paleo-cene	Eo-cene	Oligo-cene	Mio-cene	Plio-cene
Eurya stigmosa	+	+	+	+	
Rhamnospermum bilobatum		+	+		
Decodon vectensis		+	+	+	
Microdiptera parva		+	+	+	
Cladiocarya trebovensis		+	+	+	
Glyptostrobus europaea		+	+	+	
Saururus bilobatus		+	+	+	+
Decodon gibbosus		+	+	+	+
Cladiocarya europaea		+	+	+	+
Platanus neptuni			+	+	+
Poliothyrsis eurorimosa			+	+	
Swida gorbunovii			+	+	
Sparganium pussiloides			+	+	
Sparganium multiloculare			+	+	
Hellia salicornioides			+	+	+
Taxodium dubium			+	+	+
Pyracantha acuticarpa			+	+	+
Dulichium marginatum			+	+	+
Caricoidea jugata			+	+	+
Carpolithes natans			+	+	+
Azolla ventricosa				+	
Azolla nikitinii				+	
Salvinia cerebrata				+	
Myrica wiesaensis				+	
Myrica stoppii				+	
Arctostaphyloides globula				+	
Ilex saxonica				+	
Scirpus ragozinii				+	
Cladium reidiorum				+	
Cladium bicorne				+	
Pistia sibirica				+	
Aracispermum canaliculatum				+	+
Arctostaphyloides menzelii				+	+
Halesia crassa				+	+
Aldrovanda praevesiculosa				+	+
Mneme menzelii				+	+
Sambucus pulchella				+	+
Potamogeton heinkei				+	+
?Epipremnum crassum				+	+
Actinidia sp.					+
Total 40 species	1	9	20	38	19

Some genera which Mai (1970) has studied systematically and stratigraphically are also represented by species in the Fasterholt Flora. *Mastixia menzelii* Kirchheimer, *Ilex saxonica* Mai and 6 (-7) species of *Symplocos* (ref. table 14) are exclusively Miocene, except *Symplocos lignitarum* (Quenstedt) Kirchheimer, which also occur through the Oligocene.

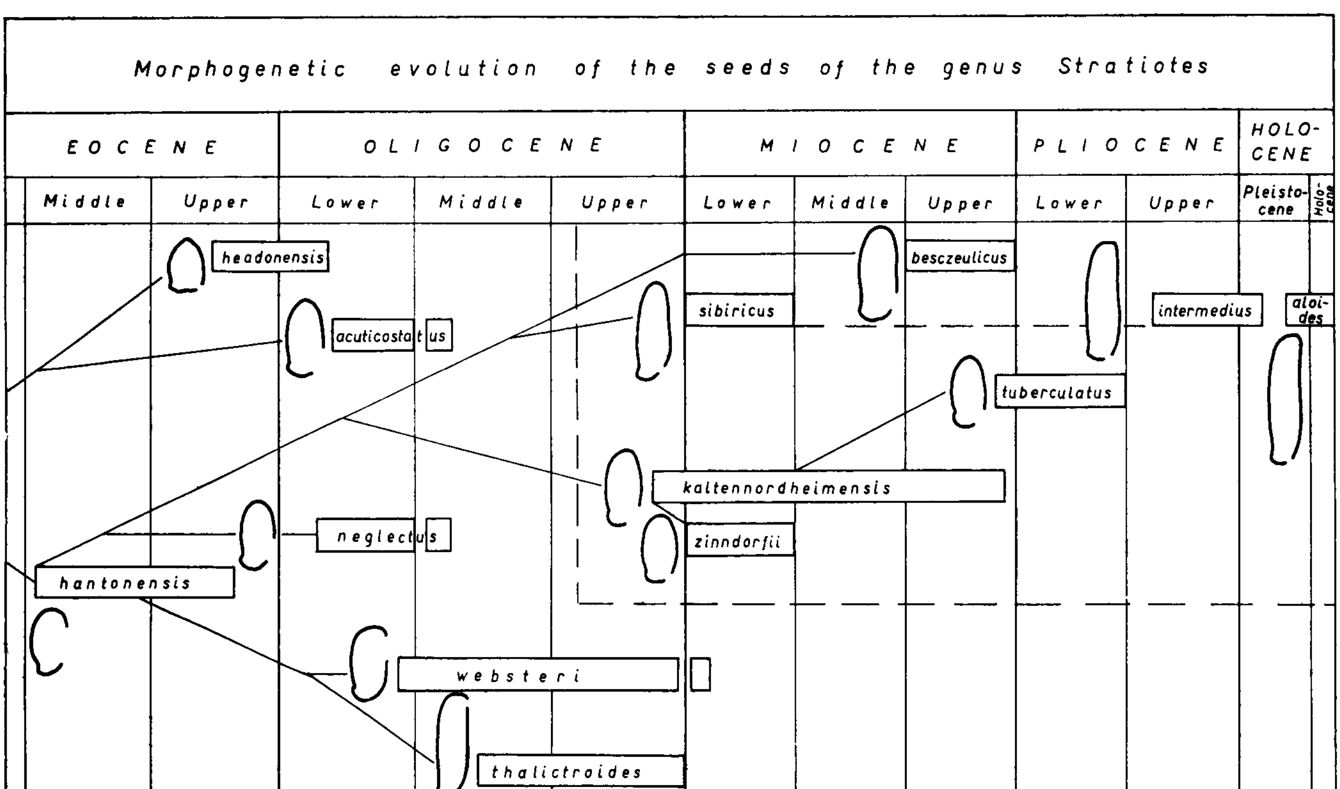
Among the extensive carpological material described by Friis 1985 from the Fasterholt Flora some species are exclusively Miocene: *Myrica wiesaensis* Kirchheimer, *Aldrovanda praevesciculosa* Kirchheimer (Miocene to the N. of the Alps) and *Ilex saxonica* Mai.

Hence, there are ample evidence for a Miocene age of the *Fasterholt Flora.*

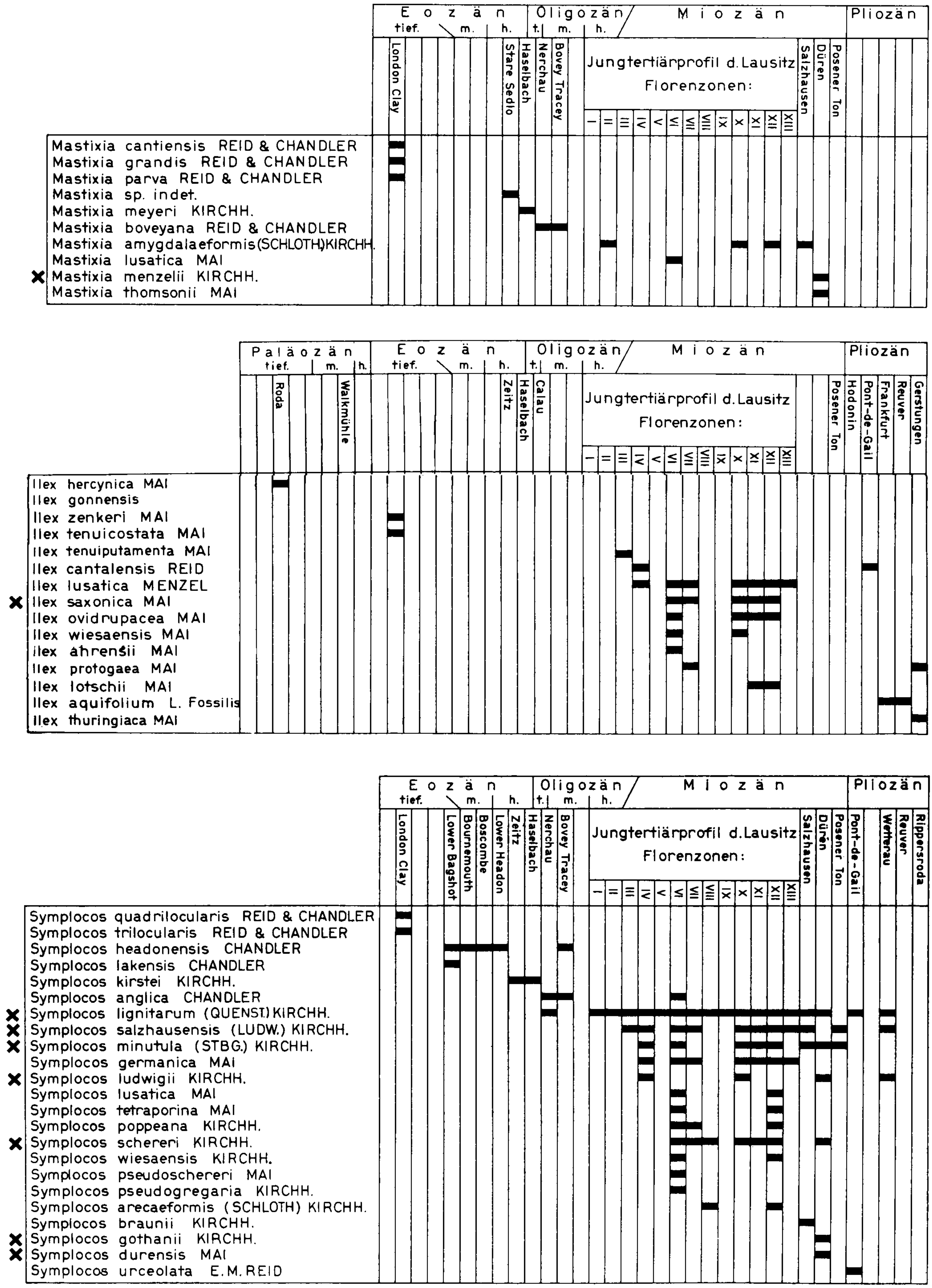
Many examples of Miocene flora and browncoal deposits in Northwestern Europe from South, South-west and South-east of Denmark have been described in the literature. Most of these were deposited in local basins (e.g. Ostheim of the Hessian basin; Wölfersheim in Vogelsberg, Rhein-Hessen; Wackersdorf browncoal sequence, Franken; all from West Germany (FRG)). Browncoal bearing and fossiliferous deposits from the Lower Rhenian province in northwestern Germany, and in East Germany (GDR) and Czechoslovakia (Lower and Upper Lausitzer sequences) are geographically widespread in considerably thick sequences. In the Lower Lausitz, East Germany (GDR), are large sections (profiles) with many fossiliferous localities (stratigraphical levels) and thick pollen-bearing continuous deposits well suited for stratigraphical study. In the GDR several authors have studied the megafossils (leaf flora: H. Jähnichen, H. Walther et al., carpological fossil floras: D.H. Mai) and the fossil pollen (W. Krutzsch). D.H. Mai and W. Krutzsch have undertaken extensive studies and established a paleobotanical, stratigraphical system. Hence, the interval Upper Oligocene-Upper Miocene has been divided into 13 floral zones. Unfortunately the political East-West situation has prevented fertile discussion of this system and its stabilization into a general practical stratigraphical tool for Central Europe.

In the Lower Rhenian area (North West Germany) a number of fossil flora have been described. These include studies of fossil leaf flora: The Fischbach Flora, Vereinigte Ville near Cologne (K. Kramer); the Kreuzau flora (D. Ferguson); the Pliocene fluviatile deposits of the browncoal quarry of Fortuna Garsdorf near Cologne also including fossil diaspores (J. van der Burgh) Carpological collections have been described from a multitude of localities (F. Kirchheimer, H. Weyland, K. Kilpper et al.). The stratigraphical synthesis of the Lower Rhenian area is mostly based on pollen-analytical criteria (G. von der Brelie, P.W. Thomson et al.) combined with geological studies (H. Hager, J. Gliese et al.) and facilitated by the mutually interfingering of non-marine browncoal bearing deposits and littoral-marine formations in the Lower Rhenian province at the Dutch-German border zone (ref. numerous studies by Anderson, Fabian, Zagwijn & Doppert).

The correlation between the Miocene of the Søby-



Text-Fig. 50. Morphogenetic chart after Holý & Bůček (1966).



✖ = Fasterholt-flora species

Table 14. Stratigraphical analysis of the genera Mastixia, Ilex and *Symplocos* (Mai, 1970).

Fasterholt area and the Lower Rhenian province was achieved by pollen stratigraphical study (Koch, 1984) (ref. also this paper Chapt. 7).

The stratigraphical correlation with the Miocene deposits of the southeastern vicinity (GDR) concentrated on the bio stratigraphical system of the Lower Lausitz region (Mai, 1967) consisting of the 13 zones.

Besides the basic floristical composition of the fossil flora on genus and species levels, vegetational and phytogeographical studies have been involved in the stratigraphical investigations of Mai et al., and consequently also in the stratigraphical study of the Fasterholt Flora (Koch et al. (1973), Friis, (1975 and 1985), Koch & Christensen (1979)). Hence, as a supplement to the ordinary stratigraphical qualitative study, analysis on 76 genera of the Fasterholt Flora based upon the information of frequency (qualities: dominant, common and rare); kind of fossil plant organs analyzed; phytogeographical elements in sensu Engler (1882) and Mai (1965); palecology; vegetational and climatological

Stratigraphical range of 44 Fasterholt Flora species in common with the localities of

Niederlausitz, GDR (13 zones according to MAI, 1967),

arranged in Paleotropical (22) and Arcto-Tertiary (22) species.

Frequency symbols:

Fasterholt Flora: D, dominant; C, common; R, rare
Niederlausitz,GDR: Wide bar (▬), common; medium bar (—), rare;
thin bar (---), problematic record

PALEOTROPICAL SPECIES		Niederlausitz-zones (I-XIII) I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Selaginella pliocenica	R	—	—	—	—	—	---		---		—			—
Salvinia cerebrata	C			—	—		—	—			—	—	—	—
Hellia salicornioides	C	—	—	—	—	—	—		—		—			—
Myrica stoppii	R						—							
Myrica wiesaensis	C				—		—		—		—	—		
Eurya stigmosa	R	—	—	---	—	—	—	—	—		—	—	—	---
Arctostapylloides globulus	R						—		—			—	—	
Symplocos gothani (incl. *ludwigi*), loc.:Düren	C				—						—	—	—	
Symplocos lignitarum	R	—	—	—	—		—	—	—	—	—	—	—	—
Symplocos minutula	R				—		—				—	—	—	
Symplocos salzhausenensis	C			—	—		—	—			—	—	—	—
Symplocos schereri	R						—	—	—		—	—	—	
Sphenotheca incurva	R						—		—		—	—	—	
Aldrovanda praevesiculosa	R				—		—		—			—		
Microdiptera parva	R		—	—	—		—				—			
Mastixia menzelii, loc.:Düren	R											—	—	
Ilex saxonica	R						—	—			—	—	—	
Tetrastigma chandleri	R						—				—	—	—	
Spirematospermum wetzleri	D	—	—	—	—		—	—	—		—		—	—
Cladium reidiorum	R				—				—		—			
Aracispermum canaliculatum	R				—		—	—				—	—	
Spondiaecarpum turbinatum	C		—	---	—					—			—	—
Number of Fasterholt Flora species in common with the single zones (13) of the Niederlausitz-biostratigraphy:														
P (Paleotropical) total:		5	7	7	15	3	17	8	10	2	16	15	15	7
Points: N1: D= 3, C= 2, R=1		8	11	10	23	4	23	12	14	3	23	19	21	13
N2: D= 30, C=10, R=1		43	54	63	98	12	82	55	57	11	90	51	80	72
N3: D=100, C=10, R=1		113	124	133	168	12	152	125	127	11	160	51	150	142

N1 - N3: Stratigraphical comparison of the 22 P-species of the table, involving the frequency in the Fasterholt Flora, expressed in points (experiments with 3 models of varying progression of points for D, C and R).

Table 15. Stratigraphical range of 44 Fasterholt Floraspecies that are known in localities (Zones) from Niederlausitz, GDR. They are arranged in Paleotropical- and Arcto-Tertiary groups, after Mai (1967) and the concepts of Engler, 1882. E.K. comp. (Koch et al. 1973).

analysis, has been carried out (in continuation of the preliminary information presented by Koch et al. 1973). This new and revised information is presented below. The percentual representation of the Arcto-Tertiary and Paleotropical elements of the Fasterholt Flora of Koch et al. (1973) and of the present analysis have been plotted on the diagram from Mai (1965) (Text-Fig. 51) showing, as a standard, the fluctuations of the corresponding values of the succession of fossil floras in the Lower Lausitz region. The resulting fits may be helpful as a supplement to the stratigraphical investigation.

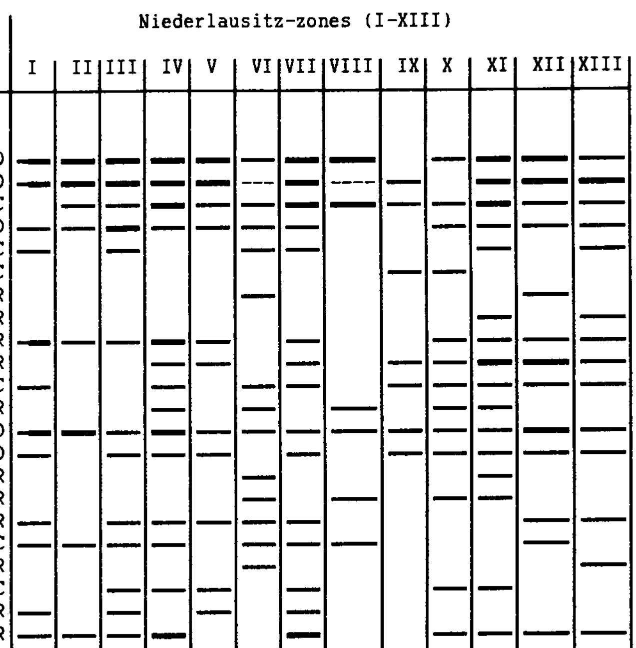
A group of 44 species of the Fasterholt Flora that are in common with the fossil floras of the Lower Lausitz region (Mai 1967), have been divided between two phytogeographical categories (Arcto-Tertiary and Paleotropical, Engler 1882, Mai, 1964, 1965, 1967, 1968, 1970) and compared with the stratigraphical information of Mai (1967) (Table 15).

Friis (1985), on the same basis and premises as Mai

Frequency symbols:

Fasterholt Flora: D, dominant; C, common; R, rare
Niederlausitz,GDR: Wide bar (▬), common; medium bar (—), rare;
thin bar (---), problematic record

ARCTO-TERTIARY SPECIES	
Sequoia langsdorfii	D
Taxodium dubium	D
Glyptostrobus europaeus	C
Liquidambar europaea	D
Cyclocarya nucifera	C
Pterocarya limburgensis	C
Prunus langsdorfii	R
Potentilla pliocenica	R
Decodon vectensis	R
Mneme menzelii	R
Swida gorbunovii	C
Nyssa disseminata	R
Nyssa ornithobroma	D
Paliurus thurmannii	D
Vitis globosa	R
Vitis parasilvestris	R
Vitis teutonica	R
Stratiotes kaltennordheimensis	C
Potamogeton heinkei	R
Scirpus ragozinii	C
Sparganium multiloculare	R
Carpolithus natans	R



Number of Fasterholt Flora species in common with the single zones (13) of the Niederlausitz-biostratigraphy:	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
AT (Arcto-Tertiary) total:	12	8	13	14	11	13	15	6	7	13	16	13	14
Points: n1: D= 3, C= 2, R=1	25	19	28	29	24	24	31	13	17	26	31	27	28
n2: D= 30, C=10, R=1	184	142	194	195	174	136	205	82	131	165	197	185	186
n3: D=100, C=10, R=1	534	422	544	545	524	346	555	222	331	445	547	535	536

n1 - n3: Stratigraphical comparison of the 22 AT-species of the table, involving the frequency in the Fasterholt Flora, expressed in points (experiments with 3 models of varying progression of points for D, C and R).

	Niederlausitz-zones (I-XIII)												
D : C : R	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
AT+P = 3-2-1	33	29	37	51	27	46	42	26	19	48	49	47	40
AT+P = 30-10-1	227	196	257	293	186	218	260	139	142	255	248	265	258
AT+P = 100-10-1	647	546	677	713	536	498	680	349	342	605	598	685	678
AT+P = 1-1-1	17	15	20	29	14	30	23	16	9	29	31	28	21

(1967), has presented a graphical representation of the extant phytogeographical elements of the carpological fossil floras of the Søby-Fasterholt area using the closest relatives. The analysis is based on the geographical distribution of the closest modern relatives to the fossil species. In the present work this compilation has been compared with the similar representation of Mai (1967). This is found in outline on Text-Fig. 52.

Finally the proportional representation of the components of the Arcto-Tertiary and Paleotropical elements at the genus and species level are presented in different graphs and analysed (tables 11 and 15).

4.B.7.3.2. Stratigraphical Analysis of the Fasterholt Flora founded on species level, in total and subdivided into Paleotropical- and Arcto-Tertiary elements (in sensu Engler 1882–Mai 1965, 1967) (Table 15)

A bio-stratigraphical analysis on species level normally includes a survey of the general stratigraphical range of the involved species. In the restricted region and narrow stratigraphical interval in question, the evolutionary changes are too discrete, even on a specific level, to give clear stratigraphical evidence. But it may be possible to correlate at least locally. Therefore, in table 15 the range of the Fasterholt Flora species are expressed in terms of the Oligo-Miocene zonation of the brown coal bearing sequence of Niederlaustitz, East Germany (GDR). The Paleotropical- and Arcto-Tertiary elements play an important role in characterizing these zones (I-XIII) and they are used to subdivide table 15, even at the quantitative analysis that has been made separately for these two elements and in total.

The main purpose of table 15 is to present a quantitative stratigraphical analysis, in two ways. First in the classical way, recording the number of Fasterholt Flora species occurring in each zone of the Lower Lausitz system, and in total; with equal weight given to all species. Information was obtained from the Paleotropical and Arcto-Tertiary species separately to get an idea of the influence of these elements on the sum counted, i.e. the points attained for the warmer (tropical-subtropical) zones and for the cooler (temperate-subtropical) zones which in different and uncontrolled ways may affect the stratigraphical conclusions of the countings. Secondly by a quantitative analysis (as an experiment) taking in account the differences in frequency of the species involved in the Fasterholt Flora. This has been attempted by applying a simple scale of frequency with 3 steps: Dominant-Common-Rare; and by applying 3 numerical progressions of points to this frequency scale (ref. table 15 and page 258). The frequency-steps are given the symbols D-C-R with which all species are marked in table 15. These symbols are applied in the description of the analysis. The frequency values have been established from information from Friis, 1985 and the collections studied by Koch & Friedrich (Geological Institute, Aarhus University).

A. Qualitative Analysis (table 16)

1) An inspection of the stratigraphical distribution of the species of the Fasterholt Flora through the interval of zone I-XIII of the Niederlausitz region reveals a group of at least 13 species which occur throughout this interval:

Carpolithus natans	*Stratiotes kaltennordheimensis*
Hellia salicornioides	*Cyclocarya nucifera*
Selaginella pliocenica	*Liquidambar europaea*
Spirematospermum wetzleri	*Decodon vectensis*
Taxodium dubium	*Paliurus thurmannii*
(Glyptostrobus europaea)	*Swida gorbunovii*
Sequoia langsdorfii	*Vitis teutonica*

Most of these species are well known as geographically widespread and occur throughout the Tertiary, and are not useful for this investigation.

2). Another more important group consists of 18 species which are absent in zones I-III (IV) of the Niederlausitz succession and continues into and/or through its upper range:

Aldrovanda praevesciculosa	*Potentialla pliocenica*
Arctostaphylloides globulus	*Prunus langsdorffii*
Aracispermum canaliculatum	*Pterocarya limburgensis*
Cladium reidiorum	*Symplocos gothani/ludwigi*
Ilex saxonica	*Symplocos minutula*
Mastixia menzelii	*Symplocos scheerei*
Mneme menzelii	*Tetrastigma chandleri*
Myrica wiesaensis	*Vitis globosa*
Nyssa disseminata	*Vitis parasilvestris*

In addition to this list 2 species, *Scirpus ragozini* and *Symplocos salzhausenensis* are lacking in the lowermost zones (I and II).

Of this group 3 species are restricted to the upper part of the interval between zones I – XIII:

Mastixia menzelii, XI-XII
Potentilla pliocenica, XI-XIII
Pterocarya limburgensis, IX-X- into Pliocene

Related to this group are
Nyssa disseminata, IV-XI, a generally younger species continuing through Upper Miocene into Pliocene.
Prunus langsdorffii, IV-XII
Symplocos gothani/ludwigi, VI-XII

Symplocos scheerei, VI – Upper Miocene (Posener beds)
Tetrastigma chandleri, IV-XII

Two of the last mentioned species reaches into the Pliocene: *Pterocarya limburgensis* is abundantly represented (dominant) in the Fasterholt Flora. *Nyssa disseminata* is a rare species in the Fasterholt Flora, representing 2-3% of all Nyssa endocarps. *Nyssa disseminata* is generally a Pliocene species and its rarity in the Fasterholt Flora is well in accordance with its stratigraphical status.

3) 5 species with a restricted range within the Oligo-Miocene of the Lower Lausitz region between zones (IV) VI-XI:

Aldrovanda praevescicu-losa | *Myrica wiesaensis*
Cladium reidiorum | *Vitis globosa*
| *Vitis parasilvestris*

Fasterholt Flora species in common with the fossil floras of Niederlausitz, GDR	Miocene biostratigraphical zones of Niederlausitz, GDR, based upon fossil plants/pollen												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Sparganium multiloculare	—		—		—		—						
Carpolithus natans	—	—	—	▬			▬			—	—	—	—
Selaginella pliocenica	▬	▬	▬	—	▬	---		---		▬			—
Taxodium dubium	▬	▬	▬	▬	▬	---	▬	---	—		▬	▬	▬
Glyptostrobus europaeus		—	—	▬	—	—	▬	▬	—	—	▬	—	—
Sequoia langsdorfii	▬	▬	▬	▬	▬	—	▬	▬	---	—	▬	▬	—
Hellia salicornioides	▬	▬	▬	—	▬	—		—		—			—
Cyclocarya nucifera	—		—			—	—				—		—
Liquidambar europaea	—	—	▬	—	—	—	—			—	—	—	—
Decodon vectensis	▬	—	—	▬	—		—			—	—	—	—
Paliurus thurmannii	—		—	—	—		—		—	—	—	—	—
Swida gorbunovii	—			—		—	—		—	—	—	—	—
Vitis teutonica	—		—	—	—	—	—					—	—
Stratiotes kaltennordheimensis	—	—	—	—		—	—	—				—	
Spirematospermum wetzleri	—	—	▬	—		—	—	—		—		—	—
Eurya stigmosa	—	—	---	▬	—	—	—	—		▬	—	—	---
Mneme menzelii				—	—		—		—	—	▬	▬	—
Symplocos salzhausenensis			—	—		▬	—			▬	—	—	—
Salvinia cerebrata			—	—		▬	—			▬	—	—	—
Arctostapylloides globulus						—		▬			—	—	
Aracispermum canaliculatum				—		—	—				—	—	
Ilex saxonica						—	—			—	—	—	
Nyssa disseminata				—		—		—		—	—		
Scirpus ragozinii			—	—	—		—			—	—		
Symplocos minutula				—		—				—	—	—	
Symplocos schereri						—	—	—		—	—	—	
Tetrastigma chandleri						—				—	—	—	
Aldrovanda praevesiculosa				—		—		—			—		
Cladium reidiorum				—				—		—			
Myrica wiesaensis				—		—		—		▬	—		
Vitis globosa						—					—		
Vitis parasilvestris						—		—		—	—		
Mastixia menzelii											—	—	
Potentilla pliocenica											—		—
Prunus langsdorfii						—						—	
Pterocarya limburgensis									—	—			
Symplocos gothani				—						—	—	—	

Signs: Wide bar (▬), common; medium bar (—), rare; thin bar (---), problematic record

Table 16. Stratigraphical distribution of Fasterholt Flora species in the Oligo-Miocene zones of Niederlausitz, and arranged in groups according to their range and to the qualitative analysis (ref. page 251 ff). Koch comp. according to Mai, 1967.

Of these species *Myrica wiesaensis* has a restricted geographical range. It has been found only in the Fasterholt and the Lower Lausitz area. *Aldrovanda praevesciculosa* appears stratigraphically restricted in the Lower Lausitz region (its northern occurrence), but in Balkan to the south, it also occurs in the Pliocene (Palamarev, 1970).

A stratigraphical pattern which should be expected, namely species entering from the Oligocene and ending their range within the 13 zones of the Lower Lausitz sequence, are not found among the Fasterholt Flora species.

The interesting stratigraphical evidence from the qualitative analysis of the species in common to the Fasterholt Flora of Jutland and the floras of the Lower Lausitz region in GDR comes from the analytical sections 2 and 3 of this chapter:

18 species do not occur in the interval zone I-III. Consequently correlation with these zones is unlikely.

3 species have a stratigraphical range restricted to the uppermost part of the Lower Lausitz succession (zones X-XIII). These species have only zone XI in common, 8 species occurring in the upper half part of the Lower Lausitz succession (zones VI XIII) have only the zones X-XI in common. Hence the zone(s) (X-) XI is (are)in focus as an interval for correlation. One species exclusively occurs in zone XII.

The existence of 2 generally Pliocene species (*Pterocarya limburgensis* and *Nyssa disseminata* (the first mentioned being a dominant), support the general correlation to the upper part of the Lausitz sequence (I-XIII).

Interesting are 5 species in the Fasterholt Flora with a stratigraphical range ending with zone XI, among them *Myrica wiesaensis* represented with intermediate abundance in the Fasterholt Flora. This strongly points to zone XI as the only interval in common for the group of Fasterholt Flora species analyzed here. This inference must be adjusted to the paleoclimatic information from the Fasterholt Flora and the climatic indications of the zones (X-) XI (-XII) of the Lower Lausitz (Mai, 1967), ref. page (see also chapter 5: Conclusions, paragraph 10).

B) Quantitative Analysis

A quantitative analysis of the 44 species which occur in the Fasterholt Flora and Lower Lausitz floras was undertaken to evaluate the number of species in common at different stratigraphical intervals in search for optimal correlation. In this analysis the frequency (of individuals) with which each species occur in the Fasterholt Flora is taken into account. This factor to some extent involve ecological, climatogical, sedimentological, and other environmental factors as an ingredient of, or besides the stratigraphical information and as it comes out below, the stratigraphical information can be severely obscured by these factors.

It is presumed that the climatical, ecological and sedimentological data influence the results which can be obtained from the table 15. A bio-stratigraphy of the Miocene based on fossil plants concerns a time-interval with very little evolutionary potential. Therefore the stratigraphical information must be extracted from combined paleontological data and geological history. As a consequence, the 44 species of the Fasterholt Flora are subdivided into two, the Paleotropical and the Arcto-Tertiary elements (Engler 1882). A Phytogeographical division plays an important role in the study of the Oligo-Miocene floras to the north of the Alps and may be useful for separating some of the influence of phytogeography and climate from the genuine stratigraphical criteria.

It shall be practical here to point out that the paleoclimatic analysis of Mai (1965, 1967) based on fossil flora generally gives indication for temperate climate in odd number zones in the stratigraphical succession of the Niederlausitz Floras (zones I XIII) and indication for subtropical climate in the zones with even number. Hence the succession reveals a history of climatic oscillation.

Analysis I

The first step of the quantitative analysis is concerned with the basic numerical information: The 44 species of the Fasterholt Flora recorded from the different zones (I-XIII) of the Niederlausitz sequence. The present analysis gives a survey of the number of Fasterholt Flora species which are represented in each of the 13 zones of Niederlausitz, GDR, giving the same importance to all species without regard to their frequency.

It must be remarked that, as the Niederlausitz-zones are defined (Mai 1965, 1967), there is a correlation between phytogeographical element and Niederlausitz zones so that subtropical climate is connected with the Paleotropical element, and the Arcto-Tertiary element consists of species favoured by temperate climate which also gave access to some subtropical species (but is unsuited for tropical species).

This has the effect that most even-numbered zones have an optimal affinity for Paleotropical species and indicates subtropical climate (an exception is zone IV with intermediate status); and all odd-numbered zones have an affinity to Arcto-Tertiary species indicating temperate (and partly subtropical) climate. This bias is taken into account when the countings are interpreted (ref. page 257).

In the following Text optimal Correlation is indicated by:

1) The number of zones by roman numerals.

2) Sum of correlative species by greek letters in parenthesis.

The 22 Paleotropical species (P):

IV (15) VI(17) X(16) XI(15) XII(15)

This group of high values stands clearly out from the remaining low values.

It is expected that an optimal correlation for the Paleotropical species would occur in even numbered zones of tropical subtropical climatic conditions. It is remarkable that zone XI appear with optimal correlation (15 species in common). This must be independent of the climatic (temperature) and phytogeographic factors, therefore being stratigraphical important.

The 22 Arcto-Tertiary species (A):

I(12) III(13) IV(14) V(11) VI(13) VII(15) X(10) XI(16) XII(13) XIII(14)

Most of the zones (10) have relatively high values, only 3 are poorly represented. The indistinct extreme values of zones IV, VII, XI and XIII are linked by transitional high values in intervening zones. The largest value is found by zone XI(16).

It is expected that an optimal correlation for the group of Arcto-Tertiary species should be found in odd-numbered zones. The optimal number of species from the Fasterholt Flora in common with Niederlausitz is found in zone XI(16). Exceptional is zone IV(14) as even-numbered zone with high correlation under this group. But among the group of Paleoetropical species, zone IV(15) show a modest numerical correlation. This fits excellently with the climatical determination of Mai (1967): Warm temperate subtropical, an intermediate status for zone IV.

The undivided group (A+P) of 44 species occurring in the Fasterholt Flora and the Floras of Niederlausitz.

(1) The optimal correlation:

IV(29) VI(30) X(29) XI(31) XII(28)

(2) Also 3 intermediate but relatively high values are found:

III(20) VI(23) XIII(21).

The optimal number of species in common is found in zone XI (31).

Conclusion of quantitative analysis I:

In the analysis of (P) and (A) we find the optimal numerical correlation for the Paleotropical element preferably in zones with even numbers (with a subtropical indication): IV, VI, X, XII. The optimal correlation for the Arcto-Tertiary element preferably falls in zones with odd numbers, but there is a tendency for optimal correlation with odd and even numbered zones connected with subtropical – temperate climatical indication.

Provided the Fasterholt Flora consists of 2/3 Arcto-Tertiary species (ref. page 237) the numerical correlation of this stratigraphical analysis should be found in zones with an optimal correlation under the conditions A or A+P. In general, the best correlations between the Fasterholt Flora and the floras of Niederlausitz for these reasons fall within the intervals of the Niederlausitz zones III-VII and zones X-XIII, which is stratigraphically unsatisfactory.

Within these intervals the zone XI shows the highest numerical value under A and A+P: 16 and 31 points; and even a high value for zone XI in the analysis of the P-fraction, combined with a high value in zone X. Critical is here the low scatter of the relatively small numerical material.

Analysis II

The next procedure is an analysis in principle repeating that of Analysis I of this chapter, but deviating by taking into account the relative frequency of each of the Fasterholt Flora species. Table 12 divides the species into 3 categories of frequency, as represented below with their respective symbols added:

Dominant species:	D	(D > 1000 specimens)
Common species:	C	(C = 1000-10 specimens)
Rare species:	R	(R < 10 specimens)

Abbreviations of phytogeographical elements analyzed (identical with Analysis I):

P:	Paleotropical element	22 species
A:	Arcto-Tertiary element	22 species
A+P:	Sum of A and P	44 species

As an experiment different sets of numerical values (progressions) have been applied to indicate frequency of the species (=D, C or R) as follows:

	D	C	R	
points	3	2	1	(progression 1)
–	30	10	1	(progression 2)
–	100	10	1	(progression 3)

Each of these sets of points (with successively steeper gradients) are supposed to afford progressive differentiation (scatter) of the values calculated for each zone.

Each of these numerical sets were applied to the same data in separate analyses adding the frequency-points of the individual species in each zone to a sum

Analysis applying progression 1:

	Zones with an optimal sum of points				
P. 3-2-1:	IV(23)	VI(23)	X(23)	XI(19)	XII(21)
A. 3-2-1: 1)	II(28)	IV(29)	VII(31)	XI(31)	XIII(28)
2)	I(25)	V(24)	VI(24)	X(26)	XII(27)
P+A. 3-2-1: 1)	IV(51)	VI(46)	VII(42)	X(48)	XI(49) XII(47)
2)	III(37)	XIII(40)			

Analysis applying progression 2:

	Zones with an optimal sum of points				
P. 30-10-1:	IV(98)	VI(82)	X(90)	XII(80)	XIII(72)
A. 30-10-1:	I(184)	III(294)	IV(195)	VII(205)	XI(197)
	XII(185)	XIII(186)			
A+P.30-10.-1: 1)	IV(293)				
2)	III(257)	VII(260)	X(255)	XI(248)	XII(265)
	XIII(258)				

(ref. table 15). This sum is supposed a measure for level of correlation.

The first two progressions appear sufficient for our purpose, the highest progression tended to give an exaggerated scatter without adding to clearness.

From the data analyzed in section II (including the progression 100-10-1 not specified here, but see table 15) it appears that the results from the first progression 3-2-1 are about the same conclusion as Analysis I indicating the optimal correlations as between the two groups: zones III-VII and X-XIII. The provision that the Fasterholt Flora has a majority (2/3) of Arcto-Tertiary species (A) underlies the tendency to optimal correlation with zone XI. The Paleotropical element has the highest values in the even numbered zones and the Arcto-Tertiary element has the highest values in a range of zones according to its definition, but preferably in the odd numbered zones.

The progression 30-10-1 represents a more differentiated system of frequencies of the species in question with differentiated scatter of the points. Hence, it presents a more differentiated material practical for our analysis.

The data (table 15) still show two groups of optimal correlation, but the lower one consists of only zones IV and VI(VII) with a relative low sum of points. The upper group of the zones X-XI-XII-XIII all with large values and as a group definitely in excess of points. The individual zones IV and VII show optimal sum of points.

The stratigraphical results of the numerical analysis are not unequivocal and so not satisfactory, to be the sole criterion for correlation. Combined with other evidence it is interesting, underlining the correlation to the upper part of the Oligo-Miocene Lower Lausitz browncoal bearing sequence. Analysis I seems to be the best indicator.

It is interesting to find that the optimal values for the Paleotropical element in the progression 30-10-1 are definitely smaller than the values of the Arcto-Tertiary element. This underlines the importance of the Arcto-Tertiary element involving the temperate as well as an important part of the subtropical species. This is in agreement with the analysis based on 76 genera (ration P:A = 33:66) described previously in this paper (ref. page 109).

