PALYNOLOGY OF THE MIOCENE BROWNCOAL MINED AT HAANRADE (LIMBURG, NETHERLANDS)

A. A. MANTEN
(*Botanical Museum and Herbarium, Utrecht*)

(*received February 24th, 1958*)

A. Introduction

In the Netherlands browncoal is found in the miocene and, to a minor degree, also in the pliocene (Pannekoek a.o. 1956, p. 67, 70). This paper deals with the miocene coal only, viz. that which belongs to the continental miocene and is found in Southern Limburg. It forms part of the western edge of the extensive Lower-Rhenish browncoal formation.

The palynological analysis of this coal was carried out at the Botanical Museum and Herbarium, Utrecht (director Prof. Dr. J. Lanjouw) under the direction of Dr. F. P. Jonker. I am very much indebted to Prof. Dr. C. E. B. Bremekamp for critical reading the english text of the manuscript.

The Rhenish browncoal in Germany

The main deposit ("Hauptflöz") of the Rhenish browncoal shows its greatest thickness (up to about 100 metres) in the eastern part of the Erft rift-valley in the environment of Bergheim and in the adjacent part of the Ville-horst. Towards the south the lowermost parts of the browncoal formation are replaced by clay.

Towards the NW the "Hauptflöz" splits up in three distinct layers, which can be followed over a long distance and which are separated by marine sands, together forming the browncoal formation. These layers are called (Breddin 1950):

Garzweiler layer (G)
Frimmersdorf layer (F)
Morken layer (M).

While the upper layer (G) gives out on the line Geilenkirchen-Erkelenz-Jüchen, the two other ones, layer F and layer M extend farther towards the NW, and are found also in the German-Dutch border area. Although the thickness of the browncoal layers decreases, the more strongly increasing thickness of the intervening sandy layers makes that the total thickness of the series of strata corresponding with the main browncoal formation, increases gradually from SE to NW, and finally reaches a value of about 180 metres. This greater increase towards the NW may be ascribed to a more rapid subsidence of the surface in that direction during the formation of the sediment.

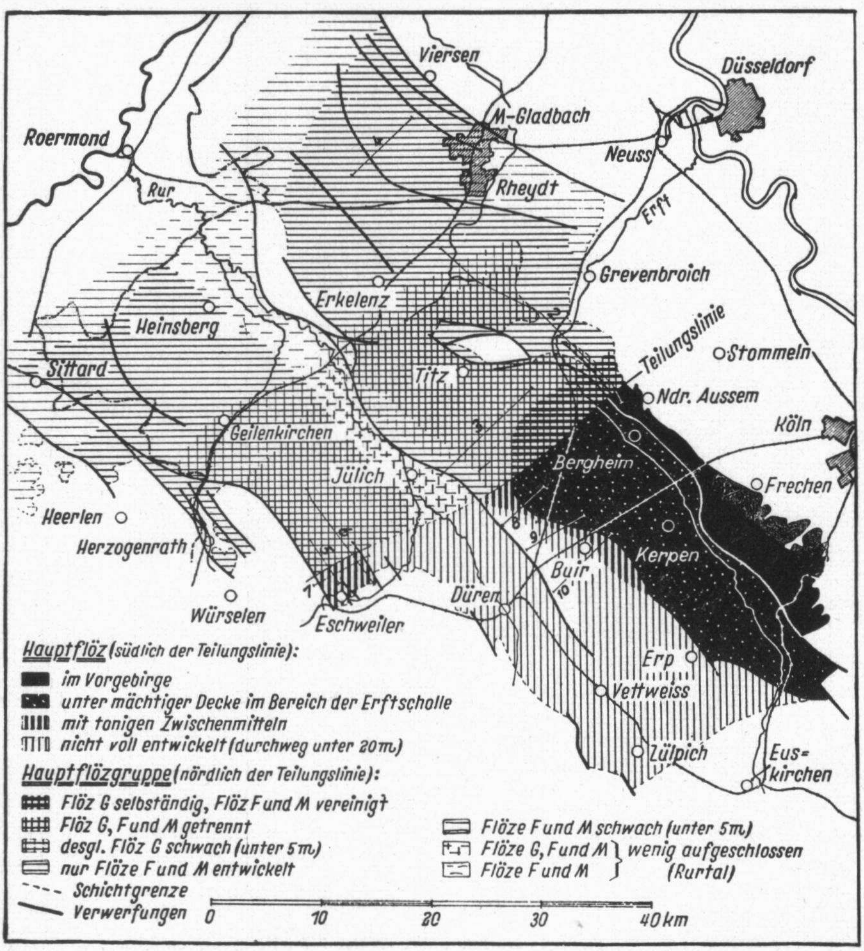

Fig. 1. Survey map of the Lower-Rhine browncoal formation (from Breddin 1950).

Within the Lower-Rhine area there have been differences in subsidence between the individual blocks. As a rule it can be said that the browncoal is thickest where the strata below it too reach their greatest thickness, or in other words: the thickness of the browncoal is greatest in those blocks which have undergone a comparatively strong subsidence. In the areas with a lesser subsidence the thickness of the coal too is less. These fluctuations not always agree with the present, tectonically influenced, topographic height of the blocks.

At the base of the sand packet beneath layer G in most places a thick layer of sand is found, which contains a large amount of coarse, rounded flints. This layer can be followed from Frimmersdorf towards the north-west and west in a great number of drillings and is found always at the same height above layer F. It is present in Dutch Limburg too, e.g. in the quarry "Anna".

The rounded flints can be regarded only as a marine beach deposit, indicating a shifting of the shore line from the west in the direction of the Lower-Rhenish Bight, as argued earlier by Breddin (1932). The layers with the coarse flints, which because of the size of these pebbles are very different from the other sediments, possibly have to be considered catastrophe deposits. At any rate, it seems plausible to assume that they belong to the same stratigraphic level. By this the surface of the layer F, immediately below it, obtains the character of a stratigraphic time horizon, as it will have been formed in the whole area at about the same time.

The Frimmersdorf layer begins in the region of the quarry "Neurath". It rests on a thin stratum of clay, which a short way towards the north is replaced by

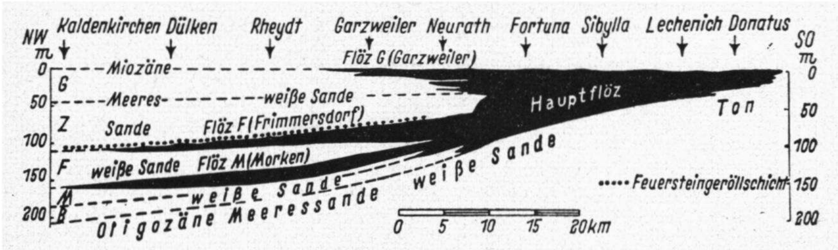

Fig. 2. The splitting of the "Hauptflöz" towards the NW (from BREDDIN 1950).

sand. The thickness of the coal layer decreases towards the north-west, whereas the thickness of the accompanying sand stratum increases in the same direction. Because the upper surface of this layer is stratigraphically fixed by the flint horizon, we have to assume that the browncoal moor was originally smaller and that it expanded gradually over the sand flats to the NW of it. The underside of layer F can therefore not over its whole extent be regarded as a stratigraphically constant level.

The browncoal in Southern Limburg

The bulk of the browncoal formation in the Netherlands is generally assigned to the miocene (IV), mostly to the middle miocene. JUX and PFLUG (1957) defend an oligocene age, but their arguments are not sufficiently convincing and in my opinion their view will not be able to replace the earlier estimate by Breddin (MANTEN 1958).

Roughly the following stratigraphical table for the continental miocene in Southern Limburg can be given. It has been adapted from JONGMANS and VAN RUMMELEN (1930) and is based on the study of several boreholes and cuttings. This series is of course not everywhere present in the same degree of completeness; the total thickness in one profile can reach a value of 148 metres.

				thickness:
PLIOCENE —				
MIOCENE	Browncoal formation	*g.*	Sand; white, or sometimes of a somewhat faded yellow colour; at the base sometimes a layer with blue, rounded flints.	max. 57 m
		f.	Browncoal, occurring in big lenses, occasionally with inserted sandstones (layer F).	0,50–20 m
		e.	Sand, white, or sometimes of a somewhat faded yellow colour.	1,50–53 m
		d.	Browncoal, in big lenses, sometimes the coal is formed in several beds with sand lenses between them.	1,0–35,50 m
		c.	Sand, white, or sometimes of a somewhat faded yellow colour; locally a few rounded flints. Locally the sand may also be cemented and hardened to sandstone, which is called Nivelsteiner sandstone.	0,40–50,0 m
		b.	Browncoal, in smaller lenses. Rarely developed as a browncoal layer.	0,10–15,50 m
		a.	Sand, fine, white, or sometimes of a somewhat faded yellow colour, with at the base an up to 30 metres thick layer with blue, rounded flints.	6,0–64 m
			Sand, fine, argillaceous, with glauconite.	
			Elsloo-layer.	

Under the influence of greater and smaller faults the series is thicker in the eastern blocks than in the western ones.

For a general survey three areas can be distinguished (JONGMANS and VAN RUMMELEN 1930):

1) West of the Heerlerheide fault;
2) Between Feldbiss and Heerlerheide fault;
3) Between Feldbiss and Sandgewand.

1) In the block west of the Heerlerheide fault only thin erosion remains are found. In most places they comprise only the lowermost zone (a), occasionally also a part of zone b, but browncoal has been found only here and there in this area.

2) In the block between the Heerlerheide fault and the Feldbiss a miocene cover is found, extending over a large area, from Obbicht to a little south of Heerlen. In the south it wedges out. South of the general boundary line an occasional island is found resting on the oligocene. Both layer M and layer F are represented in this block.

3) In the block between Feldbiss and Sandgewand the browncoal formation withdraws far to the south. In small erosion remains it is still present as far as Maubach, south of Stolberg. In all deep-borings on Dutch territory the browncoal formation proved to be complete. As in the other blocks the browncoal layers are not continuous.

4) Drillings carried out east of the Sandgewand proved the whole series of the browncoal formation well developed below the overlying pliocene deposits.

In the concession "Anna" browncoal is exploited from layer F, which here has a thickness varying between 9 and 20 metres. It is covered by a layer of sand with rounded flints and by postmiocene sediments. The browncoal series that was studied palynologically, had a thickness of about 17 metres.

Age of the coal in relation with the sediments above and below it

In Germany the Rhenish browncoal formation in the south, with the exception of the Antweiler Graben, directly rests on pretertiary (paleozoic, resp. triassic) deposits, but in the north "Septarien" clay and marine sands, and in the central part terrigenous premiocene sediments are inserted between the browncoal series and the pretertiary rocks. It is regarded as certain that marine upper oligocene (middle stampien) is represented in these older tertiary deposits, while an occurrence of the coal series above the horizon of Rott (upper stampien) seems probable (QUITZOW 1952).

In Limburg below the browncoal formation a thin bed with glauconite sand is found, with at its base a conglomerate, the so-called "Elsloo layer" which contains among other fossil remains rounded shark teeth, and this may indicate a miocene age of this deposit, because some of these teeth are known from the miocene of the basin of Vienna (LERICHE 1920). Other fossils also point in this direction (HALET 1920, 1937). Even a pliocene age has been defended (VAN DE GEYN 1937) because of rounded miocene fossils, but this seems very unlikely. The Elsloo layer is known from the Belgian Kempen also, where it overlies upper oligocene deposits and is considered to be marine bolderien (upper helvetien). Thus it seems very likely that the browncoal in Limburg is not older than middle miocene (MANTEN 1958).

In Germany the browncoal is covered by the so-called Fischbach- and Kieseloolith Schichten. Between these and the coal there is a discordance and a stratigraphical gap of unknown duration. For the Fischbach Schichten—fluviatile sands and clays—WEYLAND (1934) assumes a late miocene age. It then would be the uppermost miocene (sarmatien), as is also thought by THOMSON and GREBE (1951). The Kieseloolith Schichten generally are classified as lower pliocene.

In Limburg there is also a stratigraphical gap between the browncoal and its overlying deposits, which partly are of pliocene and partly of pleistocene age.

Thus the sediments above and below the browncoal formation do not give precise data as to the age of the coal. A miocene, especially middle miocene age, however, seems most likely. I return to this later on.

B. Historical review

The scientific interest for the browncoal found in the south-eastern part of the Netherlands has so far been slight, but that for the coal in the neighbouring German area has been considerable. This is not astonishing as the enormous amounts of coal in Germany are of great economic importance, while in the Netherlands the coal is scarce and unimportant. In this chapter I will give a short review of the work of the most important investigators who have been engaged in the study of the browncoal deposits, and mention the titles of some of their publications, so far as these are of direct or indirect value for the study of the mode of formation and the age of the Dutch browncoal series.

Fliegel

The modern geological study of the German coal in the Lower-Rhine area was begun by G. FLIEGEL (1910). He first mapped this area and cleared up its stratigraphy. For the browncoal formation he assumed a lower miocene age, an opinion that he still adhered to in 1937, for then he wrote that the browncoal peat "entstand in der der Meeres-regression (viz. of the upper oligocene sea) nachfolgenden Süsswasserphase des Untermiocäns". However he seems to have changed this opinion later on, for, according to AHRENS (1942), he finally assumed, after a study of unverifiable drillings, that the browncoal was synchronous with oligocene marine sands.

Fliegel developed the following hypothesis to explain the greater thickness of the "Flözgraben der Ville": the thick browncoal packet was formed on a subsiding basement, while in the environment the coal originated in "normal thickness" on an undisturned subsoil. That the Ville nowadays represents a horst, he explained by assuming an upward movement along the same faults, viz. those that separate the Ville from the Rhine- and Erft valleys.

This theory gave an acceptable explanation of the data that were available at that time. Only after 1927, when in the Erft valley too many borings were carried out, which showed that the coal deposit here was of the same thickness, this hypothesis was rejected and replaced by the theory of Breddin of one great Rhenish browncoal area, divided by faults into a number of tectonical blocks. Fliegel himself too accepted this view. From this time on the Dutch coal also was included in the whole, and became of importance for the explanation of age and facies of the browncoal formation.

FLIEGEL 1910*a*, 1910*b*, 1927, 1931*a*, 1931*b*, 1937.

Klein

The first to be scientifically engaged with the corresponding Dutch browncoal series, was C. W. Klein. His findings have been published under the title "De bruinkoolformatie in Limburg" in the "Handelingen (13) van het Natuur- en Geneeskundig Congres te Groningen" (1911). Although part of his results have been negatived by later studies, his work surely has been valuable.