C) Stratigraphical Analysis based on Phytogeographical Information

The stratigraphical system of 13 zones in which the brown coal bearing sequence in the Lower Lausitz has been divided by Mai and Krutzsch et al. is based upon changes in the fossil flora. Among these changes climatic fluctuations are causally involved and can be expressed by the ratio between the number of species of the general phytogeographical elements (of Engler, 1882) represented at the locality or in the individual zone: The Paleotropical (P) – and the Arcto-Tertiary (A) elements (ref. Mai, 1965, 1967). Mai has expressed in different ways the relationship between these elements and the stratigraphical system of 13 zones in question.

In Text-Fig. 51 (reproduced from Mai, 1965) the ratio between the Paleotropical- and Arcto-Tertiary elements is expressed in a diagram which shows curves for the ratio P:A in relation to the stratigraphical order (or time). In the actual case it represents the succession of fossiliferous localities in Niederlausitz. In this diagram the values P:A of the Fasterholt Flora are plotted in an attempt to find information for stratigraphical correlation. The difference in climate and vegetation between Central Jutland and Niederlausitz in the Miocene must be taken in consideration, but in general is probably of a small scale. The P:A ratio has been calculated at different times during the present investigation with small deviations. These values have been added to the original diagram of Mai (Text-Fig. 51) by the present author: Two sets of the ratio P:A of the

Fasterholt Flora expressed by horizontal lines are found to cut the P:A ratio curves at two positions where the values of P:A equal 100%. These two fits occur in the upper part of the Spremberger beds (zone VI-VII) and at a higher level in the Upper Browncoal Seam of the Lower Lausitz (zone XI-XII).

Text-Fig. 52 (reproduced from Mai, 1967) represents the different floras of Niederlausitz that were analyzed phytogeographically. The results are expressed in histograms, arranged in stratigraphical (zonal) succession. The same method and units have been used by Friis (1985) for the Søby-Fasterholt area and are positioned on Text-Fig. 52 and with a legend of the phytogeographical units added.

The succession of phytogeographical units in the histograms of Mai (1967) is arranged in a manner that generally separates the evergreen- and deciduous elements. A curve expressing the ratios between these qualities is analogous to the climatic correlation from the Paleotropical:Arcto-Tertiary ratio of phytogeographical elements (Text-Fig. 51). Also the diagram Text-Fig. 52 may in detail and in general deviate from an equivalent hypothetical expression because the Søby-Fasterholt area is located slightly more north and nearer to the Miocene North Sea with its northward connection to the (boreal) ocean. We can expect the numerical value for tropical-subtropical genera and species to be slightly smaller, but, the general fluctu-

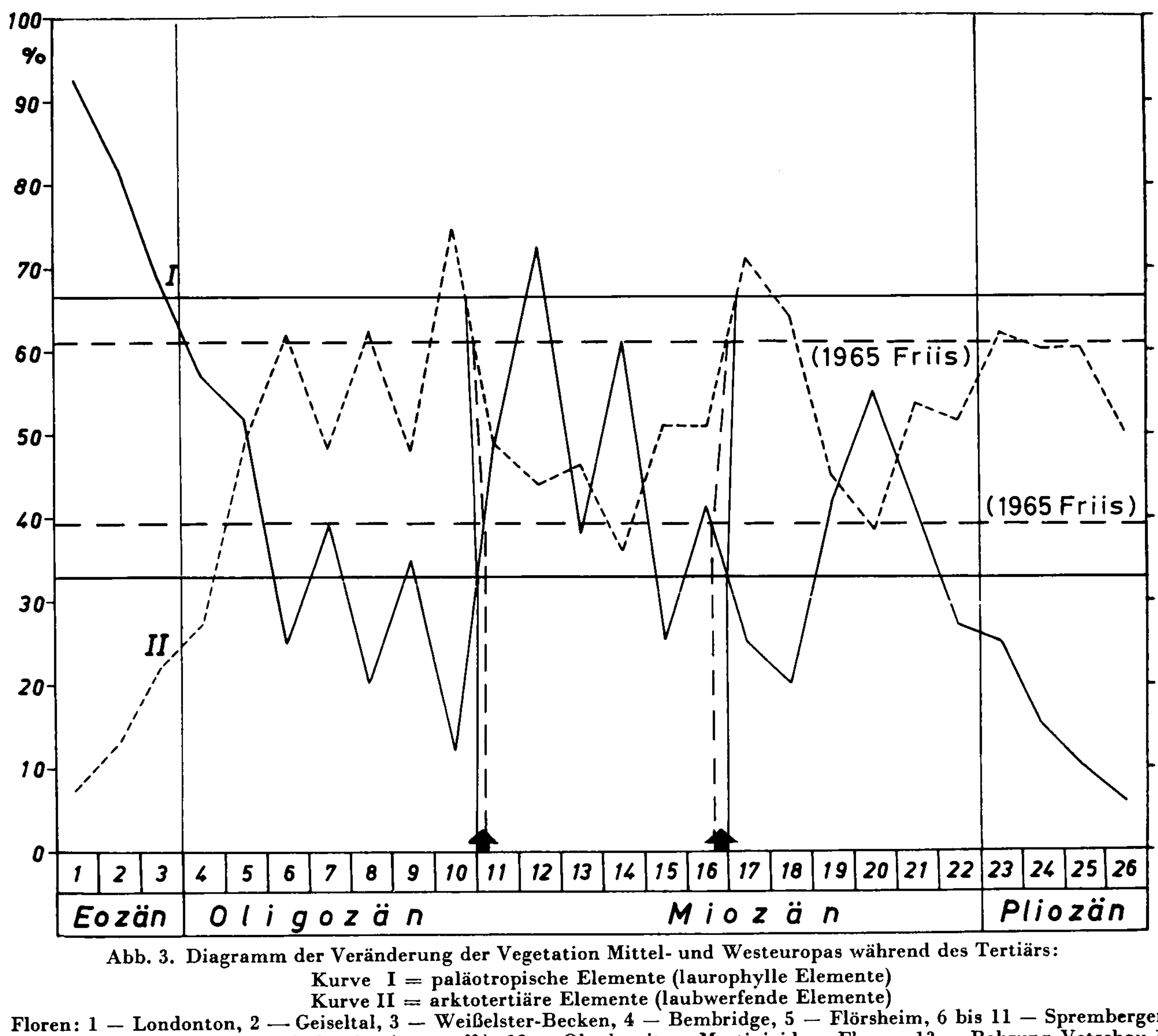


Abb. 3. Diagramm der Veränderung der Vegetation Mittel- und Westeuropas während des Tertiärs:
Kurve I = paläotropische Elemente (laurophylle Elemente)
Kurve II = arktotertiäre Elemente (laubwerfende Elemente)
Floren: 1 — Londonton, 2 — Geiseltal, 3 — Weißelster-Becken, 4 — Bembridge, 5 — Flörsheim, 6 bis 11 — Spremberger Schichten der Zentralen Niederlausitz (unveröff.), 12 — Oberlausitzer Mastixioideen-Floren, 13 — Bohrung Vetschau 1 (unveröff.), 14 — Niederlausitzer Unterflöz, 15 — untere Raunoer Schichten von Klettwitz (unveröff.), 16 — Niederlausitzer Oberflöz, 17 — Wieliczka, 18 — Stare Gliwice, 19 — Düren, Herzogenrath, Konzendorf, Zülpich, 20 — Randecker Maar, 21 — Türkenschanze, 22 — Oeningen, Schrotzburg, 23 — Brunn-Vösendorf, Laaerberg, 24 — Brunssum, 25 — Reuver, Swalmen, 26 — Rippersroda

Text-Fig. 51. Graph showing the fluctuation in percentage values of Arcto-Tertiary and Paleotropical species of an Oligo-Miocene stratigraphical sequence with fossil floras in the East-German Region (GDR) (after Mai, 1965 Abb. 3). Inserted in the diagram are percentage values of the Fasterholt-Flora from two stages of investigation (Friis, 1965 and the present paper). The younger fit is in general accordance with criteria from paleobotanical and stratigraphical study, the older fit is disharmonous. E.K. comp.

ations of climate and flora can be expected to be similar.

Hence, it is relevant to compare the fossil flora succession in the Søby-Fasterholt area (Friis, 1985) of 5 stratigraphical levels (D and S near to each other), with the fossil floras of the Lower Lausitz region.

In the floral succession of the Søby-Fasterholt area the tropical-subtropical element declines, and the introduction of a Mediterranean element and the expression of an East Asiatic/N. American element is fitting the best and only convincing fit to the interval zone X-XI. The general evolution of the diagram of Text-Fig. 52, especially the tropical-subtropical element, excludes the first (lower) half of the diagram (zones I-VII) from correlation.

4.B.7.4. Conclusion of the Stratigraphical Analysis of the Fasterholt Flora

The stratigraphical information extracted from the Fasterholt Flora has been interpreted from genus and species level.

Information from Friis (1985) and the author's analysis support a Miocene age. The data is partly from a review of a large sum of genera and from determination of stratigraphical range of selected species.

The stratigraphical subdivision of the Miocene nonmarine deposits is confronted with the difficulty that so short-lived species as needed, are rare in the Miocene flora. Synthesis of different kinds of data are necessary.

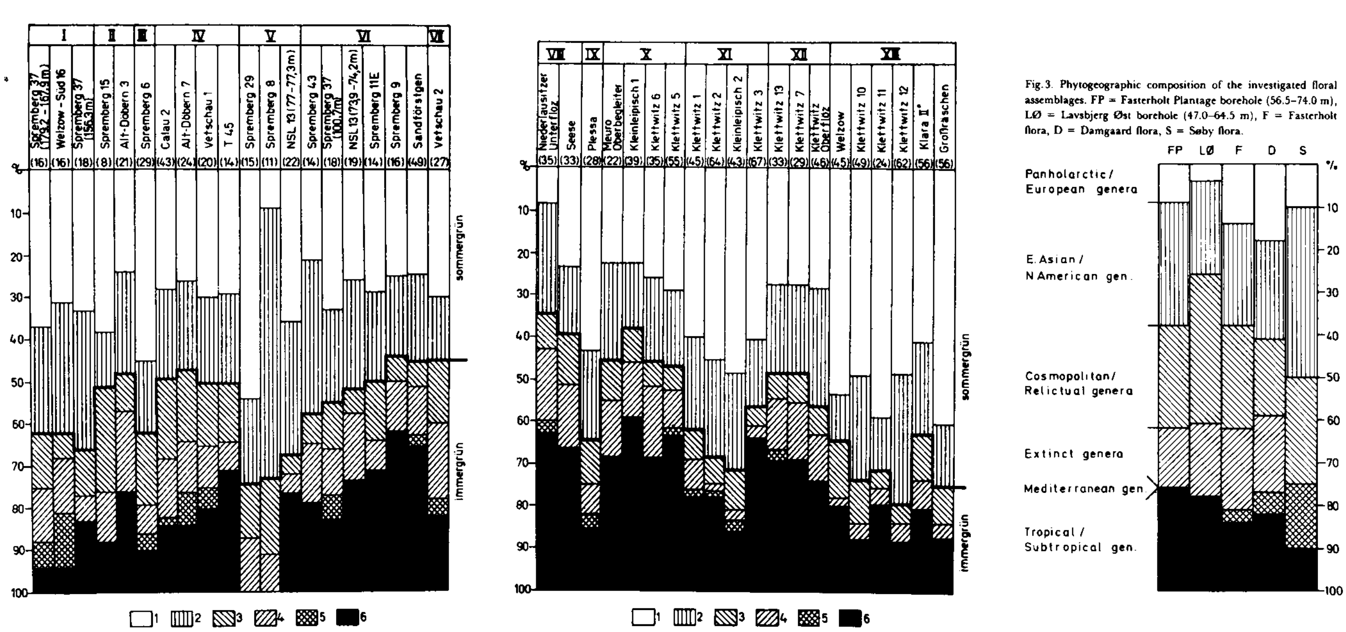
From the available information of the range of the fossils of the 13 zones of Niederlausitz the overlapping of younger and older species of the *Fasterholt-Flora,* led to a possible correlation because the overlap for a number of species is restricted to zone XI – (+X). There is a marked tendency to exclude zones I-III as correlative because 18 Fasterholt-Flora species do not occur in these lowermost zones. This agrees with the general determination to the Miocene, because the lowermost zones in Niederlausitz are overlapping into the Oligocene.

Three species are concentrated in the zones X-XIII and a number of species occurring in the same zones extend into the Pliocene. Among these *Nyssa disseminata* and *Pterocarya limburgensis* are generally Pliocene species.

Six species are concentrated in the middle zones (IV) VI-XI, and of these 4 continue into zone XII.

In a survey of the *Fasterholt-Flora* species in common with each zone of Niederlaustiz (I-XIII) zone XI attains optimal correlation in competition with zone X. This becomes convincing because the *Fasterholt-Flora* consists of 2/3 Arcto-Tertiary species favouring the odd numbered zones. However, the total number of species involved is modest and the excess of points of the numerical analysis assigning zone XI amounts only 6-7% in the numerical analysis.

When the frequency of the species (in the *Fasterholt-Flora*) is involved in the numerical evaluation this conclusion becomes modified according to the gradient of the progression involved in the numerical scale of frequency. The frequency-progression 3-2-1 repeats the priority of zone XI. But with the wider scatter and steeper gradient in the progression the zone IV and VII compete severely with zone XI. In the latter case a



Text-Fig. 52. Diagram comparing the stratigraphical sequence of the Miocene fossil flora of East Germany (GDR) and the Søby-Fasterholt area based on phytogeographical and paleofloristical information published by Mai 1967 and Friis 1985. The best fit occurs in the upper end (zones X-XI) of the stratigraphical sequence (ref. the text page 261). E.K. comp.

general conclusion of optimal correlation with the lower zones III-VII and the upper zone X-XIII is retained. The higher progression seems to give higher weight to the climatical-phytogeographical factor without adding to clearness regarding stratigraphical correlation. But the group of zones X-XIII as a sum is still definitely in excess of points compared with other intervals of the stratigraphical succession of zones.

The quantitative analysis alone does not present a convincing correlation, but the results are in accordance with that of the qualitative analysis, also pointing to correlation with the upper zones of Niederlausitz, especially zone XI (X-XII).

This synthesis is supported by the experience of the changing relative proportions between the Arcto-Tertiary and Paleotropical elements through the Oligo-Miocene history of Niederlausitz (Mai 1965, Abb 3) which is a function of the changing climate and phytogeographical elements (changing flora). The values of the ration P:A, (i.e. between the numbers of Paleotropical and Arcto Tertiary species) of the *Fasterholt-Flora* projected on to the Lower Lausitz diagram of Mai 1965 (Text-Fig. 51) gives two fits, one in the upper part of the Spremberg beds (zones VI-VII) and another at a higher level, the Lausitz upper browncoal seam (Lausitzer Oberflöz), (zones XI-XII). The last mentioned fit is supported by the above mentioned qualitative analysis of the Fasterholt and the Lausitz floras.

Finally, diagrams demonstrating the phytogeographical composition of the Oligo-Miocene floras of Lower Lausitz (Mai, 1967 Abb. 3 and 4) and the floras of the Søby-Fasterholt area have been compared (Friis, 1985, fig. 3).

Taking into account the trend of changes represented in the progression of time of the Søby-Fasterholt diagram of Friis, 1985 (Text-Fig. 52, to the right), the following characteristics are found: 1. A trend of declining values for the tropical subtropical element, 2. A trend of the ratio between evergreen: deciduous species, and 3. the introduction of Mediterranean element becoming more important with time. With these characteristics in mind correlation with the upper part of the stratigraphical succession of Niederlausitz is the only relevant interval for comparison, with the best fit being the interval zones X-XI. When the distinct Paleotropical element of the *Fasterholt-Flora* (1/3) is taken into account an intermediate position in the zone interval X-XI (subtropical – temperate zones) may be suggested.

4.B.7.5. The Damgaard Flora

The Damgaard-Flora has been collected and described by E.M. Friis (1979) and it was collected in cooperation with a sedimentological team from Geologisk Institut, Aarhus. The flora is from the uppermost part of the deltaic sands ("Upper Sands") underlying the Hodde Clay at the Damgaard S former browncoal pit in the western part of the Søby-Fasterholt area, and consists of fossil fruits and seeds. The fossils are generally rather corroded and except for the new species *Comptonia srodoniowae* the different species are represented by few specimens.

The content of the fossil flora does not allow for a separate stratigraphical conclusion, but is obviously near to the stratigraphical level of the Søby-Flora. The outstanding species *C. srodoniowae* n. sp. of the Damgaard-Flora was recorded also from the *Søby-Flora* (ref. Friis, 1979, Christensen (unpubl. dissertation 1979) and his chapter of the Søby Flora in the present paper). Friis (1985) presents the following information of this flora including the list of the fossil species:

GYMNOSPERMAE
Coniferopsida
Pinus sp. (1 seed)
Taxodium dubium (5 seeds and many fragments)
Hellia salicornioides (8 fragments of leaf whorls)

ANGIOSPERMAE
Dicotyledones
Brasenia cf. *tenuicostata* (22 seeds and fragments)
Myrica sp. (23 endocarps and many fragments)
Comptonia srodoniowae (100 endocarps and fragments)
Pterocarya sp. (1 endocarp)
Eurya stigmosa (2 seeds)
Visnea sp. (4 seeds)
Epacridicarpum chandlerae (5 fruits, 16 fragments)
Ericaceae genus? sp. (1 fragment of fruit)
Empetrum sp.
Halesia crassa (1 endocarp)
Intratriporopollenites instructus (1 cluster of anthers)
Aldrovanda praevesciculosa (1 fragment of seed)
Decodon gibbosus (2 seeds)
Proserpinaca brevicarpa (2 endocarps)
Paliurus sp. (1 fruit, 1 fragment of fruit)
Vitis cf. *silvetris* (1 seed, 3 fragments)

Monocotyledones
Alismataceae genus? 1 (7 seeds).
Potamogeton heinkei (2 endocarps)
Scirpus ragozinii (12 fruits, 8 fragments)
Cladium reidiorum (1 endocarp, 1 fragment)
?Eriophorum sp. 2 (1 fruit)
Cladiocarya europaea (1 endocarp)
Cladiocarya trebovensis (2 endocarps)
Sparganium pusilloides (1 endocarp)
Sparganium cf. *simplex* (2 endocarp)

Incertae sedis
Carpolithes sp. 1-4 (1 fruit of each species)

The material includes about 280 specimens of which about 95 per cent are angiosperms. Fruits of the Myricaceae (*Myrica* sp. and *Comptonia srodoniwae*) make up more than half of all the specimens. Fruits related to the Ericaceae and the Cyperaceae, and seeds of the Cabombaceae are also well-represented in the Damgaard Flora, while the remaining taxa each includes only a few specimens.

4.B.7.6. The Søby Flora

by E. Fjeldsø Christensen.

The *Søby Flora* (Christensen, 1975, 1976, 1979) is found in a clay bed in the abandoned browncoal pit Damgaard N. The clay bed is rich in fossil leaves, seeds and fructifications in a good state of preservation. It occurs in the top of the Odderup Formation (Text-Figs. 37, 44-45), and it is succeeded by the Middle Miocene Hodde Clay, it self overlaid by Upper Miocene Glauconite Clay. More than 1200 fossil plant specimens were collected for taxonomical treatment.

1. Composition of the flora

Although the Søby plant bed is very rich in well-preserved macroscopic plant material, the number of taxa has proved to be limited. 23 kinds of plant organs have been described and referred to 16 taxa. The described taxa are listed below.

In addition to the macroflora the smaller seeds and fruits were examined. The material has been determined by E.M. Friis and is listed separately below. This material adds a good deal of new taxa to the flora. Especially the herbaceous plants are well represented. 13 taxa are herbaceous, and 5 are woody plants.

In total the *Søby Flora* contains at least 34 taxa. The pollen flora has not been examined.

<u>*The Søby Flora:* List of fossil species:</u>

Christensen, 1978 (Fossil leaves and fructifications):

Pinus thomasiana (Goepp.) Reichenbach
Taxodium dubium (Sternb.) Heer
Smilax weberi Wessel
Magnolia sp.
Comptonia acutiloba Brongniart
Junglans acuminata A. Braun
Alnus julianaeformis (Sternb.) Kvaček et Holý
Castanea atavia Unger
Liquidambar europaea A. Braun
Ulmus pyramidalis Goeppert
Salix lavateri A. Braun sensu Hantke
Halesia crassa (C. et. E.M. Reid) Kirchheimer
Diospyros brachysepala A. Braun
Leguminocarpon sp.
Acer soebyensis n. sp.
Fraxinus cf. *ungeri* (Gaudin) Knobloch et Kvaček

Friis, 1985 (Fossil fruits and seeds):

GYMNOSPERMAE
Coniferopsida
Pinus sp. (1 seed, few cones; Christensen, 1975)
Taxodium dubium (Many seeds, cones, leaves; Christensen, 1975)
Hellia salicornioides (3 leaf whorls)

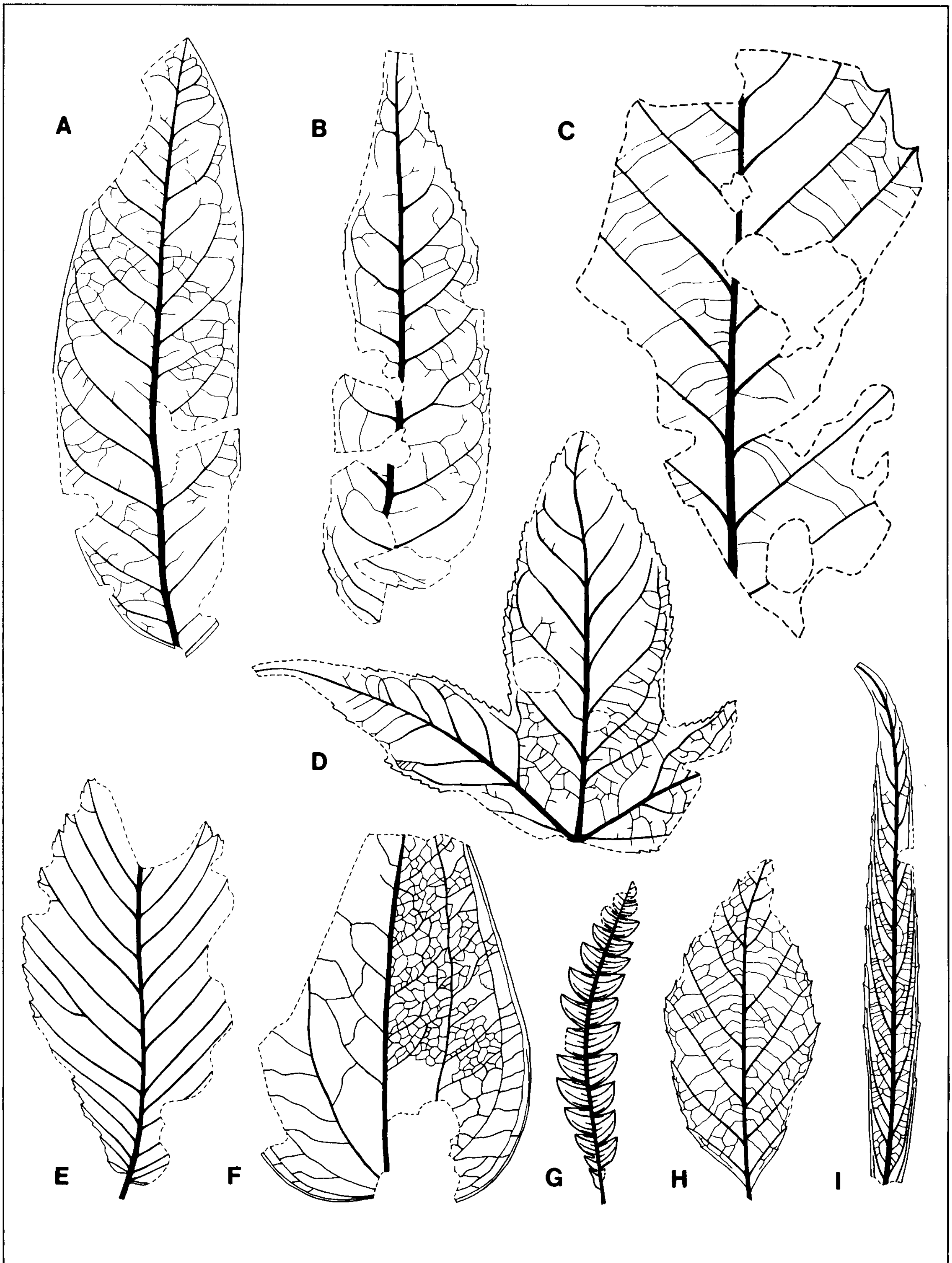
ANGIOSPERMAE
Dicotyledones
Saururus bilobatus (6 seeds)
Platanus neptuni (1 fruiting head)
Myrica sp. (1 endocarp)
Comptonia srodoniowae (9 endocarps, fragments)
Hypericum danicum (5 seeds, fragments)
Poliothyrsis eurorimosus (2 seeds)
Halesia crassa (many fruits; Christensen, 1978)
Symplocos gothanii (1 fragment of endocarp)
Lysimachia sp. (1 seed)
Leguminocarpon sp. (several fruits, Christensen, 1978)
Microdiptera sp. (1 seed)
Ludwigia corneri (1 seed)
Proserpinaca brevicarpa (2 fruits)
Cephalanthus pusillus (16 fruits)
Teucrium sp. 2 (8 nutlets)
Monocotyledones
Alismataceae genus? sp. 1 (44 seeds)
Potamogeton heinkei (1 endocarp)
Scirpus ragozinii (7 fruits)
Dulichium marginatum (13 fruits)
Carex sp. 2 (11 fruits)
Carex sp. 3 (2 fruits)

2. Numerical representation of the macroflora

In order to get an impression of the ancient vegetation 2.702 specimens were identified and counted.

At the top of the fossiliferous bed a bedding plane was exposed, and the fossil plants were counted on a surface with an area of approx. 3/4 m^2. Seven levels of especially high concentrations of fossil plants were registered. Numerical counting was carried out for each level in a narrow zone around a marked bedding plane densely covered with fossils.

A survey of table 17 leaves little doubt as to the representative dominance of *Taxodium dubium, Alnus julianaeformis* and *Juglans acuminata* in the vegetation near the place of deposition, or of the common occurrence of 10 other species that are represented by more than 1 per cent of the fossil flora. However, these



Text-Fig. 53. A number of species of fossil leaves from the Søby-Flora reproduced in the original drawing from Christensen (1975, 1976) and reproduced by Koch (1977). A) Juglans acuminata; B) Fraxinus cf. ungeri; C) Castanea atavia; D) Liquidambar europaea; E) Ulmus pyramidalis; F) Smilax weberi; G) Comptonia acutiloba; H) Alnus julianaeformis; I) Salix lavateri. E.F.C. del.

Fossil species	Number of speci-mens	Per cent	5 10 15 20%	Assumed growth habit	Importance
Taxodium dubium	604	22.4		tall tree	abundant
Alnus juli-anaeformis	368	13.6		small tree	abundant
Juglans acuminata	302	11.2		tree	abundant
Halesia crassa	233	8.7		small tree large shrub	common
Acer soebyensis	191	7.1		large tree	common
Castanea atavia	182	6.7		tree	common
Fraxinus cf. ungeri	177	6.3		tree	common
Ulmus pyramidalis	144	5.3		large tree	common
Smilax weberi	135	5.0		vine	common
Magnolia sp.	122	4.5		shrub or tree	common
Salix lavateri	86	3.1		shrub or tree	common
Comptonia acutiloba	86	3.1		low shrub	common
Liquidambar europaea	73	2.7		medium to large tree	common
Leguminocarpon sp.	9	0.3		?	rare
Diospyros brachysepala	5	0.2		tree	rare
Pinus thomasiana	5	0.2		large tree	rare
Total	2702				

Table 17. Frequency and growth habit of important fossil leaf species of the Søby Flora. E.F.C. comp. (Koch & Christensen, 1979).

figures do not represent the correct composition of the vegetation. For a more reliable picture the growth habit must be taken into consideration. The growth habit listed in table 17, is the presumed growth habit as judged from the living relatives showing the closest resemblance of the fossils. According to Chaney (1959, p. 19) leaves from shrubs and vines are much less numerous on the ground than those of trees, even though they were abundant members of the understory. This consideration leaves no doubt that *Smilax weberi* and *Comptonia acutiloba* must be underrepresented in the Søby deposit.

Judging from the habit of the closest living relatives, all the Søby flora species (except Pinus thomasiana) are believed to be deciduous. Also, the cuticles of the fossil leaves are delicate and difficult to prepare, which makes it unlikely that the leaves were active for more than one season. Hence, a correction in the produced number of leaves of evergreen and deciduous species is not to be needed.

The representation expressed in percentages of taxa in the deposit only gives a general impression of the ancient vegetation. Conclusion on the palaeoecology must involve a comparison with recent plant communities and above all the mechanism of transportation must be considered.

3. Geographical distribution of recent genera

In the taxonomical treatment of the Søby Flora macrofossils, 15 of the 16 taxa were referred to living genera. This taxonomical affinity to living plants raises the question whether the Søby Flora may resemble any living plant communities that can give information on the environmental conditions under which the "Søby forest" existed.

Fifteen of the Søby Flora genera are to-day found in southeastern USA; 13 in southeastern China and 9 in southern Europe. This indicates that the most likely place to look for comparable communities must be in southeast USA and southeast China.

Plant communities from a number of localities in China (the mixed mesophytic forest of the Yangze provinces) and USA (the Mississippi Valley and Coastal Plain) were studied through literature and compared to the Søby Flora. The closest resembling recent vegetation to the Søby Flora is found in the Coastal Plain of the Carolinas. The Cypress swamps and its nearest surroundings seem to display the best environmental parallel to the ancient environment of the Søby Flora.

Plant remains from the Søby Flora deposit represent the following communities. 1. Swamp forest. 2. Bottomland hardwood forest. 3. Well drained lowland or slopes forest. *Taxodium distichum* was the dominating tree of the swamp. *Acer soebyensis, Ulmus pyramidalis, Liquidambar europaea, Halesia crassa, Fraxinus* cf. *ungeri, Alnus julianaeformis* and *Salix lavateri* were the most important members of the hardwood bottom bordering the swamp. *Smilax weberi* was an important vine in this community. Typical member of the well drained forest slopes are *Castanea atavia, Juglans acuminata, Diospyros brachysepala,* and probably *Comptonia acutiloba* and *Magnolia* sp. Most of the carpological species are swamp or aquatic plants characteristic in the swampy and wet lowlands.

The reference of the fossils to communities and environments must necessarily be a generalization. Transitional species occur between the recent communities, and species characteristic to one community might be found in adjacent communities. Therefore this interpretation does not intend to give more than a generalized picture of the past.

4. Vertical variation in the numerical representation

By counting the plant remains in each of the seven zones with a specially high concentration of fossils, a vertical variation in the relative abundance of each species appeared as seen in the graphs of table 18.

The species tends to follow two kinds of vertical variation from bottom to top of the plant bearing layer: 1. General decrease in relative abundance. 2. General

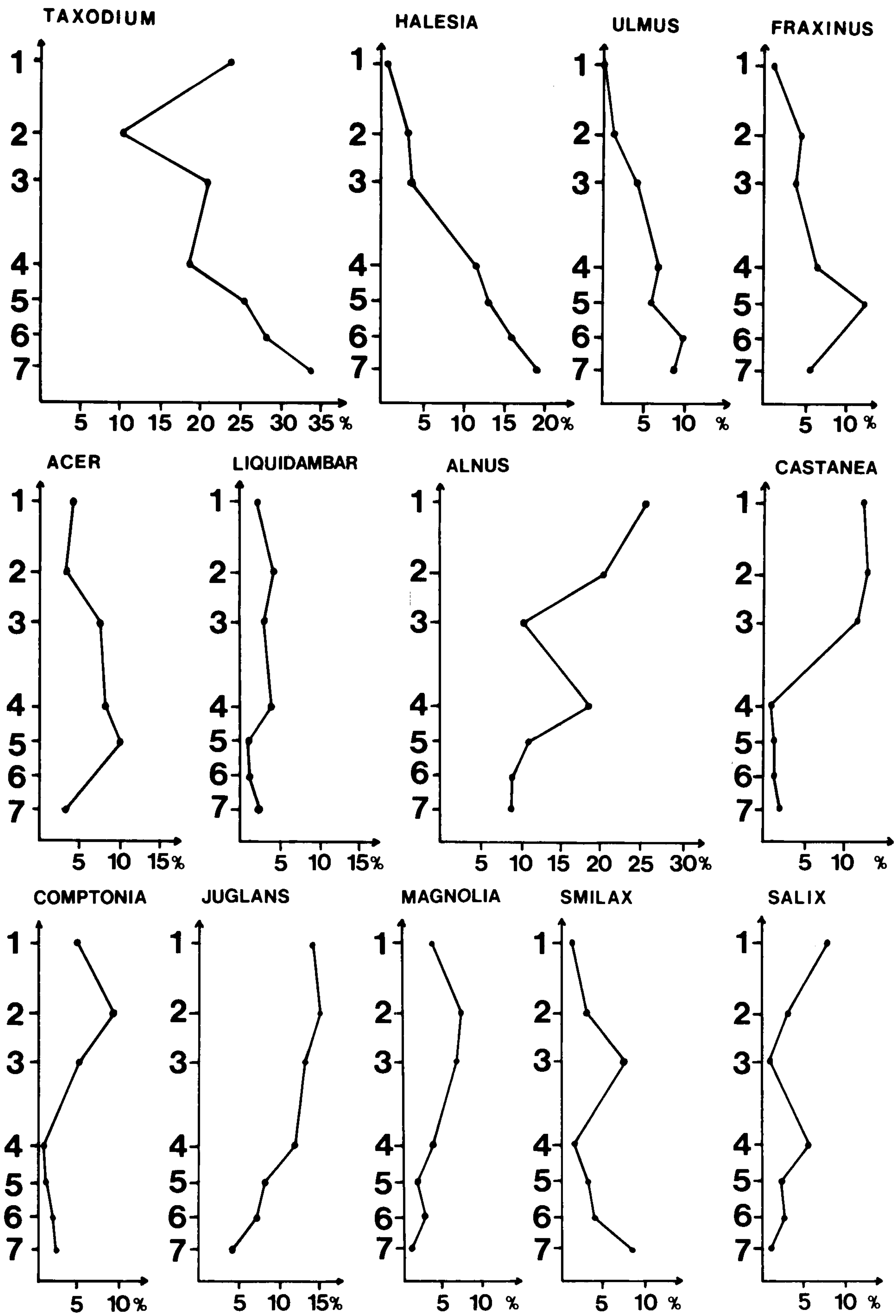


Table 18. The vertical variation in the relative abundance of the most important Søby Flora fossils. The scale on the ordinate axis represents the zones where the plants were counted.

increase in relative abundance. The species of *Taxodium, Ulmus, Fraxinus, Acer* and *Halesia* are placed in the first group, while the species of *Alnus, Castanea, Comptonia, Juglans* and *Magnolia* are placed in the second group.

The relative, abundance of *Liquidambar* is more or less unchanged. *Smilax* and *Salix* show a random type of variation. It is interesting to note that most of the species which are believed to have grown in wet environments show a decrease upwards in relative abundance, while the species believed to have grown in well-drained environments increase toward the top of the layer. Therefore the vertical variation of species can be expressed also in terms of extant plant communities. The total percent of abundance for species referred to the swamp forest, the hardwood bottom, and the forest of well drained sites are then summarized in table 19. The relative importance of *Taxodium* in the Søby Flora clay bed decreases from zone 7 to zone 2 and increasing again in the top of the layer (zone 1). The representation of the hardwood bottomland species (*Alnus* excluded) rises to a low maximum in zone 5, after which the relative share of this group declines. *Alnus,* previously excluded as a member of the hardwood bottomland community, increases in relative representation in contrast to the general tendency of this community. The vertical change in the abundance of *Alnus* is better compared with the model of increasing representation in species of the well-drained forest.

By simplifying the vertical variation to a question of relations between different communities, the following description can be given. A decline in the fossil representation of the swamp forest plants and hardwood bottom plants (*Alnus* excluded) from zone 7 to zone 2, corresponds to an increase in the representation in plants of the well-drained forest community inclusive *Alnus.* A rise in the representation of *Taxodium* in the top of the layer (zone 1) corresponds to a decrease in abundance of dry growing species.

This shows that species from a community of well-drained environment become more numerous in the deposit upwards to zone 2, followed by a drop at the very top of Søby Flora clay bed (zone 1).

To explain the vertical change in the relative composition of the fossil flora, the sediment was examined. In the field a low sand content was found in the lower part of the clay bed, while a number of thin sand lamina occurred in the upper part. Further, it was noted that the clay of the upper part was sandy. To examine this vertical variation, the sand percentage was calculated from samples taken in the clay for every two cm. The results are plotted in the diagram table 19. In zone 6, 5 and 4 the sand percentage is extremely low, while it is a little higher in zone 7. In the upper part of the bed the sand percentage is variable, but much higher. The fossils in zone 3 and 2 are collected in clay with a high sand content, while the fossils in zone 1 are found in a horizon poor in sand. The sand curve reflects the curve representing the relative share of the dry growing species. High sand values correspond to a high relative abundance of species representing the dry forest community.

A low sand content in the lower part of the layer reflects a quiet depositional environment with low energy and low transport capacity. This means that plants from the local communities would be dominant. The highest representation of species pointing to swamp forest and hardwood bottom land environments are found in this part of the bed.

The concordance in increasing sand content and the number of dry forest species is best explained by the presence of a small river system draining a dry forest area. Plant material from the vegetation bordering the river system, could easily be transported into the lake along with the load of sand to become relatively important (common) in the upper part of the fossiliferous bed.

The plant remains in the lower part of the Søby Flora clay bed represent for the majority local plant communities bordering the lake. In the upper part of the Søby Flora bed, plant remains further upstream from a different ecological environment are intermixed with plant remains of local origin. Judged from the ecology of living genera and species the existence of different environments in the Søby area is due to the ground water level. A change in topography of only a few meters could result in different plant communities.

5. *Palaeoclimatic indications*

Due to insufficient amount of quantitative data on the Søby Flora none of the commonly used statistical methods permits detailed palaeoclimatic conclusions. As a first approach, conclusions on the palaeoclimate is often based on the principles put forward by Bailey and Sinnott (1916). They showed the existence of a relationship between the nature of the leaf margin of living dicotyledonous species and the climate in which these species lived. Thus the number of dicotyledonous species having an entire-margin increases toward the tropics.

The Søby Flora only contains ten leaf species with a preserved margin. Of these only two species are entire-margined. Based on such low amounts of data no definitive conclusions can be drawn, except that the flora does not appear to be tropical.

To make an interpretation of the paleoclimate based on the carpological material of the Søby Flora, the fossil species are grouped into paleotropical and arctotertiary elements. These terms are defined by Engler (1882, p. 327 and 328). The only paleotropical species in the flora is *Hellia salicornoides.* The statistical material is still too restricted to permit detailed conclusions

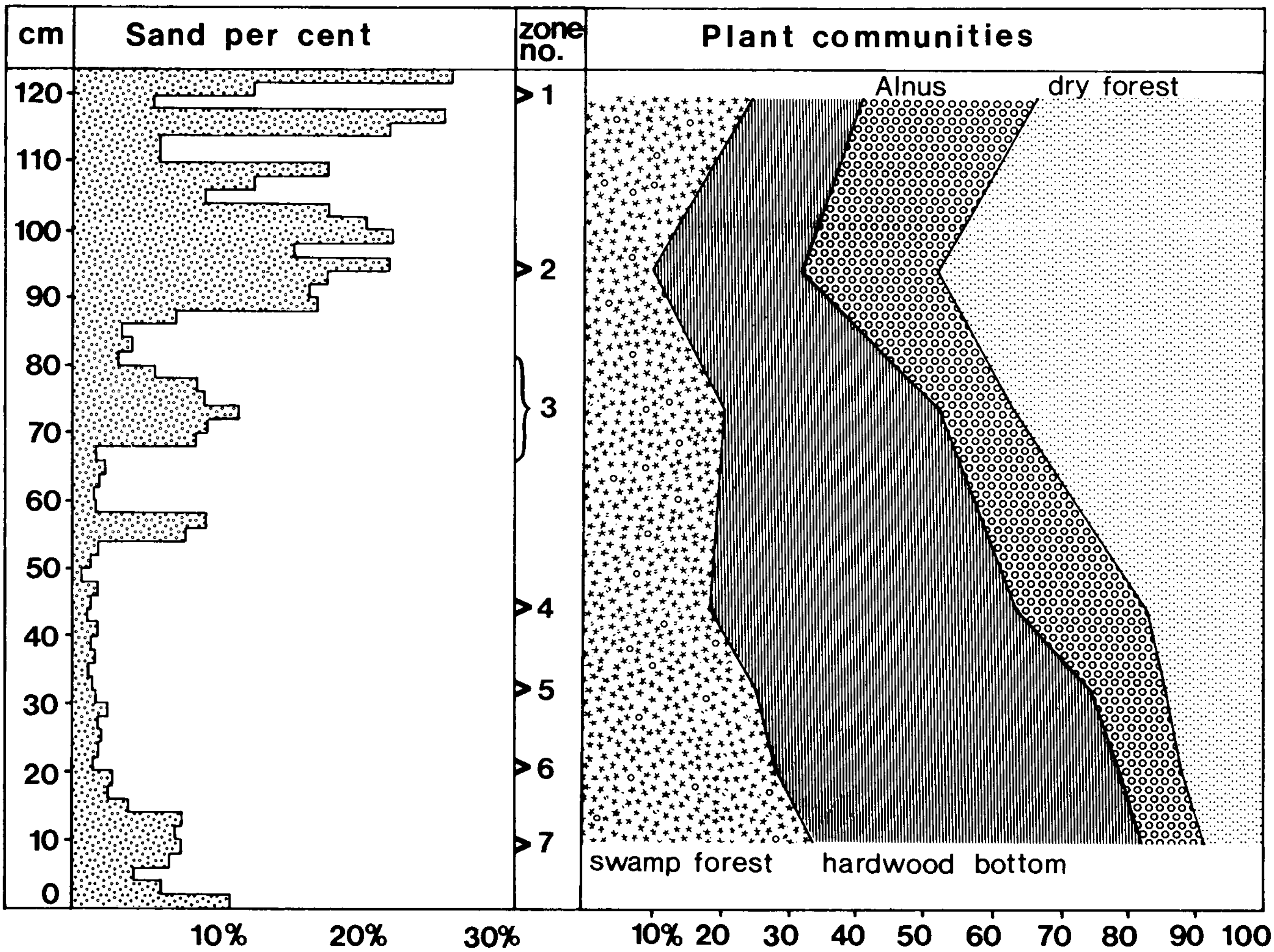


Table 19. The right side of the diagram shows the vertical variation in the representation of the different plant communities found in the Søby Flora. To the left the sand content in the clay bed is graphed. Note the correlation between the rising sand percentage and the increasing share of plants from the dry forest.

on the paleoclimate, but it indicates that the climate was neither tropical nor subtropical.

However, the flora can be compared in general to the mixed mesophytic forest of the Yangze province of China and to the bottomland forest in the Carolinas and the upper part of the Mississippi River Valley. By considering the climate under which related recent communities grow, it is natural to assume that the Søby Flora grew under similar climatic conditions. All the above mentioned regions floristically related to the Søby Flora lie within the zone of warm temperate climate. Hence the Søby Flora must have grown in a warm temperate climate.

6. The relation of the Søby Flora to the paleobotanical stratigraphy of continental Neogene

The Søby Flora is compared to the floras correlated stratigraphically to zone XIII of Mai (1965, 1967). This is the zone above the upper browncoal seam of the Lower Lausitz area. Further the Søby Flora is compared with floras regarded to be younger than G.von der Brelie's microflora zone E, (Brelie, 1967, 1968) and to floras considered to be Sarmatian or younger: The fossil floras from Fischbach, Frechen (both NW-Germany), Stare Gliwice and Schossnitz (both Poland); Rauno, Groos Räschen, and Zschipkau (localities in East Germany (GDR)). The fossil floras from these localities are some of the best described floras containing leaves from the stratigraphical interval in question. These floras contain a large number of fossil plants which are characterized as "younger elements" by Knobloch (1969). According to Knobloch (1969) a striking floral break took place throughout Central Europe in the Upper "Tortonian" (Upper Bardenian), when a number of important, stratigraphically young species began to appear. Among these are: *Platanus platanifolia* (Ett.) Knobl. (=*Platanus aceroides* Geopp.), *Monopleurophyllym quercifolium* (Geopp.) Kotl. (=*Rhus quercifolium* Goepp.), and *Buxus pliocenica* Sap. et Mar. Other relevant species are listed in Knobloch's table (1969, p. 153), but these are known from relatively few localities, and their stratigraphical range is not completely known. None of the younger species

PLATE 3

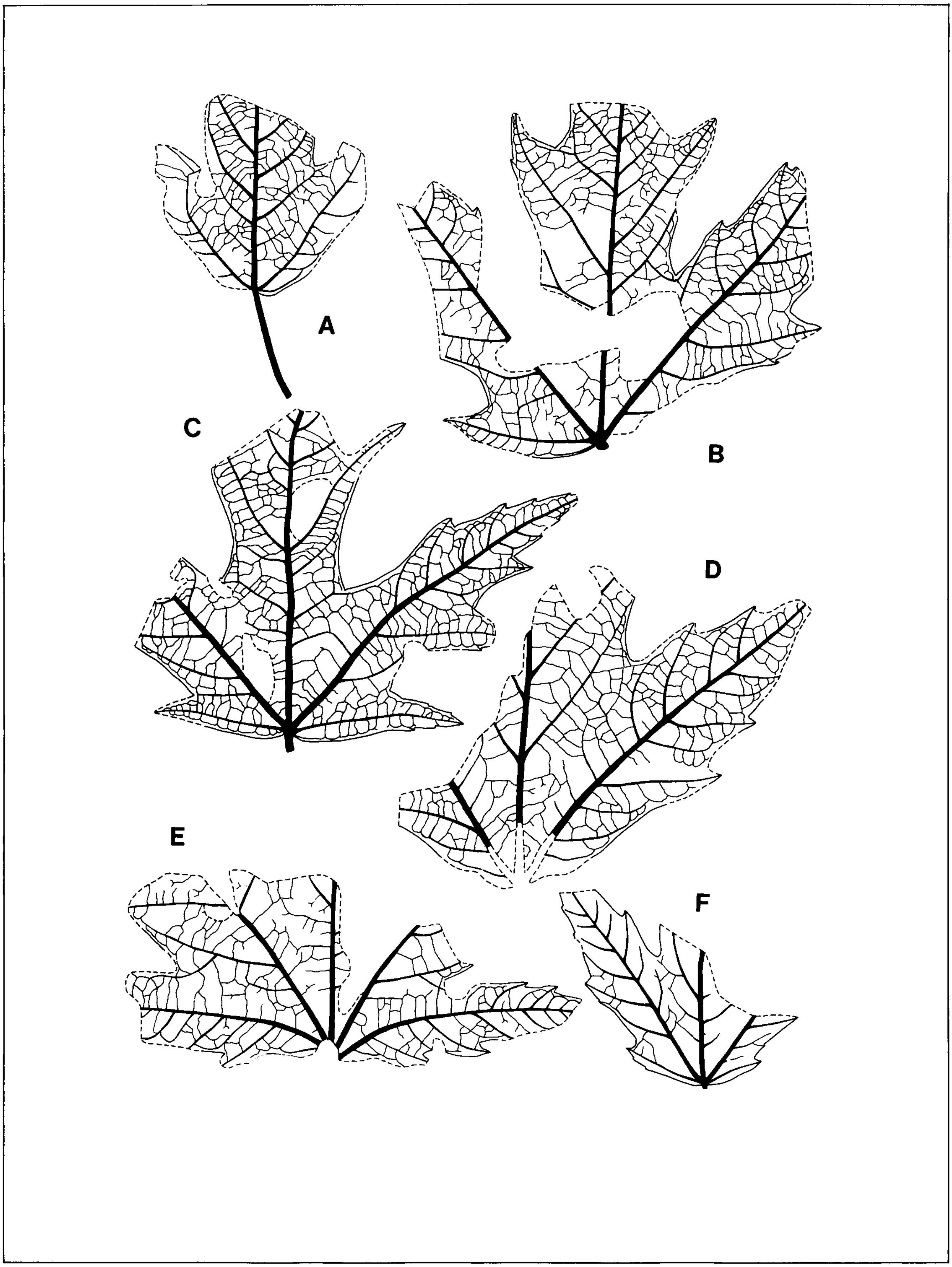


PLATE 3. Acer soebyensis n. sp. A-F: Leaf morphology and venation, x 1. The Søby Flora. From Crhistensen, E.F.(1978).

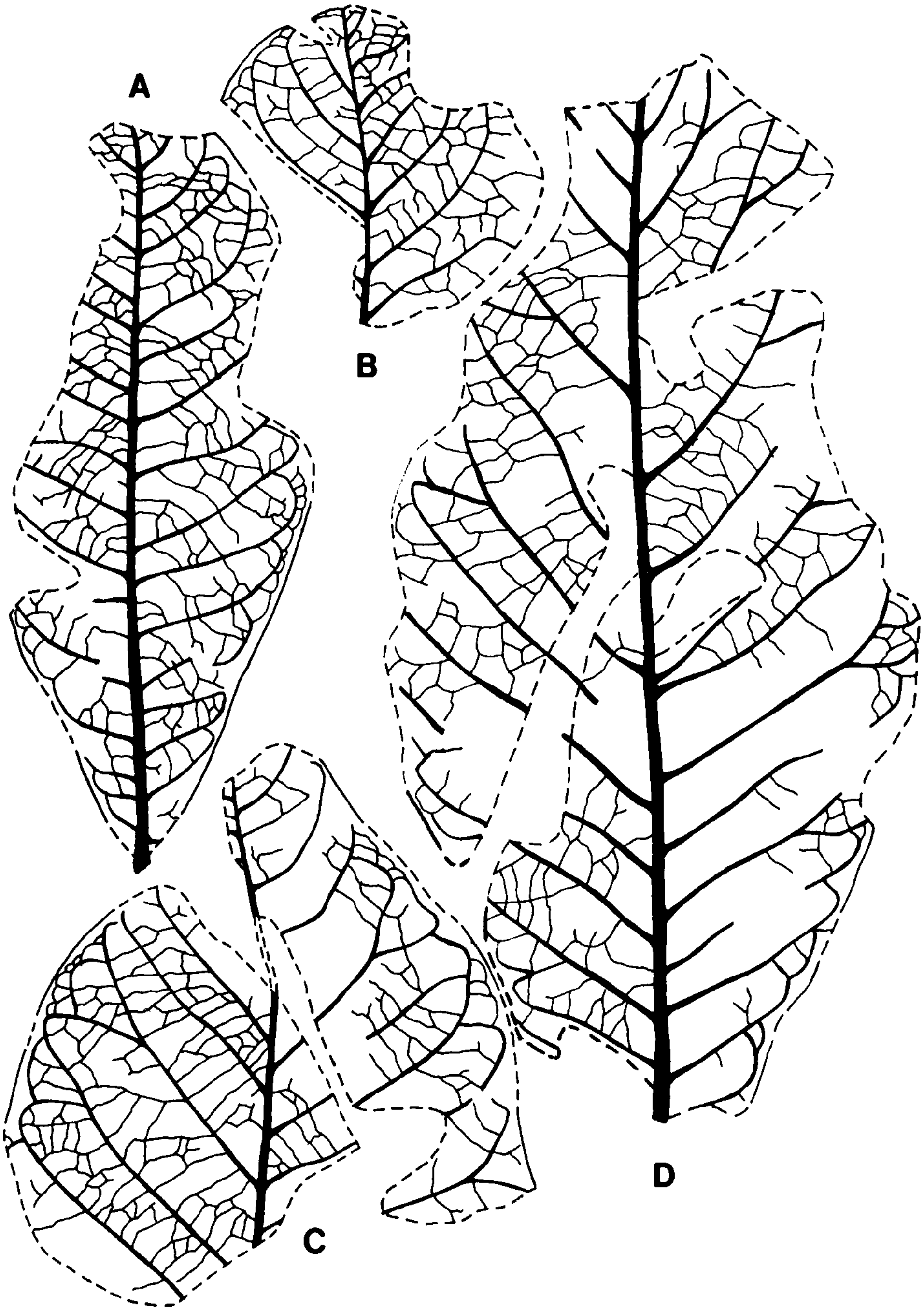


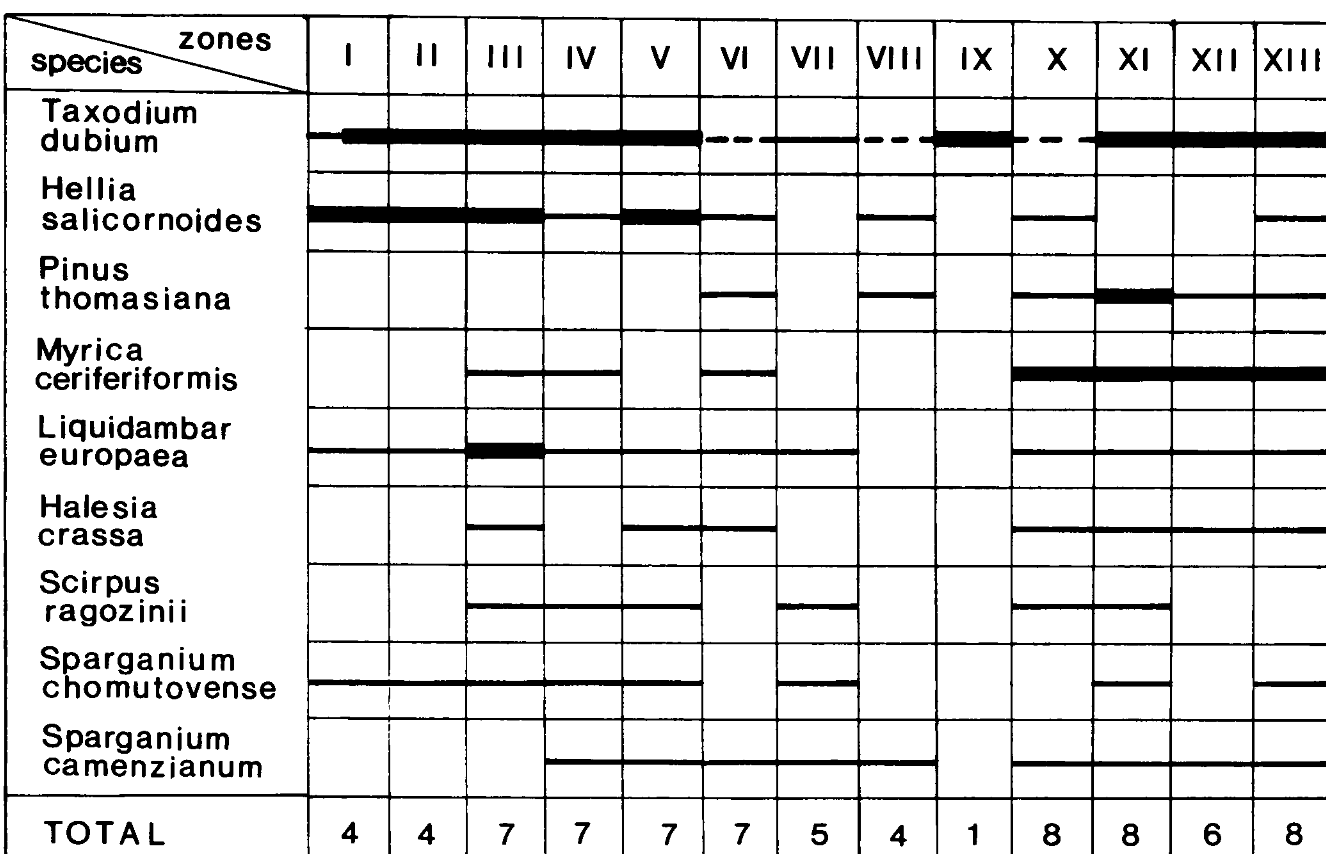
PLATE 4. Magnolia sp. Leaf morphology and venation. The Søby Flora. From Christensen, E.F. (1978).

mentioned here are found in the Søby Flora. Therefore the Søby Flora must necessarily be regarded as older than the above mentioned floras and a pre-Late Bardenian age is likely.

The Søby Flora shows a greater similarity to the Kreuzau Flora than any younger flora. The following Søby species are also found in the Kreuzau Flora: *Taxodium dubium* (Sternb.) Heer, *Hellia salicornoides* Unger, *Smilax weberi* Wessel, *Juglans acuminata* A. Braun, *Alnus julianaeformis* (Sternb.), Kvaček et Holý, *Castanea atavia* Unger, *Liquidambar europaea* A. Braun, *Ulmus pyramidalis* Goepp., *Fraxinus ungeri* (Gaud.) Knobl. et Kvaček?, and *Diospyros brachysepala* A. Braun. According to Knobloch and Kvaček (1976, p. 102) a number of stratigraphically younger species occurs in Kreuzau leading to the conclusion that the Kreuzau flora should be referred to Upper Bardenian. The species are: *Platanus leucophylla* (Ung.) Knobl. (=*Platanus aceroides* Goepp.), *Monopleurophyllum quercifolium* (Goepp.) Kotl., *Quercus sapperi* (Menzel) Mai, *Acer obtusilobum* Ung. (=*Acer subcampestre* Goepp.), and probably *Betula subpubescens* Goepp., and *Quercus pseudocastanea* Goepp. These species are not found in the Søby Flora. Hence the Søby Flora must be older than the Kreuzau Flora, which supports the conclusion that the Søby Flora must be of a pre-Late Bardenian age.

Mai (1967), p. 65-66 presents a list of the stratigraphical range of important species from the continental deposits of GDR. Nine of the Søby Flora species are in common with this list. These species are listed in page 126. The range of eight of these species involves the zones X, XI and XIII, and seven species are found in the zones III, IV, V and VI. So any of these zones could correspond stratigraphically to the Søby Flora. However, it can be concluded that the climatic indication of zone V is cooler and that of zone VI warmer than the climate indicated by the Søby Flora. Zone XIII can be excluded because it has previously been shown that the floras from this time are younger than the Søby Flora. This leaves two possibilities, zones III-V and zones X-XI, to which the Søby Flora might be related. In order to further narrow the possibilities the Søby Flora is compared to the fossil flora of Cermniky of North Bohemia (ČSR).

The similarity between these two floras is mainly due to the resemblance in climatic and ecological conditions indicated by the floras. The basic difference between the floras is expressed by the existence of a number of Lower Miocene species in the flora of Cermniky.



Tabel 20. Stratigraphical range of Søby-flora species in relation to the flora-zone system of Mai (1965, 1967).

According to Knobloch and Kvaček (1976, p. 105) these are: *Salix haidingeri* Ett., *Comptonia acutiloba* Brongn., *Phyllites nemejcii* Bůžek, *Koelreuteria reticulata* (Ett.) Edwards, *Phyllites kvacekii* Bůžek, and *"Virburnum" atlanticum* Ett. Only *Comptonia acutiloba* is found in the Søby Flora. Therefore the Søby Flora is considered younger than the flora of Cermniky.

This attempt to relate the Søby Flora to the existing palaeobotanical stratigraphy of Europe can be expressed in the following conclusions:

The Søby Flora is judged to be older than the Kreuzau Flora and younger than the Wackersdorf Flora. Expressed in stratigraphical terms the Søby Flora must be pre-Upper Bardenian, and it must be older than the upper browncoal seam of Lausitz. It probably corresponds to Mai's zone XI and X. Further it must correspond to microflora D of G. von der Brelie.

7. *References*

Bailey, I.W. & Sinnott, E.W., 1916: The climatic distribution of certain types of Angiosperm leaves. – Am. J. Bot. 3, 24-39.

Brelie, G. von der, 1967: Quantitative Sporenuntersuchungen zur stratigraphischen Gliederung des Neogens in Mitteleuropa. – Rev. Palaeobotan. Palynol., 2, 147-162.

Brelie, G. von der, 1968: Zur mikrofloristichen Schichtengliederung im rheinischen Braunkohlenrevier. – Fortschr. Geol. Rheinld. u. Westf., 16, 85-102.

Bůžek, C, 1971: Tertiary Flora from the Northern Part of the Pětipsy Area (North-Bohemian Basin). – Rozpr. Ústř. geol. 36, 1-118.

Chaney, R.W., 1959: Miocene Floras of the Columbia Plateau. – Carnegie Inst. Washington Pub. 617, 1-134.

Christensen, E.F., 1975: The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. Part I. – Danm. geol. Unders. (II), 103, 1-41.

Christensen, E.F., 1976: The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. Part II. – Danm. geol. Unders. (II), 108, 1-49.

Christensen, E.F., 1978: The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. Part III. – Unpublished thesis, University of Aarhus, 1-48.

Engler, A., 1882: Versuch einer Entwicklungsgeschichte der Extratropischen Florengebiete der Südlichen Hemisphäre und der Tropischen Gebiete. – Engelmann, Leizig, 386 pp.

Ferguson, D.K., 1971: The Miocene flora of Kreuzau, Western Germany, I. The leaf-remains. – 297 pp. Amsterdam, London.

Jähnichen, H., 1965: Beiträge zur Tertiärflora der Lausitz – inkohlte Blätter und Epidermisstrukturen. – Mber.Dtsch. Akad. Wiss. Berlin, 7 (9), 664-670.

Knobloch, E. & Kvaček, Z., 1976: Miozäne Blätterfloren vom Westrand der Böhmischen Masse. – Rozpr. Ústř. geol. 42, 1-131.

Kramer, K., 1974: Fossile Pflanzen aus der Braunkohlenzeit. Die obermiozäne Flora des unteren Fischbachtones im Tagebau Frechen bei Köln. – Mitt. Dtsch. Dendrol. Ges., 67, 199-233.

Mai, D.H., 1964: Die Mastixoiden-Flora im Tertiär der Oberlausitz. – Paläont. Abh. B, 2 (1), 1-192.

Mai, D.H., 1967: Die Florenzonen, der Florenwechsel und die Vorstellungen über den Klimaablauf im Jungtertiär der Deutschen Demokratischen Republik. – Abh. zentr. geol. Inst., 10, 55-81.

Sinnott, E.W. & Bailey, I.W., 1915: Investigation on the phylogeny of the Angiosperms, 5: Foliar evidence as to the ancestry and early climatic environment of the Angiosperms. Amer., J. Bot. 2, 1-22.

Szafer, W., 1961: Miocene Flora from Stare Glivice in Upper Silesia. – Prace Inst. geol., 33, 1-205.

4.B.7 Stratigraphical Study of the Browncoal Bearing Sequence of the Søby-Fasterholt Area based on Fossil Pollen

by B. Eske Koch

1. INTRODUCTION

The Browncoal Bearing Sequence of the Søby-Fasterholt area contains different fossil floras (the Fasterholt flora, the Søby Flora, the Damgård flora) which were described in the former chapter; and from which fundamental stratigraphical information has been extracted. Comparison of these fossil floras of the Neogene in the neighbouring areas of Europe by itself does not allow for a stratigraphical determination of the Jutlandish Browncoal Bearing Sequence. A correlation between the continental and marine facies of the Søby-Fasterholt area has not been established. The nearest region where such a correlation has been sufficiently established is the Lower Rhenian area (Hager, 1981). Here the enormous resources from Tertiary browncoal has initiated intense geological studies, including a detailed pollen stratigraphy erected on empirical basis. The Jutland material is restricted in occurrence and too small to serve as a foundation for a similar fundamental study. Instead an attempt to investigate the possibility of a pollen-stratigraphical correlation between the Lower Rhenian area and Central Jutland was made by the author. This study has resulted in a pollen stratigraphical correlation between the Lower Rhenian area and Central Jutland extending the range of the pollen-stratigraphical system from the Lower Rhenian Neogene.

The fossil pollen-flora of the browncoal beds in the Søby-Fasterholt area proves to be stable in qualitative composition of the pollen-spectra through the entire Browncoal Bearing Sequence and well into the Hodde Formation. This is in accordance with the huge empirical material from the Neogene of Central Northern Europe, especially expressed by the studies of the Lower Rhenian browncoal province (Brelie, 1967). This stability, which is also evident from the macroscopic fossil floras of the Central European Neogene, has defied stratigraphical subdivision of the non-marine Miocene by classical bio-stratigraphical methods using species renewals and extinctions. This time interval is presumably too short for the introduction of sufficient well-defined guide fossils. Quantitative factors, which have been employed with success in the Quaternary, can be used here with modification. In contrary to the Quaternary fossil pollen which can generally be referred to extant genera and to a wide extent also to recent species, the Miocene pollen can only partly be reliably referred to extant genera, and must generally be arranged in an artificial pollen systematics. Therefore the quantitative factors of an analysis of Neogene pollen is under much lesser control and the same methods of the Quaternary pollen analysis can only be employed with modifications. The investigation of Neogene pollen-stratigraphy must be founded upon quantitative information and empiricism. A large material from an extended province with a concentration of outcrops necessary for a reliable stratigraphy has been available in the Lower Rhenian area and collected by the Geological Survey of Nordrhein Westphalia.

G. von der Brelie (Krefeld) (1967, 1968) published important information on the pollen-stratigraphy of the Lower Rhenian, Neogene browncoal deposits. He arranged a frame of 7 microflora units (A-G), and extended the method in question into Central Europe (1967). A few pollen samples from the browncoal seams of the Søby-Fasterholt area, collected by W. Quitzow, 1960, had been analyzed by Brelie (1967). These samples (brown coal beds) were preliminary correlated with his microflora zone C, but with relationship as far as into the microflora E as concerns the upper part.

Hager (1968) changed the well known concepts of the Main Seam Group ("Hauptflöz") and the Upper Seam Group ("Oberflöz") into a 3-dimensional model with the Main Seam being the dominant seam (max. thickness 90 metres) in the SE region of the Lower Rhenian Graben, and the Upper Seam becoming more dominant to the west (max. thickness about 50 metres). This became the signal to further change of opinion on important factors. Hence, Gliese & Hager (1978) in a general survey published evidence for an Upper Miocene age of the Upper Seam Group based upon new information from the deep drilling Asten 1 near the Dutch-German border where marine facies interfingers with the limnetic Neogene. This led to a discussion on the existing stratigraphical concepts of the non-marine Neogene, questioning the stratigraphical value of the microfloras D and E. This was the background for the author's preliminary conclusion (Koch, 1979b), based upon the first stage of this pollen-stratigraphical analysis.

In 1981 revisions appeared, based upon combined new evidence from sedimentology, geophysics, stratigraphy (pollen, and marine fossils) and coal petrology (Hager, 1981; Brelie & Wolf, 1981 a, b; Brelie, Hager & Weiler, 1981) of the former stratigraphical model of the Neogene of the Lower Rhenian Graben. This revision included the combined efforts of the stratigraphers under I.G.C.P. project 124, subsection North European Tertiary Basin, who contributed with important evidence (reports not yet published). The combination of these studies (Hager, 1981) resulted in a change of stratigraphical concepts of the Oligocene-Neogene stratigraphy of the Lower Rhenian area. Hence, the "Kölner Schichten" (the Cologne Series) was replaced into the Oligocene; and the "Oberflöz Gruppe" (the Upper Seam Group) and the microflora E (Brelie, 1967) was replaced into the Upper Miocene. Also, the introduction of geochronology in the (Oligocene-) Neogene stratigraphy (Hager, 1981), and the introduction of correlations based upon nannoplankton and foraminiferal stratigraphy combined with the well-known pollen stratigraphical systems of the Lower Rhenian area was important in this revision.

So the Lower Rhenian Graben is the nearest region with an established modern stratigraphy presenting correlation between the marine and non-marine Neogene and a pollen-stratigraphy based upon browncoal. Similar conditions and types of data could serve as a reasonable basis for an attempt to establish stratigraphical correlation and to determine the Browncoal Bearing Sequence in the Søby-Fasterholt area to the stratigraphical level of stage/substage for both the marine and non-marine deposits.

2. METHOD AND TECHNICAL INFORMATION

The pollen-stratigraphical method used for the present study is after G. von der Brelie (1968). In the cited paper the basic literature is listed.

The method during a long period of continued studies of thousands of profiles at the Geological Survey of Nordrhein-Westphalia (Krefeld) under the leadership of Dr. G. von der Brelie and his predecessors professor P.W. Thomson and Dr. U. Rein, became established as a stratigraphical working tool for the lower Rhenian Browncoal Province and has successively been elaborated into detail.

This method is based upon a systematics of Tertiary pollen and spores from Central Europe surveyed by Thomsen & Pflug, 1953 and a general investigation of their occurrence in relation to time and facies normal for paleontology and stratigraphy. Quantitative analysis proved to be necessary and the empirical information from comparative analysis, facies analysis, and correlation of profiles led to the choice of a number of well represented pollen species, pairs or assemblages of pollen species, the quantitative stratigraphical variation of which was found to be characteristical for and obviously could describe the sequence of time in being less dependent on facies and/or ecological factors. This finally led to subdivision of the Lower Rhenian browncoal bearing sequence based upon microfloras with defined stratigraphical occurrence (micro-floras A-G), (fig. 59), (Brelie, 1967). A stock of publications has appeared during the last about 50 years (ref. Brelie, 1968).

In the present study samples were selected from the browncoal beds, and in a few cases from bituminous clay (Hodde Clay). The statistical analysis used here is based upon a minimum of (250-300) determined pollen grains per slide. Percentage values have been calculated upon the total number of determined pollen. This is in accordance with the standard procedure of G. von der Brelie. Critical levels were controlled by additional sample slides. So, each level of the Hodde Formation is represented by a minimum of 2 slides (500-600 pollen counted) and the 5th browncoal seam by 4 slides pro sample (1000-1500 pollen counted).

All the slides were re-examined after 1-2 years as an act of control, allowed only insignificant deviations in the percentage values of the spectra of the two examinations.

During the investigation of the browncoal bearing sequence of the Søby-Fasterholt area paleontological, stratigraphical and coal petrographical study (E. Thomsen) was conducted simultaneously. During the coal-petrographical facies analysis (E. Thomsen, ref page 38) fossil pollen and spores from the coal beds were also studied. A comparison of our different pollen countings served as another control on the determination and statistics of the pollen.

In order to make our results directly comparable with the investigations of the Lower Rhenian area E. Thomsen and B. Eske Koch studied at the palynological laboratory with Dr. G. von der Brelie in Krefeld and have followed his technical methods in our studies.

This investigation is to add supplementary criteria for a stratigraphical determination of the Browncoal Bearing Sequence of Central Jutland, and concentrated on the attempt to correlate with the Lower Rhenian browncoal province. The pollen stratigraphical method of G. von der Brelie et al. has proved helpful and the nomenclature and systematics of fossil Neogene pollen used in the many papers of Brelie has been applied in this paper. Hence, the artificial nomenclature of genera of Thomson & Pflug, 1953, are generally used, with exceptions for the stratigraphical important species of Brelie's pollen stratigraphical diagrams (for the practical purpose of facilitating comparison in text and diagrams). Being aware of the later revisions the names of his stratigraphically useful species shall be cited here:

Stratigraphical Tables (G. von der Brelie)	Revison
S. polyformosus	*Sequoiapollenites largus* (Kremp 1949) Manum 1962.
Tsugapoll. sp.	Cfr. *Zonalapollenites rueterbergensis* Krutzsch 1971.
S. serratus	*Sciadopityspollenites serratus* (R. Potonie & Veinitz 1934) Raatz 1937.
I. emmaensis	*Inaperturopollenies emmaensis* Muriger & Pflug 1952
E.punctatus	*Momipites punctatus* Nagy 1969
E. microcoryphaeus	*Platycaryapollenites miocaenicus* Nagy 1969
Q. henrici	*Tricolpopollenites henrici* (R. Potonie 1931) Thomson & Pflug 1953.
Q. microhenrici	*Tricolpopollenites microhenrici* (R. Potonie 1931) Thomson & Pflug 1953.
T. villensis	*Tricolpopollenites villensis* (Thomson 1950) Thomson & Pflug 1953
R. pseudocingulum	*Tricolporopollenites psuedocingulum* (R. Potonie 1931) Thomson & Pflug 1953.
C. fusus	*Tricolporopollenites cingulum* ssp. *fusus* (R. Potonie 1934) Thomson & Pflug 1953.
C. megaexactus	*Tricolporopollenites megaexactus* (R. Potonie 1931) Thomson & Pflug 1953.
Nyssapoll. sp.	*Nyssapollenites krutzschi* (R. Potonie 1931) Nagy 1969.
L. stigmosus	*Periporopollenites stigmosus* (R. Potonie 1931) Thomson & Pflug 1953.
C. simplex	*Subtriporopollenites simplex* (R. Potonie 1931) Raatz 1937.
P. stellatus	*Pterocaryapollenites stellatus* (R. Potonie 1931) Thiergart 1937.
Sapotaceoidaepoll.	*Tetracolporopollenites sapotoides* Thomson & Pflug 1953.

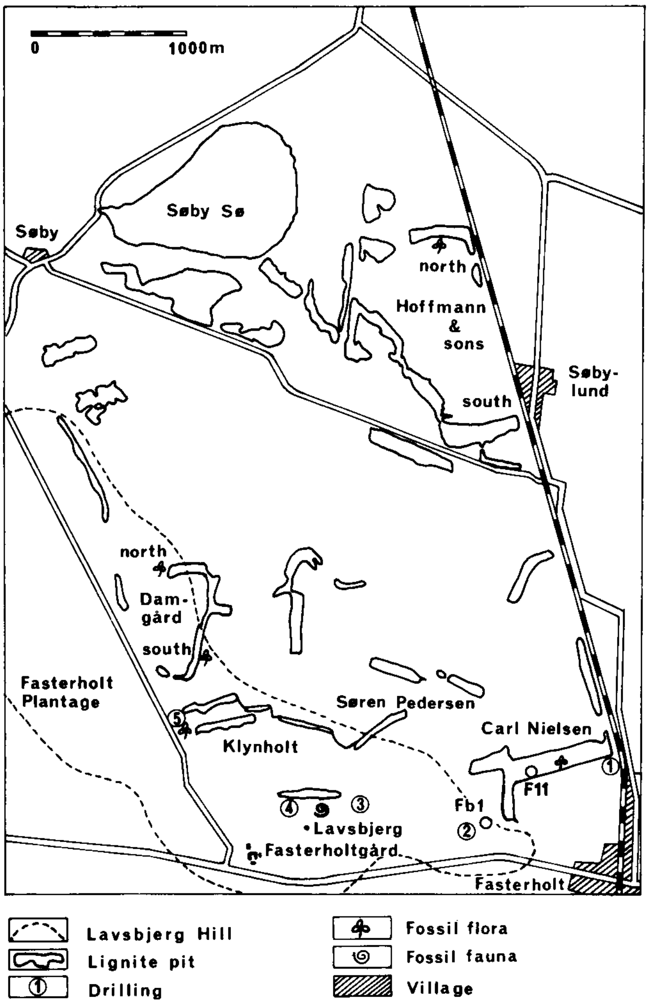
3. RECORDS

The present investigation was based upon 3 separate profiles:

1. The profile F 11, the Carl Nielsen Ltd. Browncoal Pit at Fasterholt, extended by probe Fb 1 (1979), at Fasterholt Bjerg (hill) (Text-Fig. 54, 55).
2. The borehole Fasterholtgaard 1 (1973), Klynholt Vest (Text-Fig. 54 (5), 56).
3. The borehole Fasterholt Bjerge (1970), at Fasterholt railway station (Text-Fig. 54 (1), 57).

The General Representative Stratigraphical Diagram, (Text-Fig. 58)

A general pollen-stratigraphical diagram representative for the Søby-Fasterholt area has been compiled from the above mentioned 3 profiles. It is assumed that the succession of analytical frequency spectra (reflecting the sedimentary sequence) involved, represents a continuous and true stratigraphical sequence. And provided that the samples involved are suited for study in accordance with the provisions of the original method (Brelie, 1968).



Text-Fig. 54. Map of the Søby-Fasterholt area specifying involved localities: l) Borehole "Fasterholt Bjerge" 3) Borehole "Lavsbjerg Øst", 5) Borehole "Fasterholtgaard 1" and outcrop "Klynholt Vest" (EM), F 11) Profile F 11 of the Carl Nielsen Ltd. browncoal pit, Fb 1) Probe Fb 1 in the hill of Fasterholt Bjerg.

This pollen diagram is based upon the type section F 11 and the Fb 1 probe (1979) with minor additions from other sections. The profile F 11 at the west end of the Carl Nielsen Ltd. browncoal pit has supplied the majority of samples, to which have been added the samples from the 4th seam of the Lavsbjerg Øst borehole, the local 5th seam of the outcrop of Klynholt Vest (alternative to the occurrence of the 5th seam in the Fasterholtgård 1 borehole (1973)) and from the basal gravel- sand-clay bed of the Hodde Formation at Klynholt. The stratigraphical position of the last mentioned is fixed by the upper root-stump horizon and the lower boundary of the Hodde Clay respectively. Samples from probe Fb 1(1979) start above this bed.

Addenda to the pollen stratigraphical diagrams fig. 55-58:

Lower level of record in the histograms: 1% (0.7% <)

0 (zero): Inconsiderable representation (0.1-0.6% and doubtful specimens).

4. COMPARATIVE ANALYSIS OF THE 3 POLLEN-STRATIGRAPHICAL DIAGRAMS (PROFILES) OF THE SOUTHERN PART OF THE SØBY-FASTERHOLT AREA

A: The Browncoal Bearing Sequence (Fasterholt Member)

The 3 profiles to be compared are (from east towards west):

1. The Fasterholt Bjerge borehole (at Fasterholt railway station (1970), Text-Fig. 57).
2. The profile F 11 of the outcrop of the browncoal pit of Carl Nielsen Ltd. (1970), (Text-Fig. 55).
3. The Fasterholtgaard 1 borehole (1973), (Text-Fig. 56).