Berg

The lower miocene age assumed for the Lower-Rhenish browncoal by Fliegel, was accepted also by Berg, who in 1913 indicated that in the Lower-Elbe region this deposit was covered by marine middle- and upper miocene deposits.

Jurasky

In 1928 Jurasky gave a valuable contribution to the study of the browncoal. On the base of his studies of the so-called "Haarknabben" he proved in 1930 the presence of the remains of *Palmae* in the Lower-Rhenish browncoal. From this he concluded that the coal must be of a lower miocene age. Still earlier P. Menzel came to a similar conclusion by a study of the fossil flora.

JURASKY 1928, 1930.

Kräusel and Schönfeld

Kräusel and Schönfeld examined a number of wood remains from the most important sites of browncoal in Southern Limburg. All these occurrences are considered by them to belong to one and the same formation. These wood remains gave no definite indication as to the age of this deposit. The only thing that could be said is that the results of their investigations are not in contradiction with the lower miocene age generally accepted in that time.

The number of species of fossil wood found in Limburg is very small. *Juniperoxylon silesiacum* proved to be the most common one. Besides the latter *Pinuxylon*, *Laurinoxylon nectandrioides* and *Cornoxylon* have been found.

Besides these wood remains Kräusel also studied a number of leaf remains from the browncoal quarry "Herman". As far as I know, he has never published a paper on the results of this study. To Jongmans he wrote (JONGMANS 1935): "Die Flora der Grube Herman enthält nur wenig bestimmbare Formen. Ich nenne *Cinnamomum*, eine *Lauraceen*frucht, *Salix*, *Myrica*, *Juglans*, vielleicht auch *Ficus*. Eine Altersbestimmung ist danach nicht eindeutig möglich. Jedenfals macht die Flora einen recht altertümlichen Eindruck, älteres Miocän dürfte wohl das richtige sein".

KRÄUSEL 1918, 1921; KRÄUSEL und SCHÖNFELD 1922.

Jongmans

Together with Van Rummelen Jongmans published in 1930 a survey of the occurrence of browncoal in Southern Limburg. A few fragments from this publication have been worked up in the first pages of this paper. The mode of occurrence completely links up with the German coal; as its age they accepted lower miocene.

In a paper published a few years later, in which Jongmans described the presence of palmal remains in Dutch browncoal from the quarry "Carisborg", he still accepts the same age for the browncoal: "Der Fund der Palmenreste darf nun wohl als endgültiger palaeobotanischer Beweis des Unter-Miocänen Alters unserer Braunkohle gelten."

JONGMANS en VAN RUMMELEN 1930; JONGMANS 1935.

Breddin

The generally accepted opinion that the Lower-Rhenish browncoal formation was of lower miocene age, changed when BREDDIN (1932[a]) showed that the coal was interleaved with marine deposits, for which at that time only an upper oligocene age could be assumed, because the marine miocene seemed to reach its extreme eastern boundary at a distance of 60–80 km from the Lower-Rhenish browncoal deposits. Therefore the age of the Lower-Rhenish browncoal as a whole was changed by Breddin in upper oligocene, although with some reserve, because conclusive evidence still was lacking and no marine fossils had been found in the deposits that were interleaved with the coal. On the other hand, however, this assumption also was not contradictory to the facts known in that time. This upper oligocene age has since then been accepted by several others, e.g. by Kirchheimer, but without the reserve made by Breddin.

How much this prudence was justified, appeared later on when Breddin himself was forced to put the browncoal back into the miocene. This new opinion was based on the observation that in the German-Dutch borderland the three separate browncoal horizonts do not agree with marine upper oligocene, as he thought before, but with the marine deposits of the Hemmoorer- and Dingdener Stufe (Helvetien) of the Dutch Peel area. For this reason for the upper layer an upper miocene, for the two other ones a middle miocene age had to be assumed. Because the network of drillings is not yet close enough to prove this synchronism with absolute certainty, this opinion cannot yet be considered final.

For the sands enclosed between the browncoal deposits Breddin proved a marine origin (BREDDIN 1932[b]). That glauconite is missing in them, is not quite sure, but the quantities must at any rate be very small. As a result of this marine origin of the sands the coal must have been formed paralic (BREDDIN 1935).

BREDDIN 1930, 1931, 1932*a*, 1932*b*, 1935, 1950.

Wölk

E. WÖLK tried to draft a standard table of the Lower-Rhenish browncoal (1934) by the use of macroscopically ascertained facts.

He based this mainly on the occurrence of lighter and darker zones in the coal and on the presence of stump horizons. In several cases it proved indeed possible to correlate the series found in the different quarries, and later palynological researches have often confirmed his results. It can be applied, however, only to the deposits of one and the same tectonical block, in which the same rhythm of subsidence occurred. Between two blocks there might have been clear differences by which a marsh in one block may be synchronous with an open peat swamp in another. Besides it is difficult to apply this method to drillings, because it is based on profiles which have been allowed to dry by exposition to the air during a certain time.

The opinion of Wölk that the origin of the "hellen Schichten" was connected with a selective decomposition of the peat constituents, has proved to be untenable in the light of the studies carried out by P. W. Thomson (THOMSON 1950[a]). The layers with the lighter tints turned out to correspond more or less to the "offene Niedermoore vom Everglades Typus", while the "dunklen Bänke" represent the farther advanced stages of peat growth.

WÖLK 1935, 1936.

Kirchheimer

F. Kirchheimer has deserved well of us because of his scrupulous study of many vegetable macrofossils from the browncoal, especially of a group of fruits and seeds, hardly studied before, on which he has published from 1934 on a large number of papers.

In the Lower-Rhenish browncoal he found e.g. remains of *Pinaceae* and *Taxodiaceae*. Especially, however, he indicated remains of *Mastixia* and other genera belonging to a subfamily of the *Cornaceae*, together with representatives of the *Symplocaceae*, *Castanopsis*, *Magnoliospermum* and *Arctostaphyloides*. Kirchheimer regarded them as belonging to one plant community, which he called "Mastixioideenflora". It occurs, locally even very frequently, in the browncoal itself as well as in the accompanying sediments.

The stratigraphic value, which Kirchheimer attached to this Mastixioideenflora, however, is very contestable, ... and has lead to great difficulties. The upper oligocene age ascribed in 1932 by Breddin with some reserve to the Rhenish browncoal has simply been taken over by Kirchheimer, when he described his "Mastixioideenflora", and also assigned to this plant community. After that he regarded all other deposits in which this plant community has been found as oligocene. Even when Breddin later on was forced to return the Rhenish browncoal to the miocene and deprived in this the opinion of Kirchheimer as to a middle- to upper oligocene age of all *Mastixioideae* of its most important support, Kirchheimer stubbornly maintained an oligocene age for it. In 1951 he even turned against Breddin with the declaration that a miocene age of the Rhenish coal was impossible because of the Mastixioidal fruits found in it. As to this QUITZOW (1952) rightly remarks that in this way we fall into a vicious circle, so that all further comment becomes superfluous.

KIRCHHEIMER 1934, 1937.

Ahrens

In 1942 W. Ahrens published a short article concerning the geological age of the Rhenish browncoal. From this paper it is clear how many data of drillings, carried out in the years around 1930 are uncertain. Without more they do not provide us with a base for assuming an oligocene age. Ahrens himself thinks it most likely that "die Grenze Miozän–Pliozän wahrscheinlich durch den obersten Teil des Flözes hindurchgehen" will, for which assumption "manche, auch paläobotanische Beobachtungen zu sprechen scheinen".

In a publication together with H. Karrenberg in 1950 he came to a similar conclusion: "Die sichere stratigraphische Eingliederung der Braunkohlenformation ist auch jetzt noch nicht gelungen. Dass die tieferen Teile in das Oberoligozän gehören ist sicher. Das Jungtertiär möchte Thiergart mit dem Sciadopitys-Vorstoss beginnen lassen; die Grenze Oligozän-Miozän würde dann in das Flöz hineinfallen. Einen weiteren Anhaltspunkt bieten Untersuchungen von Thomson; er konnte nachweisen, dass die unteren Braunkohlensande von Hamburg, die wahrscheinlich dem Burdigal angehören, jünger sind als das Hauptflöz — Das Einhängen der höheren Teile des Hauptflözes in ein marines Profil, auch durch schrittweisen Vergleich, ist bis jetzt noch nicht möglich gewesen".

AHRENS 1942; AHRENS und KARRENBERG 1950.

Quitzow

H. W. Quitzow subjected the determination of age of the younger German browncoal deposits to a critical and very thorough examination. Besides the sediments beneath and above the coal and the publications by Breddin he minutely discusses the stratigraphic value of the "Mastixioideenflora" described by Kirchheimer. The opinion of Kirchheimer that all places where this plant community is found, are of the same age, turns out to be certainly untenable. The "Mastixioideenflora" is characteristic for nearly the whole middle tertiary period. It appears in the middle oligocene, reaches its maximum development in the upper miocene and occurs also in nearly the whole miocene series of strata. *Mastixia* itself still occurs recently in the indomalayan area.

In other publications Quitzow discussed among other things the rhythm observed in several deposits of coal and adjoining rocks and the tectonics in the Ville area.

QUITZOW 1952, 1955; PETLZ und QUITZOW 1954.

Potonié

Of great importance for the development of tertiary palynology has been the work of R. Potonié and his pupils (H. Venitz, F. Thiergart), of which the results have been embodied in a great number of publications. Many tertiary spores and pollen grains have been described and figured by them and, when possible, brought into relation with natural taxonomic groups. In this last respect Thiergart often goes farther than his master, but his identifications did not in all cases turn out to be correct. The study of the stratigraphic distribution of the several types too was started vigorously by them.

POTONIÉ 1948, 1951; POTONIÉ und VENITZ 1934; POTONIÉ, THOMSON und THIERGART 1950; THIERGART 1940, 1949, 1950.

Thomson

After the second world war it was in the first place P. W. Thomson who began to busy himself vigorously with the palynological study of the Rhenish browncoal. Numerous are his publications on this subject, partly in co-operation with other authors. Wellknown is his systematical study of the series exposed in the quarry "Liblar", carried out to make up a standard-table for the Rhenish browncoal formation. Also other series were studied by him; he described many pollen grains, made correlations possible. His great knowledge of recent pollen grains was of great importance in the determination of the botanical origin of the fossil types. Besides he has had the merit that he recognized certain regularities in the succession of peat types, and studied their floristic composition at the hand of pollen diagrams, as far as this was possible without knowing the part played by the pollen grains of plants that are pollinated by insects. (Fig. 3).

THOMSON 1949, 1950*a*, 1950*b*, 1950*c*, 1950*d*, 1951, 1954, 1956; THOMSON und REIN 1950; POTONIÉ, THOMSON und THIERGART 1950; THOMSON und GREBE 1951.

Pflug

H. Pflug too has been engaged in the palynology e.g. of the Rhenish browncoal. Here may be named his atlas of spores and pollen grains from the middle european tertiary, which he published in 1953, together with P. W. Thomson. He also developed a method by which with very simple expedients the changes of first order (Thomson) or "Absenkungsrhythmuswechsel" (Potonié) in a browncoal series can be established, the so-called "stereoskopische Auflichtmethode" (THOMSON and PFLUG 1952). This method can be applied to the coal without any preliminary treatment. It aims at a quantitative estimation of wood and other component parts in coal, and the state of preservation of these. The results are indicated with the aid of resp. ten figures and some characters. Also colours are of importance in ascertaining the required data.

Together with Jux he published a new theory as to the origin of the three coal layers in the NW of the Rhenish browncoal area. They supposed that they represent the layers occurring beneath the "Hauptflöz", the so-called "Unterflöze", and are of oligocene age. This hypothesis, however, is still too less founded to replace the generally accepted view of Breddin.

THOMSON und PFLUG 1952, 1953; JUX und PFLUG 1957.

Rein, v. d. Brelie

G. v. d. Brelie and U. Rein made a great number of pollen analyses for practical purposes. For this Rein created a greatly simplified method. From the great number of pollen types present in the Rhenish

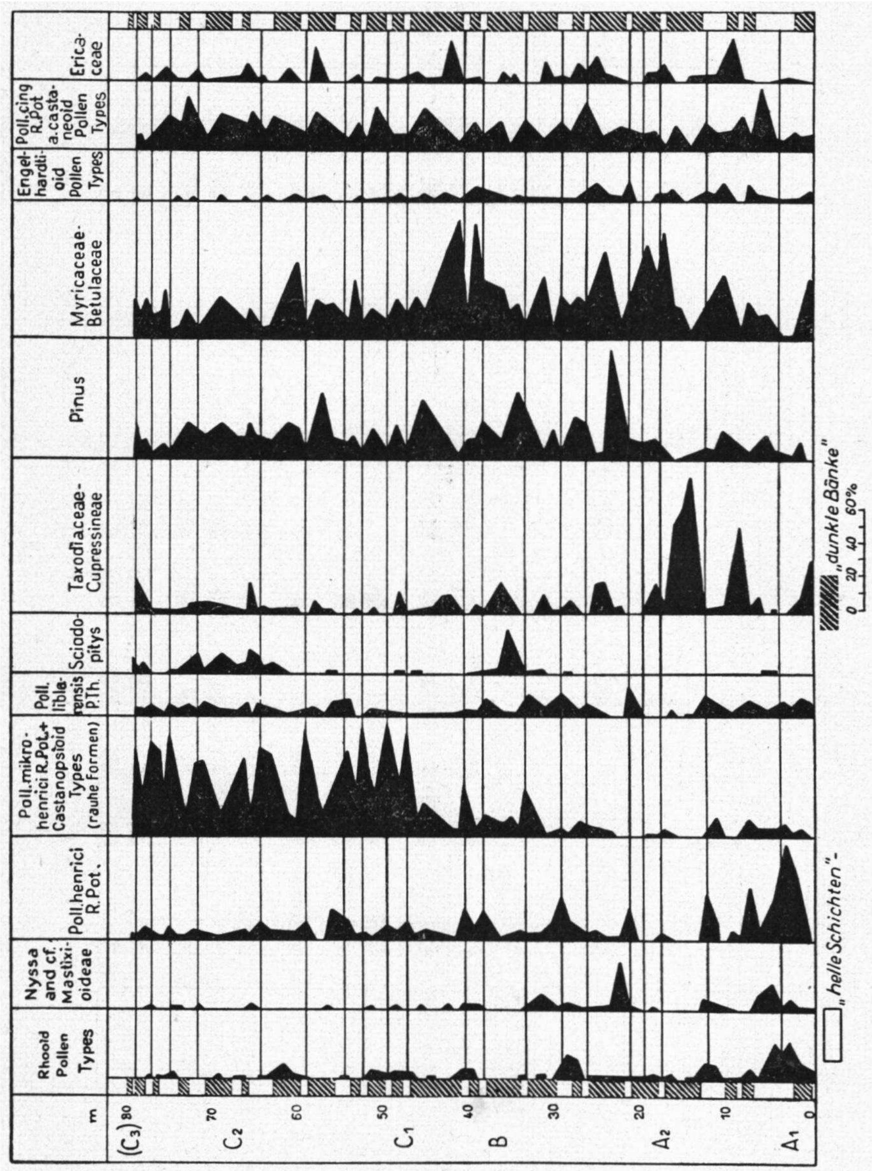

Fig. 3. Pollen diagram of the browncoal quarry "Fortuna" in the German Rhine area by P. W. Thomson (from Thomson 1950*a*).