From the base to the top the quantitative variation of the pollen species for a large proportion of the involved species show similar trends when we compare the 3 diagrams. There are some minor deviations in the details, presumably due to a difference in frequency of sampling. In the stratigraphical succession of the diagrams the lowermost and uppermost analytical spectra of the 2nd and 3rd browncoal seams differ, suggesting different times for the initiation and termination in deposition of browncoal ooze for the involved localities. Regarding the 1st browncoal seam a comparison is difficult because only in profile F 11 (the Carl Nielsen Ltd. browncoal pit) is the seam represented by a succession of samples (spectra).

Comparing the 3 diagrams it is possible to point out the following similarities:

Sequoiapollenites polyformosus and *Sciadopityspollenites serratus* show a general similarity in the trend of values through the 3 diagrams. A local peculiarity in common in the 3 diagrams is the maximum in the 1st seam. A general distinctive feature is the increasing and marked representation of *S. serratus* in the 3rd (and 4th) seam(s).

Quercoidites henrici and *Quercoidites microhenrici* each have the same trend through the 3 diagrams, as well as their relative representation.

Though there are deviations in values of these pollen species between different diagrams in corresponding or near related spectra, the proportion *Q. henrici*/*Q. microhenrici* follows identical trends through all three stratigraphical successions. In the 1st seam, *Q. henrici* is quantitatively absolutely dominating over *Q. microhenrici* (Qh:Qm $>$ 1). This dominance grades into equality through the 2nd seam (Qh:Qm = 1). An identical succession is found in microflora-interval C of the Lower Rhenian diagrams.

Q. microhenrici is absolutely dominant over *Q. henrici* (Qh: Qm $<$ 1) through the succession of the 3rd, 4th and 5th seams, analogous with the microflora D interval in the Lower Rhenian diagram (op. cit.).

In the basal transgressional bed of the Hodde Formation this ratio is again nearly equal continuing with a less pronounced dominance of *Q. henrici* over *Q. microhenrici* in the overlying Hodde Clay.

Engelhardtioipollenites punctatus shows a similar trend throughout the 3 diagrams.

Engelhardtioidites microcoryphaeus shows a nearly identical succession of quantitative values through 1st, 2nd and 3rd browncoal seams of the three diagrams.

Inaperturopollenites emmaensis is represented with values less than 1% only in the 3rd browncoal seam.

Tricolporopollenites villensis shows optimal values (1-2%) in the 3rd to 5th seam and occurs sporadically with values less than 0.7% in the remaining parts of the profile.

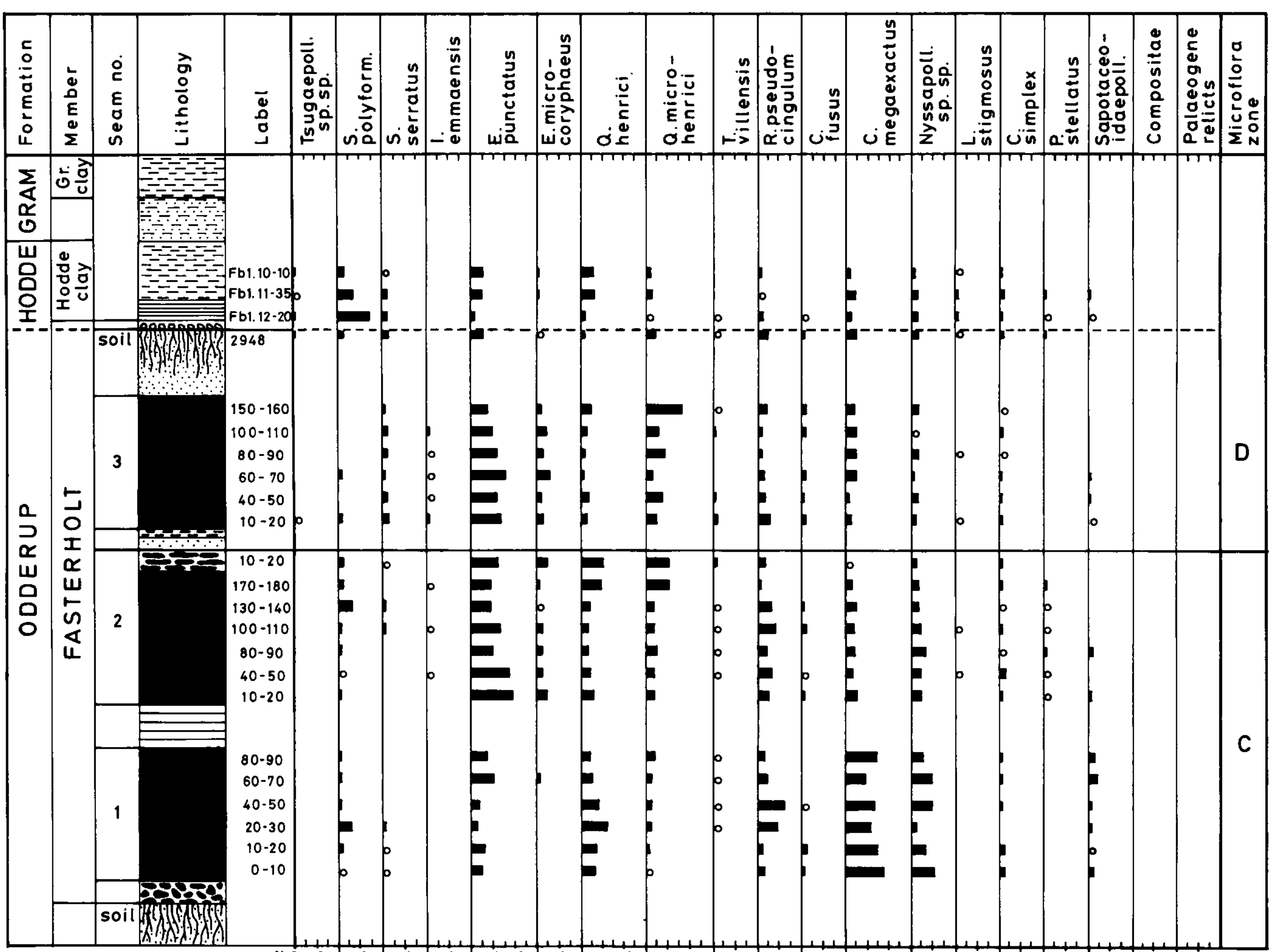
Rhoipites pseudocingulum. Profile F 11 contains a succession of 6 spectra in the 1st browncoal seam, with small values (in total 4 spectra) in the bottom (2 spectra) and the top (2 spectra). The other 2 drillings have only one spectrum (one sample analyzed) from this seam and also show small values. A common trend found through the 2nd seam shows a symmetrical evolution of frequencies around a central optimum. Through the 3rd seam the opposite trend is found (with a central minimum).

Cyrillaceaepollenites megaexactus. Large values in the 6 spectra of the 1st browncoal seam as well as the other 2 drillings with only 1 spectrum of this seam each showing a large value. As a common general trend the 2nd seam shows small values, and medium values are registered in the 3rd browncoal seam with an optimum in the top of the seam.

Nyssapollenites sp. sp. shows medium values that decrease upsection at least from an optimum in the middle in the 2nd seam; and small-medium, irregularly scattered values with 2(3) maxima in the 3rd seam (deviation in Fasterholt Bjerge borehole). (The minor deviations in some details may be owing to difference in frequency of sampling of the F 11 outcrop and the boreholes).

Caryapollenites simplex is discontinuous, with small values and a tendency for values to increase in the lower (and middle) part of the 2nd and 3rd browncoal seams.

Sapotaceoidaepollenites sp. sp. is discontinuous with small, scattered values at approximately correlated levels of occurrence. So, in the bottom of the 2nd seam and at the middle of the 3rd seam (profile F 11 and Fasterholtgaard 1 borehole (1973)).



Text-Fig. 55. Pollen Diagram of Profile CN. F11 + Probe Fb1 (Hodde Clay-Gram Clay), Browncoal Pit of Carl Nielsen LTD (Fasterholt).

The spectral successions (of samples) of the 3 diagrams do not represent exactly the same stratigraphical range. The profile F 11 is the most extensive and so its succession of spectra. It includes a xylitic coal bed on top of the 2nd browncoal seam, representing a unique local driftwood accumulation. The pollen spectrum (labelled 10-20) of this bed is not represented in the two borehole profiles. Also the stratigraphical range of the spectra of the 3rd seam of profile F 11 correlate with the 3rd and 4th seam of Fasterholtgaard 1 borehole.

Hence, the deviations can be described as follows:

The 2nd browncoal seam: In the Fasterholt Bjerge borehole and profile F 11 this seam begins at approximately the same spectral level (but the Fasterholt Bjerge borehole lacks the lowermost spectrum of *Q. henrici, Q. microhenrici,* and *E. punctatus*) suggesting that deposition started synchronously. The initial spectrum may be lacking in the Fasterholtgaard 1 borehole, suggesting a later initiation of deposition.

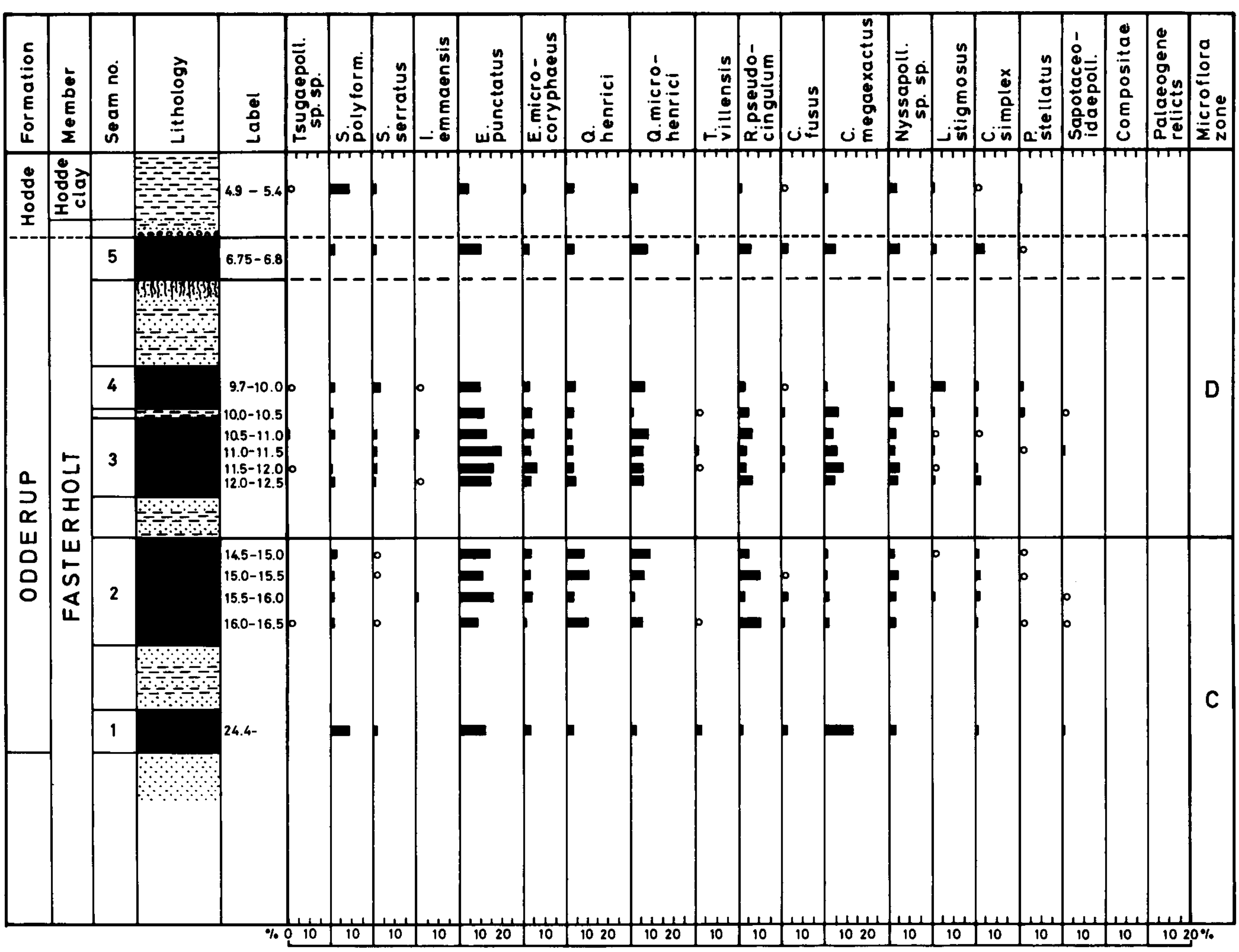
The 3 diagrams end with similar spectra if the uppermost spectrum of F 11 (the driftwood accumulation, the top bed of the 2nd browncoal seam) is excluded, suggesting synchronous termination of deposition of the allochthonous browncoal ooze.

The 3rd browncoal seam: Profile F 11 and Fasterholtgaard 1 borehole begins with the same spectrum, the succession of Fasterholt Bjerge borehole starting approximately 2 spectra later. This suggests synchronous initiation of deposition at the localities of profile F 11 and Fasterholtgaard 1 borehole with later initiation of deposition at Fasterholt Bjerge borehole. The succession of spectra of the 3rd seam at F 11 presumably correlates with the sum of spectra of the 3rd and 4th brown coal seams in Fasterholtgaard 1 borehole suggesting synchronous termination in deposition of the 3rd seam at profile F 11 and the 4th seam of Fasterholtgaard 1 borehole. There is a good correlation between the succession of spectra in the 3rd seam at the Fasterholt Bjerge borehole and the 3rd seam at the Fasterholtgaard 1 borehole.

B. The Hodde Formation and the transition to the browncoal bearing sequence (Fasterholt Member).

The upper part of the geological succession considered here is represented in 2 diagrams (profiles):

1. The profile F 11 + probe Fb 1 (1979) of the browncoal pit of Carl Nielsen Ltd. and the neighbouring hill Fasterholt Bjerg (Text-Fig. 55).



Text-Fig. 56. Pollen Diagram of drilling Fasterholtgård 1+5° browncoal seam of Klynholt Vest (probe B II).

2. The Fasterholtgaard 1 borehole (1973), (Text-Fig. 56).

Other localities are also included into the general pollen stratigraphical diagram for representing this stratigraphical level (the 5th seam and the basal bed of the Hodde Formation).

This stratigraphical interval includes the root/stump horizon ending the 4th rhythmical unit, the 5th browncoal seam, the basal transgressional and clastic bed of the Hodde Formation and the Hodde Clay proper on top.

The succession of spectra from this stratigraphical level is nearly identical.

A comparison between the succession of the quantitative variation (percentage values) of important pollen species from the two diagrams shows obvious similarities as demonstrated below:

S. polyformosus. Below the Hodde Formation this species has small values, in the Hodde Clay high values.

S. serratus shows similar modest values through the profiles.

E. punctatus shows medium values in the Hodde Clay, the 5th browncoal seam and the underlying soil/root horizon.

E. microcoryphaeus shows minor values in the 3rd and 4th seam and small values in the Hodde Clay.

Q. henrici shows similar or larger values in the Hodde Formation than in the 5th browncoal seam and the underlying root/horizon.

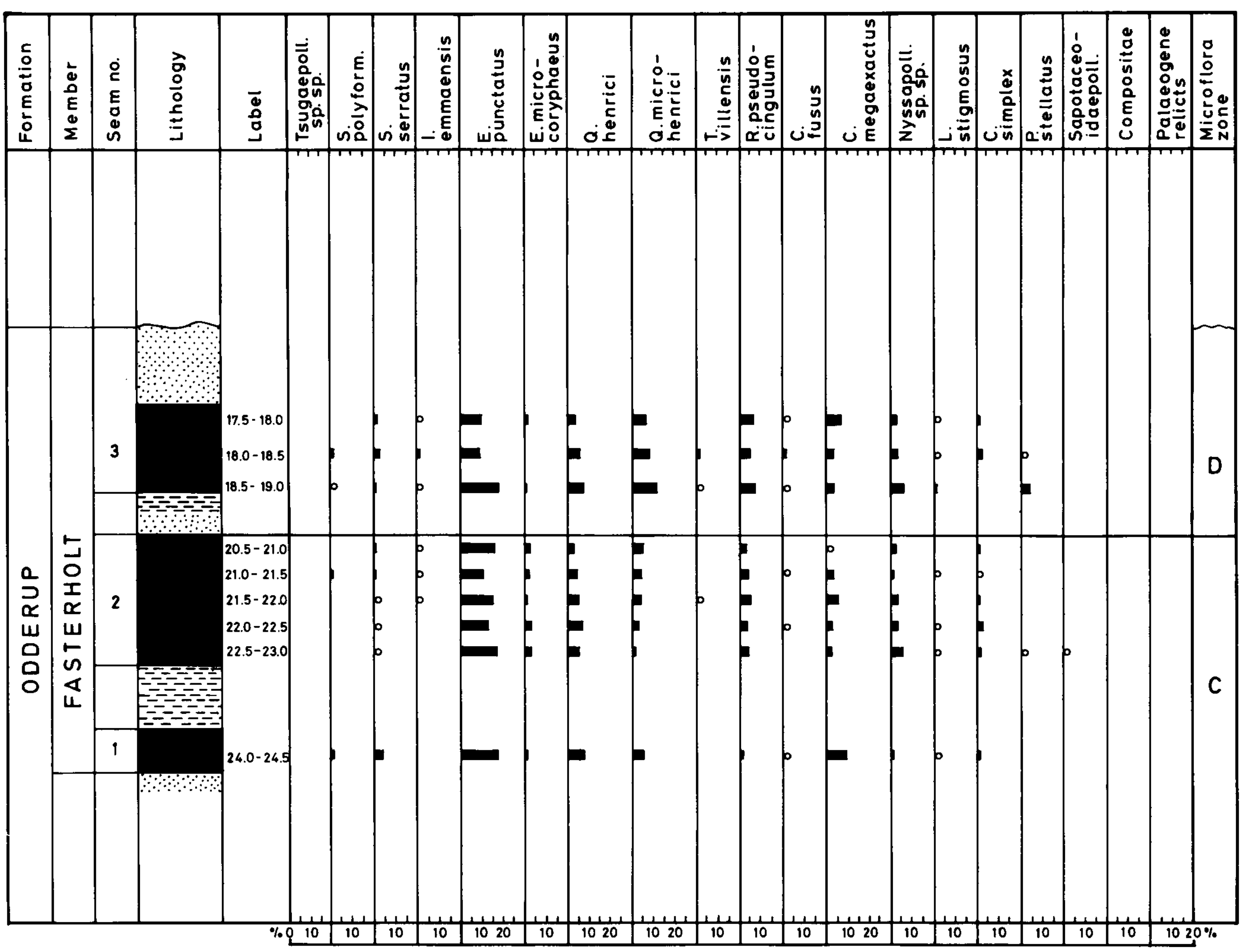
Q. microhenrici shows small values but smaller values in the Hodde Clay than in underlying basal bed of the Hodde Formation (sample 2982.2), the 5th browncoal seam and the underlying soil/root horizon.

The ratio *Q.henrici/Q.microhenrici:* Immediately below the Hodde Formation the values of *Q. microhenrici* just exceed those of *Q. henrici* (Qh/Qm < 1), i.e. are near a balance (Qh/Qm = 1).

In the Hodde Formation, the values of *Q. henrici* just exceed those of Q. microhenrici (Qh/Qm > 1), but near to equality (Qh/Qm = 1).

T. villensis is generally lacking in the Hodde Formation.

T. cingulum subsp. *fusus.* Small values (1-2%) are



Text-Fig. 57. Pollen Diagram of drilling Fasterholt Bjerge, at Fasterholt railway station. Fasterholt Member overlain by Quaternary sands.

continuously represented up to the base of the Hodde Formation. Values below 1% or zero are found in the Hodde Formation.

C. megaexactus. Distinct medium values occur below the Hodde Formation. Declining values were recorded upwards through the Hodde Clay (small values).

Nyssapoll. sp. sp. Medium values in the lower levels of the profile with a tendency to declining values upwards through the Hodde Formation.

Besides the pollen species which are standard ingredients in the pollen stratigraphical method after Brelie, (1967) there are pollen species that occur in restricted intervals and may be useful indicators for a local stratigraphy. At the moment the remaining sum of pollen species from the Søby-Fasterholt area has not been thoroughly analyzed in detail, but a single case should be mentioned:

Intratriporopollenites instructus (Pot.) Th. & Pf.

This pollen species has been found in low (to medium) percentage values, approximately restricted to the 4th rhythmic unit of predominantly fluviatile sands ("Upper Sands"), to the west substituted by lacustrine clay-sand facies. Associated with small fossil seeds an anther containing this pollen species has been reported from the upper part of this sand at the east front of the Damgaard S pit (Friis, 1979). *I. instructus* was recorded by the present author from 7 localities and 14 different stratigraphical levels within the 4th rhythmical unit in the southern half of the Søby-Fasterholt area (see below):

The Hodde Formation:	Klynholt Vest, probe
Basal transgressional bed	BII-5.30
(Hodde Formation):	Klynholt N-section, label 2982.2
The 5th browncoal seam:	Klynholt Vest, label 2962
	Klynholt Vest, probe BII-6.80
	Klynholt Vest, probe BII-6.85
The Upper Sands: Soil/root horizon	Carl Nielsen pit, K6-K7
The Upper Sands: Upper part, E.M. Friis (1979)	Damgaard S pit, east front
The Upper Sands: Lacustrine facies, middle part	Klynholt Vest, probe BI-8.20
	Damgaard N pit, probe D.N.-10.9
Lacustrine facies, bottom clay	Klynholt Vest, probe BI-10.1
Lacustrine facies, bottom clay	Klynholt Vest, probe BI-10.3
The 4th browncoal seam:	Lavsbjerg Øst, dril. 10.9-11.4
	Fasterholtgaard 1, dril. 9.7-10.0
Clay below the 4th seam:	Klynholt Vest, probe BI-11.1
	Fasterholtgaard 1, dril. 10.0-10.5

Conclusion 1

From the above analysis 1) a general similarity between the 3 profiles is obvious and 2) a good correlation between the 3 profiles is demonstrated which allows for the compilation of a general pollen-stratigraphical diagram valid for this sequence in the Søby-Fasterholt area.

Also, by a comparison between the individual profiles from the Søby-Fasterholt area and the succession of typical pollen associations of stratigraphical value from the Lower Rhenian area (Brelie, 1967, fig. 1, profile 36) it is possible for each of the 3 profiles of Søby-Fasterholt area, on palynological evidence, to correlate a narrow interval between the 2nd and 3rd browncoal seams with the limit between the microflora zones C and D (Brelie, 1967). The scale of deviations of pollen spectra of the samples and of the succession of spectra of the important stratigraphical indicator-species allows of a general practical definition, fixing this stratigraphical limit to the boundary between the 2nd browncoal seam and the overlying sand (-clay) bed, well known as the bed of the *Fasterholt Flora.*

In the profile of the Carl Nielsen Ltd. browncoal pit and the Fasterholtgaard 1 borehole (1970) the appearance of a marked rise in frequency of *Sequoiapollenites polyformosus* in the spectra of the Hodde Clay (initiated in the 5th browncoal seam) may indicate that this part of the succession reaches into the Rhenian microfloristic "Abschnitt" III b (Rein, 1950), (ref. page 304), which is again approximately at the interval of the Main Seam to be correlated with the Lower Rhenian marine "Höheres Miozan" (Hager, 1981) (=basal Upper Miocene); Alternatively this *Sequoiapollenites polyformosus* maximum appears in the uppermost Reinbekian in the Danish area.

A general correlation between the two drillings at the west and east border of the Søby-Fasterholt area and from the intermediate profile F 11 + Fb 1 (1979) is suggested and expressed in terms of Lower Rhenian microflora-intervals, i.e. at a stratigraphical level of stage/substage. In addition, this local correlation is supported by an interval between the 4th browncoal seam and the basal transgressional gravel-sand-clay bed of the Hodde Formation containing common and continuous occurrence of *Intratriporopollenites instructus* (Pot.) Th. & Pf.

A comparison between the succession of spectra from the 2nd and the 3rd browncoal seams in each of the 3 diagrams allows an independent correlation between the 3 occurrences in question of these 2 particular seams (as stratigraphical levels). When the 4th seam of drilling Fasterholtgaard 1 is included the relative time of initiation and termination of deposition of these browncoal seams can be inferred (ref. Text-Figs. 55-57).

Hence, in this local area the sequence of pollen spectra of the 2nd and 3rd seam is sufficient characteristical and similar in the 3 profiles to allow for local stratigraphical correlation. This suggests that extended analysis might afford local zonation of units of the stratigraphical extent of the browncoal seams, especially when stratigraphical extensions of the 3 profiles of this chapter in future should be available in the region.

5. COMPARATIVE ANALYSIS OF THE GENERAL POLLEN-STRATIGRAPHICAL DIAGRAM OF THE SØBY-FASTERHOLT AREA AND THE POLLEN STRATIGRAPHICAL DIAGRAMS OF THE LOWER RHENIAN AREA (Text-Fig. 58-59)

The following is a pollen stratigraphical comparison between the Browncoal Bearing Neogene of the Søby-Fasterholt and the Lower Rhenian areas based upon variation in the relative quantitative representation of the different stratigraphical indicative pollen species selected for the method of G. von der Brelie (1967, 1968), (Text-Fig. 58-59). In this analysis deviations of the absolute values from species of a particular seam are affected stratigraphically from irrelevant factors introduced by species not involved in diagrams (e.g. of the saccate pollen) the frequency of which may be strongly dependent of ecology, sorting during transport etc. This factor can be suggested, but at this moment not expressed and corrected for in rational terms.

Hence, pollen correlation is to be found preferably in the relative factors in the succession of percentage values of the species of the diagrams.

It must be recognized that the general pollen-stratigraphical diagram of the Lower Rhenian region represents a general and more concentrated information than the Søby-Fasterholt diagram. A single spectrum in the former diagram may be represented by a sequence of two or more spectra in the latter. Consequently, the spectra of the Søby-Fasterholt diagram cannot individually serve as a basis for analysis in comparison with the former diagram. The important evidence for stratigraphical correlation comes from the trends of variation through the succession of pollen spectra (in stratigraphical sequence).

Correlation between the Lower Rhenian and the Søby-Fasterholt diagrams is most astonishing when the vertical stratigraphical variation of the percentage values of the single pollen species are considered, especially in the lower part of the successions (compare microflora interval C with the 1st and 2nd seams). Local differences are also involved and the following analysis support this view:

One obvious similarity between the two areas is the stratigraphical range of *Sciadopityspollenites serratus* showing significant values and a continuous representation introduced at the level of the 3rd browncoal seam/ microflora-interval D. Also *Inaperturopollenites emmaensis* represented by of small values is restricted occurring only in the 3rd seam/microflora-interval D. These isolated occurrences may be a random fit and hence without stratigraphical weight in contrary to *Sciadopityspollenites serratus* appearing as a succession of events.

Detailed evidence is found from comparison of the trend of variation of the percentage values of the following pollen species in the diagrams in question. These species show obvious similarity in percentage variation (through the stratigraphical sequence) for the two regions compared, that is suggested to be indicative of stratigraphical correlation.

So a high degree of similarity in the trends of variation of the statigraphical sequences that are compared, are found for: *Q. henrici, Q. microhenrici, Rhoipites pseudocingulum,* and *Cyrillaceaepoll. megaexactus,* all of them distinctive species of stratigraphical value. Of these species *Q. henrici* shows a nearly identical stratigraphical variation and *Q. microhenrici* a very similar variation through the diagrams of the Lower Rhenian area and the Søby-Fasterholt area (for details, see Koch, 1984 and the abstract below).

A general similarity between the trends of percentage variation of the two diagrams are found for: *Engelhardtioipoll. punctatus, Tricolpopoll. villensis, Nyssapoll.* sp. sp. and *Caryapoll. simplex. Liquidambarpoll. stigmosus* occurs scattered through the stratigraphical column of both diagrams: Rare, with scattered low values.

Sapotaceoidaepollenites sp. sp.: Continuous representation of small values in the 1st seam, grading into the 2nd seam/microflora-interval C with an optimum uppermost in the 1st seam/middle microflora-interval C. Some small values in continuation occur in the 3rd seam/middle interval D, and a single small value in the Hodde Clay.

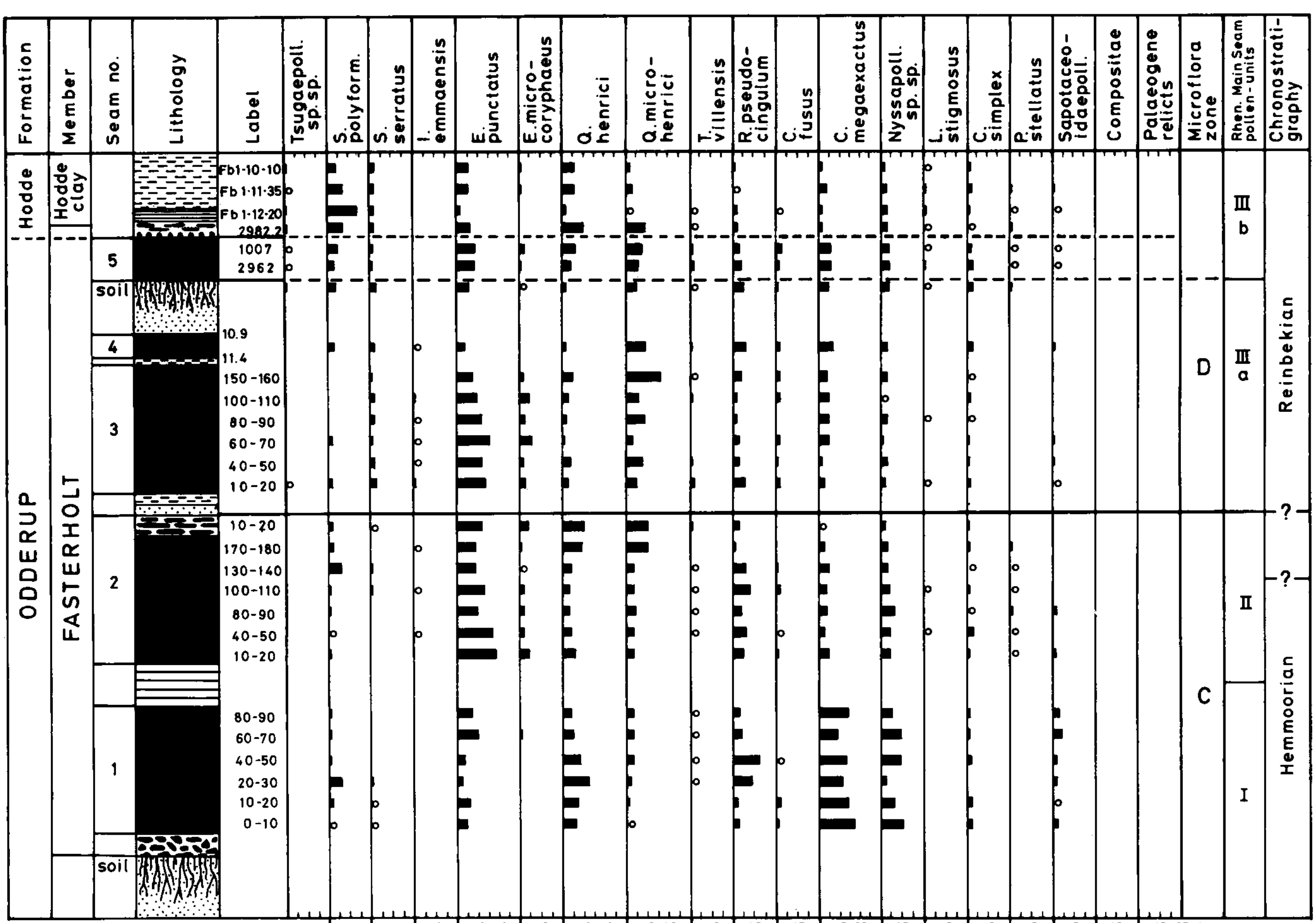
In this comparison the relative proportion between the quantitative representation of *Q. henrici* and *Q. microhenrici* is especially interesting. Though there are deviations between the absolute values of these pollen species in corresponding or near related spectra, the proportion *Q. henrici*/*Q. microhenrici* follows indentical trends through the stratigraphical successions in question. In the 1st seam *Q. henrici* is quantitatively absolute dominating over *Q. microhenrici* (Qh:Qm > 1). This dominance grades through the 2nd seam into a balance (Qh:Qm = 1). An identical succession is found in microflora-interval C of the Lower Rhenian diagrams.

Through the succession of spectra for the 3rd, 4th, and 5th seams the *Q. microhenrici* is predominant over *Q. henrici* (Qh:Qm < 1) like the microflora D interval in the Lower Rhenian diagram. In the basal transgressional bed of the Hodde Formation this ratio changes into balance continuing in a less pronounced dominance of *Q. henrici* over *Q. microhenrici* in the Hodde clay. This may correlate with the microflora zone E of the Lower Rhenian diagram, though in the latter this dominance is more pronounced. However, for reasons appearing from the compilation of the total pollen-stratigraphical information correlation with microflora E is not likely.

There are restrictions for a comparative pollen-stratigraphical study of the Hodde Formation, because the method of G. von der Brelie (1967, 1968) is based upon browncoal exclusively. The Hodde Formation consists of marine clays, so its allochtonous pollen-flora probably have been sorted in a different way (Brelie, 1958). The high proportion of worn and strongly corroded pollen occurring together with excellently preserved pollen and a marked dominance of coniferous pollen in the Hodde Formation in contrast to the underlying browncoal bearing sequence excludes the pollen spectra of the Hodde Clay proper from this comparative study that is based on the premises of G. von der Brelie; or it must be handled with extreme care, e.g. with discrimination of secondary and long distance transported pollen.

A correlation between the Hodde Formation and microflora-interval E of the Lower Rhenian area (ref. Qh:Qm) can be questioned due to marine stratigraphical evidence: The Hodde Formation is correlated with the *Reinbekian* (on molluscs; Rasmussen 1961, 1966, supported by dinoflagellates: Piasecki, 1981) which according to Hager, (1981) can be correlated with (or enclosed into) the stratigraphical interval of the middle (-upper) part of the Main Seam ("Hauptflöz") of the latter area. (see stratigraphical discussion, page 303-304). The lower Rhenian Upper Seam Group ("Oberflöz") which contains microflora E of Brelie, 1967 (before 1981 correlated with the Reinbekian) is now assumed to correlate with the *Upper Miocene*.

A comparison between the pollen-stratigraphical succession of the browncoal bearing sequence of the Søby-Fasterholt area (below indicated by seam numbers) and the total succession of typical pollen associ-



Text-Fig. 58. General Pollen-Stratigraphical Diagram of the Søby-Fasterholt area, Central Jutland (prof. CN. F11 + probe Fb1 + dril. Lavsbjerg Øst + Klynholt Vest).

ations of stratigraphical value of the NW-Germany including the Lower Rhenian area (microfloras of the diagram of Brelie (1967) fig. 1, below indicated by capitals) is based especially upon trends of quantitative variation seen in the analytical spectra of the following Pollenites species:

S. serratus: Appears essentially above the boundary between microflora zones C/D and 2nd/3rd seams.

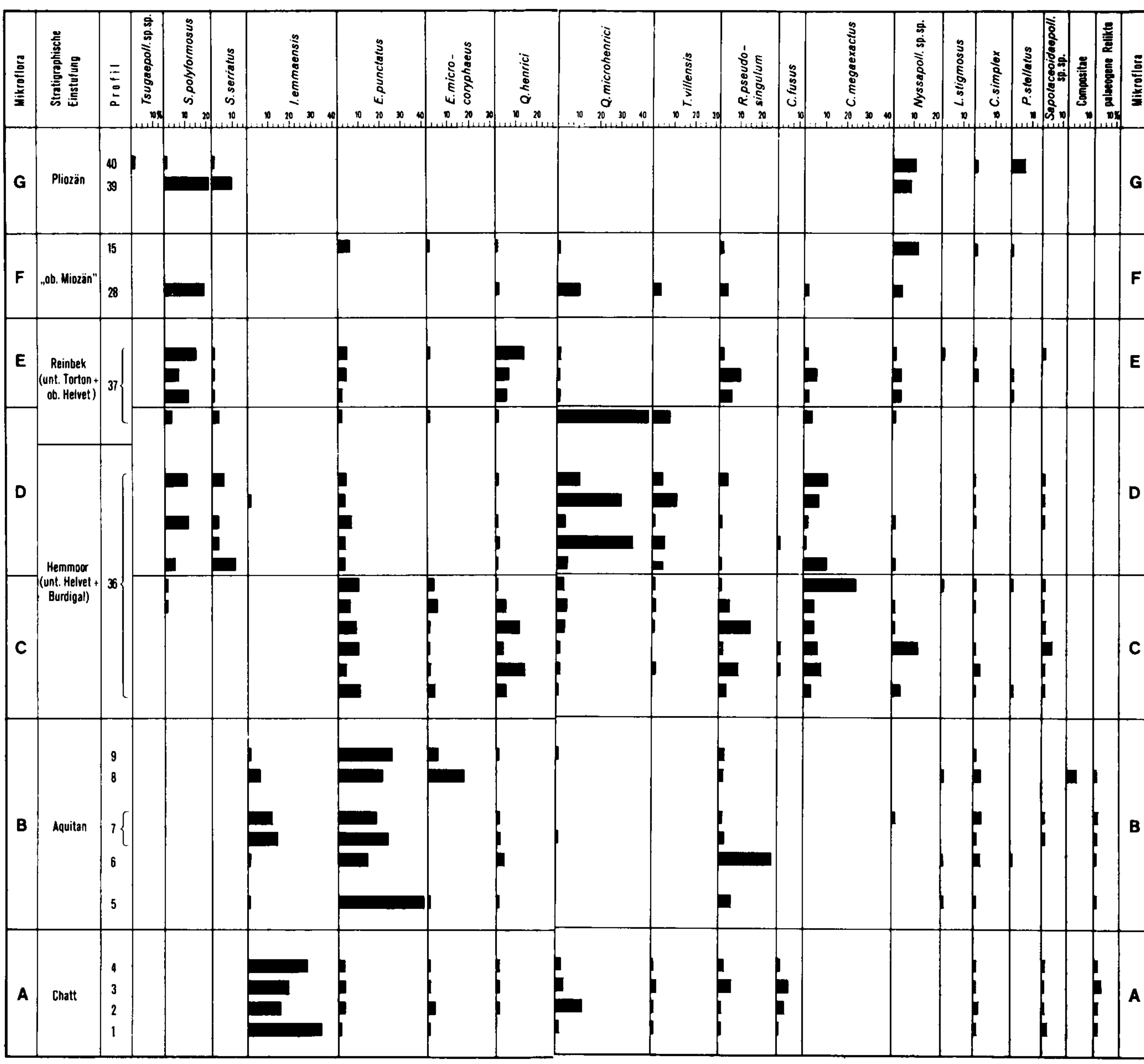
E. punctatus: Agreement of the quantitative sequence with rapidly changing optima and minima through the microflora interval C and the basal part of D, respectively the interval 1st, 2nd, and 3rd seam, of the Søby-Fasterholt area, continuing upwards in the sequence with declining percentage values.

Q. henrici: Agreement of the quantitative sequence with two optima in microflora interval C corresponding with one optimum in the middle of the 1st seam and one uppermost in the 2nd seam changing into low values in microflora interval D and in the succession including the interval 3rd-4th seam is similar.

Q. microhenrici: Agreement of the quantitative trend of the sequences, especially through microflora interval C and the 1st 2nd seams. So the succession begins with small values lowermost in microflora interval C/1st seam, increasing into a significant optimum uppermost in C/2nd seam. The remarkable change between low and high values in microflora interval D and the interval 3rd-4th seam is similar.

T. villensis: Extremely low values are found through microflora interval C and the interval 1st-2nd seam and a change into higher values upwards from the limit microflora C/D and the interval 3rd-5th seam with similar trends.

R. pseudocingulum: Agreement in the trend of the quantitative sequence through microflora interval C and the interval 1st-2nd seam with two optima, the first



Text-Fig. 59. Quantitative distribution (%) of stratigraphical important Pollenites in characteristic pollen spectra from various levels of the central European Neogene (Brelie, 1967, fig. 1); Profile numbers refer to list of localities, (ibid. table 1).

in 1st seam and the next in the 2nd seam corresponding to one lowermost and uppermost in microflora interval C. The agreement is less significant in microflora interval D and the 3rd seam respectively, where the succession ends with an optimum of medium percentage value in the middle of interval D; this may correspond to an optimum in the 4th seam (or the 5th seam).

In comparing the two areas of Central Jutland and NW Germany it must be pointed out that the record of samples of the Lower Rhenian Main Seam is represented by stratigraphically continuous samples in the central area of distribution, while in the Søby Fasterholt area there are lacuna due to paraconformities and clastic sediments devoid of fossil pollen.

The present correlation involves the stratigraphical information of Hager (1981 and personal communication) which correlates the marine *Rheinbekian* of the Dutch-German border area (boreholes Straten 1, Asten 1, and Heidhausen) with approximately the middle of the *Frimmersdorf a Subseam* of the Main Seam (at about the middle. According to Hager the *Frimmersdorf Subseam* in pollen stratigraphical terms ranges from the upper part of microflora zone C and to the beginning of microflora zone D). Also, it is taken into account that the Søby-Fasterholt Hodde Clay presumably is a late deposit of the *Reinbekian* transgression.

The stratigraphical diagram based upon the typical Pollenites associations (Brelie, 1967, 1968) in principle rests upon the browncoal seams of the Lower Rhenian area as concerns the microfloras C and D. Hence, there is assumed a direct correlation between this stratigraphical system of G. von der Brelie (1967) and the subdivisions of the Lower Rhenian Main Seam ("Hauptflöz") constructed by Rein (1950):

Nannoplankton zone (IGCP Project 124) (approximations)	Rein 1950		Brelie	Hager 1981
		d		
				Höheress Miozan
		c	D	(Flöz Frimmers-
	III			dorf b)
NN 5		b		
		a		
		b		
	II			
		a		(Flöz Frimmers-
			C	dorf a)
				Rheinbekian
		b		
	I			
		a		
NN 4				
				Hemmoorian
NN 3				

Correlation between the browncoal bearing sequence of Central Jutland, Denmark with the microflora-stratigraphy of NW-Germany developed on coal-bearing strata (Brelie, 1967) is actually a correlation with the pollen-stratigraphical subdivision of the Lower Rhenian Main Seam (Rein, 1950). Rein's subdivision is based upon another method of calculation of the "percentage" values attributed to the Pollenites species of the sample which gives higher nominal values of the individual species or group of species used in his diagrams and so a better and more detailed visual representation of the variation in frequency of the pollen species throughout the profiles.

Nevertheless, it is possible to compare the general trends of relative variations through the succession presented by the different Pollenites species of the diagrams based upon Rein's method and the general diagram of the Søby-Fasterholt area what concerns the stratigraphical successions at and below the *Reinbekian* level (in the Rheinian Main Seam this level is situated at about the middle of this seam (Hager, 1981 and personal communication)). In the Søby-Fasterholt area, the Hodde Formation is enclosed in this stage, presumably representing the uppermost part of the Reinbekian transgression. Also, the absolute occurrences of a particular species can be taken into account in this comparison.

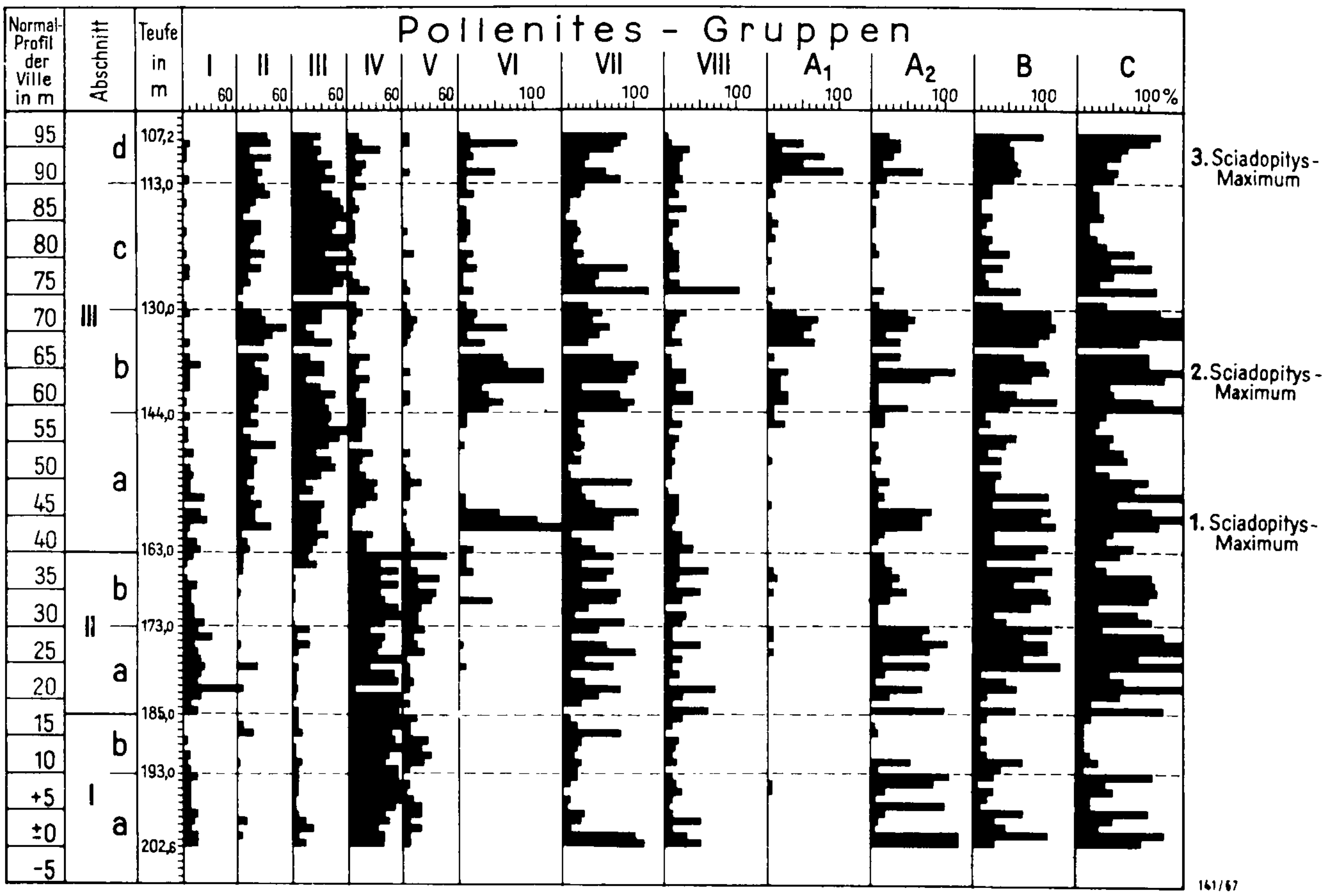
The pollen diagrams based on the method of U. Rein (see Text-Fig. 60, 61) give a detailed representation resting upon the analysis of the original borehole profiles and are more directly comparable with the information from the Søby-Fasterholt area than the data of the general diagram of Brelie (1967, 1968).

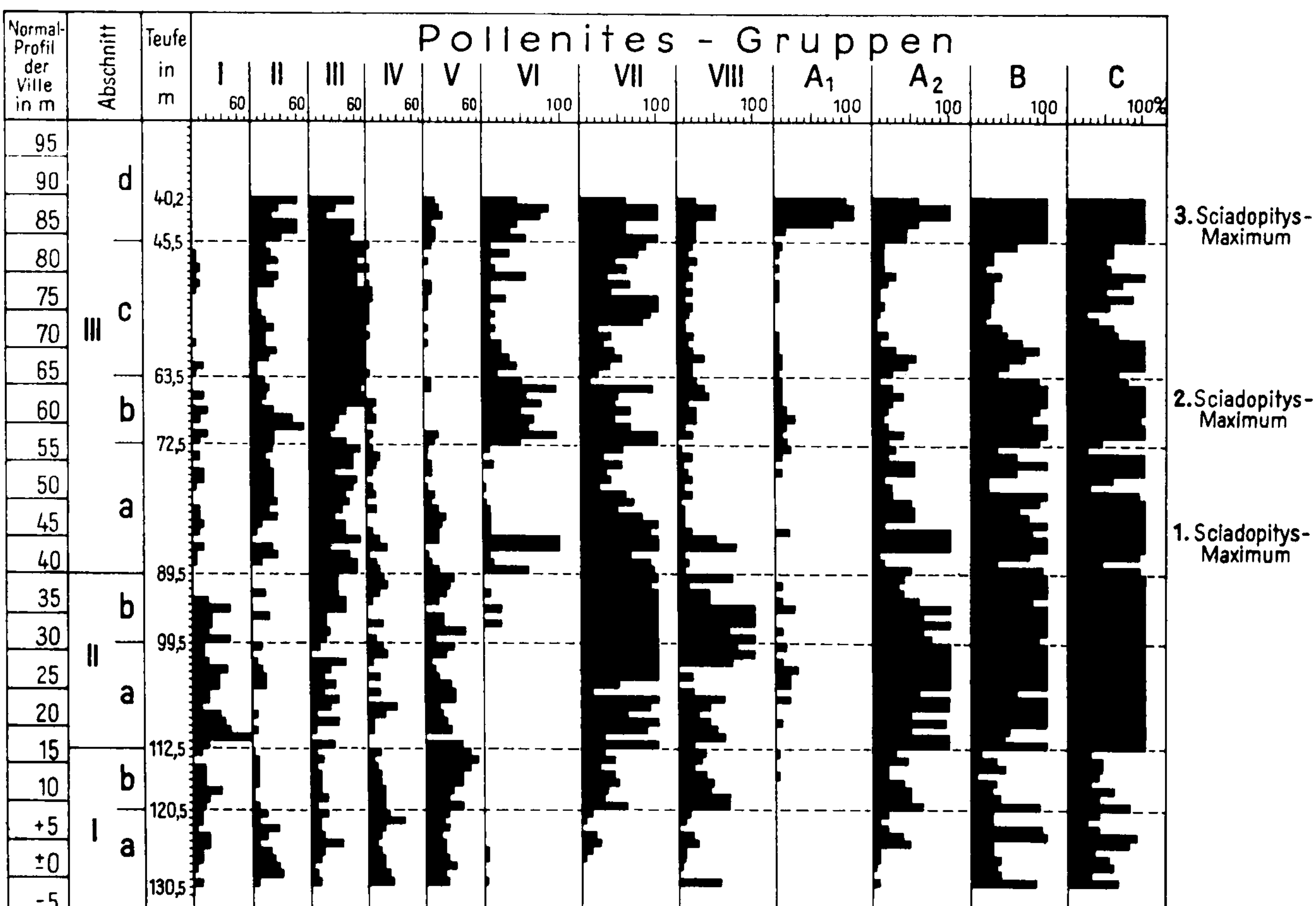
Hence, the following important features are pointed out. It must then be remembered that the boundary between microflora zones C/D is identical with the boundary between the microfloristic intervals ("Abschnitte") II/III of the Lower Rhenian Main Seam.

S. serratus: The continuous occurrence of this pollen species in the succession of the Søby-Fasterholt area begins at the basis of 3rd seam with a tendency for maximal number in the Hodde Formation and with a few records of low percentage value at the top of 2nd

Pollenites-Gruppen

I. *Engelhardtioipollenites punctatus* (POT.) POT.
Engelhardtioidites microcoryphaeus (POT.) POT., TH. & THIERG.
II. *Tricolporopollenites villensis* (TH.) TH. & PF.
III. *Quercoidites microhenrici* (POT.) POT., TH. & THIERG.
IV. *Quercoidites henrici* (POT.) POT., TH. & THIERG.
V. *Rhoipites pseudocingulum* (POT.) POT.
VI. *Sciadopityspollenites serratus* (POT. & VEN.) RAATZ
VII. *Cyrillaceaepollenites exactus* (POT.) POT.
Cupuliferoipollenites oviformis (POT.) POT.
VIII. *Cupuliferoidaepollenites liblarensis* TH.
Tricolpopollenites fallax (POT.) TH. & PF.
A_1. *Sequoiapollenites polyformosus* THIERG.
A_2. *Taxodiaceaepollenites hiatus* (POT.) KREMP
Inaperturopollenites dubius (POT. & VEN.) TH. & PF.
B. Disaccites
C. triporate Pollenites
(*Triatriopollenites* und *Triporopollenites*
im Sinne von THOMSON & PFLUG 1953)





Text-Fig. 60-61. Quantitative pollen-analytical diagrams of the Lower Rhenian Main Seam (Hauptflöz) after the method of Rein (1950) with explanations (Brelie, 1968, figs. 2-3; 85-102). – Geol. Landesamt Nordrhein-Westfalen, Krefeld 16, 1967-1969).

seam. This model fits well with the Lower Rhenian Main Seam where the notable and nearly continuous occurrences of this species begin at the boundary between units II and III with only a few scattered minor occurrences below in II, preferably in IIb. This means a positive correlation.

S. polyformosus: In the Søby-Fasterholt area this species is continuously represented in the 5th seam and Hodde Formation with high-medium values showing an optimum. It occurs sporadically throughout the entire Browncoal Bearing Sequence represented by small values but by a single medium value ((optima) in 1st and 2nd seam respectively. The first large maximum in the Rheinian Main Seam is in unit III (Text-Fig. 60) and can well correlate with that of the Hodde Clay *(Reinbekian)*. Hence, the small scattered occurrences below subunit III b in the Rhenian diagrams (Rein, 1950, Brelie, 1968) agree with the situation in the Søby-Fasterholt sequence.

E. punctatus and *E. microcoryphaeus* are treated together in the diagram of the Lower Rhenian Main Seam (Rein, 1950, Brelie, 1968). The two pollens species are easy to sum up in the Søby-Fasterholt diagram and to compare with the Lower Rhenian Main Seam. Their sum underlines the contrast between the relatively lower and higher values in the whole succession except the 1st seam where *E. microcoryphaeus* is nearly unrepresented. In the Lower Rhenian Main Seam we find higher values in units I-II and III a, and declining values upwards. The higher values are separated in 3 groups (one in each of the units I-II and III a) with one or two optima in each.

This trend is found in pollen samples reproduced in the Søby-Fasterholt diagram.

It must be observed that the Søby-Fasterholt sequence of pollen samples is discontinuous, the brown coal seams being interrupted by paraconformities and non-fossiliferous clastic sediments.

One unit of smaller-medium values in the 1st seam is corresponding to unit I of the Lower Rhenian Main Seam, a unit represented by medium-large values of the 2nd seam corresponding to unit II. And a succession of medium-large values of the 3rd-4th seams corresponding to subunit III a. Finally, an optimum of small-medium values in the 5th seam (and the Hodde Formation) fits well with a small optimum in subunit III b.

Q. henrici is represented by high-medium values in the 1st and 2nd seams and small values in the 3rd-5th seam interval with marked change in frequency in the pollen-stratigraphical lacuna between 2nd and 3rd seam. In the Rhenian Main Seam a continuously high representation occurs in unit I continuing in unit II with generally high but changing values. This abruptly changes into lower frequency values through unit III.

A general relationship underlines the significance of the boundary between the 2nd and 3rd seams of the Søby-Fasterholt area and between the units II and III of the Lower Rhenian area and the importance of this boundary in regional stratigraphy defined by Brelie (1967) as the boundary between microfloras zones C and D.

Q. microhenrici: In the Søby-Fasterholt area this species is continuously represented by small values in the 1st and 2nd seams except for two high values near the upper surface of the 2nd seam. It is represented continuously in the interval 3rd-5th seams with changing high and medium values.

In the Lower Rhenian Main Seam we find a similar trend of representation: In units I and II relatively small values and a tendency for increasing values uppermost in unit II to the generally high, but changing values of unit III a-b.

Also *Q. microhenrici* reflects the importance of the limits between the 2nd and 3rd seams and units II/III in agreement with the indication of *Q. henrici.*

T. villensis: In the Søby-Fasterholt area this species is continuously represented by single specimens in the 1st and 2nd seams, and by low percentage-values in the 3rd-5th seam interval. In the Lower Rhenian Main Seam this species is represented nearly continuously through the units I-III, but there is a marked contrast between small values and discontinuous occurrence in units I and II changing at the boundary II/III to much higher values or continuous representation.

There is general similarity in the occurrence of the species at the boundary of units II/III (=C/D) and 2nd seam/3rd seam as mentioned above.

R. pseudocingulum: Is represented by changing medium to high values in the 1st and 2nd seams of the Søby-Fasterholt diagram changing to a succession of small and medium values near the boundary between 2nd and 3rd seam and in the 3rd seam through Hodde Formation, obtaining an optimum in the 5th seam. The same feature is generally seen in the Lower Rhenian area with medium to high values recorded in the units I and II changing near the boundary of units II/III into sporadic occurrences of small and medium values through III a-b.

Also, here a general similarity is found in the trends of frequency of *R. pseudocingulum* of the Søby-Fasterholt and the Lower Rhenian Main Seam diagrams, supporting the stratigraphical boundary between 2nd/3rd seam and between units II and III and the correlation between these units of the two localities in question.

Conclusion 2
(Text-Figs. 58-59).

The trend of quantitative variation of pollen-species shows a convincing similarity between the general pollen-analytical diagrams from the Søby-Fasterholt area and the succession of typical associations of stratigraphical value of the Lower Rhenian area (Brelie, 1967, fig.

1, profile 36). This justifies a general correlation based upon microfloras or microfloristic "Abschnitte" (Rein, 1950) as presented in the general pollen-stratigraphical diagram of the Søby-Fasterholt area (Text-Fig. 58). The similarities are most obvious between microflora interval C of Brelie (1967) and the interval 1st-2nd seam of the Søby-Fasterholt diagram. Obviously there are deviations and variations between the structures of the two areas. The deviations do not negate the general similarity, the general regional trends overprinting a strong, local influence. Deviations are especially expressed in the absolute quantitative measures, while the relative quantitative trends within the spectra and through the succession are often identical or similar as to allow regional correlation.

The succession of pollen spectra in the 1st and 2nd browncoal seams (in their position in the total succession) is correlative with the greater part of the stratigraphical interval of microflora C (Brelie, 1967). According to the comparative studies, the 1st seam reaches near to the base of the microflora C interval.

The boundary between microflora C and D (resp. unit II and III) stratigraphically correlates with a level in the clastic beds (devoid of fossil pollen) between the 2nd and 3rd browncoal seams of the Søby-Fasterholt diagram and must be finally fixed by definition.

6. ENVIRONMENTAL (FACIES) INDICATIONS FROM THE MICROFLORA

The constant occurrence of *Polyporina multistigmosa* (R. Potonié) R. Potonié (Chenopodiaceae) in the 5th browncoal seam and the basal transgressional bed (sand and black clay) and its sporadical occurrence in the Hodde Clay, both of the Hodde Formation, is useful as a palynological indicator of the transition of facies from the limnetic-fluviatile browncoal bearing sequence to the marine deposits. This interval is in bio-stratigraphical terms corresponding to the local *Reinbekian* sequence. According to G. von der Brelie (1958, 1963) and Averdieck (1958), chenopodiaceous herbs are predominantly halophilous and when a relatively large representation of the pollen occur in terrestrial deposits, they indicate a marine influence on the environment in question (when other kinds of saline environments can be excluded). Therefore, the occurrence of *Polyporina multistigmosa* in the transitional interval between the limnetic-fluviatile and the marine facies of the sequence in question is interesting, supporting our facies model (ref. chapt. 4.B.6 page 212), even that the chenopodiaceous pollen occur in small quantities. This so more as *Polyporina multistigmosa* is unrecorded from the underlying brown coal seams 1-3(4).

7. GENERAL CONCLUSION

The stratigraphical conclusion from the presented analysis is based on the following provision:

1) The stratigraphical succession from which the analytical samples have been collected, is indisputable, for the vast majority resting on direct observation and continuous sequence.

2) The investigated Browncoal Bearing Sequence is directly overlain by a succession of well-known marine units which are dated by means of marine molluscs (Rasmussen, 1966, 1968, 1979), by foraminifera (Kristoffersen, 1972) and by dinoflagellate cysts (Piasecki, 1980), in comparison with types of stages of the NW German Neogene stratigraphy. The Hodde Clay is correlated with the *Reinbekian* Stage (in German: Reinbeker Stufe) of *Upper Middle Miocene*. In an attempt to correlate the Browncoal Bearing Sequence of the Søby-Fasterholt area with the browncoal profiles of the Lower Rhenian area and NW-Germany in general by means of fossil pollen, the *Reinbekian* stratigraphical level must therefore indicate the upper boundary (possibility) for correlation. In this particular case the existence of a reliable, marine marker horizon (the Hodde Clay = Reinbekian) is especially important because the evolution of pollen spectra in the relevant interval: Upper microflora D-microflora E, is ambiguous in the Lower Rhenian area.

An analysis of 3 profiles (1 outcrop and 2 boreholes) situated along an east-westerly line across the Søby-Fasterholt area shows so much mutual resemblance concerning the evolution in stratigraphical important pollen species (in sensu Brelie, 1967) and mutual correlation that a general diagram for the Søby-Fasterholt area can be constructed. This general pollen stratigraphy can be compared to the well studied pollen associations of the Lower Rhenian area (Brelie, 1967, fig. 1, profile 36, ref. also Brelie, 1968) (ref. Text-Fig. 58-59).

From the correlation between the pollen-stratigraphical diagrams of the Lower Rhenian area (Brelie, 1967, 1968) and the general pollen-stratigraphical diagram of the Søby-Fasterholt area, as a sum of 3 separate local diagrams, it is concluded that the microflora-intervals C and partly D are represented in the Søby-Fasterholt area (ref. Text-Fig. 58).

The boundary between microfloras C/D is identical with the boundary between the units ("Abschnitte") II and III from the Lower Rhenian Main Seam (Hauptflöz), and is also well-marked by similar criteria in the Søby-Fasterholt area. The C/D boundary in the latter area appears to be best correlated (by definition) to the boundary between the 2nd browncoal seam and the overlying clastic sediments (sand (bed 3 + 4) and clay (bed 5)).

The pollen-stratigraphical spectra of microflora intervals C and D from NW-Germany (Brelie, 1967) are predominantly based upon studies undertaken in the Lower Rhenian Main Seam (Hauptflöz) (Rein, 1950) (ref. Brelie, 1968). Important similarities in the succession of frequency spectra of the stratigraphically important species of the general Søby-Fasterholt diagram and those of the Lower Rhenian Main seam (after Rein, 1950) support the indirect correlation with the intervals ("Abschnitte") I, II, III a, and III b.

Also, in consequence of the correlations of the Browncoal Bearing Sequence of the Søby-Fasterholt area to the microflora intervals C and D ex parte, the *Reinbekian* (Reinbek Stufe) and the *Hemmoorian* (Hemmoor Stufe) substages (the latter of least partially) are indirectly correlative with an interval enclosing the Hodde Formation and the Browncoal Bearing Sequence of the Søby-Fasterholt area, respectively. This statement is adjusted through correlations between the limnetic-fluviatile and the marine facies in the Lower Rhenian area from the Asten 1, Straten 1, and Heidhausen boreholes, that correlate the *Reinbekian* substage with an interval about at the middle of the Lower Rhenian Main Seam ("Hauptflöz").

According to the Lower Rhenian pollen-stratigraphy (Brelie, 1967) and the latest stratigraphical survey (Hager, 1981) the boundary between the microfloras C and D is not identical with the boundary between the marine substages (Stufen) involved. Actually the position of the boundary between *Reinbekian* and *Hemmoorian* should be placed somewhere in the upper half of the microflora interval C.

The lower limit of the *Reinbekian* (in German: Reinbeker Stufe) should be expected to lie somewhat lower than the Hodde Clay in the Søby-Fasterholt area. The *Reinbekian* is defined in the Lower Elbe area (Reinbek near Hamburg) and its marine fauna is correlated with the Upper Middle Miocene transgression, that also affected the Central Jutland area. But the Søby-Fasterholt area is in an extreme marginal position in relation to the entire North Sea basin, then transgression must have reached this area at a later stage. Hence, the Hodde Clay from the Søby-Fasterholt area ought to be correlated with a late interval of the *Reinbekian,* and some of the deposits underlying the Hodde Clay without an intervening marked lacuna also might be expected *Reinbekian* in age.

The *Reinbekian* substage is connected with the Upper Middle Miocene transgression. In the Søby-Fasterholt area, the soil and root horizon on top of the "Upper Sands" and below the 5th browncoal seam represents a time of non-deposition before the transgression. The onset of the transgression (of the Hodde Clay) is known in detail in the western part of the Søby-Fasterholt area based on geological and paleontological criteria. The forest was destroyed leaving the disintegrated stumps under swamp and lake deposits, followed by coastal sand and gravel and marine clays successively. When the dynamics of the transgression (regional tectonics), rising of groundwater, lowering of erosional basis-level and deposition are correlatable factors under transgressive conditions, it is reasonable to combine the initial deposits of the succeeding depositional cyclus (the 5th browncoal seam) stratigraphically with its marine successor of the geological sequence, the Hodde Formation.

Hence, as a consequence of the geological history, the 5th brown coal seam should also, at least be involved in *Reinbekian.*

The remaining part of the Browncoal Bearing Sequence in the Søby-Fasterholt area is equivalent to the lowermost part of microflora interval D and to most of interval C, and consequently, according to the Lower Rhenian internal correlation (Hager, 1981), correlates with the *Hemmoorian* (ex parte) and a lower part of the *Reinbekian* substages of the North Sea (Lower Saxony type).

The paraconformity between the 5th browncoal seam and the underlying sands including a root-horizon does not definitely oppose a stratigraphical model involving inclusion of the Browncoal Bearing Sequence partly or in extenso in the *Reinbekian.* The root-stump horizon and the depositional lacuna alone do not indicate the scale of change of the geological environment involved.

The pollen-statistical, stratigraphical method of G. von der Brelie (Krefeld) is valid with some restricting provisions in the non-marine Neogene of Jutland, Denmark. One provision is that a stratigraphical succession with several levels (pollen spectra) of brown coal must be available.

In this particular case the existence of a reliable, marine marker horizon (the local Hodde Clay sequence = Younger Reinbekian) is especially important because the pollen spectral succession of the uppermost part of the Lower Rhenian Main Seam (the interval Uppermost microflora D-microflora E) is ambiguous.

Hence, a stratigraphical method valid for the non-marine Neogene has been introduced to Jutland though it must be handled with caution.

Of interest for the local stratigraphy is the indication of a marked occurrence of *Intratriporopollenites instructus* (Potonie, 1931, Thomson & Pflug, 1953) in the uppermost part of the Browncoal Bearing Sequence (Fasterholt Member). It extends from the local 4th seam through the intervening sands and/or silt-clay sequence, and continues into the 5th seam. This may be useful for determining a bio-zone when thorough study of more Jutlandish localities becomes possible.

The constant occurrence of *Polyporina multistigmosa* (Potonié) Potonié (Chenopodiaceae) in the 5th seam and the basal transgression bed (sand and black clay) and its sporadical occurrence in the Hodde Clay of the Hodde Formation is useful as a palynological indicator of the transition of facies from the limnic-fluviatile Browncoal Bearing Sequence to the marine facies. This interval is equivalent to the local *Reinbekian* transgressive sequence and according to Brelie (1963) and Averdieck (1958), chenopodiaceous herbs are predominantly halophilous. So, when a relatively large representation of these pollen occurs in terrestrical deposits, they indicate a marine influence on the environment in question during deposition of the sediments (when other kinds of saline environments can be excluded). The transitional interval between the limnetic-fluviatile and the marine facies of the sequence in question is still indicated, even that the chenopodiaceous pollen occur in small quantities. This so more so as *Polyporina multistigmosa* is unrecorded from the browncoal seams 1-3 (4).

8. A LIST OF THE COMMON FOSSIL POLLEN SPECIES OF THE BROWNCOAL BEARING SEQUENCE AND THE HODDE FORMATION OF THE SØBY-FASTERHOLT AREA

The following table demonstrates the fossil pollen-species encountered in the study and their occurrence in important stratigraphical levels from the browncoal bearing sequence (seam no. 1-4), the fossil root/soil horizon (6) on top, the 5th seam (5), and the marine Hodde Formation (bituminous clay) (7). Only very sporadically occurring and doubtful pollen-species have been omitted.

Table 20

	1	2	3	4	5	6	7
Taxodiaceaepollenites hiatus (Pot.) Kremp	+	+	+	+	+	+	+
Sequoiapollenites polyformosus Thi.	+	+	+	+	+	+	+
Sciadopityspollenites serratus (Pot. & Vein.) Raatz	+	+	+	+	+	+	+
Tsugaepollenites sp. sp.			+	+	+	+	+
Abietineaepollenites microalatus Pot.	+	+	+	+	+	+	+
Pinuspollenites labdacus (Pot.) Raatz	+	+	+	+	+	+	+
Piceapollenites alatus Pot.	+	+	+	+	+		
Inaperturopollenites dubius (Pot. & Vein.) Th. & Pf.	+	+	+	+	+	+	+
Inaperturopollenites emmaensis Muriger & Pf.		+	+	+			
Monocolpopollenites areolatus Pot.	+	+	+	+	+		+
Monocolpopollenites tranquillus Pot.	+	+	+	+	+	+	+
Tricolpopollenites confinis (Pot.)	+	+	+	+	+		+
Tricolpopollenites densus Th. & Pf.	+	+	+	+	+		+
Tricolpopollenites fallax (Pot.) Th. & Pf.	+	+	+	+	+	+	+
Tricolpopollenites parmularius Pot.	+	+	+	+	+	+	+
Tricolpopollenites pudicus Pot.		+	+				+
Tricolpopollenites liblarensis (Th.) Th.& Pf.	+	+	+	+	+	+	+
Tricolpopollenites spinosus (Pot.) Th.& Pf.	+	+					
Tricolpopollenites vegetus (Pot.) Krutzsch		+	+		+		
Platanoidites gertrudae (Pot.) Pot.,Th.& Thi.	+	+	+	+	+	+	+
Quercoidites henrici (Pot.) Pot., Th.& Thi.	+	+	+	+	+	+	+
Quercoidites microhenrici (Pot.) Pot., Th. & Thi.	+	+	+	+	+	+	+
Tricolporopollenites edmundi (Pot.)Pot.	+	+	+	+	+		+
Tricolporopollenites euphorii Pot.	+	+	+				
Tricolporopollenites borkenensis Th. & Pf.		+	+				
Tricolporopollenites eschweilerensis Th. & Pf.		+					
Tricolporopollenites fusus (Pot.)	+	+	+	+	+	+	+
Tricolporopollenites oviformis (Pot.) Pot.	+	+	+	+	+		+
Tricolporopollenites pusillus (Pot.) Pot.	+	+	+	+	+	+	+
Tricolporopollenites marcodurensis Th. & Pf.		+	+	+			
Tricolporopollenites margaritatus (Pot.) Pot.	+			+			
Tricolporopollenites microreticulatus (Th. & Pf.) Pot.	+	+	+		+	+	+
Tricolporopollenites porasper (Pf.) Th. & Pf.	+	+	+				
Tricolporopollenites satzveyensis Th. & Pf.	+	+	+		+		+
Tricolporopollenites villensis (Th.) Th. & Pf.	+	+	+	+	+	+	+
Cyrillaceaepollenites megaexactus (Pot.) Pot.	+	+	+	+	+	+	+
Cyrillaceaepollenites exactus (Pot.) Pot.	+	+	+	+	+	+	+
Ilexpollenites iliacus (Pot.) Thi.	+	+	+	+	+		+
Rhoipites pseudocingulum (Pot.) Pot.	+	+	+	+	+	+	+
Nyssapollenites sp. sp.	+	+	+	+	+	+	+
Sapotaceoidaepollenites sp. sp.	+	+	+	+	+		+
Monoporopollenites graminoides Meyer	+	+	+		+		+
Triatriopollenites bituitus (Pot.) Pot.	+	+	+	+	+	+	+
Triatriopollenites myricoides (Kremp) Pf.	+	+	+	+	+	+	+
Triatriopollenites rurensis Th. & Pf.	+	+	+	+	+	+	+
Engelhardtioipollenites punctatus (Pot.) Pot.	+	+	+	+	+	+	+
Engelhardtioidites microcoryphaeus (Pot.) Pot., Th. & Thi.	+	+	+	+	+	+	+
Plicatopollis plicatus (Pot.) Krutzsch	+	+	+		+		
Plicapollis pseudoexcelsus (Krutzsch) Krutzsch			+		+		+
Triporopollenites coryloides (Pf.) Th. & Pf.	+	+	+	+	+	+	
Triporopollenites labraferus Pot.							+
Triporopollenites rhenanus Th.							+
Triporopollenites robustus (Pf.) Th. & Pf.	+	+	+		+	+	+
Triporopollenites simpliformis (Pf. & Th.) Th. & Pf.		+	+				
Myricaceoipollenites megagranifer Pot.	+	+	+	+	+		+
Trivestibulopollenites betuloides (Pf.) Th. & Pf.	+	+	+	+	+	+	+
Intratriporopollenites instructus Pot. & Vein.				+	+	+	+
Caryapollenites simplex (Pot.) Th. & Pf.	+	+	+	+	+	+	+
Subtriporopollenites annulatus Th. & Pf.	+	+	+	+	+		
Polyporopollenites carpinoides (Pf.) Th. & Pf.	+	+	+		+		
Alnipollenites verus Pot.	+	+	+	+	+	+	+
Pterocaryapollenites stellatus (Pot.) Pf.		+	+	+	+	+	+
Ulmipollenites undulosus Wolff		+	+		+		+
Liquidambarpollenites stigmosus (Pot.) Th. & Pf.	+	+	+	+	+	+	+
Periporopollenites (Smilacites) echinatus Wodehouse			+				
Polyporina multistigmosa (Pot.) Pot.					+		+
Multiporopollenites maculosus (Pot.) Th. & Pf.	+		+		+		+
Porocolpopollenites orbis Th. & Pf.		+	+	+	+	+	
Symplocospollenites rotundus (Pot.) Pot., Th. & Thi.	+	+	+		+		+
Symplocospollenites vestibulum (Pot.) Pot.	+	+	+		+		+
Ericipites sp.	+	+	+	+	+	+	+

The qualitative stability of the fossil pollen-microflora of the Søby-Fasterholt area is obviously demonstrated.

The pollen-flora in the above list and the quantitative proportions of stratigraphical important Pollenites species involved in this paper show without doubt a *Miocene* association. The low representation of important Lower Miocene species (e.g. *Inaperturapollenites emmaensis*) and presence of few Paleogene relicts adds to this determination. Even the absence of important species characteristical of the younger Neogene (incl. the Upper Miocene) like *Faguspollenites verus* and the lack of large number of *Sequoiapollenites, Sciadopityspollenites* and *Tsugapollenites* characteristical for the Upper Miocene deposits is characteristical.

Hence, the present pollen flora indicates the *Middle Miocene* of Northwestern Europe.

9. References

Anderson, H.-J., 1958: Zur Stratigraphie und Paläontologie des marinen Oberoligozäns und Miozäns am Niederrhein auf Grund des Mollusken Faunen. - Fortschr. Geol. Rheinl. u. Westfalen 1, 177-195, Krefeld.

Anderson, H.-J., 1966: Die Schichtenfolge des Tertiärs und Quartärs. - In: Geologische und bergbauliche Übersicht des rheinischen Braunkohlenreviers. Brochüre z. Frühjahrstagung d. Deutsch. Geol. Ges. 1966, 2-5, Krefeld.

Anderson, H.-J., 1972: Die Bohurung Wildenrath 2 und des Alter der unteren Villeschichten (Tertiär südliche Niederrheinischen Bucht). - Geologica et Palaeontologica 6, 1969-1975, Marburg.

Averdieck, F.R., 1958: Pollen vom Chenopodiaceen-Typ im Flöz Frimmersdorf. - Ein Hinweis auf seine strandnahe Entstehung. Fortschr. Geol. Rheinl. u. Westfalen 1, 1958, 101-112, Krefeld.

Brelie, G. von der, 1958: Sporen und Pollen im marinen Tertiär der Niederrheinischen Bucht.- Fortschr. Geol. Rheinl. u. Westfalen 1, 185-204, Krefeld.

Brelie, G. von der, 1963: Nachweis mariner Beeinflussung mit Flagellaten, Hystrichospaeriden und Pollen. - Fortschr. Geol. Rheinl. u. Westfalen 10, 107-120, Krefeld.

Brelie, G. von der, 1967: Quantitative Sporenuntersuchung zur stratigraphischen Gliederung des Neogens im Mitteleuropa. – Rev. Paleobot. Palynology 2, 371-388, Amsterdam.

Brelie, G. von der, 1968: Zur mikrofloristischen Schichtengliederung im rheinischen Braunkohlenrevier. - Fortsch.Geol.Rheinl. u. West. 16, 85-102, Krefeld.

Brelie, G. von der, Hager, H. & Weiler, H., 1981: Pollenflora und Phytoplankton in den Kölner Schichten sowie deren Lithostratigraphie im Siegburger Graben. - Fortschr. Geol. Rheinl. u. Westfalen 29, 21-58, Krefeld.