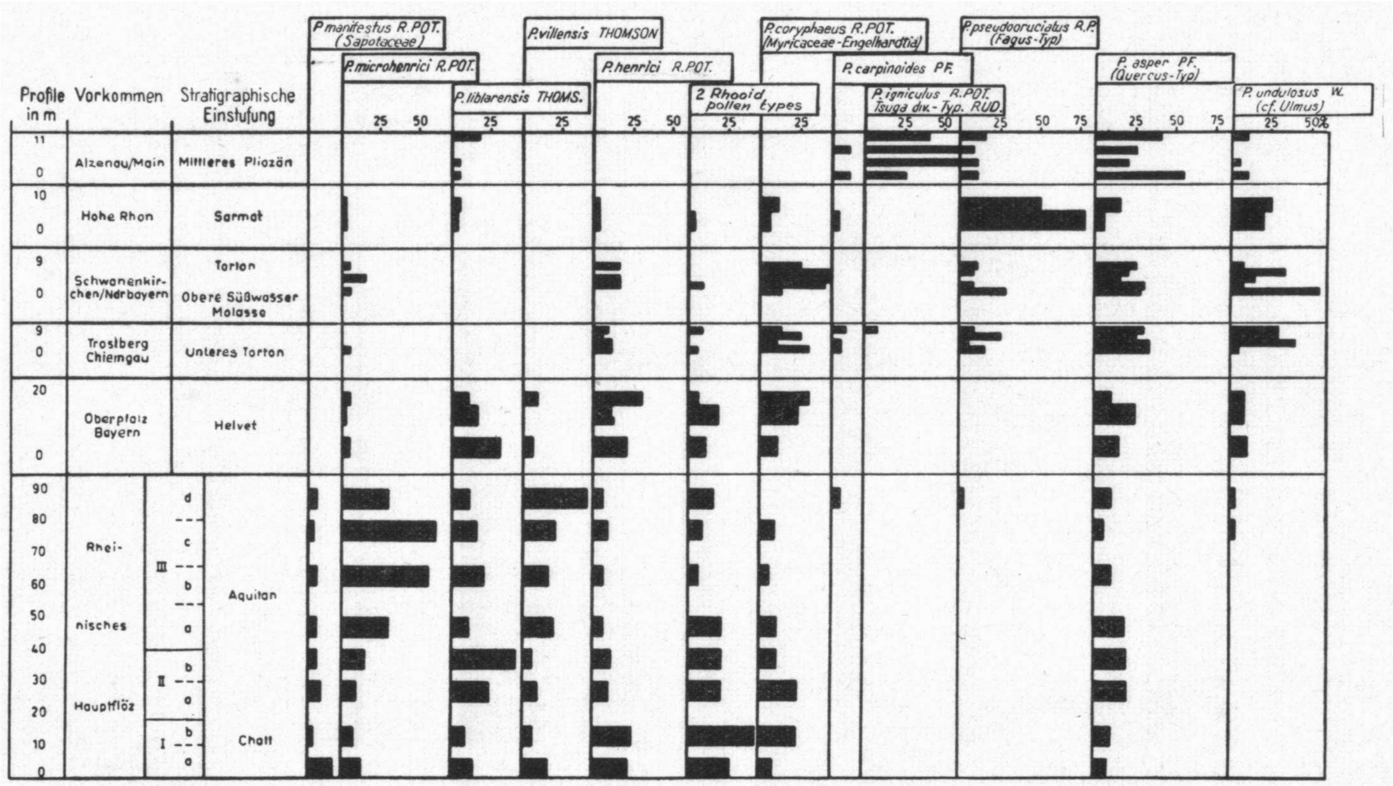

Fig. 4. Palynological standard table of middle and upper tertiary in Central Europe, according to Rein (from Rein 1956).

browncoal, he used only 12. These types have each to form at least 5 % of the pollen spectrum, and their frequences have to show certain variations, making them useful for a subdivision of the standard diagram. Of these twelve Rein after that takes five, the occurrence of which, according to him, seems to be independent of local circumstances, and puts their joint percentage at 100. The values of the seven other types, showing often very sharp, but only local, maxima and minima, are expressed as a percentage of this, and represented by this percentage in the diagram.

For correlations over greater distances he used a similar method Here too he put aside 12 pollen types, which, however, are not quite the same as those used for the Rhenish browncoal. This time, however, he takes the total percentage of all 12 and puts this at 100 (Fig. 4). All other pollen grains and all spore-types he neglected. The result is a facies picture, not a real list of guide fossils.

It is clear that, although this working method has a direct practical value for the browncoal-mining, the scientific value of it is very small.

REIN 1950*a*, 1950*b*, 1956; v. D. BRELIE und REIN 1954.

C. METHOD OF INVESTIGATION

The hydrogen peroxide treatment

For making pollen preparations of the collected browncoal samples the hydrogen peroxide method of P. W. Thomson has been used. This is as follows:

1) About 1 gram of pulverized browncoal is heated together with a 20 times larger quantity of 10 % H_2O_2 on a boiling ring for about 10 minutes, however, in such a way that the mixture does not boil. Softly boiling during a few seconds is not very harmful, it often even benefits the preparation; when it has been boiled longer, however, the pollen grains appear to be damaged.
2) When necessary: sieve, in many cases this proves to be superfluous.
3) Centrifuge.
4) Wash with water; should there be froth, this can be removed with a little aceton or alcohol.
5) Centrifuge.
6) Boil with dilute alkali: NaOH or KOH of a strength of up to 10 %, in a porcelain saucer. (This is better than boiling on a water-bath).
7) Centrifuge.
8) Wash with water.
9) Centrifuge.
10) Add dilute glycerol.
11) Mount.

Because the colours of the sporomorphae in the preparation often are weak, for counting often staining is desirable, e.g. with a solution of safranin in alcohol. This, however, has the disadvantage that the finer structures of the pollen grains sometimes disappear. When using the nitric-acid-method, however, this bleaching at least is equally strong.

That the hydrogen peroxide method was preferred above the nitric acid-method of Thiergart (THIERGART 1940) mainly has three reasons:

1) Compared with the H_2O_2-method it has no advantage, also the amount of pollution in the preparation is not less, rather more.

2) The HNO_3-method is much more digressive, not only because of the more time-consuming treatment but also because of the greater volumes that are required.

3) The danger of damaging the sporomorphae is rather greater than less. The few times that I used this method I observed several damaged pollen grains, although Thiergart remarks that every material endures a prudent treatment with nitric-acid without visible damage. Still he too obviously does not feel quite secure, for he adds to this: "Es muss allerdings zugegeben werden, dass eine reiche Erfahrung dazu gehört, die Konzentration und Einwirkungsdauer der Salpetersäure so zu wählen, dass Fehlschläge, die hier auch beobachtet wurden, im Laufe der Zeit völlig vermieden werden" (THIERGART 1940, p. 8).

Number of pollen grains, pollen sum

When one wishes to study a browncoal series in all its oecological variations a very thorough sampling is necessary, partly even sampling centimetre for centimetre will be necessary. For stratigraphic use, however, much larger relative distances are permissable. For this first diagram of the Dutch browncoal as a rule a standard distance of 50 cm between the places where two successive samples are taken, has been used.

The browncoal as a rule is very rich in pollen grains. Cautious estimations in a great part of the studied samples yield numbers of 5–10 millions of sporomorphae in one cubic centimetre. 250 of these were usually counted in a sample. This number seems fully justified. In Germany in many cases only 100 sporomorphs are counted. The error than, according to THOMSON and REIN (1950) amounts to 2–5 %, when 150 grains are taken it is still 1–4 %.

The distinction between arboreal pollen and non-arboreal pollen (A.P. and N.A.P.), used in quaternary palynology, was not made for our miocene pollen grains, because for quite a number of grains it is uncertain where they have to be placed. Therefore I put the total of all 250 sporomorphae at 100 %, and calculated for all species the percentages. This not only is the most secure method, but it also provides the best possibility for comparison with the results of other authors, because conversion always is simple. With other methods this is not always so.

Nomenclature and taxonomy of the sporomorphae

When counting the samples for the nomenclature and classification of the miocene spores and pollen grains, the morphological system of PFLUG and THOMSON (1953) has been used. For this there were the following arguments:

1) Of several sporomorphae it can not at all or only with vague approximation be said to which plant or group of plants they belong. A division in organ species and -genera therefore is necessary. This

naturally does not affect their significance for micro-paleontological-stratigraphical work.

2) Of a number of other sporomorphae it can be said that they show an unmistakable resemblance with the spores and pollen grains of plants that occur also in the recent flora. An identification with these, seen the long time between the miocene and now, will always be more or less hypothetical (see also THOMSON and THIERGART 1950, p. 38 and POTONIÉ 1951). Of some recent and the great majority of fossil plants the pollen grains are not or only insufficiently known. It is known also that in several species, genera and even families very similar pollen types are found. All this has its effect on the interpretation of the tertiary spores and pollen grains. So several forms still repeatedly have changed their botanical position. *Tricolporopollenites cingulum non ssp. fusus* e.g. initially by Potonié was referred, although with two notes of interrogation, to the *Punicaceae*, and also compared with the *Hippocastanaceae*. After that Thiergart ascribed it to *Castanopsis*, because fossil fruits too of *Castanopsis* had been found. In 1950, however, Thomson says of the whole *cingulum* group (p. 115): "Sicher nicht *Castanopsis*, vielleicht *Cyrilla*?" (on this also has been of influence that *Tricolporopollenites megaexactus brühlensis* then was referred to this group too). In 1953 (PFLUG and THOMSON 1953) Thomson indicates it as *Castanea* type. *Tricolporopollenites villensis* now by Thiergart is taken for *Castanopsis* pollen, what, however, by other authors is thought debatable. So there are many examples.

Even the presence of macrofossils is not necessarily an argument that turns the scale when we wish to ascribe certain fossil pollen grains to these plants on account of resemblances with their recent relatives, although macrofossils may be a good indication (see also POTONIÉ 1948).

3) For those pollen grains and spores of which with some probability the botanical position is known (e.g. *Pinus*, *Tilia*) the names that are used in the natural system could be applied. The great objection against this procedure is that in that case two disagreeing systems have to be used at the same time: an artificial system for the systematically still insufficiently known forms, and the natural system for the other sporomorphs. To avoid every entanglement and wrong conclusions in determining and counting, in my opinion therefore the use of one system is preferable. The objection of the botanists that a list of those names does not directly say something on the flora of that time, can be met with by stating the botanical position — as far as known. Conclusions as to the fossil flora thus do not become impossible. On the contrary! Here they are, however, the results of an interpretation of the research data, instead of direct establishments and therefore in general more reliable.

4) It is not unlikely that with an increasing knowledge of the spores and pollen grains of recent plants the taxonomic place of several tertiary sporomorphae can be established more accurately. When the names of the organ genera and -species are used, more recent data can immediately be taken into account when judging

our own findings, and this would not have been possible when in counting botanical names had been used. Than a fully new counting out would become necessary.

5) Because these organ genera and -species are also used by other, especially German authors, a good comparison is possible with e.g. palynological results of the study of the Rhenish and other tertiary browncoals. For stratigraphic use it generally is unimportant whether the botanical origin is known or not, and a well-defined morphological description is often preferable above a discutable botanical name.

6) Of many pollen grains it can only approximately be said to which family or group they belong. Within this group in many cases several types can be distinguished (e.g. in *Fagaceae*, *Symplocaceae*, *Sapotaceae*, *Anacardiaceae* and others), that cannot be separately indicated with botanical names. For stratigraphic use such a separate representation can be of great importance. From the diagram given by Thomson for the quarry "Fortuna" (Fig. 3) e.g. it very clearly appears to be reasonable to record separately the amounts of *Tricolpopollenites henrici* and of *Tricolpopollenites microhenrici* (R. Pot.) Pf. et Th. When using botanical names only both forms, together with others, should have been placed under *Fagaceae* of uncertain generic position. Several other organ species as *Porocolpopollenites vestibulum*, *Tricolporopollenites cingulum* and others, would lose their individual importance in the same way.

7) The system is purely phytographic, does not point to taxonomic groups, which later on may appear to be wrongly identified, as this is e.g. the case with the "oid" system of Potonié a.o., and is practically more useful than the method by which all unknown forms are classified in two organ genera: "*Sporites*" and "*Pollenites*". The system follows the international code of botanical nomenclature.

D. Species descriptions

For descriptions of the miocene spore- and pollen types I may refer the reader to the publications of Potonié and Venitz (1934). Potonié (1951), Potonié, Thomson and Thiergart (1950), Thiergart (1940 and 1950), Thomson (1949) and especially to the comprehensive study of Thomson and Pflug (1953). Here I will confine myself to describe those species that are not mentioned in the abovenamed literature.

Section Bilateres Pf.

Organ genus *Monoporites* van der Hammen 1954

Pollen grains provided with one pore only (see v. d. Hammen 1956).

Monoporites circumvallatus n.sp.

Under this name pollen grains are classified that are provided with a single pore, surrounded by a distinct ring, which protrudes somewhat above the surface of the pollen grain. They agree with the pollen of the recent *Gramineae*. In view of their size (20–27 μ), it is not unlikely that most of these pollen grains have come from the genus *Phragmites* (Erdtman 1943, plate I, Fig. 13–14), of which of other miocene deposits (e.g. the Hydrobian limestone of Mainz-Kastel), macroscopic remains too are known. From no other plant family than that of the *Gramineae* up to now a similar pollen type has been reported.

Monoporites circumvallatus: 20–27 μ; pollen monoporatus, porus manifeste circumvallatus; pollen congruens cum *Phragmite*.

Section INAPERTURES Pf. et Th.

Organ genus *Inaperturopollenites* Pf. et Th.

Inaperturopollenites paluster n.sp. (Fig. 5).

Pollen grain of more or less elliptical shape; 18–30 μ; shows an approximately egg-shaped, faint depression; without colpes or pores. Exine reticulate, very thin and pliable. Ectexine of about equal thickness as the endexine.

Natural relationship: presumably *Potamogetonaceae*, perhaps genus *Potamogeton*, with the recent pollen grains of which it shows a very striking resemblance.

Found only once, quite at the bottom of the series. Type specimen in the Botanical Museum, Utrecht.

Inaperturopollenites paluster: pollen fere forma elliptica; 18–30 μ, cum leve depressione ovata; sine colpis aut poris; exina reticulata, tenuissima et plicabilis; ectexina aeque ferme crassa ac endexina.

Inaperturopollenites sacculiformis n.sp.

This organ species comprises the pollen grains that agree with those of the recent *Cyperaceae* (ERDTMAN 1943, plate I, Fig. 6–9), and which in all likelihood have also been produced by *Cyperaceae*. They have 1–4 pores, which, however, always are very vague, and they may therefore be included in the genus dignosis of *Inaperturopollenites* given by Pflug and Thomson, viz. "ohne oder mit undeutlichem Germinalapparat". Only in the general absence of an equatorial plane of symmetry they differ from the other *Inapertures*.

Inaperturopollenites sacculiformis: idem pollen *Cyperaceae*.

Section BREVAXONES Pf.

Organ genus *Polyporopollenites* Pf.

Polyporopollenites obscurus n.sp. (Fig. 6).

Measures 23–28 μ; pollen grain appears as more or less quadrangular. Pores always four, big, equatorially situated. In the surface of the grain there is a remarkable, thin, walled place, 6–8 μ in diameter. Therefore it might be better to classify it in a new organ genus. Exine smooth. Endexine a little thicker than the ectexine.

Natural relationship uncertain; perhaps there may be a relation with *Juglandaceae*. Rather rare; only three times observed. Type specimen in the Botanical Museum, Utrecht.

Polyporopollenites obscurus: 23–28 μ; pollen se ostendit ferme quadratum, tetraporatus, cum tenui loco circumvallato, magnitudine 6–8 μ; exina aequa; éndexina paulo crassior quam ectexina.

Section LONGAXONES Pf.

Organ genus *Tricolpopollenites* Pf. et Th.

Tricolpopollenites fruticis n.sp. (Fig. 7–8).

27–31 μ. Pollen grain very coarsely reticulate; provided with three clear colpes. Near the colpes the reticulum is somewhat less coarse

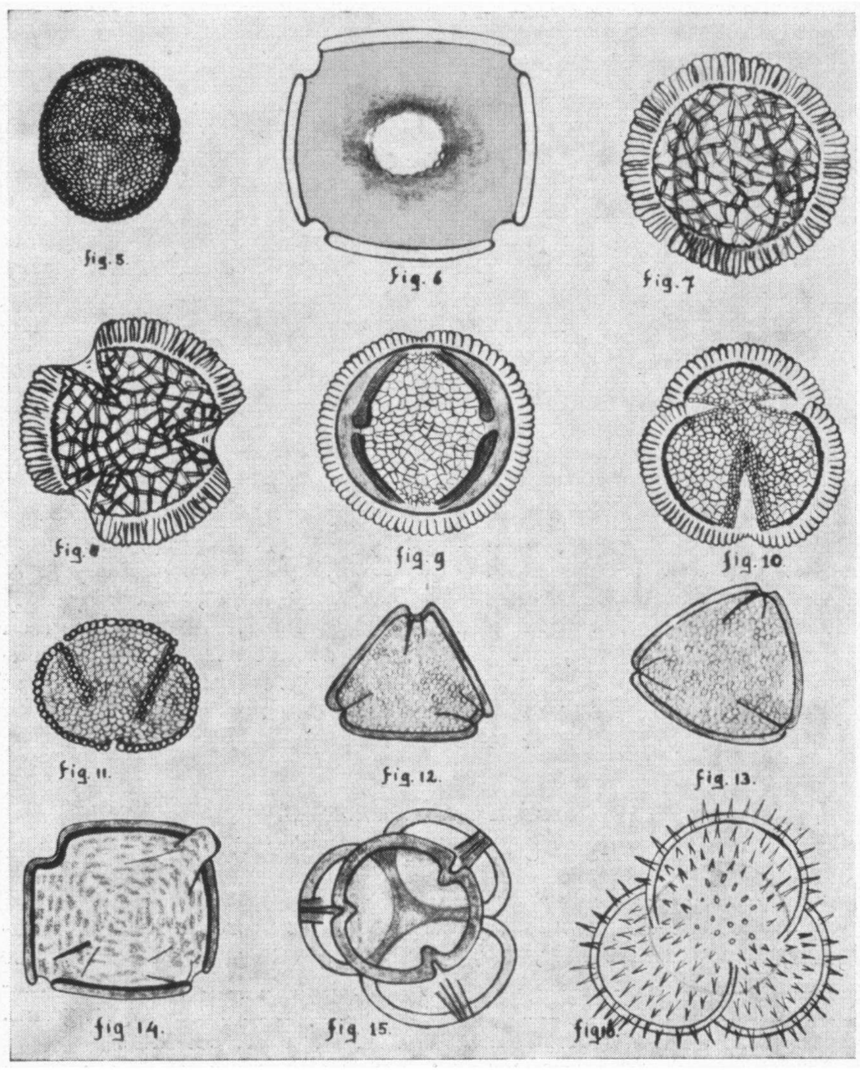

Fig. 5—16. Some miocene pollen grains from the quarry „Anna". Fig. 5. *Inaperturopollenites paluster* n.sp.; Fig. 6. *Polyporopollenites obscurus* n.sp.; Figs. 7–8. *Tricolpopollenites fruticis* n.sp.; Figs. 9-10. *Tricolporopollenites eureticulatus* n.sp.; Fig. 11. *Tricolporopollenites reticulatus* n.sp.; Figs. 12–13. *Tricolporopollenites haanradensis* n.sp.; Fig. 14. *Tetracolporopollenites insolitus* n.sp.; Fig. 15. *Tetradopollenites concubinatus* n.sp.; Fig. 16. *Tetradopollenites echinatus* n.sp.

than elsewhere. Intectate; baculate to clavate. Ectexine about three times the thickness of the endexine.

Very rare; found only once. Type specimen in the Botanical Museum, Utrecht.

Natural relationship still uncertain. There is some resemblance with the pollen grains of *Ligustrum*, while there is also a faint resemblance with some pollen grains belonging to the family *Plumbaginaceae*. Because the last-named pollen grains always are much bigger than *Tricolpopollenites fruticis*, an origin from this family seems less probable, although on the other hand the supposed paralic origin of the browncoal would not exclude a relationship with the recent *Plumbaginaceae*, which usually are halophytes. For the time being, however, I think it most likely that it will belong to a representant of the family *Oleaceae*.

Tricolpopollenites fruticis: 27–31 μ; pollen tricolporatus; exina reticulata raramacularis, intectata, clavatobaculata; prope colpos reticulum minus raramaculari est; ectexina triplo crassior quam endexina.

Organ genus *Tricolporopollenites* Pf. et Th.

Tricolporopollenites eureticulatus n.sp. (Fig. 9–10).

Pollen grains 18–24 μ, tricolporate, with three short transversal colpes. Exine thick, intectate with reticulate sculpture; near the colpes the reticulum becomes somewhat vague. Endexine rather thick.

Is identical with recent pollen grains from the Caprifoliaceous genus *Viburnum*.

Not very rare in the series of the quarry "Anna".

Tricolporopollenites eureticulatus: pollen 18–24 μ, tricolporatus exina crassa, reticulata, intectata; prope colpos reticulum paulum incertum fit; endexina modice crassus; pollen congruens cum *Viburno*.

Tricolporopollenites reticulatus n.sp. (Fig. 11).

15–19 μ, rather small pollen grains of about spheroidal shape, and provided with three colpes and pores. Exine with a reticulate sculpture, ectexine and endexine of about the same thickness.

Natural relationship: presumably *Hamamelidaceae*, probably genus *Hamamelis*. Type specimen in the Botanical Museum, Utrecht.

Four times observed.

Tricolporopollenites reticulatus: 15–19 μ; pollen modice parvus; tricolporatus; exina reticulata; ectexina et endexina fere aequa crassitudine.

Tricolporopollenites haanradensis n.sp. (Fig. 12–13).

15–22 μ. Pollen grains about triangular, with three colpes and three distinct pores. Pores annular. Exine reticulate, intectate; extexine and endexine are both thin.

Natural relationship: in all likelihood *Rhamnaceae*, but *Vitaceae* is not entirely excluded.

Altogether five specimens have been observed in the browncoal of the quarry "Anna". Type specimen in the collection of the Botanical Museum, Utrecht.

Tricolporopollenites haanradensis: 15–22 μ; pollen fere triangulus tricolporatus; exina reticulata, intectata; porus cum annulo.

Organ genus *Tetracolporopollenites* Pf. et Th.

Tetracolporopollenites insolitus n.sp. (Fig. 14).

Pollen grain 20–26 μ, tetracolporate, with four distinct pores. Exine firm, with a vague striate sculpture. Endexine thicker than ectexine.

Rare, only once found. Deposited in the Botanical Museum, Utrecht.

Natural relationship still fully unknown.

Tetracolporopollenites insolitus: 20–26 μ; pollen terracolporatus exina incerta striata; endexina crassior quam ectexina.

Section Massuloides Pf.

Organ genus *Tetradopollenites* Pf. et Th.

Tetradopollenites concubinatus n.sp. (Fig. 15).

Pollen grains united in tetrads, 25–31 μ; the individual grains in the tetrad are sharply delimited against each other, exine thick (about 2–4 μ). Every grain provided with one distinct colpe. Surface practically smooth.

Agrees completely with the recent pollen from the genus *Empetrum*. Only once observed.

Tetradopollenites concubinatus: pollen in tetradi; 25–31 μ; exina crassa; omnia grana monocolporata; superficies satis aequa.

Tetradopollenites echinatus n. sp. (Fig. 16).

Pollen grains easily identifiable, always united in tetrads. Size of the tetrad 25–50 μ. Exine thin and very pliable, echinate; endexine and ectexine about equally thin.

Natural relationship: perhaps *Droseraceae*, which also show echinate pollen grains united in tetrads. The organ species, however, is not identical with one of the recent west-european species of *Drosera*, from which it differs in two points, viz. that the distal surface is provided with spines and that the grains do not converge so clearly toward the centre of the tetrad.

Rather rare; three specimens have been observed. Type specimen in the collection of the Botanical Museum, Utrecht.

Tetradopollenites echinatus: pollen semper in tetradi; magnitudo tetrados 25–50 μ; exina tenuis et plicabilissima, echinata; ectexina et endexina fere aequa tenuitate.

E. Survey of the spores and pollen grains

It is evident that, when we wish to do a little more with the obtained palynological data than only using them for stratigraphical purposes, we will have to try to determine the taxonomic position of the tertiary spores and pollen grains. Our final aim always has to be to place fully circumscribed distinct fossil pollen forms in the natural family to which they belong (Traverse 1957). On the other hand I believe that we should not hurry with this, and will do better to use a purely phytographical system so long as our knowledge is still so incomplete. In this way we will avoid creating a confusing lot of synonyms by transferring insufficiently known forms from one natural group to the other.

In search of the taxonomic position of our fossil spores and pollen grains the starting-point has to be a comparison with the spores and pollen grains of recent plants, because those of the fossil ones generally are not at all or only badly known. Because the macrofossils proved that there are no essential differences between the representatives of the tertiary and those of the recent flora, this in many cases leads to appeasing results. The species of then and now may be different, the recent families and often also their genera largely existed during the tertiary.

For geological-stratigraphical age determinations this has the consequence that good guide fossils for correlating floras over large distances are rather rare. Fortunately, there is a rather large number of facies fossils, which, besides giving data as to the landscape of that time, can tell us also much with regard to the climate, the migrations a.o. and besides, may it be over shorter distances, allow the establishment of good correlations. When interpreting tertiary pollen diagrams, however, we always will have to ask in how far the data may have been influenced by local differences.

In the next pages we will have a try to connect the organ species with taxonomic groups. The artificial, phytographical names, however, are still maintained. The sequence of orders and families of the higher plants, used here, is that found in Dr A. A. PULLE "Compendium van de terminologie, nomenclatuur en systematiek der zaadplanten", 3rd ed., Utrecht 1952.

SPORITES

Spores are much less common in the miocene browncoal than pollen grains. In the diagram of the quarry "Anna" they only constitute 0,9 % of the total number of sporomorphae. Of these 0,3 % has to be counted to the mosses and 0,6 % to the ferns and fern allies.

BRYOPHYTA

Sphagnaceae

The *Sphagnaceae* form 0,3 % of the sporomorphae in the browncoal I studied; a percentage therefore that is far smaller than that in which *Sphagnaceae* may occur in quaternary pollen diagrams. In the pliocene *Sphagnum* spores become for the first time more common. The observed miocene types may be classed into two organ species: *Stereisporites* (*Triletes*) *psilatus* (Ross) Pf. et Th. and *Stereisporites stereoides* (R. Pot. et Ven.) Pf. et Th.

In 1937 Thiergart proved that during the formation of the Rhenish browncoal a number of different *Sphagnum* species must already have been present.

PTERIDOPHYTA

Lycopodiaceae

Reticulatisporites caelatus R. Pot. was rather rare in the diagram. It belongs to a *Lycopodium*.

Osmundaceae

Osmunda spores are represented in the miocene by the organ species *Rugulatisporites quintus* Pf. et Th., by most authors registered as *Sporites primarius* Wolff. Wolff, however, under this name depicted the baculate *Pteris* type and also described this. For this reason Pflug and Thomson rightly gave the *Osmunda*-type a new name. Potonié compared this form with *Osmunda*, as well as with the liverwort *Anthoceros*. According to Thomson it is certain that it belongs to *Osmunda*. Confusion with *Anthoceros* spores, however, is possible, as well as with those of *Pteridium*, *Lycopodium inundatum* and *Ophioglossum*. *Rugulatisporites quintus* occurs from the upper oligocene up to the great interglacial. In the coal studied by me rather rare.

Schizaeaceae

Laevigatisporites pseudomaximus Pf. et Th. presumably comes from the genus *Lygodium*. In the browncoal examined by me it showed an average percentage of 0,05.

Gleicheniaceae

Concavisporites obtusangulus (R. Pot.) Pf. et Th. agrees with the spores of *Gleichenia gigantea* Wall. Very rare.

Polypodiaceae

The *Polypodiaceae* with nearly 0,5 % are by far the best represented fern family in the browncoal of the quarry "Anna". Five organ species are referred with more or less certainty to this family.

Laevigatisporites neddeni R. Pot. is a collective-group of smooth, trilete spores without special characteristics, as these are found in several *Polypodiaceae* and in some *Cyatheaceae*. According to Selling a few species of *Adiantum* have also to be counted among the possible suppliers. Occurs rather regularly.