Brelie, G. von der & Wolf, M., 1981a: Sequoia und Sciadopitys in den Braunkohlenmooren der Niederrheinischen Bucht. - Fortschr. Geol. Rheinl. u. Westfalen, 29, 177-191, Krefeld.

Brelie, G. von der & Wolf, M., 1981b: Zur Petrographie und Palynologie heller und dunkler Schichten im rheinischen Hauptbraunkohlenflöz. - Fortschr. Geol. Rheinl. u. Westfalen, 29, 95-163, Krefeld.

Fabian, H.J., 1958: Die Aufschlussbohrung Straeten 1.- Fortschr. Geol. Rheinl. u. Westf. 1: 11-28, Krefeld.

Friis, E.M., 1979: The Damgaard Flora: A new Middle Miocene flora from Denmark. - Bull. geol. Soc. Denmark 27, 117-142, Copenhagen.

Gliese, J. & Hager, H., 1978: On Browncoal Resources in the Lower Rhine Embayment (West Germany). - Geologie en Mijnbouw 57 (4), 517-525, Amsterdam.

Hager, H. 1968: Zur Gleichstellung und Genese der Flöze im Rheinischen Braunkohlenrevier. - Fortsch. Geol. Rheinl. u. Westf. 16, 73-84, Krefeld.

Hager, H., 1981: Das Tertiär des Rheinischen Braunkohlenreviers, Ergebnisse und Probleme. - Fortschr. Geol. Rheinl. u. Westfalen 29, 529-563, Krefeld.

Hiltmann, W., 1976: Pollenanalytische Untersuchungen im Rheinischen Kohlenflöz der Tagebau Frechen und Fortuna unter besonderer Berücksichtigung der makropetrographischen Ausbildung der Kohle. - Thesis Technischen Hochschule Aachen.

Koch, B. E., 1977: Stand der geologisch-paläobotanischen Untersuchung miozäner Ablagerungen des zentralen Jütlands, Dänemark. - Cour. Forsch. Senckenberg 24, 77-82, Frankfurt a.M.

Koch, B.E., 1979a: Das kontinentale Miozän im Söby-Fasterholt Gebiet, Zentral-Jütland: Geologie u. Stratigraphie. - Proc. Sympos. on the Continental Miocene of Central Jutland, June 11th-16th, 1979, 22-35, Aarhus.

Koch, B. E., 1979b: Neogene stratigraphy of the Søby-Fasterholt area. - Proc. Sympos: The Continental Miocene of Central Jutland, June 11th-16th, 1979, 49-55, Aarhus.

Koch, B.E. & Christensen, E.F., 1979: Introduction to the Symposium "The Continental Miocene of Central Jutland (Denmark): Geology - Brown coal facies - Stratigraphy - Paleontology". 11th-16th June, 1979, Aarhus University, Aarhus.

Koch, B.E., 1988: Denmark, the Danish Subbassin. – In: R. Vinken (Compil.). The Northwest European Tertiary Basin. Results of the Internat. Geol. Correlation Programme, Project 124. – Geol. Jahrb., A. 100, 318-320. Fig. 163.

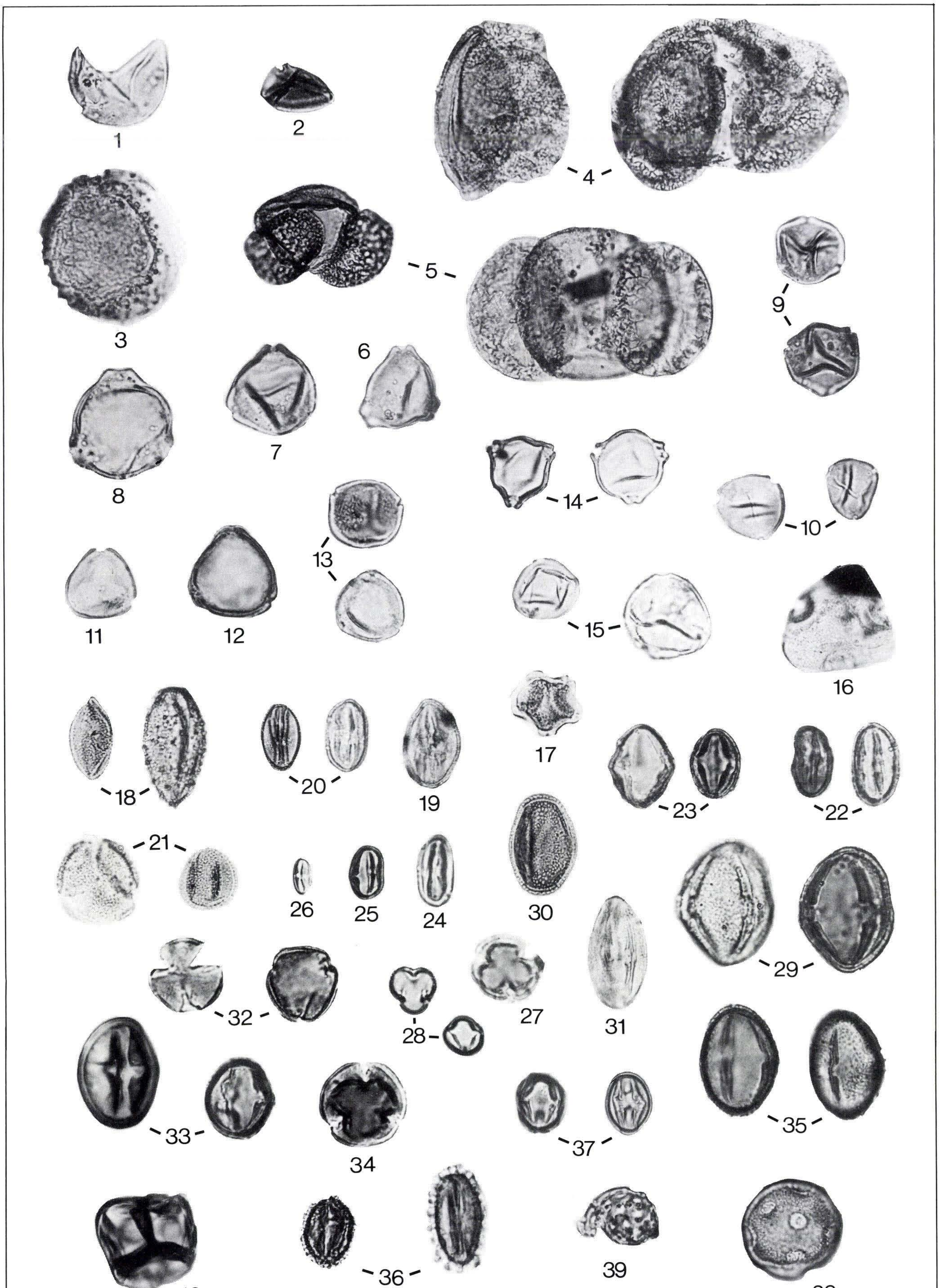
Koch, B.E. & Friedrich, W.L., 1970: Geologisch-paläobotanische Untersuchung der Miozänen Braunkohlen bei Fasterholt in Jutland, Dänemark. Bull. Geol. Soc. Denmark 20, 169-191, Copenhagen.

Koch, B.E. et al., 1973: Den miocæne Brunkulsflora og dens geologiske miljø i Søby-Fasterholt området sydøst for Herning. Dansk geol. Foren., Årsskrift for 1972, 1-57, Copenhagen.

Kristoffersen, F.N., 1972: Foraminiferzonering i det jyske Miocæn. - Dansk geol. Foren., Årsskrift for 1971, 79-85, Copenhagen.

PLATE 5 Collective representation of fossil pollen from the Fasterholt Member, the Klynholt Vest Tongue of the Odderup Formation and the Hodde Formation of the Søby–Fasterholt area (numbers 1–40). Magnification: ×320. E.K. Photo. Concerning revision of the palynological nomenclature of the pollen–species in question, ref. chapt. Method and Technical Information page 286. And concerning distribution in the stratigraphical column in question, ref. table 20.

1. *Taxodiaceaepollenites hiatus* (Pot.) Kremp
2. *Sequoiapollenites polyformosus* Thi.
3. *Sciadopityspollenites serratus* (Pot. & Vein.)
4. *Abietineaepollenites microalatus* Pot.
5. *Pinuspollenites labdacus* (Pot.) Raatz
6. *Triatriopollenites bituitus* (Pot.) Pot.
7. *Triatriopollenites rurensis* Th. & Pf.
8. *Triatriopollenites rurobituitus* Pf.
9. *Triatriopollenites myricoides* (Kremp) Pf.
10. *Engelhardtioipollenites punctatus* (Pot.) Pot.
11. *Triporopollenites coryloides* (Pf.) Th. & Pf.
12. *Triporopollenites robustus* (Pf.) Th. & Pf.
13. *Myricaceoipollenites megagranifer* Pot.
14. *Trivestibulopollenites betuloides* (Pf.) Th. & Pf.
15. *Caryapollenites simplex* (Pot.) Th. & Pf.
16. *Intratriporopollenites instructus* Pot. & Vein.
17. *Alnipollenites verus* Pot.
18. *Monocolpopollenites areolatus* Pot.
19. *Quercoidites henrici* (Pot.) Pot., Th. & Thi.
20. *Quercoidites microhenrici* (Pot.) Pot., Th. & Thi.
21. *Platanoidites gertrudae* (Pot.) Pot., Th. & Thi.
22. *Tricolporopollenites villensis* (Th.) Th. & Pf.
23. *Rhoipites pseudocingulum* (Pot.) Pot.
24. *Tricolporopollenites fusus* (Pot.)
25. *Tricolporopollenites pusillus* (Pot.) Pot.
26. *Tricolporopollenites oviformis* (Pot.) Pot.
27. *Cyrillaceaepollenites megaexactus* (Pot.) Pot. (subsp. *ventosus* Pot.). Polar view.
28. *Cyrillaceaepollenites exactus* (Pot.) Pot.
29. *Tricolporopollenites edmundi* (Pot.) Pot.
30. *Tricolporopollenites borkenensis* Th. & Pf.
31. *Tricolporopollenites marcodurensis* Th. & Pf.
32. *Nyssapollenites* sp. sp. (*N. kruschi* (Pot.) *pseudolaesus* Th. & Pf.). Polar view.
33. *Nyssapollenites* sp. sp. (*N. kruschi* (Pot.) *contortus* Th. & Pf.). Equatorial view.
34. *Nyssapollenites* sp. sp. (*N. kruschi* (Pot.) *pseudolaesus* Th. & Pf.). Polar view.
35. *Tricolporopollenites genuinus* (Pot.) Th. & Pf.
36. *Ilexpollenites iliacus* (Pot.) Thi.
37. *Sapotaceoidaepollenites* sp. sp.
38. *Liquidambarpollenites stigmosus* (Pot.) Th. & Pf.
39. *Polyporina multistigmosa* (Pot.) Pot.
40. *Ericipites* sp.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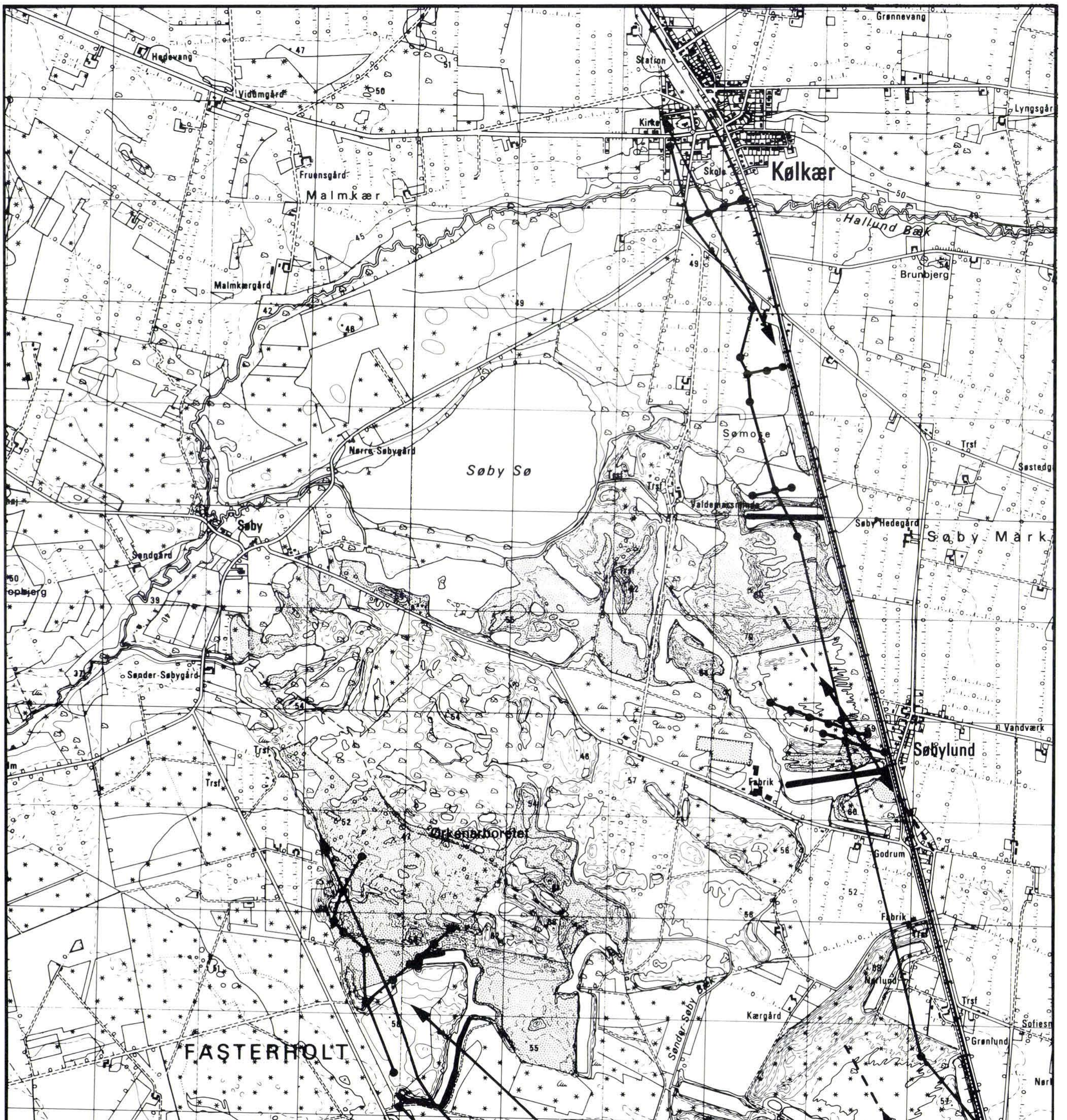


Text-Fig. 62. *Map demonstrating the location of the boreholes, probes and outcrops used for the tectonical model. Arrows indicate tectonic axes. Black dots indicate boreholes and probes; lines connecting black dots represent profiles; heavy black lines indicate outcrops of the quarries of the region. These localities are concentrated along two NNW-SSE profile lines. And an E-W profile line from Fasterholt to Klynholt west front that is based on the boreholes of Text-Fig. 38 and the Lavsbjerg outcrop. Based on Geodetic Institute, Denmark, 1:25000, 1214 IV SV Kølkær. E.K. comp.*

Kristoffersen, F.N., 1973: Oligocæn og Miocæn i Nøvling nr. 1 Dybdeboringen Nøvling Nr. 1 i Midtjylland (The deep test well Nøvling no. 1 in Central Jutland, Denmark). - Bull. Geol. Surv. Denmark III, 40, 63-70, Copenhagen.

Krutzsch, W., 1962-1970: Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen sowie der Mikroplanktonformen des nördlichen Mitteleuropas, I-VII, Berlin.

Mohr, B., 1972: Die Mikroflora in den Deckschichten der rheinischen Braunkohle (Obermiozän - Unterpliozän). - Inaugural-Dissertation zur Erlangung des Doktorgrades der Hohen Mathem. - Naturw. Fakultät der Rheinischen Friedrich - Wilhelms-Universität zu Bonn. 1982.

Nagy, E., 1969: Palynological elaborations of the Miocene layers of the Mecsek Mountains. - Magy. áll. Földt. Intéz. Évk., 52 (2), 474 et pl. LIII, 25, 26. Budapest.

Piasecki, S., 1980: Dinoflagellate cyst stratigraphy of the Miocene Hodde and Gram Formation, Denmark. - Bull. geol. Soc. Denmark 29, 53-76, Copenhagen.

Pflug, H.D., 1966: Zur Stratigraphie des mittleren Tertiärs in Hessen und in benachbarten Gebieten. Notizbl. hess. L. -Amt Bodenforsch. 94, 259-268.

Pflug, H.D., 1975: Sporenstratigraphische Korrelation des Vogelsberg-Gebietes mit benachbarten Tertiärbecken (Das Nordwest deutsche Tertiärbecken, Beitrag 13). Oberhessische Naturwis senschaftliche Zeitschrift, 42, 21-30.

Rasmussen, L.B., 1961: De miocæne Formationer i Danmark. - Geol. Surv. Denmark IV 4.5, 1-45, Copenhagen.

Rasmussen, L.B., 1966: Biostratigraphical Studies on the marine younger Miocene of Denmark. - Bull. Geol. Surv. Denmark II, 88, 1-358, Copenhagen.

Rasmussen, L.B., 1968: Molluscan Faunas and Biostratigraphy of the marine younger Miocene formations in Denmark.- Bull. Geol. Surv. Denmark II, 92, 1-265, Copenhagen.

Rasmussen, L.B., 1979: The stratigraphy of the marine Neogene of Denmark. - Proc. Sympos. on the Continental Miocene of Central Jutland, June 11th-16th, 1979, 11-21, Aarhus.

Rein, U., 1950: Die Bedeutung der Flözfeingliederung für den rheinischen Braunkohlenbergbau und ihre Anwendung in der Praxis. - Braunkohle, Wärme u. Energie, 1/2: 72-78. 7 Abb.; Düsseldorf.

Thiele-Pfeiffer, H., 1980: Die Miozäne Mikroflora aus dem Braunkohlentagebau Oder bei Wackersdorf/Oberpfalz. - Palaeontographica 174, B, (4-6), 95-224, Stuttgart.

Thomson, P. W. & Pflug, H., 1953: Pollen und Sporen des mitteleuropäischen Tertiärs.- Palaeontolographica 94, B, 1-4: 1-138.

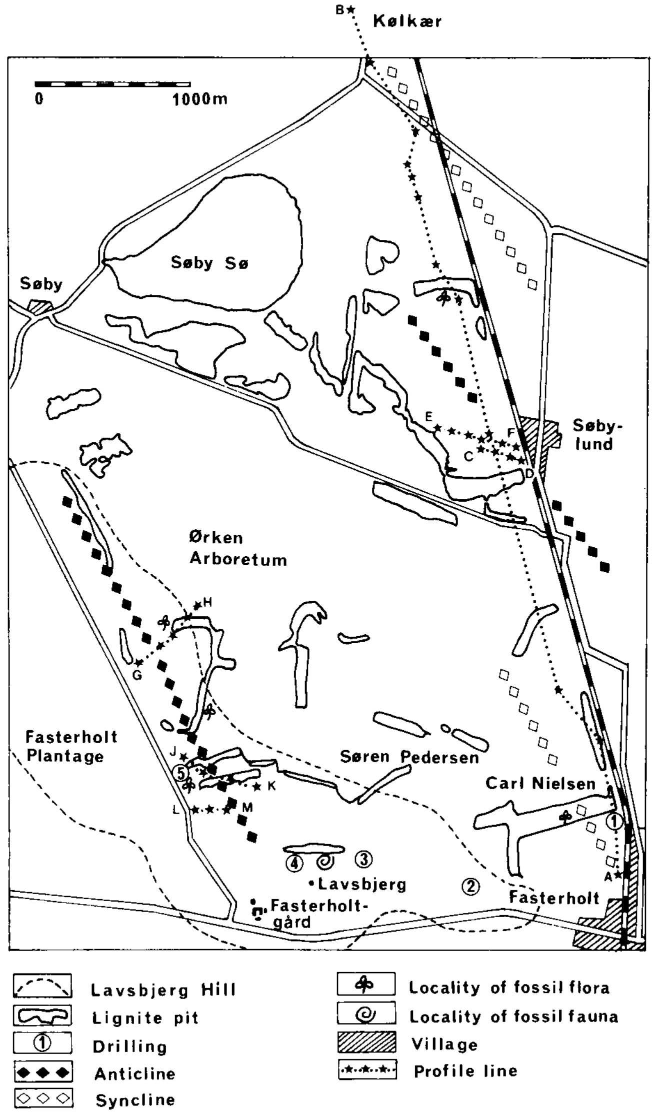
4.C. Tectonics

A thorough tectonical investigation of the Søby-Fasterholt area is outside the scope of this work. However our geological observations have revealed a tectonical pattern that has made necessary a survey to create a reliable background for an interpretation of structures of the area. This is to allow us to determine whether we in some particular cases of importance for the paleontological and sedimentological environmental conclusions, are confronted with primary depositional basin structures or shallow synclines (ref. chapter 4 B.4.1: The Hodde Formation).

During the field work in the open cast mine of Carl Nielsen Ltd. at Fasterholt, it became obvious that the Browncoal Bearing Sequence is folded. In 1968 the mining trench was 1 km long stretching in an E-W direction, long enough to allow the exposure of two flat synclines and an intervening flat anticline. (Koch & Friedrich 1970, Koch et al. 1973 (Text-Fig. 1, Atlas-Figs. 109, 112, 113).

During the years 1968-70 these undoubted tectonical structures were observed in a number of mining fronts in the same pit while the mining of the trench moved towards the south. Hence, it became possible to combine the current observations into a 3 dimensional model of these structures into a general pattern. Some profiles based upon a number of drillings and probes further delineated the structure to determine the dimensions of the fold structures involved and their regional extent.

Age: Only the Tertiary beds of the outcrops were affected by the folding, and this concerns the entire Tertiary sequence of the exposures. The folds were truncated by the Quaternary deposits which in this way discordantly overly the folded Tertiary strata (Atlas-Figs. 109-111). The Hodde Clay and Gram Clay of the exposure of Lavsbjerg are also affected (Atlas-Figs. 115, 116). Hence, the tectonic episode can be dated to the have occurred between the Upper Miocene and Weichselian (Quaternary).



Text-Fig. 63. Generalized sketch map of the Søby-Fasterholt area indicating the axis of the anticlinoria and synclinoria and major locations used in the text. Encircled numbers: Deeper drillings. Asterisks: Shallow browncoal prospecting drillings. E.K. comp. E.F.C. del.

1. Observations from the Carl Nielsen Ltd. pit at Fasterholt.
(Atlas-Figs. 36, 40, 107, 109-120)

In the eastern half of the Carl Nielsen Ltd. pit the 2nd and 3rd brown coal seams were exposed. The 3rd seam was mined on a terrace, 20 m wide, but the mining was preceded by an operation which uncovered the seam and exposed its surface along the whole front. Here, good 3-dimensional exposures of the shallow folding were often found (Atlas-Fig. 40, 109, 112). 2 flat synclines and an intervening flat anticline were seen in vertical section of the limiting front of this terrace and 3-dimensionally represented by the topography of the 20 m wide terrace (Atlas Figs. 36, 48, 112, 113) the surface of which was identical with the upper surface of the 3rd brown coal seam. Text-Fig. 64,A shows the vertical section in the mining front A, where the optimal wave-length of these particular folds was observed. The synclines, especially the easterly one were seen to become narrower and shallower as the mining proceeded in a southerly direction. The easternmost syncline disappeared finally between the mining fronts H and K. The axial direction appeared to be NW-SE. The axial plunge was undoubted to the NW at the narrow south eastern end, shallowing to nearly horizontal in the northernmost front (A) (Text-Fig. 64, B). The maximum wave-length of these particular folds seems to be on the order of 100 metres and the amplitude on the order of 5 metres.

This folding is somewhat irregular what concerns the western asymmetrical syncline. The western limb of the syncline rises to double altitude (i.e. about 8 m) (Text-Fig. 64, Atlas-Fig. 113) and continues nearly horizontally westwards about 300 metres at this higher level through the western end of the pit creating a tectonical terrace.

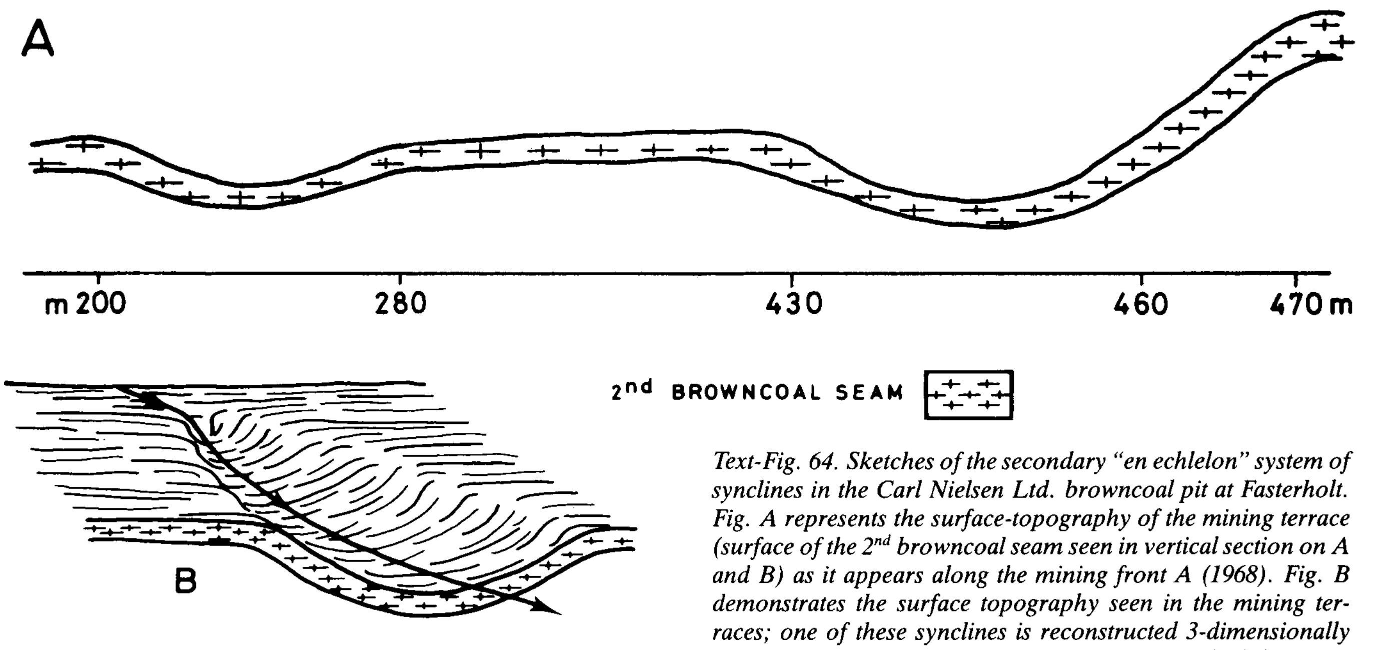
The limbs of the synclines are deformed by reverse faulting or a fault system, the sum of which is a reverse sheer (Atlas-Fig. 41, 42). This is magnificently illustrated in the eastern syncline (Atlas-Fig. 114) (ref. Koch and Friedrich 1970, Larsen & Kuyp 1971 and also in the "Upper Sands" (Atlas-Figs. 110, 111). The reverse faults are in general taken as criterion for compression.

Between the fronts G and K a subordinate syncline appeared in the eastern flank of the westernmost of the 2 above mentioned synclines. Between the two major synclines and on the intervening flat anticline that here might be called a tectonic terrace, another (3rd) synclinal depression was initiated. It happened at mining front G and this structure widened along the axial plunge towards the southeast. Because mining was abandoned along front K we had no opportunity to trace out its continuation.

Supposedly we are dealing with doubly plunging synclines separated by flat anticlines that seem to fit together in an "en échelon" system, but combined with very wide, flat structures (tectonical terraces) or fold-structures of higher order. This system has proved to be of 2nd order, subordinate to a 1st order large scale, shallow folding (synclinoria, anticlinoria, ref. below: Section 7: Compilation .... , and 8: Conclusion).

2. Tectonic information from Profiles based upon Borings.

Profile 1: A number of borings have been drilled by the Geological Survey of Denmark across the southern



Text-Fig. 64. Sketches of the secondary "en echlelon" system of synclines in the Carl Nielsen Ltd. browncoal pit at Fasterholt. Fig. A represents the surface-topography of the mining terrace (surface of the 2nd browncoal seam seen in vertical section on A and B) as it appears along the mining front A (1968). Fig. B demonstrates the surface topography seen in the mining terraces; one of these synclines is reconstructed 3-dimensionally (compiled from a number of mining fronts). Black line with arrows indicate the axis of the syncline. E.K. comp. et del.

part of the Søby-Fasterholt area in order to supplement our brown coal investigation (ref. chapter 4.B.2.2.2). They provided the basic evidence for construction of an E-W profile through the southern part of the Søby-Fasterholt area (ref. Text-Fig. 38). This profile was established for the purpose of stratigraphical correlation, but it revealed additional important tectonic information.

Additional evidence is supplied by a large number of prospecting probes and drillings made by private companies and placed at our disposal with the courtesy of the Geological Survey of Denmark. Based upon selected borings from this file of wells and a number of probes made by the Department of Paleontology and Stratigraphy, Geological Institute , Aarhus University, the following profiles have been constructed (ref. map Text-Fig. 62):

Profile 2: NNW-SSE profile along the railway line from Fasterholt to Kølkær. Including a few ENE-WSW profiles crossing the main profile.

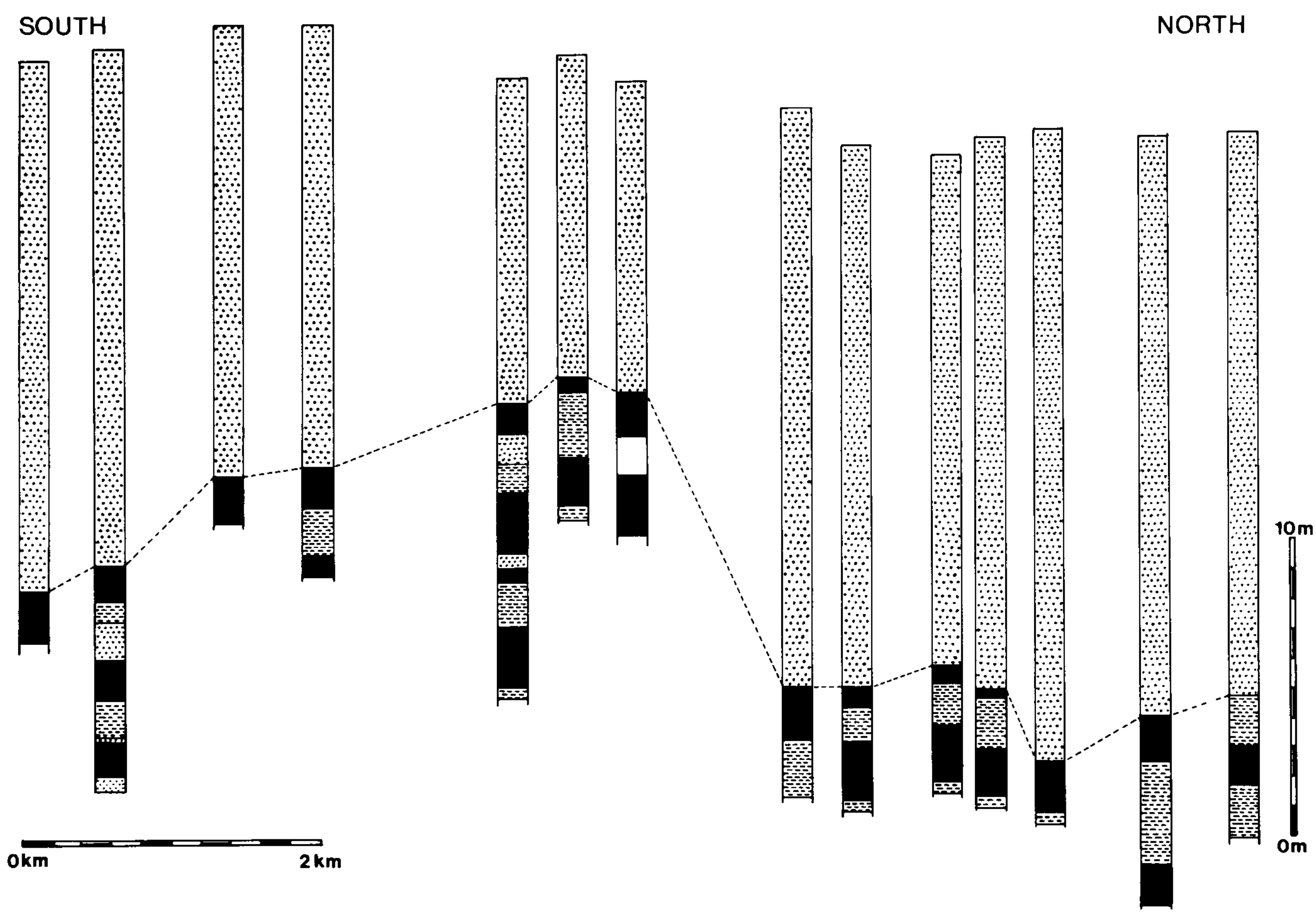
Profile 3: NNW-SSE profile along the western side of the Søby- Fasterholt area.

The map of Text-Figs. 62, 63 shows the location of boreholes and profiles in question.

Profile 1 (E-W, southern part of the Søby-Fasterholt area) shows an anticlinal culmination in the Tertiary sequence in the area around Lavsbjerg point, and we find a synclinal depression in the area near Fasterholt railway station.

In profile 2 depressions occur near Fasterholt railway station in accordance with profile 1 and at the village of Kølkær, and between the depressions an anticlinal culmination at the settlement Søbylund (at the factory "Søbyværk"). Profile 2 crosses the axes of these structures at an acute angle. Two short cross-profiles with direction ENE-WSW at Søbylund obviously pass the crest of this anticlinal culmination (Text-Fig. 66).

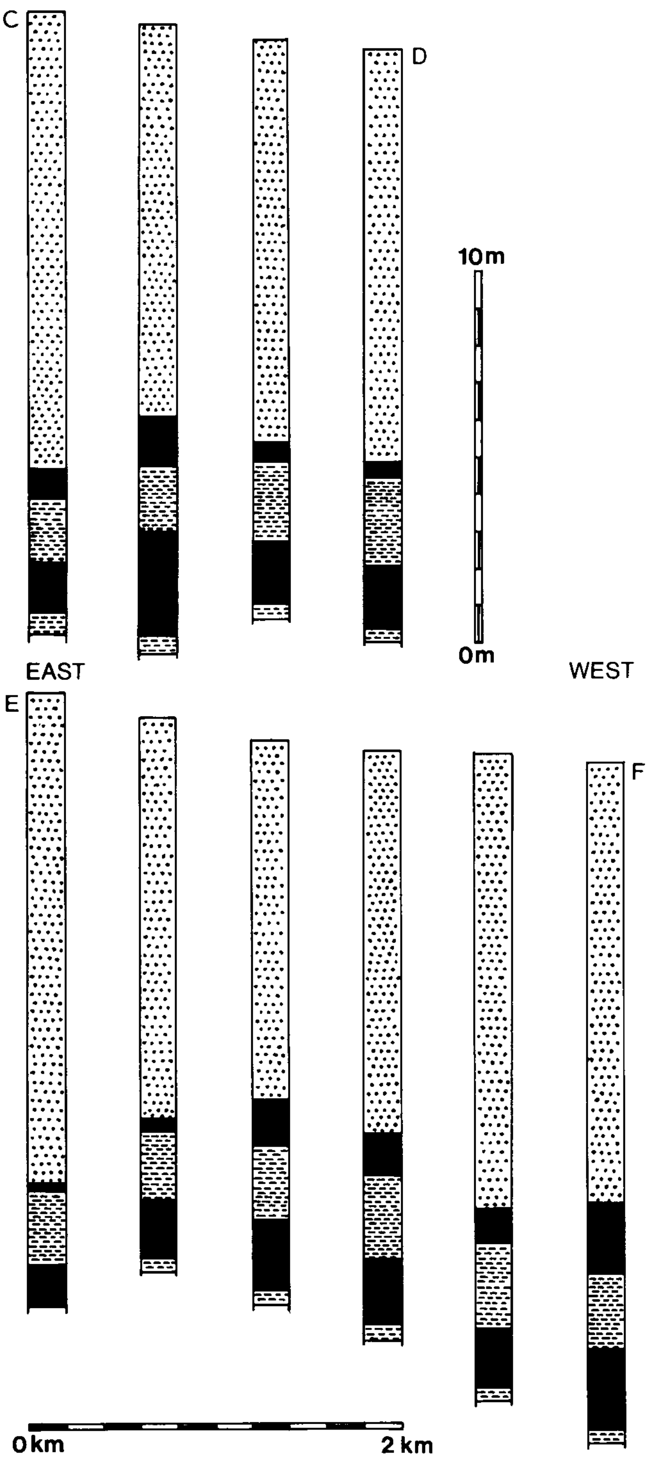
Profile 3 follows the west side of the Søby-Fasterholt area. It is based upon points of observation situated along the axial zone of the western anticlinal culmination and to both sides of it as well as in the axial zone. Hence, the fix-points of the crest of the culmination at the west end of the Klynholt area (a boring), at the south front of the Damgaard mining area and a boring on the crossing profile G-H, near to the former coal stock of the Damgaard mine, are included in profile 3.



Text-Fig. 65. Generalized logs of browncoal prospecting drillings from profile line A-B of Text-Fig. 63 (Fasterholt-Kølkær). Black: browncoal; dotted: sand; Hatched: clay. From south to north the cross-section begins in the area of a synclinorium at Fasterholt, passing through an anticlinorium at Søbylund ending in a synclinorium S of Kølkær. E.K. comp.

The basic evidence of profile 3 is heterogeneous consisting of different kinds of borings and probings supplemented by a few outcrops. And the location of this basic information is irregularly scattered along the axial zone, preferably to the west, but a small number of points are to the east of the crest (axis), and (as mentioned above) a few observations of the crest of the culmination are involved.

At 4 points of observation in common with crossing profiles the sedimentary sequence (preferably based on the brown coal beds) shows a dip to the east along lines in direction SW-NE, WNW-ESE and NW-SE, i.e. in direction of the Fasterholt synclinal depression (synclinorium?). At one crossing profile (in Klynholt) to the west of the crest (axis) a dip in a westerly direction is found. To the west of the road Fasterholtgaard-Søby no further information of folding is available. Hence the borings and probes give important supplementary evidence to the outcrops to the existence of a NNW-SSE striking anticlinal culmination along the west border of the Søby-Fasterholt area.



Text-Fig. 66. E-W profiles across the "Hoffmann & Sønner" mining area at Søbylund (lines C-D and E-F) (see Text-Fig. 63 for location) crossing line A-B of Text-Fig. 65. E.K. comp.

This anticlinal culmination (axis) aiming from the coal stock of the Damgaard mine towards southeast can be connected with the culmination seen in profile 1 at Lavsbjerg. This stroke follows the crest of the sand ridge which divides into two the Hodde Clay area located at the Klynholt-Damgaard mines. Obviously this line follows the crest of an anticline and marks the position and direction of its axis (NW-SE).

But, in the Klynholt area the pattern is probably complicated by a supplementary anticlinal axis, departing approximately from the coal-stock of the Damgaard mine and passing in direction of the east end of the Klynholt area and Munkballe farm respectively. Between the western main axis and the supposed supplementary eastern axis of Klynholt the shallow syncline of the Klynholt north-front outcrop is situated (ref. Text-Fig. 62, Atlas-Fig. 117). It is so shallow that the intervening area between the axes might better in general be termed a tectonical terrace.

Hence, the Søby-Fasterholt area is diagonally crossed (direction NW-SE) by two anticlinal structures with a synclinal trough in between them. This was already predicted by Koch et al. 1973 on the basis of a preliminary inspection of a number of drillings. These fold-structures have an amplitude of dimensions 15-18 metres and a wave length of about 3 km. This means shallow undulations. These structures affect the whole sequence coordinated, including the brown coal seams as well as the Hodde Clay (and Gram Clay). They are lst order structures superior to the smaller (2nd order) structures found in the quarry of Carl Nielsen Ltd. at Fasterholt.

3. The outcrop of Lavsbjerg

As mentioned in the chapters on the Hodde Formation and the Gram Formation, a sequence comprising these two formations (Upper Middle Miocene and Upper Miocene) is exposed at an outcrop in the northern flank of the point Lavsbjerg (at the southern border of the Klynholt mining area) (ref. page 96 and 97; Text-Figs. 20, 21). The entire sequence of these 2 formations together with a few metres of the underlying "Upper Sands" of the Odderup Formation (a stratigraphical column of about 15 m) has been recognized here in a 6-7 m high exposure, owing to what in this restricted outcrop looks like a flexure. Along this "flexure" the Hodde Clay has been uplifted in the western end of the outcrop (to the west of Lavsbjerg) (ref. Atlas-Fig. 115, 116).

In the light of the information presented above, this outcrop is near to or at the highest level of the anticlinal culmination in profile 1 (E-W profile based upon borings). What looks like a flexure may be the eastern flank of the anticlinal crest and like the reverse faults in the small synclines of the pit of Carl Nielsen Ltd. at Fasterholt it may be details of a fold structure. The outcrop with the "flexure" and the borehole Fasterholtgaard no. 2. (Lavsbjerg) (DGU file no. 95.2164) are situated N of the Lavsbjerg point (level 71 m). The well site is located in the "shelf" just above the precipitous "flexured" outcrop. The crest of the tectonic culmination (anticline) must be situated at a short distance to the west (the magnitude of 10 m) of this place.

In the southwestern part (corner) of the Klynholt mining area, three prospecting probes (DGU file no.1-Søby 583, 2-Søby 584, 3-Søby 585) were respectively set along a line from W to E and with a mutual distance of 120 m. They penetrated the 2nd and 3rd brown coal seam and clearly indicate a consequent dip of these beds towards the west. They are obviously on the western flank of a culmination (anticline).

4. The outcrops at the North Front of the Klynholt mining area.

The north front of the Klynholt mining area is about 1100 m long (Text-Figs. 62,63) and consists of 3 sectors with a slightly differing, but in general with an east-west orientation. They are mutually stepwise displaced a little to the N and together the 3 sectors describe a flat bow convex to the north. The front is a steep cliff rising from the ponds of 3 submerged pits. The front is highest in the eastern sector (about 10 m) decreasing westwards. The eastern sector comprises about 500 metres and its exposure is the object of the area that the first calls for attention. It gives an excellent exposure of the Hodde Clay through the whole outcrop (ref. Atlas-Fig. 67, 117). As appears from the figure, the black Hodde Clay is thickest (5 m) in the central part of the outcrop, thinning towards the east and the west owing to a lateral, slightly upwards curved bedding. It is underlain by white, cross-bedded sand ("Upper Sands", see page 87,119) in thick tabular and very long lenticular beds. At first glance from a distance it looks like a very shallow depositional basin and without the regional analysis based upon drillings, probes and the scattered exposures this idea would be difficult to disprove based only on the local evidence. The Hodde Clay passes over a threshold to the east of the Klynholt mining area, but continues in the neighbouring pit of Søren Pedersen, where it disappears owing to the topography of the hill dropping downwards towards the east. The Hodde Clay disappears at the western end of the middle sector and is replaced by the underlying white sand which reaches the surface in the westernmost sector of the north front. The structure of the Tertiary deposits is to a certain extent obscured by the Quaternary deposits, e.g. the fossil solifluction.

A structural study of the Hodde Clay reveals, especially after a dry period, a basal sequence with 7 concordant layers that are also concordant in relation to the curved lower boundary of the Hodde Clay structure (with the underlying light sands rising gently to the east and west) (Atlas-Fig. 16, 117). This concordance also concerns the underlying, non-marine tabular sand beds or very long sand-lenses. There is a consequent large scale concordance through the outcrop which also concerns the upper homogeneous Hodde Clay which becomes thinner in the flanks of the outcrop owing to erosion in combination with the lateral concavity of the general structure. This also concerns the uppermost green-grey glauconitic clay that is found only in the center of the outcrop and which disappears very soon in westerly as in easterly direction, also owing to superficial erosion. The 7 beds of the lower Hodde Clay are equidimensional individually and in total; their thickness does not vary according to a sedimentary basin structure of the dimensions and shape in question.

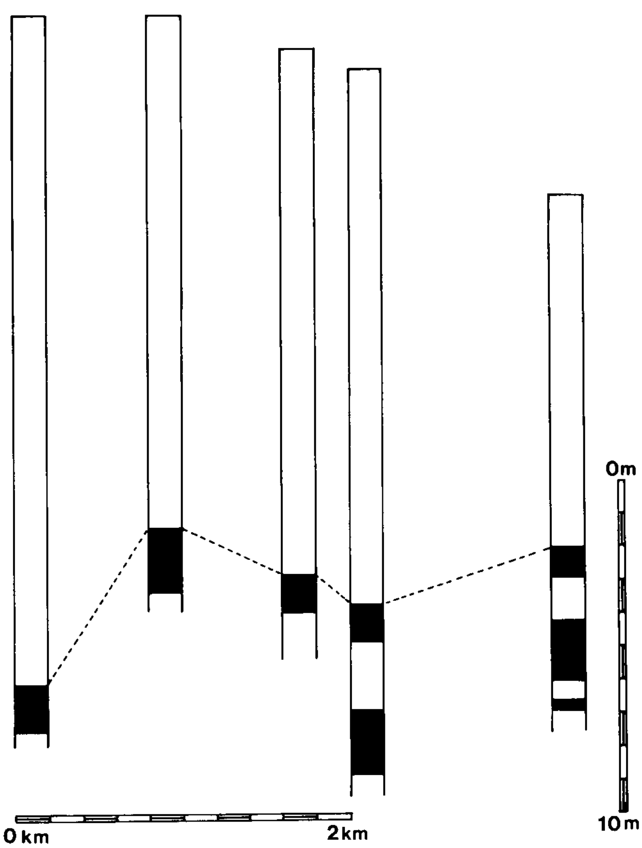
This structure would be unlikely for a depositional basin where the beds should be expected to onlap the lateral margin. The conclusion must be that we are dealing with a local shallow syncline with its axial plane cutting the center of the eastern sector of the north front. Towards the west the underlying sand ("Upper Sands") of the north front merges into a low anticline. This anticline section is a 5th fix-point establishing the anticlinal culmination met with from the south at Lavsbjerg and to the north into the Damgaard mining area (ref. the south front of the latter area, Atlas-Figs. 119, 120 and the N-S drilling profile, Text-Fig. 62).

On the western side of this sand crest (anticline), near to the west front and near to its junction with the north front of Klynholt, a borehole (Fasterholtgaard no. 1, DGU file no. 95.2163) and a few probes have revealed thin occurrences of the Hodde Clay (ref. also the information from probes in the area between Klynholt and the south front of the Damgaard mining area page 162 and Text-Fig. 40). Obviously the Hodde Clay also appears at a lower level to the west of the Klynholt sand ridge.

Three probes, placed on a WNW-ESE line in the NW sector of Klynholt (DGU file no. 4-Søby 586, 5-Søby 587, 6-Søby 588 respectively) and with a mutual distance of 150 m, penetrated the 3rd and 2nd brown coal seams. This short profile must be near to or over the crest of the previously mentioned anticline. In the middle probe (587) the respective beds are at their highest elevation. The same beds are about 2 m lower in the westerly probe (586). In the easterly probe (588) again the surface of the 3rd brown coal bed is 0.5. m lower than seen in the middle probe. This fits exactly to the tectonic model in question, the 300 m long profile-line of the 3 mentioned probes being situated over the crest of the western anticline.

5. The outcrops of the East and South Fronts of the pit of Damgaard S.

Concerning the east front of the pit of Damgaard S a structural analysis of this fine outcrop is a repetition of the eastern sector of the north front of the Klynholt mining area (ref. page 55, 66-68, resp. 159-160 and Atlas-Figs. 98, 99, 119, 120), and it also obviously represents the same individual structure which is here cut at approximately right angle to the outcrops at Klynholt. The underlying "Upper Sands" appears more complicated containing a disconformable body of "channel sand" in the central part of the outcrop. Most instructive is the south front, which is at a right angle to the east front (ref. Atlas-Figs. 119, 120). In the approximately 200 m long south front (direction WNW ESE)



Text-Fig. 67. NE-SW profile line G-H (see Text-Fig. 63 for location) of 5 browncoal prospecting drillings, crossing the westerly anticlinorium in the Damgaard N mining area. Black: browncoal seams. E.K. comp.

and partly continuing in the south end of the east front the Hodde Clay disappears at the surface and is substituted by the underlying "Upper Sands,", which raises into a culmination over a short distance (of about 75 metres). Then the black Hodde Clay appears again at the western end of this front and in the uppermost part of the outcrop. The Hodde Clay gradually increases in thickness towards the west and gradually substituting the white sand and becomes 3 m thick and dominant at the west end. The crest of this sandy culmination is one more observation point on an NW-SE trending anticlinal axis occurring on the western side of the Søby-Fasterholt area.

6. The pit of Damgaard N.

Regarding this locality it is sufficient to refer to a description of the Damgaard N pit in Christensen (1975). The bedding planes seen in the approximately N-S striking west profile dip to the northeast (or NNE) as expected for the east flank of a NW-SE striking anticlinal structure (ref. Text-Fig. 45, Atlas-Fig. 73).

7. Compilation of the Tectonic Observations from the Søby Fasterholt area.

A synthesis of the observations presented above of the structural geology of the Søby-Fasterholt area obviously indicates that the Brown Coal Bearing sequence is folded and provide a relative age determination (as well as direct and detailed information) of the folding from the outcrop in the Carl Nielsen Ltd. pit at Fasterholt.

The combined profiles based upon borings demonstrate the existence of large anticlinal culminations and synclinal depressions in the Tertiary sequence, regardless of whether the brown coal beds or the Hodde Clay - "Upper Sands" boundary are used as a datum surface, and the whole sum of observations fit together into the following model:

A western anticlinal culmination exists at 1) Lavsbjerg, 2) Klynholt North-front, 3) South-front of the Damgaard mining area, 4) a SW-NE cross section through Sønderborg-Damgaard N (borings), and 5) at the coal stock of the Damgaard mine in the N-S oriented profile along the west front of the Søby-Fasterholt area (borings). Hence, this anticlinal culmination can be mapped as continuous from Lavsbjerg along a NE-SE striking axis to the coal stock of the Damgaard mine near the Fasterholtgaard-Søby road. This fits well with the field observations of a sand ridge which crosses the distribution area of the Hodde Clay on the Lavsbjerg Hill and the information of different smaller profiles based upon probes and drillings.

The south-profile based on borings that also records the western culmination, grades into a large synclinal depression at Fasterholt village.

Combination of the South profile (direction E-W) with the N-S profile along the railway Fasterholt-Kølkær reveals the depression at Fasterholt, and the N-S profile in addition cuts an anticlinal culmination at Søbylund which is also supported by small ENE-WSW profiles crossing the latter N-S profile (borings). The strike of the fold axis can be suggested to be approximately NW-SE. The east profile continues in direction of Kølkær village to the north and another synclinal depression appears to pass Kølkær in NNW-SSE direction.

Therefore an apparent gross fold structure of 2 anticlinal culminations and an intervening synclinal depression with axial strike in approximately NW-SE direction is evident.

The observations of tectonical details as the synclines and the tectonic terraces at the Carl Nielsen Ltd. pit and the "flexure" at Lavsbjerg may be 2nd order structures within a general large scale lst order pattern of large depressions and culminations. The pattern could be characterized as a system of shallow synclinoria and anticlinoria with 2nd order "en echelon" folding, tectonic terraces etc. The depositional "basins" of the Hodde clay of Klynholt and the Damgaard mining area suggested by Koch et al. 1973 should be regarded elements of the large scale tectonic pattern.

8. Conclusion on Tectonics of the Søby-Fasterholt area.

The Tertiary sequence of the Søby-Fasterholt area has been affected by a weak folding some time after the Upper Miocene and before the Weichselian glaciation. The folds are shallow, the amplitude varying between 5-18 metres and the wavelength between 100 m and 3 km. We have seen the small, symmetrical syncline at the Carl Nielsen pit (amplitude 5 m, wavelength 100 m), the somewhat asymmetrical syncline of similar dimensions combined with a monocline and tectonic terrace at the Carl Nielsen pit, a large anticline at Lavsbjerg and a large, wide and shallow syncline (amplitude 8 m, wavelength about 1000 m) at the Klynholt north front and Damgaard S.

The available observations do not allow for more than a general conclusion. A general large scale pattern appears obvious. The Søby-Fasterholt area includes 2 large scale anticlinal culminations (anticlinoria) and a large synclinal depression (synclinorium) with a general axial strikes in a NW-SE direction. The profiles based upon boreholes point to a maximal amplitude of about 20 metres and a distance of about 3 km between the crests (wave length). Details from the profiles are not evident, but irregularities of smaller dimensions such as the 2nd order folds in the eastern part of the Carl Nielsen Ltd. pit at Fasterholt seem to be present in the eastern as well as the western N-S borehole profiles. Also the reverse faults or systems of faults in the flanks of the small "en echelon" folding (the Carl Nielsen Ltd. pit) must be pointed out, as a normally accepted criterion for compression.

It is reasonable to combine the smaller folds, especially those with lesser amplitude as structures of 2nd order within the general larger scale pattern. Tectonical terraces seem to be involved and explain the extended wave-lenght of the large scale structures. The sum of observations might give the impression of shallow disharmonic folding.

This conclusion contradicts a preliminary suggestion of the Hodde Clay occurrence and the boundary relationship Hodde Clay/Odderup Formation of Koch et al. 1973. The Hodde Clay was suggested to occur in restricted local depositional basins. The structures seen at Damgaard S and Klynholt north front etc. must according to the present analysis be tectonic structures. This does not exclude a primary sedimentary structure (fluviatile channel filling?) existing in the "Upper Sands" of the Damgaard S east front in coincidence with the syncline, and in principle not the theoretical existence of local sedimentary basins of e.g. Hodde Clay, included within the folded Tertiary of Central Jutland. As seen in the Klynholt north front and Damgaard S, it is very difficult to determine whether the shallow structures are synclines, sedimentary basins or the two things combined.

As to the causal reasons e.g. whether the compressional force causing the structural pattern described above reflects normal tectonics or "glacial tectonics" has not been thoroughly considered and is beyond the purpose of this investigation. Glacial "tectonics" is well known from Denmark in exposures of coastal cliffs and open pits. Characteristical structures are overturned and recumbent folding and overthrusted blocks.

In the browncoal bearing sequence, we have found the clays to react tectonical competent in folding, and the sands to be (as normal) tectonical incompetent, reacting by faulting (Atlas-Fig. 114). The latter seems not in accordance with a permafrozen state which should be expected for these superficial formations during the Quaternary glaciations. Hence, normal tectonics is relevant. Unfortunately, we do not know whether the deeper seated formations below the Miocene have been involved.

5. Conclusion

The geological and paleontological evidence presented in the preceding chapters can be fitted together and concentrated into general characteristics of the browncoal bearing sequence from the Central Jutland area just north of the Jutland-Funen High.

Earlier studies, especially concerning the Neogene from the Danish and especially the Jutland area, involve that we are doing with a sector of the Tertiary (Neogene) North Sea basin, and therefore the geology is controlled by the tectonical and sedimentological mechanisms of this depositional basin in general.

The following evidence is the main-ingredients of a general characteristics and conclusion:

1. The Neogene sedimentary sequence of the Søby-Fasterholt area consists of alternating marine and non-marine formations (and members). These formations correlate with deposits that according to the preceding regional studies are generally distributed in time and area according to the dynamical-stratigraphical diagrams of Rasmussen (1961, 1966) and Hinsch (1973, 1974).

2. The Hodde Formation overlying the Browncoal Bearing Sequence shows generally a tendency to wedge out eastwards in Central Jutland with its eastern boundary of distribution not far to the east of the Søby-Fasterholt area. Dinoflagellate cysts (Piasecki, 1980), and marine molluscs (Ravn 1907, Rasmussen, 1961, 1966) and the high content of organic terrestrial debris indicates a coastal marine or estuarine environment. The non-marine Neogene facies (e.g. the Browncoal Bearing Sequence) does not reach much far the west than the extant west coast of Jutland. This is according to the principles of the dynamical-stratigraphical diagram of Rasmussen (1961, 1966), and drilling records (i.e. well Dansk Nordsø, C.1, according to Rasmussen 1974).

3. The Browncoal Bearing Sequence (the Fasterholt Member, defined in this paper) is arranged in 3-4 rhythmical units, and sometimes interrupted by a disconformity indicating weak erosion. It consists of rapidly changing sediments (facies) concerning content of organic/inorganic matter, sorting and grain-size, appearing with abrupt boundaries as a result of breaks in the depositional succession (diastems or paraconformities). Such breaks often occur between contrasting sediments and indicate rapid changing conditions. Cross-bedding, current ripples and fluviatile depositional structures are common in the arenaceous sediments. The evolution of deposition of each particular rhythmical unit is reconstructed from browncoal petrographical facies analysis as well as study of the inorganic sedimentary facies in good correlation.

4. The interpretation of the total succession of the rhythmical Browncoal Bearing Sequence points to an evolution from a relatively low-energy depositional environment with browncoal as a major constituent and sand of minor importance (1st rhythm), through intermediate conditions (2nd and 3rd rhythm) with an equal amount of fine grained deposits (clay-detrital browncoal) and sand, into a high-energy environment of predominantly sand deposition ("Upper Sands"). This seems to be a reflection of the (accelerating?) subsidence of the basin which, in this marginal area of the depositional basin with large potential of sediment under transport, is repeatedly overtaken by sedimentation.

5. The Browncoal Bearing Sequence contains abundant concentrations of Neogene plant fossils. Marine Neogene fossils and remains of terrestrial animals have not been recorded, but reworked fossils (marine invertebrates, palynomorphs) older than the Neogene are abundant. Driftwood is abundant in the cross bedded sands.

The fossil floras and root/stump horizons produce important information about the depositional and regional environments. A majority of fossils, among which are many dominant species have their closest recent relatives in swamp- and wetland environments. These fossils are often well-preserved and/or very common. Another well represented group is species with closest recent relatives living on well-drained soil (dryland). These fossils are often worn or heavily worn, but there are some well preserved fruits, seeds and even, entire leaves. The root/stump horizons with stumps of *Sequoia* or sequoide trees also indicate the relatively dryer conditions within different parts of the coastal foreland or delta environment.

6. Xylitic and detritic browncoal beds are characteristical, the detritic and impure browncoal beds are the dominant and pure xylitic browncoal are rare. Drift-

wood coal ("Schwemmkohle") occurs in one seam. The detrital browncoals often grade into clay with some organic matter (gytja) and locally contain sand- and silt inclusions. So, the dynamical sedimentary conditions were less suited for deposition of pure organic material (browncoal ooze) but allowed for impure detrital browncoal (Facies: "Schuttfächer-Flöztyp" according to Ahrens et al. 1968, i.e. Delta border type of browncoal seams).

7. The results of the coal petrographic facies analysis indicate that the four browncoal seams represent different coal-forming environments. In the Carl Nielsen Ltd. pit at Fasterholt (CN.) the 1st browncoal seam represents an evolution from a moist forest environment with sporadic open water dominated by gymnosperms *(Taxodium),* through an open water environment (reed moor) that gradually changes into a forest swamp with a mixed vegetation of conifers and angiosperms in slightly drier areas adjacent to the swamp. The 2nd browncoal seam represents the gradual development and infilling of a lake basin. The lower energy depositional environment changes into a higher energy depositional regime, which terminates with the deposition of a driftwood bed (to the west at profile F 11, the Carl Nielsen Ltd browncoal pit).

At this level a lateral shift has been observed in the east-west section (of CN) from a bush moor environment (to the east) into a reed moor environment (central outcrops) and again into a driftwood accumulation (coal). The 3rd browncoal seam represents a reed/bush moor environment.

In the Klynholt Vest pit the 5th browncoal seam probably represents a gradual development from a forest swamp into a reed moor/stagnating lake (laguna).

The variation in thickness of the detrital browncoal beds and related clay beds reveals that the local depositional basins were of restricted dimensions, but mutually connected.

8. The top and bottom of the Browncoal Bearing Sequence proper is delimited by a paraconformity (or week disconformity) with root/stump horizons and fossil soils. The stumps show affinity to the extant genus *Sequoia* (Wagner & Koch, 1974) and the roots are vertical and deeply penetrating and indicate relatively well drained environment with groundwater surface more than 2-2.5 metres below the forested surface.

9. The marine Hodde Formation overlying the Browncoal Bearing Sequence records a detailed transgressional history in the Søby-Fasterholt area. The successive stages are as follows:

1) Initial swamp deposits (5th seam: Xylitic browncoal overlaid by sapropelitic coal. 2) Evidence of tidal flooding (burrowing crustaceans). 3) Constant flooding under high-energy conditions (gravel- and silty sand facies with burrowing spatangids). 4) Deposition of changing facies (low-energy estuarine environment with periodical changing input of different types of terrestrial organic matter (ref. E. Fuglsang Nielsen 1985)and changing amount of available oxygen). 5) Deposition of dark brown to black clay (Hodde Clay proper) (low mechanical energy, low amount of available oxygen and low input of terrestrial, organic matter). 6) The succession of the Gram Formation (Glauconite Clay and Gram Clay) with no or low input of terrestrial particulate organic matter (neritic sea, gradually silting up).

10. The Browncoal Bearing Sequence is underlain by a sequence consisting of 3 units, a sand-, a sand- silt, and a clay unit, as a total amounting to about 60 metres in thickness which is again underlain by arenaceous sediments (40 m). The argillaceous member is 10 m thick and marine, as indicated by Neogene dinoflagellate cysts (Piasecki det.) and sedimentological criteria (Friis et al. 1979). A few shark teeth points in the same direction. The sedimentary succession points to a depositional history from a delta phase by a shorttermed transgression with the final silting up of the marine environment accompanied by the successive advance of a delta. The latter is represented by a sand to silt sequence (indicated by Amphibole and Epidote maximum) followed by a sequence of coarser sand facies terminating in non-marine deposits (Friis et al. 1979).

11. The fossil flora generally indicates a Miocene age, especially the interval Aquitanian - Reinbekian. The species in the *Søby Flora* agrees with the Upper Middle Miocene (Christensen, 1978), i.e. in the lower Reinbekian synchronous with microflora zone D of the lower Rhenian area (of G. von der Brelie, 1967); and with the floral zones (X-) XI of the Lower Lausitz (GDR) (Mai, 1967). Climatically the flora is most similar to zone XI (Mai, 1967: Warm temperate indication).

The *Fasterholt Flora* consists of abt. 200 determined species, sufficient for a stratigraphical analysis. A Miocene age is well determined (Koch & Christensen 1979, Friis, 1985) and different analytical methods point to an Upper Middle Miocene age. Optimal correlation with the Browncoal Bearing Sequence of Lower Lausitz (Mai, 1967, Ahrens & Lotsch, 1967) is found with the floral zone interval X-XI. Owing to the distinct paleotropical element (1/3 of the species) an intermediate position in zone interval X-XI may be suggested.

12. The pollen-flora indicates a Miocene age (the interval Aquitanian-Reinbekian) (Koch, 1984) for the total sequence recorded from outcrops and boreholes (abt. 120 m thickness).

The quantitative palynological analysis of the Browncoal Bearing Sequence indicates a Middle Miocene age, Microflora zones C and partly D (Brelie, 1967, Koch, 1984), correlative with the Hemmoorian - lower Reinbekian.

13. The 1st, 2nd and 3rd browncoal seams are generally synchronous units, but some deviations in the time of initiation and termination of the deposition of browncoal ooze of the individual seams may exist. This timing is relatively best expressed by the pollen-stratigraphical data (Koch, 1984) for the 2nd and 3rd seams.

Over a distance of 7-800 metres the 2nd browncoal seam was initiated at the same time in the Carl Nielsen Ltd. browncoal pit at Fasterholt (profile F 11 in the west end, and the Fasterholt Bjerge borehole in the east end). The Fasterholtgaard 1 borehole at a distance of 2 1/2 km towards west records initiation one pollen spectrum later (ref. Text-Figs. 56 and 55, 57). The change into very fine-grained deposits (clay and browncoal ooze) seems to be nearly synchronous in the southern Søby-Fasterholt area at this stratigraphical level. The detrital browncoal of the 2nd seam (bed no. 1) terminates simultaneously from Fasterholt Bjerge borehole via profile F 11 and on to borehole Fasterholtgaard 1. Hence, the surface of bed no. 1 can be regarded a synchronous level. The driftwood coal on top of the 2nd seam (bed no. 2) is generally younger than the detrital browncoal of this seam (bed no. 1) in this area and is separated from it by clay and occasionally by sand in the west end of the Carl Nielsen Ltd. pit at Fasterholt.

Deposition of the 3rd browncoal seam began later (2 pollen spectra) (see pollen diagrams of Text-Figs. 55-57) in the Fasterholt Bjerge borehole than in profile F 11 (Carl Nielsen pit, Fasterholt) and Fasterholtgaard 1 borehole. The 4th browncoal bed in Fasterholtgaard 1 borehole and the 3rd seam in profile F 11 are terminated synchronously, so the 4th browncoal bed consequently should not be regarded as a separate stratigraphical unit (seam).

The 3rd browncoal seam in Fasterholt Bjerge and in Fasterholtgaard 1 boreholes are terminated synchronously, i.e. later than in profile F 11 (the Carl Nielsen pit, Fasterholt).

Hence, the deposition of browncoal sediment begins later and ends earlier towards the east (Fasterholt Bjerge) than in the localities with an optimal thickness of browncoal deposits, i.e. in the central parts of the local depositional subbasins (F 11 and Fasterholtgaard 1) (compare the overall structure of the browncoal beds in the Carl Nielsen Ltd. browncoal pit, Fasterholt, page 81).

The 4th browncoal bed in drilling Lavsbjerg Øst is entirely or partly younger than the (3rd +) 4th browncoal seam to the west (Fasterholtgaard 1 borehole). Consequently, the last deposition of browncoal took place at Lavsbjerg Øst drilling site.

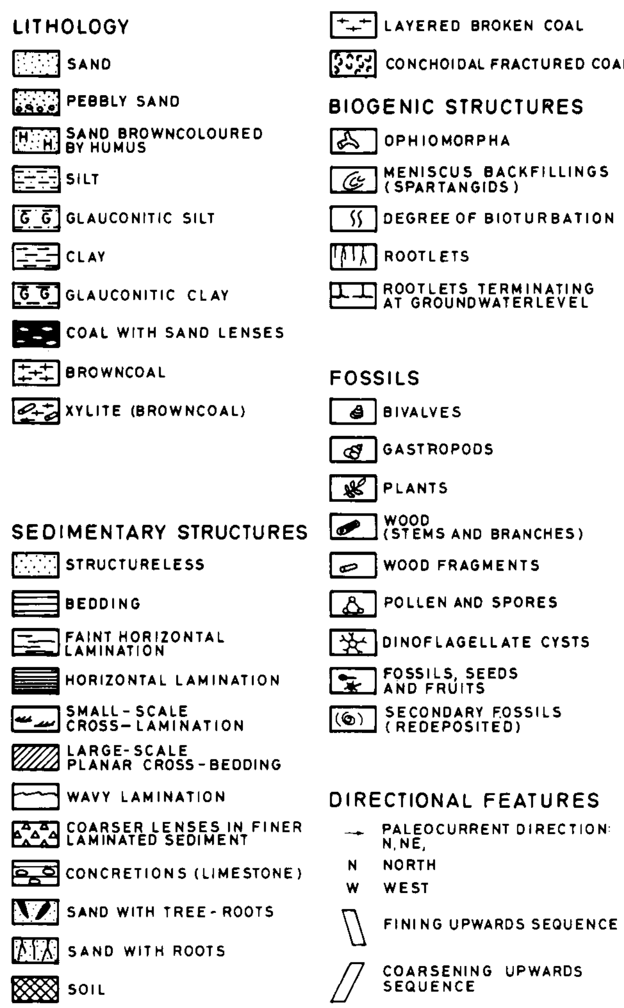
The 5th browncoal seam is definitely a distinct unit, separated from the Browncoal Bearing Sequence below by the lacustrine sand and clay of the 4th rhythm or the equivalent "Upper Sands".

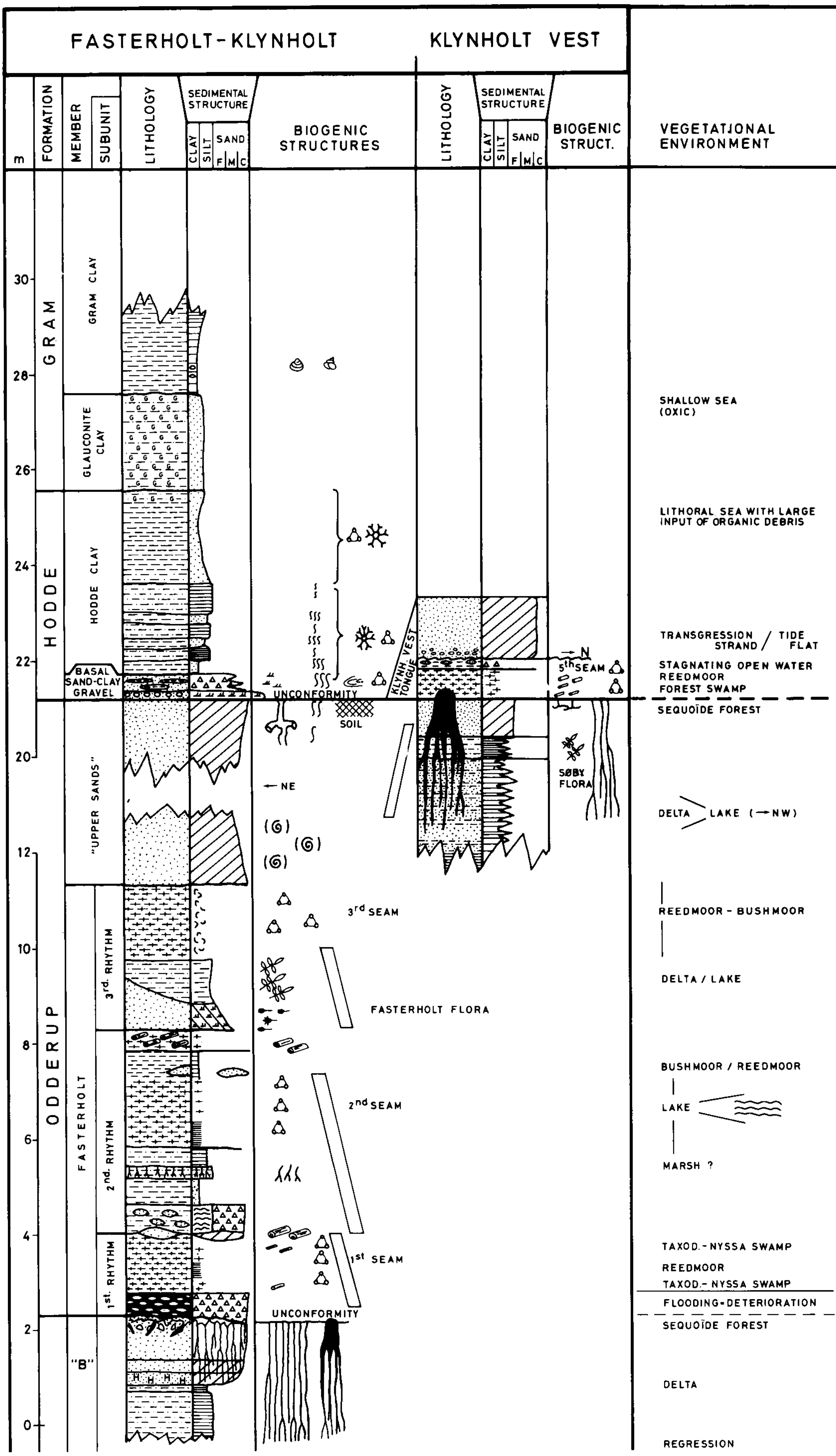
The root/stump horizons below the 5th browncoal bed in Klynholt Vest and on top of the "Upper Sands" to the east (Carl Nielsen pit, Fasterholt, profile F 11 and K6-K7) reveal very similar pollen spectra and seem to be a synchronous stratigraphical phenomenon which should be attributed to the paraconformity to which they are connected.

14. The Browncoal Bearing Sequence of the Søby-Fasterholt area fits to the definition of the Odderup Formation (Rasmussen, 1961). In this paper the Browncoal Bearing Sequence sensu stricto (including 3 (-4) seams), of the Søby-Fasterholt area is defined as the *Fasterholt Member,* of the Odderup Formation.

The uppermost browncoal bed (5th seam) above the "Upper Sands" and above the paraconformity with a root/stump horizon on top of the "Upper Sands" is defined as the *Klynholt Vest Tongue* as a local uppermost part of the Odderup Formation.

15. The Browncoal Bearing Sequence has been affected by tectonic activity (compression) later than deposition of the Gram Clay (Upper Miocene) and





Text-Fig. 68. Summary of lithostratigraphy and facies of biogenic and inorganic structures (syndepositional and early postdepositional), style of depositional history, and vegetational and environmental evolution. (see legend). Compiled by E.K., 1986.

before the Weichselian (Quaternary) glacio fluviatile sands and the underlying (earlier) pavement of ventifacts i.e. an erosional period. The tectonic pattern is disharmonic, consisting of shallow 1st order folds ("synclinoria" and "anticlinoria") of small amplitude (max. 20 meters) and a wave length of 2-3 km. 2 "anticlinoria" and one intervening "synclinorium" has been recorded in the Søby-Fasterholt mining area. These again are affected by 2nd order folds with amplitude of 5-8 meters and a wave length of the order of 100 meters. In the "synclinorium" of Fasterholt (pit of Carl Nielsen) a system of 2nd order "en echelon" folds has been recorded. The flanks of these 2nd order folds are affected by reverse faulting. The general axial orientation is NW-SE.

16. Faulting of a larger scale has displaced the Neogene sequence of Central Jutland. A fault has been recorded just to the west of Fasterholt Plantage (forest) with a minimum displacement of 20 metres. The overall primary information of the changing level of the Browncoal Bearing Sequence and the marine Miocene deposits can also be seen in the contour-maps of K. Milthers (ref. Text-Fig. 10) and K. Milthers in Heller, 1961.

It is justifiable to conclude that during the Middle Miocene (the Hemmoorian) the Søby-Fasterholt area (Central Jutland) was situated in the marginal zone of the Neogene North Sea which had oscillated during the Miocene, over the area in question.

The Browncoal Bearing Sequence represents a depositional episode (correlative with a transgression) in between two episodes of non-deposition (correlative with a regression). The changing sea level conditions are in part indicated by root/stump horizons and para- or weak disconformities. The regressive cycles were preceded and succeeded by depositional episodes of marine transgression.

The Browncoal Bearing Sequence must be a response to the initial stage of a period of subsidence influencing the marginal area of the North Sea basin as part of a delta which was responding to sea level changes during an interregnum between the *Hemmoorian* and *Reinbekian* transgressions and continuing well into the *early Reinbekian.*

The Browncoal Bearing Sequence belongs to a delta facies. This is documented by the rhythmical succession of extremely changing sediments with a high content of terrestrial organic sediment and plant fossils, distinct boundaries between the beds involving traces of week erosion and root/stump horizons and high (but with extremely changing) content of inorganic sediment (clay and mica) and inclusions of sand and silt in the browncoal. These criteria indicate deposition in the delta environment deposited under conditions where the surface was near to the erosional/depositional base level. The predominant corresponding type of impure detrital browncoal in East Germany (GDR) was named: Delta margin seams (German: Schuttfächerrand Flöz) (by Ahrens, Lotsch & Tzschoppe, (1968)). To the contrary, the type of xylitic browncoal that is poor in ash, deriving from localities protected against an influx of inorganic sediment, are rare in the Søby-Fasterholt area (e.g. the thin 1st seam).

The browncoal petrographical facies analysis has revealed the history of deposition and depositional environments of the different browncoal seams. The history and environmental conclusions fit well with the depositional history of the browncoal producing environments of this delta. Hence, calm stagnating forest swamps (Taxodium swamps?) (according to the nomenclature of M. Teichmüller, 1958) occur sporadically, but open waters are the most common and widespread. Open water graded into reed moors and these again sometimes graded into bush moors (Cyrillacean-Myricacean moor?) (according to the nomenclature of M. Teichmüller, 1958) or scattered forest swamps. River branches of different orders, heavily loaded with sediment and drift logs, have traversed through these environments ending into the open water basins, leaving small deltas. Concentrations of stranded logs are found in shallow water areas or interbedded with a sand cover on the swamps, probably as a result of temporary floodings.

The fossil floras of the Søby-Fasterholt area consist of a rich swamp- and wetland floral element and a distinct element of plants preferring well-drained environments or perhaps scattered high moor environments (Sequoia-moor). The wide variation in degree of wearing of the fossil plant remains indicate different lengths of transport (from growth habitat to place of deposition). A large element of allochtonous plant fossils mixed with autochtonous (and often well preserved) plant fossils occur. This is in agreement with the mixture of vegetational elements mentioned above and with the conditions of delta environments with lakes, ponds, swamps, river branches, levees and tree islands on hummocks (ref. the above mentioned floral elements). The floral element preferring well drained soil may have been based upon hummocks that were produced on the salt diapirs to the north or northeast of the area in question. The Jutland-Funen High cannot be neglected as a potential for retarded subsidence with high-moors or even locally well-drained soil. This is in accordance with the observation of K. Milthers (1941) that the browncoal of the pits situated on the Jutland-Funen ridge are "rich in wood" (Xylitic browncoal). The distribution of the Hodde Clay (and Gram Clay) in its large northwesterly embayment, support the idea for the tendency of this High to retard the subsidence leaving a shallow morphological ridge (peninsula) in the landscape.