Baculatisporites primarius (Wolff) Pf. et Th. shows a great resemblance to recent *Pteridium* spores. Very rare.

Laevigatosporites haardti R. Pot. et Ven. conforms to *Polypodiaceae* spores without perisporium. Relatively common.

Verrucatosporites alienus (R. Pot.) Pf. et Th. and *Verrucatosporites* (*Polypodiisporites*) *favus* (R. Pot.) Pf. et Th. also have to be referred to the *Polypodiaceae*. Of these the first one occurs regularly, the second one is found rarely.

POLLENITES

CONIFEROSPERMAE

The number of conifer pollen grains strongly increases in the course of the tertiary period. Within the miocene too this may be seen (e.g.

in the series of the "Hauptflöz" of the Rhenish browncoal), especially by an increasing percentage of *Sciadopitys* and *Pinaceae* pollen. *Taxodiaceae*, however, are more common in the older parts of the German Lower-Rhenisch browncoal than at the top of the diagrams. Perhaps this is connected with facies differences.

Pinaceae

The *Pinaceae* constitute 5,5 % of the total number of sporomorphae in the coal studied by me. Of these *Pityosporites microalatus* (R. Pot.) Pf. et Th., the *Pinus haploxylon* type, is by far the most common, with 4,5 %. After this *Pityosporites labdacus* (R. Pot.) Pf. et Th., the *Pinus diploxylon* type (*Pinus silvestris* type) is already much less common (0,9 %). The last-named form becomes in the upper pliocene much more numerous.

Kirchheimer described several cones of *Pinus laricio thomasia* (Göppert) Heer from the browncoal in the Ville and at Düren. He compared it with the present mediterranian species *Pinus nigra* Arnold. Also wood remains of *Pinus* are known from the Lower-Rhenish browncoal. Kräusel and Schönfeld (1922) also described *Pinuxylon* remains from the substratum of the browncoal in southern Limburg. A determination up to species, however, was not possible with certainty. *Pinus* wood is not very common in the Limburgian browncoal.

Pityosporites alatus (R. Pot.) Pf. et Th. corresponds to the recent *Picea* pollen. This pollen form is still very rare in the Rhenish and in the corresponding Dutch browncoal, as well as in other miocene deposits. From the pliocene on it becomes more common.

The genus *Tsuga*, represented by the organ species *Zonalapollenites igniculus* (R. Pot.) Pf. et Th. (*Tsuga diversifolia* type Rudolph) and *Zonalapollenites viridifluminipites* (Wodehouse) Pf. et Th. (*Tsuga canadensis* type Rudolph) in the miocene only plays a very subordinate part, in the browncoal studied by me it even was very rare. In the pliocene more *Tsuga* pollen grains appear, but still very scarcely.

Inaperturopollenites magnus (R. Pot.) Pf. et Th. perhaps comes from the genus *Pseudotsuga*; an origin from *Larix* seems much less probable. Rare.

The *Pinaceae* probably formed part of the vegetation in the region round the moor. Thomson partly counts them to a subsequent stage of moor vegetation. This seems less probable to me—at least in the Dutch profile—on account of their occurrence in the pollen diagram.

Taxodiaceae and *Cupressaceae*

Inaperturopollenites dubius (R. Pot. et Ven.) Pf. et Th. (*Pollenites magnus dubius* Pot. et Ven.) is a very common pollen type in the miocene browncoal, also in the series studied by me. It shows an average percentage of 3,8 per sample. According to Thomson as plants from which they may have come in the first place *Cupressaceae* deserve consideration, after that *Taxodiaceae*. Thiergart speaks of *Juniperus*, *Taxus*, *Cupressus*, a.o. On account of their mode of occurrence I consider the plants of origin as having formed part of the shore vegetation, together with e.g. the *Nyssaceae*. Especially the frequent presence of *Inaperturopollenites dubius* at the bottom of the series is a valuable indication into this direction.

A very great resemblance with pollen grains of *Taxodium* shows the pollen type *Inaperturopollenites hiatus* (R. Pot.) Pf. et Th. (*Pollenites hiatus* R. Pot.; *Taxodiodites hiatus* R. Pot.), a very common form. Also *Glyptostrobus* has to be counted among the possible pollen suppliers. "Der Pollen von *Taxodium* und *Glyptostrobus* sind einander volkommen ähnlich, nur ohne oder mit kaum wahrnehmbarer Exinenzunge versehen. Manche Botaniker vereinigen *Glyptostrobus* mit *Taxodium*". (THIERGART 1940). *Inaperturopollenites hiatus* and *Inaperturopoll. dubius* are, according to Thomson, especially numerous in strata which contain coniferous wood.

The vast part of the fossil wood, described by KRÄUSEL and SCHÖNFELD (1922) from southern Limburg, belonged to *Juniperoxylon*, a collective genus in which fossil wood with the structure of *Juniperus*, *Fitzroya*, *Libocedrus decurrens*, a.o. is taken together. All the wood found by both authors, they ascribed, although in a few cases with some reserve, to the species *Juniperoxylon silesiacum* (Prill) Kräusel, which anatomically shows a great resemblance with *Juniperus virginiana* L. This tree nowadays has its greatest development in the forests around the moors in the southern part of atlantic Northern America, in company of *Pinus* and *Cupressus* species, together with *Magnoliaceae*, oaks and many other deciduous trees. Because most fossil wood was found as "grössere Stämme im Liegenden des Flözes, wo sie oft noch in aufrechter Lage stehen" the picture of a forest on higher ground is perhaps also applicable to southern Limburg in the miocene period. "*Juniperoxylon silesiacum* muss als Charakterbaum der Limburgischen Braunkohlenwälder angesehen werden, wenn auch nicht in dem Sinn, dass es allein bestandbildend auftrat". It is remarkable that in Limburg no *Taxodioxylon* remains are found.

Inaperturopollenites polyformosus (Thierg.) Pf. et Th., although not rare, is much less common than both previous pollen types. The plants of origin here may be *Sequoia*, *Metasequoia* or *Cryptomeria*. At first *Cryptomeria* seemed to be the most likely, because this organ species showed a greater resemblance with recent pollen grains of *Cryptomeria* than with those of *Sequoia sempervirens*. Thomson (PFLUG and THOMSON 1953) considered the with *Sequoia sempervirens* closely related *S. langsdorffi* resp. *couttsiae* the possible supplier. Kirchheimer found fossil cones of *Sequoia couttsiae* Heer also in sand insertions in the quarries at Düren. This tree is for the rest especially numerous in the older tertiary. Macrofossils of *Cryptomeria* are not known from the Lower-Rhine area.

That *Monocolpopollenites serratus* (R. Pot. et Ven.) Pf. et Th. (*Sporites serratus* Pot. et Ven.) comes from the genus *Sciadopitys* seems to be certain, most likely from *Sciadopitys verticillata*. In the series of the quarry "Anna" only two specimens have been observed. This is one of the most important arguments for the view that the Dutch browncoal studied by me correlates with the older part of the Rhenish mainbrowncoal formation ("Hauptflöz"). In the middle and upper part of the Rheinish browncoal pollen grains of *Sciadopitys* are important constituents of the pollen diagrams. In the lower part they are also found, but much less frequently.

ANGIOSPERMAE

Potamogetonaceae

The newly described, very rare, *Inaperturopollenites paluster* I refer with reserve, to this family.

Arecaceae (*Palmae*)

It is very likely that *Monocolpopollenites areolatus* (R. Pot.) Pf. et Th. (*Pollenites areolatus* R. Pot.) belongs to the *Palmae*. According to Thomson it occurs together with *Palmoxylon bacillare*, Thiergart compares it with the pollen of *Sabal*. In several samples one or two specimens of this pollen type have been observed, very seldom, however, more than two. They form 0,36 % of all pollen grains counted.

Already for a very long time from the bronwcoal quarries in the German Rhine area wood remains are known, which mainly are build up of long, thin strings and are called "Haarknabben" and "Haarknabbenkohle" by the labourers. Brongniart (1822) assembled these remains in his genus *Endogenites*, and compared them with palms. Gothan collected a lot of this material, among which, later on, also parts which clearly showed the original structure. From this it appeared that it were indeed remains of *Palmae*. He also established that this material is anything but rare, but even may build up whole strata. Later on many other authors have been engaged with the study of these remains. Of them Jurasky has delivered the most important contribution. He called them *Palmoxylon bacillare* (Bgt.) Jurasky. He succeeded in making microtome-preparates of these strings and clearly proved the palm structure in all fractions. He also demonstrated fossil root remains and leaf sheaths of *Palmae* in the German browncoal and even found fossil "dates" in the quarry "Alfred" near Konzendorf and "Zukunft", Düren. Thus it was clearly demonstrated that in the miocene browncoal *Palmae* are present. Still it lasted until 1935 before in the Dutch browncoal similar fossils were found. That year Jongmans (1935) described palm remains from the quarry "Carisborg", near Heerlen. It concerns flattened parts, nearly entirely consisting of strings, build up by the sclerenchyma of the vascular strands. The other tissue had disappeared. Dr. Koopmans proved their identity with the remains described by Jurasky.

Poaceae (*Gramineae*)

Pollen grains of *Gramineae* (*Monoporites circumvallatus*) are rare appearances in the browncoal examined by me—such in contrast to quaternary deposits. Seen the great number of arboreal pollen grains it does not seem unlikely that the miocene forests around the moors had a dense tree vegetation in which so much light was intercepted by the foliage that a good undergrowth could not exist. Perhaps along the shore some *Phragmites* grew, which supplied the few *Gramineae* pollen grains that have been found. Whether the browncoal moor, as the present moors, in its development went through a reedmoor stage, seems doubtful.

Confusion of *Gramineae* pollen with certain conservation states of *Taxodiaceae* pollen sometimes is possible. The latter, however, are inaperturate.

Pflug and Thomson (1953) don't mention *Gramineae* pollen. Pollen grains exactly similar to the pollen of present-day grasses, however, are found also with a scattered distribution in some browncoal beds of Jutland (Denmark). (Ingwersen, 1954 "Some micro fossils from Danish Late Tertiary Lignites", Danmarks Geol. Unders. II Raekke, Nr 80, 30–64).

Cyperaceae

Cyperaceae pollen grains (*Inaperturopollenites sacculiformis*) are no more than those of *Gramineae* commonly represented. The highest *Cyperaceae* percentage in one sample was 1,2; on the average they even did not reach 0,2 %.

Droseraceae

The newly described pollen type *Tetradopollenites echinatus* I referred, although with some reserve, to the *Droseraceae*. From no other family I know echinate pollen grains, occurring in tetrads.

Hamamelidaceae

Periporopollenites stigmosus (R. Pot.) Pf. et Th. has been compared by Potonié and Venitz (1934) with recent pollen grains of e.g. *Liquidambar*. According to Thomson it is very likely that it belongs to this genus; according to Thiergart it is certain. In the Lower-Rhenish browncoal in Germany, although never in great numbers, it is found regularly. In the Dutch browncoal I only observed one specimen. From the pollen grains of *Alisma*, *Plantago*, *Thalictrum*, etc. those of *Liquidambar* can be distinguished owing to their irregular structure and the irregular spreading of the pores over the pollen surface.

To this family, perhaps to the genus *Hamamelis*, presumably has to be referred the here newly descibed *Tricolporopollenites reticulatus*, which is rather rare.

Platanaceae

The globose forms within the organ species *Tricolporopollenites retiformis* Pf. et Th. perhaps belong to the genus *Platanus*. Common

Betulaceae

The miocene *Betulaceae* are, in general, palynologically difficult to distinguish from the *Myricaceae*, and are often taken together with these. Besides, there are all possible transitions towards *Engelhardtia*. *Betula* pollen grains, identical with the recent ones (*Trivestibulopollenites betuloides* Pf.) are in the miocene still rather rare, but from the pliocene onwards they become more numerous. The same is the case with the *Corylus* pollen (*Triporopollenites coryloides* Pf.). It must, however, not be thought impossible that among the pollen grains, referred to the *Myricaceae*, there may have been grains which actually did come from *Corylus* species.

On the other hand *Polyvestibulopollenites* (*Alnipollenites*) *verus* (R. Pot.) Pf. et Th. corresponding to the recent *Alnus* type, is still a little more common (0,1 %). In contrast to the quaternary grains of this *Alnus* pollen the fourpore type is more common than the fivepore type.

Fagaceae

Tricolporopollenites pseudocruciatus (R. Pot.) Pf. et Th. has been described by Potonié in 1931 as a fagoid pollen form; in 1948, however, it was transferred to the *Nyssaceae*. In 1951 he has abandoned this opinion once more, and he described this pollen type again as one with the habit of *Fagus silvatica*. Pflug and Thomson follow this last opinion. In the browncoal studied by me this type has only twice been observed, both times at the top of the series. Fossil leaves of *Fagus* are not rare in the Rhenish browncoal.

To the *Fagaceae*, with or without a certain reserve, several other types are referred, viz.:

Tricolpopollenites henrici (R. Pot.) Pf. et Th.
Tricolpopollenites asper Pf. et Th.
Tricolpopollenites microhenrici (R. Pot.) Pf. et Th.
Tricolpopollenites liblarensis (Thoms.) Pf. et Th.
Tricolporopollenites villensis (Thoms.) Pf. et Th.
Tricolporopollenites genuinus (R. Pot.) Pf. et Th.
Tricolporopollenites porasper Pf.

The *Fagaceae* or *Cupuliferae* thus form one of the most important allochthonous pollen groups in the browncoal.

Tricolpopollenites henrici (*Pollenites henrici* R. Pot.; *Quercoidites henrici* R. Pot.), called after Henri Potonié, is very common. From the bottom of the series (nearly 4,5 %) towards the top (about 2,2 %) there is a clear decrease in its percentage. *Pollenites henrici* by R. Potonié was compared with *Quercus*. Also the other authors refer it to the group of *Cupuliferae*, related to *Quercus*. Potonié and Venitz (1934) regard it as "für das Miozän bezeichnende Art", Thiergart takes it for a "sicheres Zeichen für das Miozän, wenn in Masses auftretend", a stratigraphic occurrence, also mentioned by Thomson. In the pliocene this pollen type disappears.

Tricolpopollenites asper is a collective group of quercoid pollen forms without special characteristics, partly perhaps coming from *Quercus* species. In our series it shows a slow increase from on the average nearly 6 % at the bottom to nearly 7,5 % at the top.