6. References

Ahrens, H. & Lotsch, D., 1967: Die geologische Grundlagen der Aufstellung der Florenzonen im jüngeren Tertiär der Lausitz. Abhandl. Zentr. geol. Inst. H.10, 39-54.

Ahrens, H., Lotsch, D. & Tzschoppe, E., 1968: Gesetzmässigkeiten der Braunkohlenbildung in der "Jüngeren Braunkohlenformation" der Deutschen Demokratischen Republik. – Internat. Geol. Congr. Rept. 23. Session Czechoslovakia 1968, Proc. sect. 11: Origin of Coal Deposits, 9-21.

Andersen, S.A., 1944: Det danske Landskabs Historie. I: Undergrunden. 480 pp. København: Populær-Videnskabeligt Forlag.

Anderson, H.-J., 1958: Zur Stratigraphie und Paläontologie des marinen Oberoligozäns und Miozäns am Niederrhein auf Grund des Mollusken Faunen. – Fortschr. Geol. Rheinl. u. Westfalen 1: 177-295, Krefeld.

Anderson, H.-J., 1966: Die Schichtenfolge des Tertiärs und Quartärs. – In: Geologische und bergbauliche Übersicht des rheinischen Braunkohlenreviers. Brochüre z. Frühjahrstagung d. Deutsch. Geol. Ges. 1966: 2-5, Krefeld.

Anderson, H.-J., 1972: Die Bohrung Wildenrath 2 und des Alter der unteren Villeschichten (Tertiär südliche Niederrheinischen Bucht). Geologica et Palaeontologica 6: 1969-1975, Marburg.

Asgaard, U. & Bromley, R., 1974: Sporfossiler fra den Mellem Miocæne transgression i Søby-Fasterholt området. Dansk geol. Foren., Årsskrift for 1973, 11-19.

Averdieck, F.R., 1958: Pollen vom Chenopodiaceen-Typ im Flöz Frimmersdorf. – Ein Hinweis auf seine strandnahe Entstehung. – Fortschr. Geol. Rheinl. u. Westfalen 1 1958: 101-112, Krefeld.

Bailey, I.W. & Sinnott, E.W., 1916: The climatic distribution of certain types of Angiosperm leaves. – Am. J. Bot. 3, 24-39.

Benda, L., 1960: Beiträge zur Stratigraphie und Fazies der rheinischen Hauptbraunkohlenflözes aufgrund einer Kutikular-analytischen Untersuchung der Tagebau Vereinigte Ville, Berrenrath, Liblar, Lucretia, Sybilla, Fischbach und Fortuna. – N. Jb. Geol. Paläont., Abh. 109, 225-260.

Berthelsen, F., 1978: The Upper Triassic-Lower Jurassic Vinding and Gassum Formations of the Norwegian-Danish Basin. Danm. geol. Unders. B., 3, pp 26.

Beyrich, E., 1853-1856: Die Conchylien des norddeutschen Tertiärgebirges, Berlin.

Beyrich, E., 1856: Über den Zusammenhang der norddeutschen Tertiärbildungen. – Abh. d. Königl. Akad. d. Wiss. zu Berlin, phys. Kl., Jahrg. 1855.

Binzer, K. & Stockmarr, J., 1985: Geologi i Midtjylland. Prækvartæroverfladens højdeforhold og landskabets udformning, kortbladet 1214, Silkeborg. – Danm. geol. Unders. Miljøministeriet.

Bjelm, L. et al., 1977: Geotermisk energiudvinding i Skåne, slutrapport etapp. 1. Rep. published by Tekniska högskolan i Lund, Sweden.

Brelie, G. von der, 1958: Sporen und Pollen im marinen Tertiär der Niederrheinischen Bucht. – Fortschr. Geol. Rheinl. u. Westfalen 1: 185-204, Krefeld.

Brelie, G. von der, 1963: Nachweis mariner Beeinflussung mit Flagellaten, Hystrichosphaeriden und Pollen. – Fortschr. Geol. Rheinl. u. Westfalen 10, 107-120, Krefeld.

Brelie, G. von der, 1967: Quantitative Sporenuntersuchungen zur stratigraphischen Gliederung des Neogens in Mitteleuropa. Rev. Palaeobotan. Palynol. 2, 147-162.

Brelie, G. von der, 1968: Zur mikrofloristischen Schichtengliederung im rheinischen Braunkohlenrevier. Fortschr. Geol. Rheinl. u. Westfalen 16, 85-102.

Brelie, G. von der, Hager, H. & Weiler, H., 1981: Pollenflora und Phytoplankton in den Kölner Schichten sowie deren Lithostratigraphie im Siegburger Graben. – Fortschr. Geol. Rheinl. u. Westfalen 29: 21-58, Krefeld.

Brelie, G. von der & Wolf, M., 1981a: Sequoia und Sciadopitys in den Braunkohlenmooren der Niederrheinischen Bucht. – Fortschr. Geol. Rheinl. u. Westfalen, 29: 177-191, Krefeld.

Brelie, G. von der & Wolf, M., 1981b: Zur Petrographie und Palynologie heller und dunkler Schichten im rheinischen Hauptbraunkohlenflöz. – Fortschr. Geol. Rheinl. u. Westfalen, 29: 95-163, Krefeld.

Brocchi, G., 1814: Conchiologia Fossile Subapennina. Milano.

Bruguière, 1789-1792: Histoire Naturelle des Vers. Encyclopédie Méthodique. T. Sixième, Paris, 376 pp.

Burgh, J.v.d., 1973: Hölzer der niederrheinischen Braunkohlenformation. 2. Hölzer der Braunkohlengruben Maria-Theresia zu Herzogenrath, Zukunft West zu Eschweiler und Victor (Zülpich Mitte) zu Zülpich. – Rev. Paleobot. Palynol., 15, 73-275.

Bůžek, C., 1971: Tertiary Flora from the Northern Part of the Pětipsy Area (North-Bohemian Basin). Rozpr. Ùstř. geol. 36, 1-118.

Chaney, R.W., 1951: A revision of fossil Sequoia and Taxodium in western North America based on the recent discovery of Metasequoia. – Trans. Amer. Philos. Soc., N.S. -40, 3, 171-239.

Chaney, R.W., 1959: Miocene Floras of the Columbia Plateau. Carnegie Inst. Washington Publ. 617, 1-133.

Childs, F.B. & Reed, P.E.C., 1975: Geology of the Dan field and the Danish North Sea. – Geol. Surv. Denmark III. Ser. 43.

Christensen, E.F., 1975: The Søby-Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. Part 1, Geol. Surv. Denmark II. Ser. no. 103, 1-41.

Christensen, E.F., 1976: The Søby Flora: Fossil plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. Part II. Geol. Surv. Denmark II. Ser. no. 108, 1-49.

Christensen, E.F., 1978: The Søby Flora: Fossil Plants from the Middle Miocene delta deposits of the Søby-Fasterholt area, Central Jutland, Denmark. III (unpublished thesis, University of Aarhus, 1-48.

Christensen, W. & Larsen, G., 1960: Tungsandsforekomster i Danmark. Danm. geol. Unders. III Rk., 33, 63 pp.

Cohen, A.D., 1973: Petrology of some Holocene peat sediments from the Okefenokee swamp-marsh complex of southern Georgia. Bull., Geol. Soc. Amer., v.84, 3867-3878.

Cohen, A.D., 1974: Petrology and paleoecology of Holocene peats from the Okefenokee swamp-marsh complex of Georgia. Jour. Sed. Petrol. v.44, no.3, 716-726.

Dalgas, F., 1868: Geographiske Billeder fra Heden, H. (1-2), 125 pp.

Dawson, J.W., 1883: On the Cretaceous and Tertiary Floras of British Columbia and the Northwest Territories. Roy. Soc. Canada Trans. 1, (4), 15-34.

Dinesen, B., 1976: Geochemical properties of the marine Younger Miocene at Gram, SW Jutland. – Geol. Surv. Denmark, Yearbook 1975. 5-26.

Engler, A., 1882: Versuch einer Entwicklungsgeschichte der Pflanzenwelt seit der Tertiärperiode II, 333 pp. Leipzig: Engelmann.

Fabian, H.J., 1958: Die Aufschlussbohrung Straeten 1, – Fortschr. Geol. Rheinl. u. Westfalen 1: 11-28, Krefeld.

Ferguson, D.K., 1971: The Miocene flora of Kreuzau, Western Germany. I. The leaf-remains. – 297 pp. Amsterdam, London.

Flaig, W., 1968: Biochemical factors in coal formation. – Coal and Coal-bearing strata. Edinburgh, London.

Forchhammer, G., 1835: Danmarks geognostiske Forhold forsaavidt som de ere afhængige af Dannelser, der ere sluttede. København: Schultz, 112 pp.

Forchhammer, J.G., 1842: Den skandinaviske Rullestensformations Forhold i Danmark. – Forhandl. Skand. Naturf. Møde 1842.

Forchammmer, J.G., 1865: Oversigt over Danmarks geognostiske

Sammenhæng. - Förhandl. skand. naturf. 9. möte i Stockholm 1863, 29-42.
Friedrich, W.L. & Koch, B.E., 1970: Comparison of Fruits and Seeds of fossil Spirematospermum (Zingiberaceae) with those of living Cenolophon., Bull. geol. Soc. Denmark, 20, 192-195.
Friedrich, W.L. & Koch, B.E. 1972: Der Arillus der tertiären Zingiberaceae Spirematospermum wetzleri. Lethaea, Oslo, 1, 5, 47-59.
Friedrich, W.L. & Strauch, F., 1976: Der Arillus der Bananen. Botaniska Notiser, Lund. 128, 339-349.
Friedrich, W.L. & Schaarschmidt, F., 1977: Zwei- und drei-dimensionale Fluoreszenzaufnahmen von fossilen Pflanzen. - Cour. Forsch.-Inst. Senckenberg, Frankfurt a.M., 24, 31-49.
Friis, E.M., 1974: Taxonomy of the Tertiary fossil fruit Carpolithes oestrupii from the Pleistocene of Denmark. Bull. geol. Soc., Denmark, 23, 265-268.
Friis, E.M., 1975: Climatic implications of microcarpological analyses of the Miocene Fasterholt flora, Denmark. - Bull. geol. Soc. Denmark, 24, 179-191.
Friis, E.M., 1976: Ascomycete svampe fra den Miocæne Fasterholt Flora. - Dansk geol. Foren., Årsskrift for 1975, 5-9.
Friis, E.M., 1977 a: Leaf whorls of Cupressaceae from the Miocene Fasterholt flora, Denmark. - Bull. geol. Soc. Denmark, 26, 103-113.
Friis, E.M., 1977 b: Planter og klima i Tertiærtiden. - Varv, København, 1, 22-31.
Friis, E.M., 1977 c: EM-studies of Salviniaceae megaspores from the Middle Miocene Fasterholt flora, Denmark. Grana, 16, 113-128.
Friis, E.M., 1979: The Damgaard flora: A new Middle Miocene flora from Denmark. - Bull. geol. Soc. Denmark, 27, Copenhagen, 117-142.
Friis, E.M., 1985: Angiosperm Fruits and Seeds from the Middle Miocene of Jutland (Denmark). Det Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter, 24, 3, 1-165.
Friis, H., Nielsen, O.B., Friis, E.M. & Balme, B.E., 1980: Sedimentological and paleontological investigations of a Miocene sequence at Lavsbjerg, Central Jutland, Denmark. - Geol. Surv. Denmark Yearbook 1979, 51-67.
Garboe, A., 1959: Geologiens Historie i Danmark, I: Fra myte til videnskab, 1-283, København.
Garboe, A., 1961: Geologiens Historie i Danmark, II: Forskere og resultater, 1-522, København.
Gliese, J. & Hager, H., 1978: On Browncoal Resources in the Lower Rhine Embayment (West Germany). - Geologie en Mijnbouw 57 (4): 517-525, Amsterdam.
Grambo-Rasmussen, A., 1980: En oversigt over den marine og kontinentale stratigrafi i Nordsøbassinets sydlige og østlige dele, med henblik på en relatering af de brunkulsførende deltafacies og den marine stratigrafi. Unpublished thesis, Aarhus University.
Grambo-Rasmussen, A., 1982: Danmarks brunkulsreserver. Rapport Fase 1, Danm. geol. Unders., Råstofgeologisk Afdeling.
Grambo-Rasmussen, A., 1984: Danmarks brunkulsreserver. Rapport over Fase 2. Danm. geol. Unders. - Rapport Serie D, nr. 2.
Graversen, P., Rolle, F. & Surlyk, F., 1982: Lithostratigraphy and sedimentary evolution of the Triassic, Jurassic and Lower Cretaceous of Bornholm, Denmark. - Geol. Surv. Denmark, Ser. B, 7, 1-51.
Grönwall, K.A., 1908: En boring på Samsø og nogle deraf følgende Slutninger om Danmarks ældre Tertiær. Meddr. dansk geol. Foren. 3, 133-148.
Hager, H., 1968: Zur Gleichstellung und Genese der Flöze im Rheinischen Braunkohlenrevier. - Fortsch. Geol. Rheinl. u. Westfalen 16: 73-84, Krefeld.
Hager, H., 1981: Das Tertiär des Rheinischen Braunkohlenreviers, Ergebnisse und Probleme. - Fortschr. Geol. Rheinl. u. Westfalen 29: 529-563, Krefeld.
Hartz, N., 1909: Bidrag til Danmarks tertiære og diluviale Flora. København: Reitzel, 293 pp.
Heer, O., 1868-1883: Flora Fossilis Arctica I-VII, Zürich.
Heer, O., 1883: Flora Fossilis Groenlandica (Flora Fossilis Arctica 7), Zürich, Fr. Schultess, 275 pp.
Heer, O., 1893: Oversigt over Grønlands fossile Flora (Zürich 1883). Meddr Grønland 5, 79-202.
Heller, E., 1961 a: Keld Milthers' arbejde med brunkulseftersøg ningen. - Meddr. dansk geol. Foren. 14, 447-453.
Heller, E., 1961 b: Iagttagelser over tertiære og kvartære forhold i Tarm-Brande-Grindsted-området. Meddr. dansk geol. Foren. 14, 374-385.
Hiltmann, W., 1976: Pollenanalytische Untersuchungen im Rheinischen Kohlenflöz der Tagebau Frechen und Fortuna unter besonderer Berücksichtigung der makropetrographischen Ausbil dung der Kohle. - Thesis Technischen Hochschule Aachen.
Hinsch, W., 1972: Biostratigraphie des Miozäns im Raum Wacken (Westholstein). - Geol. Jb., A 4, 3-41.
Hinsch, W., 1973 a: Biostratigraphie des Miozäns im Kreis Pinneberg. - Mitt. Geol. u. Paläont. Inst. Univ. Hamburg. 42, 25-56.
Hinsch, W., 1974: Das Tertiär im Untergrund von Schleswig-Holstein (Das Nordwestdeutsche Tertiärbecken, Beitr. 5). - Geol. Jb. A 24.
Hinsch, W. & Ortlam, D., 1974: Stand und Probleme der Gliederung des Tertiärs in Nordwestdeutschland. - Geol. Jb. A 16, 3-25.
Holý, F. & Bůček, C., 1966: Seeds of Stratiotes L. (Hydrocharitaceae) in the Tertiary of Czechoslovakia. - Sb. geol. Ved. R. Paleont. 8 (1966), 105-135.
Ingwersen, P., 1949: Iagttagelser i de jydske Brunkulsgrave. Meddr dansk geol. Foren. 11, 486-488.
Ingwersen, P., 1954: Some Microfossils from Danish Late-Tertiary Lignites. Geol. Surv. Denmark, Ser. no. 2, 80, 31-64.
International Handbook of Coal Petrography, 1963: - 2nd ed., edited by Int. Comm. Coal Petrol. Centre National Recherche Scientifique, Paris.
International Handbook of Coal Petrography, 1971, 1975: - Suppl. to 2nd ed., edited by Int. Comm. Coal Petrol., Centre National Recherche Scientifique, Paris.
Jacob, H., 1966: Petrologische, physikalische und chemische Untersuchungen zur Frage der Bildung heller Schichten in Braunkohlenflöze. - Braunkohle, 6, 206-209, 253-259.
Juchniewics, K., 1975: The fossil flora from near Bogatynia studied by cuticular analysis. - Prace Muzeum Ziemi, 24, 116 132.
Jänichen, H., 1965: Beiträge zur Tertiärflora der Lausitz - inkohlte Blätter und Epidermissstrukturen. - Mber. Dtsch. Akad. Wiss. Berlin, 7 (9), 664-670.
Jørgensen, K.D., 1941: Det danske Pliocæn. - Meddr dansk geol. Foren., 10, 59-63.
Kilpper, K., 1960: Planzenführung, Fazies und Bildungsverhaltnisse im "Hauptflöz der Ville", eine Kutikularanalytische Untersuchung in den Tagebauen Neurath und Frimmersdorf-Süd des rheinischen Braunkohlenreviers. - N.Jb. Geol. Paläont. Abh. 109, 261-308.
Knobloch, E., 1969: Tertiäre Floren von Mähren, Brno. 1-201.
Knobloch, E. & Kvaček, Z. 1976: Miozäne Blätterfloren vom Westrand der Böhmischen Masse. - Rozpr. Ústr. Óst. geol. 42, 1-131.
Knobloch, E, 1980: Die Beziehungen der Miozänen Floren von Zentraljütland zu den mitteleuropäischen Tertiärfloren. - Bull. geol. Soc. Denmark, 28, 123-126.
Koch, B.E. & Friedrich, W.L., 1970: Geologisch-Paläobotanische Untersuchung der miozänen Braunkohlen bei Fasterholt in Jütland, Dänemark. Bull. geol. Soc. Denmark, 20, 2, 169-191.
Koch B.E. & Friedrich, W.L., 1971: Früchte und Samen von Spirematospermum aus der miozänen Fasterholt-Flora in Dänemark. - Paleoontographica. Abt. B, 136, 1, 1-46.
Koch, B.E. & Friedrich, W.L., 1972: Stereoskopische Röntgenaufnahmen von fossilen Früchten. - Bull. geol. Soc. Denmark, 21, 358-367.
Koch, B.E., 1973: Krydderi på det jyske Tertiær. Varv, 3, 72-77.
Koch et al., 1973: Den miocæne brunkulsflora og dens geologiske miljø i Søby-Fasterholt området sydøst for Herning. - Dansk geol. Foren., Årsskr. for 1972, 1-57.
Koch, B.E., 1975: Træk af brunkulsbrydningens historie i Danmark. MIV 5 (Museerne i Viborg Amt), 10-19.
Koch, B.E., 1977: De jyske brunkuls geologi. - Naturens Verden, 5-6, 233-249. (Særnummer fra Statens naturvidenskabelige Forskningsråd).
Koch, B.E., 1977: Stand der geologisch-paläontologischen Untersuchung miozäner Ablagerungen des Zentralen Jütlands, Dänemark. - Cour. Forsch.-Inst. Senckenberg, 24, 72-82.
Koch, B.E., 1978: Friedrich Jens Mathiesen (en levnedsskildring). Dansk geol. Foren. Årsskrift for 1977, 41-46.
Koch, B.E., 1979: Das kontinentale Miozän im Söby-Fasterholt Gebiet, Zentral-Jütland: Geologie und Stratigraphie. - Proceedings of the Symposium: The Continental Miocene of Central Jutland, Denmark, Aarhus University, June 11-16, 1979, 22-235.

Koch, B.E., 1979: Neogene Stratigraphy of the Søby-Fasterholt area. - Proceedings of the Symposium: The Continental Miocene of Central Jutland, Denmark, Aarhus University, June 11-16, 1979, pp. 49-55.
Koch, B.E. & Christensen, E. F., 1979: Introduction to the Symposium "The Continental Miocene of Central Jutland (Denmark): Geology - Brown coal facies - Stratigraphy - Paleontology". 1-97.
Koch, B.E.(editor), 1979: Proceedings of the Symposium "The Continental Miocene of Central Jutland (Denmark): Geology-Brown coal facies - Stratigraphy - Paleontology". 1-83.
Koch, B.E., 1984: A stratigraphical study of the Miocene Brown coal bearing sequence of the Søby-Fasterholt area, Central Jutland, Denmark, based upon fossil pollen. Søby-Fasterholt Brunkulsprojektet. Forskningsrapport no. 8. Aarhus.
Koch, B.E., 1988: Denmark, the Danish Subbassin. - In: R. Vinken (Compil.). The Northwest European Tertiary Basin. Results of the Internat. Geol. Correlation Programme, Project 124. - Geol. Jahrb., A. 100, 318-320. Fig. 163.
Koch, B.E. & Friedrich, W.L., Christensen, E. F. & Friis, E.M., 1973: Den Miocæne brunkulsflora og dens geologiske miljø i Søby-Fasterholt området sydøst for Herning. Dansk geol. Foren., Årsskrift for 1972, 1-57.
Koch, J., 1970: Petrologische Untersuchungen an niedersächsischen Torfen und Weichbraunkohlen. - Geol. Mitt., 10, 113-150.
Kramer, K., 1974: Fossile Pflanzen aus der Braunkohlenzeit. Die obermiozäne Flora des unteren Fischbachtones im Tagebau Frechen bei Köln. - Mitt. Deutsch. Dendrol. Ges., 67, 199-233.
Kristoffersen, F.N., 1972: Foraminiferzonering i det jyske Miocæn. Dansk geol. Foren. Årsskr. for 1971, 79-85.
Kristoffersen, F.N., 1973: Oligocæn og Miocæn i Nøvling nr. 1. - Dybdeboringen Nøvling Nr. 1 i Midtjylland (The deep test well Nøvling no. 1 in Central Jutland, Denmark). - Geol. Surv. Denmark, III Ser. 40, 63-70.
Krutsch, W., 1962-1970: Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen- sowie der Mikroplanktonformen des nördlichen Mitteleuropas, I-VII, Berlin.
Larsen, G., 1963: Undersøgelse af flintfattigt grus til beton. Ingeniøren, B 12, 415-426.
Larsen, G., 1966: Rhaetic - Jurassic - Lower Cretaceous Sediments in the Danish Embayment (A heavy-mineral study). Geol. Surv. Denmark, Ser. no. 2, 91, 128 pp.
Larsen, G., 1970: Hovedtræk af tungmineralanalysens resultater i Danmark. Dansk geol. Foren. Årsskr. for 1969, 36-47.
Larsen, G. & Dinesen, A., 1957: Tertiæret ved Brejning. Sedimenter og Foraminiferfauna. - Meddr. dansk geol. Foren. 13, 266 269.
Larsen, G & Dinesen, A., 1959: Vejle Fjord Formationen ved Brejning. Sedimenterne og foraminiferfaunaen (Oligocæn - Miocæn). Danm. geol. Unders. rk. 2, 82, 114 pp.
Larsen, G. & Friis, H., 1973: Sedimentologiske undersøgeler af det jyske ung-Tertiær. Dansk geol. Foren. Årsskr. for 1972, 119-128.
Larsen, G. & Kuyp, A.A., 1971: Spor efter grundvandsforekomster i ungtertiæret ved Fasterholt. Dansk geol. Foren. Årsskr. for 1970, 17-22.
Lesquereux, L., 1852: Torfbildung im grossen Dismal - Swamp. Zeitsch. deutsch. geol. Ges. 4, 695-697.
Lesquereux, L., 1883: Contributions to the fossil flora of the Western Territories III, The Cretaceous and Tertiary floras. U. S. Geol. Surv. Terr. Rept. 8, 283 pp.
Linnaeus, C., 1735 (1758): Systema Naturae. Leyden.
Mai, D.H., 1964: Die Mastixioideen-Floren im Tertiär der Oberlausitz. - Paläont. Abh. Abt. B, 2, 1-192.
Mai, D.B., 1965: Der Florenwechsel im jüngeren Tertiär Mitteleuropas. - Feddes Repert. 70, 55-82.
Mai, D.B., 1967: Die Florenzonen, der Florenwechsel und die Vorstellung über den Klimaablauf im Jungtertiär der DDR. - Abhandl. Zentr. Geol. Inst. H 10, 55-81.
Mai, D.H., 1968: Die subtropische Elemente im Tertiär Europas II. Berlin 1968.
Mai, D.H., 1970: Subtropische Elemente im europäischen Tertiär, I. - Paläont. Abh. Abt. B, 3, 441-503.
Mathiesen, F.J., 1965: Paleobotanical Investigations into some Cormophytic Macrofossils from the Neogene Tertiary Lignites of Central Jutland: I: Introduction and Pteridophytes, Kgl. Dan. Vid. Selsk. Biol. Skr. 14, 6, 44 pp.
Mathiesen, F.J., 1970: Palaeobotanical Investigations into some Cormophytic Macrofossils from the Neogene Tertiary Lignites of Central Jutland. II: Gymnosperms. Kgl. Dan. Vid. Selsk. Bio. Skr. 17, 3, 70 pp.
Mathiesen, F.J., 1970: Paleobotanical Investigations into some Cormophytic Macrofossils from the Neogene Tertiary Lignites of Central Jutland, III: Angiosperms. - Kgl. Dan. Vid. Selsk., Biol. Skr. 20 (9), 1-59.
Milde-Darmer, K., 1964: Kohlengeologiske Komplexuntersuchungen des Berzdorfer und Zittauer Flözes unter besonderer Berücksichtigung flözgenetischer Probleme. - Freib. Forsch. H., C. 154.
Milthers, K., 1941 a: Systematisk Eftersøgning af Brunkul. Geogr. Tidsskr. 44, 110-117.
Milthers, K., 1941 b: De danske Brunkul og deres Udnyttelse. Ledetraad ved folkelig Universitetsundervisning 115, 4 pp.
Milthers, K., 1944 a: Det danske Brunkulseventyr. Ingeniøren 45, 53 årg., K67-K69.
Milthers, K., 1944 b: Det danske Brunkulseventyr. Tidsskr. for Industri 1944, 15, 185-190.
Milthers, V., 1939: Kortbladet Brande. Danm. geol. Unders. rk. 1, 18, 163 pp.
Mohr, B. 1982: Die Mikroflora in den Deckschichten der rheinischen Braunkohle (Obermiozän - Unterpliozän). - Inaugural-Dissertation zur Erlangung des Doktorgrades der Hohen Mathem. - Naturw. Fakultät der Rheinischen Friedrich-Wilhelms-Universität zu Bonn. 1982.
Nagy, E., 1969: Palynological elaborations of the Miocene layers of the Mecsek Mountains. - Magy. áll. földt. Intéz. Évk., 52 (2), 474 et pl. LIII, 25, 26. Budapest.
Nathorst, A.G., 1885: Kap. 6-7 i Nordenskiöld, A.E. 1885.
Nathorst, A.G., 1888: Zur fossilen Flora Japans. Paläont. Abh. 4, 195-250.
Nielsen, E. Fuglsang, 1984: En sedimentologisk og geokemisk undersøgelse af Hodde Formationen, Miocæn, Vestdanmark. Dansk geol. Foren., Årsskr. for 1983, 29-34.
Nordenskiöld, A.E., 1885: Den andre dicksonska Expeditionen till Grönland, Stockholm.
Palamarev, E., 1970: Fossile Floren aus der Braunkohlenbecken in Südwestbulgarien. Bulg. Acad. Nauk., 20, 35-79.
Pflug, H.D., 1966: Zur Stratigraphie des mittleren Tertiärs in Hessen und in benachbarten Gebieten. Notizbl. hess. L.-Amt Bodenforsch. 94, 259-268.
Pflug, H.D., 1975: Sporenstratigraphische Korrelation des Vogelsberg-Gebietes mit benachbarten Tertiärbecken (Das Nordwestdeutsche Tertiärbecken, Beitrag 13). Oberhessische Naturwissenschaftliche Zeitschrift, 42, 21-30.
Piasecki, S., 1980: Dinoflagellate cyst stratigraphy of the Miocene Hodde and Gram Formations, Denmark. - Bull. geol. Soc. Denmark, 29, 53-76.
Pietzner, 1969: Röntgenfluoreszenzanalyse von anorganischen Bestandteilen in Braunkohle. Fortschr. Geol. Rheinl. u. Westf. 16, 595-608.
Pietzner, H. & Wolf, M., 1964: Geochemische Untersuchungen an Braunkohlenaschen und kohlenpetrographischen Untersuchungen an Braunkohlen aus dem niederrheinischen Braunkohlenrevier. - Fortschr. Geol. Reinl. u. Westf. 12, 517-550.
Radwanski, A., Friis, H. & Larsen, G., 1975: The Miocene Hagenør-Børup sequence at Lillebælt (Denmark): its biogenic structures and depositional environment. - Bull. geol. Soc. Denmark, 24, 229-260.
Rasmussen, L.B., 1956: The Marine Upper Miocene of South Jutland and its Molluscan Fauna. - Geol. Surv. Denmark, II ser. 81 pp.
Rasmussen, L.B., 1961: De Miocæne Formationer i Danmark. - Danm. geol. Unders., rk. 4, 4, (5), 45 pp.
Rasmussen, L.B., 1961: Mittel- und Ober-Miozän von Dänemark. - Meyniana Bd. 10, 59-62.
Rasmussen, L.B., 1966: Biostratigraphical studies on the marine younger Miocene of Denmark. Geol. Surv. Denmark, Ser. no.2, 88, 358 pp.
Rasmussen, L.B., 1968: Molluscan Faunas and Biostratigraphy of the Marine Younger Miocene Formations in Denmark, II: Palaeontology. Geol. Surv. Denmark, Ser. no. 2, 92, 265 pp.
Rasmussen, L.B., 1973: Nye perspektiver i kendskabet til Danmarks

marine ung-Tertiær. - Dansk geol. Foren. Årsskr. for 1972, 129 135.

Rasmussen, L.B., 1974: Some geological results from the first five Danish exploration wells in the North Sea. - Geol. Surv. Denmark, Ser. no. III, 42.

Rasmussen, L.B., 1978: Geological aspects of the Danish North Sea sector. - Geol. Surv. Denmark, Ser. no. III, 44.

Rasmussen, L.B., 1979: The stratigraphy of the Marine Neogene of Denmark. - Proceedings of the Symposium: The Continental Miocene of Central Jutland, Denmark. - Aarhus University, June 11-16 1979, 11-21.

Ravn, J.P.J., 1897: Nogle Bemærkninger om danske Tertiæraflejringers Alder. Meddr dansk geol. Foren. 1, 4, 1-6.

Ravn, J.P.J., 1906: Nogle Bemærkninger om de oligocæne og miocæne Aflejringer i Jylland. - Meddr. dansk geol. Foren. 2, 12, 1-6.

Ravn, J.P.J., 1907: Molluskfaunaen i Jyllands Tertiæraflejringer. Kgl. Dan. Vid. Selsk. Skr. 7 Rk., natv.-math. Afd. III, 2.

Ravn, J.P.J., 1928: Oversigt over Danmarks Geologi. Tertiær. Danm. geol. Unders. Rk. 5, 4, 64-77.

Rein, U., 1950: Die Bedeutung der Flözfeingliederung für den rheinischen Braunkohlenbergbau und ihre Anwendung in der Praxis. - Braunkohle, Wärme u. Energie, 1/2: 72-78, 7 Abb. Düsseldorf.

Rein, U., 1961: Die Möglichkeiten einer pollenstratigraphischen Gliederung des Miozäns in Nordwestdeutschland. - Meyniana 10, 160-166.

Rørdam, K., 1909: Geologi og Jordbundslære. II: Danmarks Geologi. 225 pp. København.

Schneider, W. 1966: Beziehungen zwischen Pflanzeninhalt und petrographischer Beschaffenheit von Weichbraunkohlen am Beispiel der miozänen Braunkohlen der Oberlausitz. - Ber. Deutsch. Ges. geol. Wiss., A 11, 615-633.

Schneider, W., 1969: Cuticulae dispersae aus dem 2. Lausitzer Flöz (Miozän) und ihre fazielle Aussage. - Freib. Forsch. H., C. 222.

Schneider, W., 1978: Zu einigen Gesetzmässigkeiten der faziellen Entwicklung im 2. Lausitzer Flöz. - Z. Angew. Geol., Bd. 24, 3, 125-130.

Sinnott, E.W. & Bailey, I.W., 1915: Investigation on the phylogeny of the Angiosperms, 5: Foliar evidence as to the ancestry and early climatic environment of the Angiosperms. Amer., J. Bot. 2, 1-22.

Sinnott, E.W. & Bailey, I.W., 1916: The climatic distribution of certain types of Angiosperm leaves. Amer. J. Bot. 3, 24-39.

Sorgenfrei, T., 1940: Marint Nedre-Miocæn i Klintinghoved på Als. Danm. geol. Unders. Rk. 2, 65, 143 pp.

Sorgenfrei, T., 1958: Molluscan Assemblages from the Marine Middle Miocene of South Jutland and their Environemnts. I-II.

Sorgenfrei, T. 1961: Die Entwicklung des unteren und mittleren Miozän im südlichen Dänemark. Meyniana 10, 53-58.

Sowerby, J.C., 1825: The Mineral Conchology of Great Britain, Vol. V. London.

Spackmann, W. et al., 1966: Phytogenic organic sediments and sedimentary environments in the Everglades-Mangrove Complex. Paleontolographica B., 117, 135-152.

Spjeldnæs, N., 1975: Paleogeography and Facies Distribution in the Tertiary of Denmark and Surrounding Areas. - Geol. Surv. Norway, 316, 289-311.

Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D. & Teichmüller, R. 1975: Stach's textbook of Coal Petrology. - Borntraeger, Stuttgart.

Szafer, W., 1961: Miocene Flora from Stare Glivice in Upper Silesia. - Prace Inst. Geol., 33, 1-205.

Teichmüller, M., 1950: Zum petrographischen Aufbau und Werdegang der Weichbraunkohle. - Geol. Jb. 64, 429-488.

Teichmüller, M., 1958: Rekonstruktion verschiedener Moortypen des Hauptflözes der niederrheinischen Braunkohle. Fortschr. Geol. Rheinl. u. Westf. 2, 599-612.

Teichmüller, M., 1974: Über neue Macerale der Liptinit-Gruppe und die Entstehung des Micrinits. - Fortschr. Geol. Reinld. u. Westf. 24, 37-64.

Teichmüller, M. & Thomsson, D.W., 1958: Vergleichende mikroskopische und chemische Untersuchungen der wichtigsten Fazies-Typen im Hauptflöz der rheinischen Braunkohlen. Fortschr. Geol. Rheinld. u. Westf. 2, 573-598.

Thiele-Pfeiffer, H., 1980: Die Miozäne Mikroflora aus dem Braunkohlentagebau Oder bei Wackersdorf/Oberpfalz. - Palaeontographica 174, B., (4-6), 95-224, Stuttgart.

Thiergart, F. 1940: Die Mikropaläontologie als Pollenanalyse im Dienst der Braunkohlenforschung. - Brennstoff-Geologie H. 13, 1-62.

Thomsen, E., 1976: En kulpetrografisk faciesanalyse af brunkulsforekomsterne i den Miocæne Odderup Formation ved Fasterholt, Jylland, (unpublished thesis, University of Aarhus), 1-110.

Thomsen, E., 1979: Description and Facies Interpretation of the Coal Seams. - The Continental Miocene of Central Jutland, Denmark. - Symposium, Aarhus University, June 11-16, 1979, 19-31.

Thomsen, E., 1980: A Coal Petrographic Facies Analysis of the Brown Coal-Bearing Sequence in the Miocene Odderup Formation at Fasterholt, Jutland, (unpublished thesis, Aarhus University) 1-28.

Thomson, P. W., 1950: Die Entstehung von Kohlenflözen auf Grund paläontologischen Untersuchungen des Hauptflözes des rheinischen Braunkohle. - Braunkohle 2, 39-43.

Thomson, P. W. & Pflug, H., 1963: Pollen und Sporen des mitteleuropäischen Tertiärs. - Palaeontographica 94, B, 1-4: 1-138. Foren.1, 2, 42-64.

Vahl, M., 1904: Om Brunkullenes dannelsesvilkaar. - Meddr dansk geol. Foren. 2, 10, 140-143.

Vaupell, C., 1896 (1853): En botanisk Undersøgelse af det fossile Træ, der findes i Leer- og Sandlagene i Danmark og af Havet opkastet med Ravet paa de danske Kyster. - Meddr. dansk geol. Foren. 1, 10, 140-143.

Vogt, W., 1970: Der makropetrographische Flözaufbau in den Tagebauen Frechen, Fortuna und Inden des niederrheinischen Braunkohlenreviers unter besonderer Berücksichtigung der Brikettiereigenschaften der Lithotypen. - Thesis, Technischen Hochschule Aachen.

Wagner, P. & Koch, B.E., 1974: Fossil Roots of Sequoia type from two localities of the Miocene delta deposits of the Søby-area. - Bull. geol. Soc. Denmark, 23, 134-158.

Ward, L.F., 1886: Synopsis of the flora of the Laramie group. U. S. geol. Surv. Sixth Ann. Rept. 1884-1885, 399-557.

Ward, L.F., 1887: Types of the Laramie flora. U.S. geol. Surv. Bull. 37, 1-353.

Weyland, H., 1957: Kritische Untersuchungen zur Kutikularanalyse tertiärer Blätter III. - Palaeontographica Abt. B, 103, 34-74.

Weyland, H., 1960: Kritische Untersuchungen zur Kutikularanalyse tertiärer Blätter V. Palaeontographica. Abt. B. 106, 1-10.

Wienberg Rasmussen, H., 1966: Danmarks Geologi. Gjellerup, København 1966.

Wolf, W., 1919: Erdgeschichte und Bodenaufbau Schleswig-Holsteins. Hamburg. 119 pp.

Wölk, E., 1935: Mächtigkeit, Gliederung und Entstehung des Niederrheinischen Hauptbraunkohlenflözes. - Ber. Vers. niederrh. geol. Ver. 28, 81-163.

Ziegler, P.A., 1975: Geologic Evolution of the North Sea and Its Tectonic Framework. - Amer. Ass. Petrol. Geol. 59/7, 1073-1097.

Ziegler, P.A., 1982: Geological Atlas of Western and Central Europe, 1-130. Amsterdam/New York.

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This book contains a description of the Miocene deltaic and coastal marine deposits, including a detailed description of the Miocene browncoal bearing deposits and the petrography of the browncoal seams, and a general description of the Quaternary deposits, based on fossil plants and pollen, is discussed. Also, pre-Weichselian disharmonic folding is described and dated.

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