According to Thomson *Tricolpopollenites microhenrici* (*Pollenites microhenrici* R. Pot.; *Quercoidites microhenrici* R. Pot.), a "Durchläufer durch Alt- und Mitteltertiär und älteres Jungtertiär", is very common in the miocene and in the Rhenish browncoal specially characteristic for the so-called "hellen Schichten" in the upper part of the series. In the pollen diagram of the quarry "Anna" it occurs in a rather varying percentage through the whole series, with an average percentage of 2,75 at the bottom to nearly 3,5 at the top. Potonié compared *Tricolpopoll. microhenrici* with *Quercus*, according to Thomson (Potonié, Thomson and Thiergart 1950) it probably belongs to *Quercus*, larger forms perhaps to *Acer negundo*; in 1953 (Pflug and Thomson 1953) he speaks more carefully of *Cupuliferae* "aus der Verwandtschaft der Gattung *Quercus*".

Tricolpopollenites liblarensis (*Pollenites quisqualis* R. Pot.) presumably also comes from the family *Fagaceae*. In the literature it is often described as "cf. *Leguminosae*" (a.o. by Thiergart). As stratigraphical occurrence Thomson writes: "Massenauftreten im Alttertiär, häufig im Mitteltertiär, selten im Jungtertiär". In the studied diagram it reached an average percentage of about 6 %. Of this the subspecies *fallax* (R. Pot.) Pf. et Th. (*Pollenites fallax* R. Pot.) forms about 0,75 %, is more common at the bottom than at the top of the profile, and shows several transitions to the main form; the rather common occurrence of this pollen type is considered by Thomson as an "älteres Merkmal der rheinischen Braunkohle".

Tricolporopollenites villensis, presumably also a Cupuliferous pollen type, is easily confused with some other pollen species. It occurs regularly, but is in the upper part of the "Anna" series evidently more common.

Of *Tricolporopollenites genuinus* it is not quite sure whether it has to be referred to the *Cupuliferae* or not. It is known from old and middle tertiary deposits, occurs rather regularly in the series, but does not reach high numbers (on the average not even 0,2 %).

Tricolporopollenites porasper phytographically agrees with a great cupuliferoid pollen type with tendency to pore formation in the endexine. According to Pflug presumably to some extent related to *Quercus*. Is like the previous pollen species not very common.

The *Fagaceae*(?) group *Tricolporopollenites cingulum* (R. Pot.) Pf. et Th. often is indicated as castaneoid-types. Of this the subspecies *pusillus* (R. Pot.) Pf. et Th., according to Thomson, agrees with the recent *Castanea* type; the subspecies *oviformis* (R. Pot.) Pf. et Th. with a smaller *Castanea* type; both are common in the browncoal examined by me. On the other hand the subspecies *fusus* (R. Pot.) Pf. et Th. is rather rare and of a still unknown origin.

By some other authors *Tricolporopollenites cingulum* is referred to *Castanopsis*; this origin, however, is less likely.

The castaneoid pollen forms an important contribution from the vegetation round the bog. Of the total number of sporomorphae in the browncoal studied by me it represents nearly 11 %.

Tiliaceae

The organ species *Intratriporopollenites instructus* (R. Pot. et Ven.) Pf. et Th. phytographically fully corresponds to the recent *Tilia* type and in all likelihood also has come from *Tilia*. In the several German browncoal deposits it occurs from the miocene up to the upper pliocene, but nowhere it reaches percentages of some importance. In the series studied by me from the quarry "Anna" this form has been observed in total seven times.

According to Thiergart a number of *Tiliaceae* genera, as e.g. *Heliocarpus*, *Holiurus*, *Sparmannia*, a.o. have pollen grains which show a certain similarity with pollen of the *Rhus* type. When these have been present during the time in which the browncoal has been formed, their pollen very presumably would not be recognized, but referred to *Rhus*.

Rutaceae

The pollen grains of the organ species *Tricolporopollenites sustmanni* Pf. et Th. in all likelihood belong to a representative of the family *Rutaceae*, presumably to *Phellodendron*. It has been found rather scarcely in the series examined by me, but is mentioned by Thomson and Pflug as a pollen type, occurring regularly in the Rhenish browncoal. In the Netherlands F. FLORSCHÜTZ (1950) demonstrated the presence of macroscopical remains of the genus *Phellodendron* in the clay of Reuver (Reuverien), while H. Weyland also has found remnants in the upper oligocene of Rott.

The recent *Rutaceae* form a large family, with a great spreading in the warm and temperate parts of the earth, but are more numerous in the tropics. Many representatives are nowadays found along shores and river banks.

Anacardiaceae

By Potonié *Tricolporopollenites pseudocingulum* (R. Pot.) Pf. et Th. (*Pollenites pseudocingulum* R. Pot.) has been brought in connection e.g. with the family of *Anacardiaceae*. THIERGART (1940) ascribed it to the genus *Rhus*, which origin is thought likely by Thomson too. This form has a stratigraphical spreading from eocene to miocene. Up till now it is not known from the paleocene and pliocene. "Sowohl in der Geiseltahlkohle wie in der untermiozänen Braunkohlenformation der Lausitz, Böhmens und der Ville ist der Pollen relativ stark vertreten" (Thiergart). In the studied series it forms 4 % of the total number of sporomorphae.

Also to the *Anacardiaceae* or to a family nearly related with these presumably belongs *Tricolporopollenites dolium* (R. Pot.) Pf. et Th., which, however, is considerably less common than the previous species.

Of the recent species of the genus *Rhus* several occur under comparable conditions in the warmer and temperate regions: along the banks of rivers and swamps (*Rhus typhina*), along the sea shore (*Rhus integrifolia*) or in swamps, inundated during a portion of the year (*Rhus vernix*).

Cyrillaceae

The organ species *Tricolporopollenites megaexactus* (R. Pot.) Pf. et Th. presumably belongs to this family; it fully agrees with the pollen of the recent *Cyrillaceae*. Weyland also has found fossil leaves belonging to this family. Two subspecies are distinguished: *T. m. brühlensis* (Thoms.) Pf. et Th. (= *Pollenites cingulum brühlensis* Thoms.) and *T. m. exactus* (R. Pot.) Pf. et Th. (= *Pollenites exactus* R. Pot.; = *Pollenites pseudocastanea* Thoms.). Between both there are, however, all possible transitions; for this reason the boundary is laid at 16 μ, which I think rather arbitrary. Both forms are „ungemein charakteristisch" for the Rhenish browncoal formation and are also very numerous in the Dutch coal studied by me. Of both forms the bigger one is most common; together they form over 11 % of all sporomorphae. Owing to this high number and the fact that they are pollinated by insects, it is certain that they have formed part of the peat vegetation, together with the *Myricaceae*, although the maxima of both groups, as a rule, do not exactly coincide in the diagram.

The recent *Cyrillaceae* are found in the temperate areas of Northern America, where they occur under comparable circumstances: e.g. *Cyrilla racemiflora*: at the margin of sandy swamps and shallow ponds; *Cliftonia monophylla*: damp sandy peat soils in swamps that are almost submerged for several months of the year, or often in shallow, rarely overflowed swamps.

Aquifoliaceae

The organ species *Tricolporopollenites iliacus* (R. Pot.) Pf. et Th. and *Tricolporopollenites margaritatus* (R. Pot.) Pf. et Th. are referred to the *Aquifoliaceae*. Of these the first one conforms with pollen of the genus *Ilex*, which is represented by several species in the North-American bogs. Thiergart also describes *Tricolporopoll. margaritatus* to *Ilex*, but this cannot yet be considered as completely certain.

Aquifoliaceae are found in nearly all preparates but only seldom reach more than 2 %; on the average they even do not form one % over the whole series. This, however, as may be the case also with some other forms, presumably is not connected with a small number of plants, but partly also with a low pollen production. In the Rhenish browncoal *Aquifoliaceae* pollen is found more frequently than in corresponding eocene deposits, which may be an indication for a cooling of the climate.

Rhamnaceae

The newly described, rather rare pollen type, *Tricolporopollenites haanradensis* belongs in all likelihood to the *Rhamnaceae*.

Vitaceae

The organ species *Tricolporopollenites marcodurensis* Pf. et Th. reminds us, according to Thomson, very much of the pollen of *Parthenocissus* and presumably has come from this genus, or a genus related with it, like *Cissus*. Very rare.

Araliaceae

The pollen types *Tricolporopollenites edmundi* (R. Pot.) Pf. et Th. and *Tricolporopollenites euphorii* (R. Pot.) Pf. et Th. suggest the pollen of the *Araliaceae*; according to Thiergart also *Cornaceae* have to be counted among the possible plants of origin. Both types occur rather regularly in the series studied by me, but they are nowhere numerous. Of the total number of all observed sporomorphae they form about a quart of a %. According to Thomson *Tricolporopoll. euphorii* is more common in the lower part of the Rhenish browncoal than in the upper part.

The recent *Araliaceae* are found in the warmer regions of our earth.

Of the family of *Cornaceae*, which together with the *Araliaceae* belongs to the order *Apiales*, Kirchheimer described several macrofossils from the Lower Rhenish browncoal, and belonging to the genera *Mastixia*, *Tectocarya* and *Ganitrocera*. The two first-named ones he classified in a new subfamily, that of *Mastixioideae*. Nowadays of this only *Mastixia* still occurs, living in tropical East-Asia.

From Southern Limburg Kräusel and Schönfeld (1922) described wood remains of the organ genus *Cornoxylon latiporosum* Kr. et Sch. This fossil may have come from the genus *Cornus* itself, perhaps, however, also from *Hamamelidaceae*. The remains were allochthonous, but in all likelihood only transported over a slight distance.

Caprifoliaceae

Pollen grains, described as *Tricolporopollenites eureticulatus* n.sp., identically with the recent *Viburnum* pollen, are not very rare in the Dutch browncoal (0,1 %).

The origin of *Tricolporopollenites microreticulatus* Pf. et Th. is still uncertain. Pollen grains somewhat comparable to them are found a.o. in *Sambucus*, but it is still very doubtful whether this plant may be considered the pollen supplier. Rare.

Nyssaceae

The organ species *Tricolporopollenites kruschi* (R. Pot.) Pf. et Th. is ascribed to the *Nyssaceae*; it is often subdivided in a number of subspecies, mainly because of their size(?!). *Nyssa* pollen occurs through the entire tertiary period. In the series examined by me they form over 1,1 % of the total.

Ericaceae

Ericaceae are represented in the quarry "Anna" by the following organ species:

Tetradopollenites ericius (R. Pot.) Pf. et Th.
Tetradopollenites callidus (R. Pot.) Pf. et Th.
Tetradopollenites discretus (R. Pot.) Pf. et Th.

Of these the last-mentioned one is rather rare; both other species are rather common, whereby, however, *Tetradopoll. callidus* is clearly the most numerous one. In total they form more than 3,5 % of all sporomorphae. They occur as part of the peat vegetation, usually together with *Myricaceae* and *Cyrillaceae*. On account of their behaviour it seems likely that the *Ericaceae* mainly have been represented by smaller plants and much less by shrubs. Especially their withdrawal, when *Myricaceae*/*Betulaceae* and *Cyrillaceae* reach relatively high percentages, indicates that they formed the undergrowth during the carr stages.

Empetraceae

This family is still very seldom represented in the miocene. Only once a tetrad has been observed, agreeing with the recent *Empetrum* pollen (*Tetradopoll. concubinatus*).

Sapotaceae

The following organ species belong in all likelihood to the *Sapotaceae*:

Tetracolporopollenites obscurus Pf. et Th.
Tetracolporopollenites kirchheimeri (Reiss) Pf. et Th.
Tetracolporopollenites sapotoides Pf. et Th.
Tetracolporopollenites manifestus (R. Pot.) Pf. et Th.

Of these the type *Tetracolporopoll. manifestus* subsp. *contractus* Pf. is most common, while *T. kirchheimeri* is poorly represented. The *Sapotaceae* form about 0,75 % of the total number.

The recent *Sapotaceae* are mainly trees and shrubs restricted to the tropics and subtropics. Several recent species live on the banks of rivers and lakes or near the sea shore.

Symplocaceae

A little more common than the *Sapotaceae* are the *Symplocaceae*, with about one %. To these in all probability belong:

Porocolpopollenites orbis Pf. et Th.
Porocolpopollenites rotundus (R. Pot.) Pf. et Th.
Porocolpopollenites latiporis Pf. et Th.
Porocolpopollenites hemicolpis Pf.
Porocolpopollenites vestibulum (R. Pot.) Pf. et Th.

Of them *P. orbis* is very rare and *P. latiporis* and *P. hemicolpis* are rare; both other organ species, on the other hand, are rather common (*P. rotundus* 0,5 %, *P. vestibulum* 0,4 %). Of *P. vestibulum* only very occasionally the old tertiary "warzige" form has been observed, for the rest always the "rauhe" form. Thomson sets no value on this distinction.

According to THIERGART (1950) *Symplocaceae* are more common at the bottom of the Rhenish browncoal series than at the top. The relatively numerous occurrence of pollen grains, which with certainty or some probability have come from the families *Sapotaceae* and *Symplocaceae* distinguish the Rhenish browncoal from the younger German browncoal deposits.

The family of *Symplocaceae* is in the present flora represented only by the genus *Symplocos* with nearly 300 species; trees or shrubs. They inhabit chiefly the warmer parts of America, Asia and Australia. In the miocene they must have formed part of the vegetation around the bog. Kirchheimer also found stone-casts of *Symplocos* fruits in the German Rhenish browncoal, together with other petrifacts, which he referred to a new genus of the *Symplocaceae*, called *Pallioporia*.

Oleaceae

The new organ species *Tricolpopollenites fruticis* perhaps has come from this family. Very rare.

Salicaceae

The elongate forms of the organ species *Tricolpopollenites retiformis* Pf. et Th. presumably belong to *Salix*. Common. In the South-Limburgian quarry "Herman" Kräusel has found also fossil leaves of *Salix* (JONGMANS 1935).

Myricaceae

The *Myricaceae* pollen grains are very numerous in the browncoal series studied by me (about 26 %) and are represented by several organ species:

Triatriopollenites rurensis Pf. et Th.
Triatriopollenites bituites (R. Pot.) Pf. et Th.
Triatriopollenites myricoides (Kremp) Pf. et Th.
Triatriopollenites coryphaeus (R. Pot.) Pf. et Th.

The distinction between all these forms is not always very easy, no more than that between some *Betulaceae*, which therefore often are taken together with the *Myricaceae*. *Triatriopoll. coryphaeus* often is divided into two subspecies: *punctatus* (R. Pot.) Pf. et Th., larger than 18 μ, and *microcoryphaeus* (R. Pot.) Pf. et Th., smaller than 18 μ. This last form also is often indicated as "Engelhardtioid pollen forms". I do not consider this artificial boundary of great scientific value.

From the South-Limburgian browncoal (quarry "Herman") leaf remains of *Myrica* too were identified by Kräusel (JONGMANS 1935). The *Myricaceae* formed a very important part of the miocene peat vegetation.

Nowadays in the Netherlands only *Myrica gale* occurs. It is found in wet heath areas, peats, swamps and some dune valleys. *Myricaceae* are found all over the earth.

Juglandaceae

Juglandaceae (*Engelhardtia* excluded) are still far from common in the miocene. *Subtriporopollenites simplex* (R. Por. et Ven.) Pf. et Th. was brought by POTONIÉ (1934) with reserve to the genus *Carya*. Thiergart and Thomson take this origin for certain. According to Thiergart *Carya* is found "vereinzelt" in the paleocene and becomes more numerous in the farther course of the tertiary. In the Netherlands fossil *Carya* pollen is known up till the clay of Tegelen, not younger. In the miocene browncoal series studied by me it forms a little less than 0,3 % of the total number of sporomorphae.

Polyporopollenites stellatus (R. Pot. et Ven.) Pf. et Th. is ascribed by Thomson and Thiergart to the genus *Pterocarya*. *Pterocarya* is found from the upper oligocene up to and including the lower pleistocene of Tegelen. In the coal it forms 0,1 % of the total.

Pollen of the organ species *Multiporopollenites maculosus* (R. Pot.) Pf. et Th., that is ascribed to *Juglans*, has only once been observed.

Whether the newly described organ species *Polyporopollenites obscurus* may be counted among the *Juglandaceae* is still very doubtable. Rare.

Pollen from the subspecies *Triatriopollenites coryphaeus* (R. Pot.) Pf. et Th. *microcoryphaeus* (R. Pot.) Pf. et Th. often are identified with *Engelhardtioid* pollen forms. There are, however, all possible transitions to the *Myricaceae* and *Betulaceae*. Therefore a border line is taken at 18 μ. All pollen grains of this type that are smaller than this measure are referred to the subspecies *microcoryphaeus*. When Thomson in his diagram of the quarry "Fortuna" (Fig. 3) represents the percentage of Engelhardtioid pollen forms he only means the percentage *Triatriopollenites coryphaeus microcoryphaeus*. In this diagran it can be seen that there is some relation between the curves for Engelhardtioid pollen forms and that for *Myricaceae/Betulaceae*. This also is likely, for, when in this case all measures are present, it is a strange supposition that *Engelhardtia* should only have provided pollen grains up to 17,9 μ and the *Myricaceae* and *Betulaceae* only of 18,1 μ and larger.

It has been found that the so-called Engelhardtioid pollen forms are most numerous in the older tertiary, in younger deposits their percentage decreases. Even in the diagram of the Rhenish browncoal formation can be seen that these smaller pollen types are more common at the bottom than at the top. It is not quite clear, however, what botanical conclusion may be drawn from this.

For a more exact proof that this border line is in itself of less value I applied the Kendall-test, well-known from the probability calculus on the percentages of *Triatr. cor. microcor.* at the one side and the quotient of the percentages of bog vegetation (*Myricaceae/Betulaceae* + *Cyrillaceae* + *Ericales*) and surrounding vegetation (*Pinaceae* + *Salicaceae/Platanaceae* + *Fagaceae*) at the other. This showed that there is a possibility of only 6,2 % that there is no correlation between both series of numbers and a still much smaller possibility for a negative correlation.

From this it is clear that there is a very strong indication for the existence of a positive correlation, that is to say a close connection between the percentages of the bog vegetation and that of *Triatr. cor. microcor.* and hardly any connection between the latter and the percentage of pollen grains provided by the forest round the bog. Because *Engelhardtia* is a big tree, not growing in the bog, we may conclude that the greatest part of the pollen grains in the subspecies *Triatr. cor. microcor.* has come from plants living in the browncoal bog and thus not from *Engelhardtia*, possibly from *Myricaceae*. The border line of 18 μ without other characteristics thus does not have any diagnostic value.

That the percentage of *Triatr. cor. microcor.* is represented separately in the diagram of Fig. 17 has therefore only a stratigraphical meaning, e.g. for comparison with Fig. 3, but no biological importance. It even is dubious whether the percentage of this "pollen type" has a great stratigraphical significance.

POLLENITES INCERTAE SEDIS

Of a few organ species the natural relationship is still fully in the dark. This is the case with:

Tricolpopollenites cf. parmularis (R. Pot.))Pf. et Th.

Tricolporopollenites cingulum (R. Pot.) Pf. et Th. subsp. *fusus* (R. Pot.) Pf. et Th.

Tricolporopollenites eschweilerensis Pf. et Th.

Tetracolporopollenites insolitus n.sp.

All these types are rare in the browncoal of the quarry "Anna".

Tricolpopollenites cf. parmularis is associated by Thiergart with the *Cornaceae*, which, however, is still very doubtful.

In the diagram (Fig. 17) a number of species are represented showing clear fluctuations and distinct percentages. Other species or groups, reaching smaller values or showing slighter variations in percentage are omitted. For comparison with other publications their percentages are mentioned in the text.

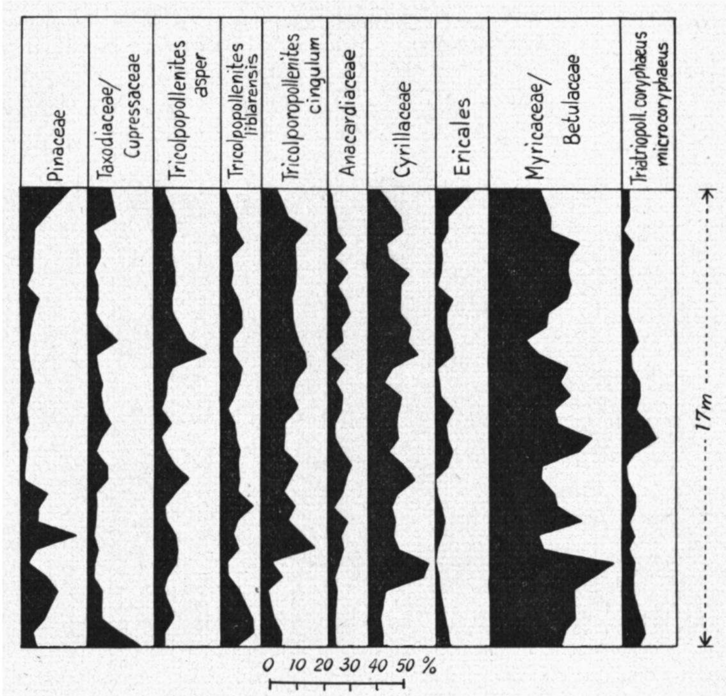

Fig. 17. Pollen diagram of the quarry "Anna" at Haanrade.

F. Discussion

Climate

When arranging the groups of plants of which we know or presume that they have been represented in the browncoal bog in the southeastern part of the Netherlands or in the environment of the latter, in a simplified way according to their recent distribution, we obtain the following survey:

Subtropical-tropical plants: *Palmae*
Rutaceae (Phellodendron?)
Vitaceae (Parthenocissus?)
Nyssaceae
Sapotaceae
Symplocaceae
Araliaceae

Subtropical-temperate plants:	*Pinaceae* *Hamamelidaceae (Hamamelis?; Liquidambar)* *Platanaceae (Platanus?)* *Anacardiaceae (Rhus?)* *Aquifoliaceae* *Rhamnaceae (Rhamnus?)* *Oleaceae (Ligustrum?)* *Salicaceae (Salix)* *Juglandaceae (Juglans; Carya; Pterocarya)*
Temperate plants:	*Taxodiaceae (Glyptostrobus/Taxodium; Sciadopitys; Sequoia/Metasequoia/Cryptomeria)* *Cupressaceae* *Potamogetonaceae?* *Droseraceae* *Betulaceae (Betula; Alnus; Corylus)* *Fagaceae (Cupuliferae;* castaneoid pollen forms) *Tiliaceae (Tilia)* *Cyrillaceae* *Caprifoliaceae (Sambucus???; Viburnum)*
In most climate belts:	*Gramineae* *Cyperaceae* *Ericaceae* *Empetraceae* *Myricaceae*

Expressed in percentages this will be:

subtropical-tropical plants:	2,6 %
subtropical-temperate plants:	12,9 %
temperate plants:	48,4 %
in most climate belts:	29,9 %
uncertain:	6,2 %

Among the representatives of the temperate flora the *Fagaceae* (30,7 %) occupy the most important place; partly they may perhaps be classified as temperate to subtropical plants. The *Myricaceae* (26 %) occur in most climate zones; on account of their wealth in species in the miocene they may have been present mainly as subtropical forms. Among the subtropical to temperate groups the *Juglandaceae* too are placed, although with the exclusion of *Triatriopollenites coryphaeus microcoryphaeus* ("*Engelhardtia*"?), which is included in the category "uncertain".

The composition of the flora makes it likely that the miocene climate has not been so very much warmer than the present one. Temperate to subtropical may be the best fitting surmise. Specifically tropical groups as *Palmae*, *Sapotaceae* and *Symplocaceae* indicate that the winters must have been very mild.

Changes in the climate were during the miocene of very subordinate character only. Fluctuating curves as are shown in quaternary pollen diagrams and a periodical disappearance of some pollen types are not to be expected here. The miocene pollen diagram shows slight changes only, in the floristic composition. Quantitative differences have other than climatological causes.

Number of species

The number of species as well in the vegetation of the bog itself as in the region around it, must have been a multiple of that in a similar area nowadays, at least if we are allowed to base our conclusion on the number of wind pollinating forms. In the diagram this finds its expression in a very great diversity of spores and pollen types; the variability of these types often surpasses the breadth of variation of a single species, and there are sometimes transitions from one group to another. Besides any pollen species may include material from two or more natural genera, and whether this is so or not can only be decided when we know the whole plant. One has certainly not to do with a limited number of distinctly circumscribed pollen forms, but with a rather large number of collective and transitional forms, and the differences between them are sometimes very slight.

In the present stage of study we have to be very prudent in drawing conclusions from the number of observed species, because every further investigation may add new pollen grains to the list of known species and forms. Potonié in his survey of the micropaleontological stratigraphy of the tertiary by means of pollen analysis (Potonié 1948) mentions from the eocene in the Geiseltal 31 known families (with 117 species and forms), from the miocene of the Lower-Rhine area 21 families (with 80 species and forms) and from the pliocene of Dettingen 14 families (with 34 species and forms). He than adds: "Wenn auch die Pollen- und Sporenniederschlag kein Bild der gesamten Flora ergibt, so war doch dieses Ergebnis ein deutlicher Hinweis für das Abnehmen der Gattungs- und Artenzahl im Verlauf des Tertiärs". I myself am declined to put a note of interrogation behind this. Our knowledge is determined by several other factors e.g. by the duration, the intensity, and eventually, by the economic utility of the investigation, the character of the site, etc.

"Die beobachteten Pollentypen sind zwar zum grössten Teil schon beschrieben, doch finden sich immer noch solche, die durch die vorhandene Literatur nicht bestimmt werden können" (Rein 1956). Why could a withdrawal of specifically tropical genera not have been compensated by an increase in the number of temperate forms? Why should the impoverishment found in the present flora, have begun so long before the glacial period? As an illustration my study of the miocene browncoal from the quarry "Anna" revealed the presence of presumably 37 families (more than 90 species and forms), among which there are many that are comparable with recent temperate species from Europe and North-America.

Character of changes in the pollendiagram

The tertiary browncoal bogs in NW. Germany, as well as those from the wealden and carboniferous belong, according to Thomson (Thomson and Pflug 1952), to the topogenous bog type of L. von Post and H. Oswald, which means that they were bogs, in which growth was determined by the height of the groundwater level. Other factors may of course also have influenced growth, as e.g. climate and food supply from the soil.

When the rhythm of subsidence and thus the velocity in which the groundwater level rises undergoes a change, the composition of the plant communities in the bog must have changed too. At a relative slight subsidence forests predominate ("Bruchwaldmoore") and peat is formed, which is mainly build up of wood and bark elements. This are the so-called "dunkle Bänke" of E. Wölk. At a stronger subsidence, on the other hand, open, treeless bogs arose, forming the "helle Schichten", in which the pollen grains from the surrounding forests predominate (THOMSON 1950[a]). These oecologically determined changes in the vegetation are called by Thomson changes of the first order. Although recognizable almost everywhere in the "Hauptflöz" the "helle Schichten" are lacking in the Dutch browncoal which forms a marginal facies of the Rhenish browncoal formation (MANTEN 1958).

On these changes of the first order other alterations in the vegetation are superimposed, the so-called changes of the second order. As well in the bog vegetation as in the composition of the surrounding forests the quantitative composition of the pollen spectrum changes. Elements, numerous at the bottom, may be less common towards the top, and vice versa. With regard to the peat growth these alterations may be connected e.g. with the normal succession of stages in peat development, going from lake dy and detritus gyttja, via swamp peat and forest peat to moss peat, so long as the groundwater level does not change during that time.

In the miocene diagram it appears e.g. that the peat was formed rather rapidly by a dense vegetation of *Myricaceae/Betulaceae*, *Cyrillaceae* and to a less extend also of *Ericaceae*.

In the forest round the bog too changes may occur. The vegetation may influence the condition and food supply in the soil, making growth possible for other plants, while earlier represented species disappear. Besides oecological factors also climatological ones may have been of influence here, as there are e.g. changes in the quantity and in the periods of rainfall.

No more than the changes of the first order these changes of the second order represent time horizons. In a local deposit, however, they may have stratigraphical value. The difference between these changes and the time-marking alterations that will be discussed hereafter, is often difficult to see in a pollen spectrum. A good example is the occurrence of *Sciadopitys*. The "*Sciadopitys*-Vorstoss" has for a long time been regarded as a new element in the Rhenish browncoal, but it appeared that *Sciadopitys* in smaller quantities also occurs at the bottom of the browncoal formation and its variations in frequency therefore must be changes of the second order.

The changes of the third order or changes connected with the course of time, finally, have the character of real time indications. To these changes belong not only the extinction of some species and the appearance of other, new, species but also climatologically determined migrations. Especially in very thick series as those of the German main browncoal deposit these are recognizable. So the cause of the gradual procentual increase of e.g. *Pinaceae* and *Aquifoliaceae* has to be sought in a slow but gradual cooling of the climate. Together with these increases there is a decrease in a number of tropical and subtropical genera from the bottom of the series towards the top. For instance here may be mentioned the numerous *Rhus* types and the common *Symplocos* forms in the "Liegendkomplex" which at the top of the Rhenish browncoal are hardly or not at all represented, while others show a considerable decrease in frequency.

It seems likely that for the Netherlands browncoal studied by me especially decrease and increase of eutrophy, together with a progressive peat formation are the main causes of the observed changes in the pollen diagram.

Stages of growth

When we compare the places where the pollen grain curves of the different plants or plant groups show their tops and depressions, the pollen diagram may tell us something concerning the peat types and the plant groups that successively have built up the browncoal deposit.

At first there was a period in which the pollen grains of the forest round the bog predominated. This forest consisted of *Fagaceae*, *Pinaceae* and *Salicaceae/Platanaceae*. This stage can be compared with the "offene Niedermoore vom Everglades-Typus" of THOMSON (1950[a]). This author, however, regards *Pinus* as belonging to a far more progressive stage of peat vegetation. Presumably we have to think here of open, half limnic bogs, periodically inundated by one or more metres of water. This first stage is hardly represented in our diagram. In the beginning of the peat formation it must have been present, but very soon it was succeeded by the next stage. During the development of the coal series it did not return; "hellen Schichten" are fully lacking.

The second stage is that, in which the pollen grains provided by the shore vegetation reach relatively high percentages; these are the *Taxodiaceae*, *Cupressaceae* and *Nyssaceae*. It is comparable to the "Taxodiaceen-Cupressineen-Bruchwald" of Thomson.

As third stage we have a predomination of the carr vegetation, the "Myricaceen-Betulaceen-Bruchwald", of which besides *Myricaceae* and *Betulaceae* also *Cyrillaceae* and *Ericaceae* form part. The tops of *Myricaceae/Betulaceae* on one side and that of *Cyrillaceae* on the other do not completely coincide in the diagram (Fig. 17). In an attempt to discover whether this might be connected with the height of the water level the Kendall-test has been applied on the quotient of the *Cyrillaceae* percentage and the *Myricaceae/Betulaceae* percentage and the amounts of pollen found in the shore vegetation. This, however, did not give any statistically significant result. Thus the difference in frequency between the two groups of pollen must have other causes than a difference in groundwater height. It is difficult to say which factors this may have been.

The *Ericaceae* occur as well together with *Myricaceae/Betulaceae* as with *Cyrillaceae*. Only when the *Myricaceae/Betulaceae* reach relatively very high percentages they show a regression. Presumably the foliage than was so dense that it strongly stunted an undergrowth of *Ericaceae*.

That the pollen diagram does not give us more detailed data concerning the different bog associations is not surprising, when we consider that in quaternary pollen diagrams too they are only reflected to a slight extent. The nearly complete absence of pollen grains of plants pollinated by insects plays an important part.

The three stages in the development of the browncoal deposit need not necessarily be present everywhere at the same time. When at the margin of the area the third stage had already been reached, farther towards the centre of the swamp, an open marsh might still have been present. When a tectonical block temporary undergoes a comparatively strong subsidence, there may be a return to the second or even to the first stage.

It is clear that these three stages in the pollen diagram are always relatively distinguishable. During the carr stage e.g. the pollen rain from the forest round the bog did not cease; the pollen grains of these trees only reached lower percentages because they were outstripped by the peat vegetation.

In Fig. 18 I represent shore vegetation, bog vegetation and surrounding vegetation side to side with each other, to give some idea of the history of the development of the browncoal deposit. It appears from this that the second stage had very soon been reached, and soon was succeeded in its turn by an explosive expansion of the bog vegetation. After that presumably the groundwater level rose, and the pollen percentage of the trees of the surrounding forests increased again compared with that of the peat builders. After that a kind of equilibrium set in, which continued during almost the whole second half of the series. The small fluctuations occurring in the percentages here may well be accidental. At the top, finally, not unlikely the approaching drowning of the peat may be reflected. The percentage of some of the pollen grains from the region round the bog, especially that of *Pinus* pollen, shows a clear rise (Fig. 17) as well as that of *Taxodiaceae/Cupressaceae*. On the other hand the *Ericaceae* also increase, which possibly is connected with the withdrawal of the *Myricaceae* and especially of the *Cyrillaceae*, through which the undergrowth became the main vegetation. Nowadays too there are *Ericaceae* that thrive very well in very swampy areas.

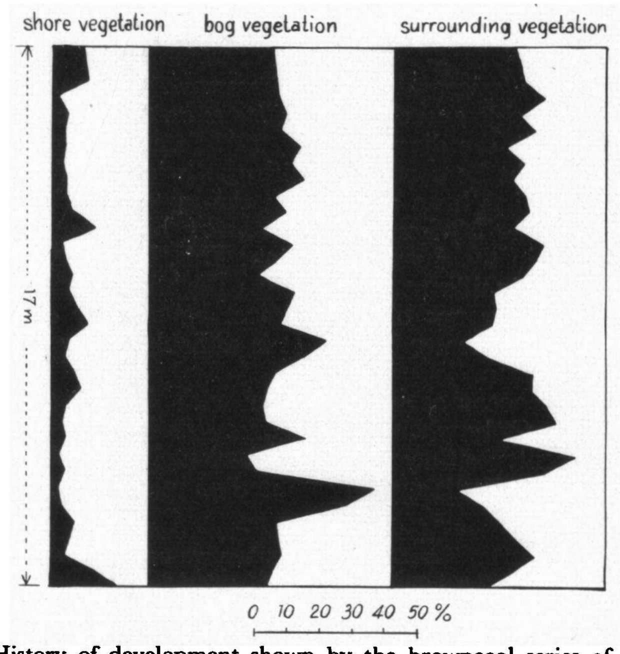

Fig. 18. History of development shown by the browncoal series of the quarry "Anna".

The age of the browncoal

As appears from the historical review there is still by no means a communis opinio as to the age of the Lower-Rhenish browncoal formation. In the light of our present knowledge a middle miocene age seems the most likely. Much detailed study, however, as well of the coal itself as of the surrounding sediments will be necessary before this can be considered an established fact.

The browncoal series of the quarry "Anna" examined by me shows palynologically many "old" characteristics of the Rhenish browncoal, as:

a) the nearly complete absence of *Sciadopitys* pollen;

b) the relatively common occurrence of *Sapotaceae* pollen forms (especially *Porocolpopollenites rotundus* and *P. vestibulum*) in a total of 0,74 % of all observed sporomorphae and a likewise common presence of *Symplocaceae* pollen grains (0,96 %).

c) the still comparatively low percentages of *Tricolpopollenites microhenrici* (on the average 3 %, compare with this Fig. 3), even when considered that "hellen Schichten" do not occur in the Dutch coal.

d) an average percentage of *Tricolpopoll. liblarensis* of ca. 6 % and of *Tricolpopoll. cingulum* of ca. 11 %, which is the same as that found in the German diagrams near the bottom (the *Tricolpopoll. liblarensis* percentage in the German Rhine area varies from ca. 8 % at the bottom, via ca. 15 % to ca. 6 % at the top, the percentage of *Tricolpopoll. cingulum* rises from bottom to top gradually from ca. 12 % to ca. 20 % on the average).

e) the very common occurrence of *Triatriopollenites* forms smaller than 18 μ (*Triatriopoll. coryphaeus microcoryphaeus*).

f) the regular presence, especially at the bottom of the series, of *Tricolpopoll. liblarensis fallax* (on the average 0,76 %), by Thomson described as an "älteres Merkmal der rheinischen Braunkohle".

g) the still very low percentage of *Tricolporopoll. villensis.*

h) a very regular and procentually similar occurrence of *Anacardiaceae* ("Rhooide Pollenformen").

The supposition of Breddin that the Dutch browncoal layers correspond with the lower part of the main browncoal deposit in the German Rhine area (Fig. 2) has therefore found here palynological confirmation.

When converting the found percentages according to the method of Rein for correlation with other deposits (see Fig. 4) and putting the percentages of 12 pollen types at 100 (strictly speaking only 8, because 4 do not occur in the coal studied by me), and comparing the so obtained results with the standard table of Rein, it appears that the Netherlands browncoal of layer F does not show a pollen content that is completely identical with one of the zones in this standard table. The resemblance with zone IIa, however, is rather striking, although there are some differences. So the percentages of *Myricaceae/Betulaceae/Engelhardtioid* pollen forms in the Dutch coal are considerably higher, that of *Anacardiaceae* (*Tricolporopoll. dolium* +

T. pseudocingulum) and that of *Tricolpopoll. liblarensis* somewhat lower. This, however, may very well be regarded as differences in facies.

Because of the fact that—as said—many German geologists nowadays assume a middle miocene age for the Rhenish browncoal formation and as the Dutch coal in all likelihood correlates with the lower part of this deposit, we have to assume for the Dutch browncoal too a middle miocene age.

SUMMARY

The browncoal of the quarry "Anna" at Haanrade belongs to layer F, the middle one of the three layers into which the main browncoal deposit splits towards the NW. It correlates with the lower part of the German series, and in all likelihood is of middle miocene age. The coal is very rich in pollen grains, and the latter belong to a great diversity of species. Spores are less common. Of all pollen species the taxonomic position has been traced. The pollen diagram shows no striking fluctuations. It seems likely that a moderately subtropical climate prevailed during the miocene.

REFERENCES

AHRENS, W. 1942. Die Erforschung des geologischen Alters der nieder-rheinischen Braunkohle. Berichte des Reichamts für Bodenforschung, Jhrg. 1942, H. *11/12*: 56–60.

——— und H. KARRENBERG. 1950. Stand der stratigraphischen und tektonischen Erforschung der niederrheinischen Braunkohlenformation. Geol. Jahrb., Hannover, *65*: 35–69.

BREDDIN, H. 1930. Eine neue Deutung der geol. Verhältnisse des Braunkohlengebietes der Ville bei Köln. Braunkohle, H. *29*: 897–900, 922–928.

——— 1931. Zur Geologie des Braunkohlengebietes der Ville bei Köln. Braunkohle, H. *30*: 271–272.

——— 1932*a*. Über die Gliederung und Altersstellung des niederrheinischen Braunkohlentertiärs. Zeitschr. deutsch. geol. Ges. *84*: 257–279.

——— 1932*b*. Die Feuersteingerölle im niederrheinischen Tertiär, ein Beweis für die paralische Entstehung der Braunkohlenflöze. Centr. Bl. Min. etc. *1932*: 395–404.

——— 1935. Die paralische Entstehung der niederrheinischen Braunkohle. Braunkohle, H. *52*: 857–862.

——— 1950. Die Hauptflözgruppe im niederrheinischen Braunkohlenrevier. Braunkohle, Wärme und Energie, Jahrg. 1950, H. *19/20*: 312–320 und H. *21/22*: 378–385.

BRELIE, G. v. D. und U. REIN. 1954. Die pollenanalytische Flözorientierung im Braunkohlentiefbau der Schachtanlage Morschenich. Geol. Jb., Hannover, B. *69*: 303–328.

BRONGNIART, A. 1822. Classification des végét. fossiles. Mém. du Mus. d'Hist. natur., *8*: 11, 44.

ERDTMAN, G. 1943. An introduction to pollen analysis. Chronica Botanica Company, Waltham, Mass. U.S.A.

FLIEGEL, G. 1910*a*. Die miozäne Braunkohlenformation am Niederrhein. Abh. Preuss. geol. Landesanstalt, Berlin, 61.

——— 1910*b*. Die Tektonik der niederrheinischen Bucht und ihre Bedeutung für die Entwicklung der Braunkohlenformation. Braunkohle, Halle, H. *9*: 212–216.

——— 1927. Die Braunkohlen des Niederrheingebietes. Handb. deutsch. Braunkohlenbergbau, Halle 3e Aufl.: 108–122.

——— 1931*a*. Der Flözgraben der Ville. Braunkohle, H. *30*: 21–28.

——— 1931*b*. Zur Geologie des Braunkohlengebietes der Ville bei Köln. Braunkohle, Halle, H. *30*.

FLIEGEL, G. 1937. Erläuterungen zu den Blättern Frechen, Köln, Kerpen, Brühl, 2e Aufl.

FLORSCHÜTZ, F. 1950. On the Palynological Boundary Pliocene-Pleistocene in Europe. Proceedings 7th Intern. Bot. Congr., Stockholm, *1950*: 883–884.

GREBE, H. 1953. Beziehungen zwischen Fusitlagen und Pollenführung in der Rheinischen Braunkohle. Paläont. Z. Stuttgart, 27 H. *1/2*: 12–15.

GOTHAN, W. 1930. Fragen der Braunkohlenentstehung vom botanischen Standpunkt aus. Ber. deutsch. geol. Ges. Stuttgart, *82*: 444–451.

HAMMEN, TH. VAN DER. 1956. A palynological systematic nomenclature. Boletin Geologico, Bogota, *4*, No. 2–3.

JONGMANS, W. J. en F. H. VAN RUMMELEN. 1930. Het voorkomen van Bruinkool en Bruinkoolformatie in Zuid-Limburg in verband met de bouw van het Steenkoolgebied. Jaarverslag Geol. Bur. Nederl. Mijngebied, Heerlen, 1930.

——— 1935. Palmenreste in der Braunkohlengrube Carisborg bei Heerlen (Nied.-Limburg). Natuurhist. Maandblad, *24*, no. 4: 46–48.

JURASKY, K. 1928. Paläobotanische Braunkohlenstudien II. Die Vorstellung vom Braunkohlenwald als irrtümliches Schema. Senckenberg, Frankfurt a.M., *10*, H. 3/4.

——— 1930. Die Palmenreste der niederrheinischen Braunkohle, Braunkohle, H. *51/52*.

JUX, U. und H. D. PFLUG. 1957. Zur Geologie und Technologie der Braunkohle in der niederrheinischen Bucht. Braunkohle, Wärme und Energie. H. *13/14*: 257–266.

KIRCHHEIMER, F. 1934. Neue Ergebnisse und Probleme paläobotanischer Braunkohlenforschungen. Braunkohle H. *45/46*: 769–774 und 788–793.

——— 1937. Grundzüge der Pflanzenkunde der deutschen Braunkohlen. Halle/Saale, 1e Aufl.

KRÄUSEL, R. 1918. Welche Ergebnisse liefert die Untersuchung tertiärer Pflanzenreste?. Naturwiss. Wochenschrift. B. *33*, Nr. 15.

——— 1921. Ist Taxodium distichum oder Sequoia sempervirens Charakterbaum der deutschen Braunkohle?. Ber. deutsch. botan. Ges. *39*: 258–263.

——— 1938. Die tertiäre Flora der Hydrobienkalke von Mainz-Kastel. Palaeontol. Zeitschr., Berlin, *20*: 9–103.

——— und G. SCHÖNFELD. 1922. Fossiele Hölzer aus der Braunkohle von Süd-Limburg, Abh. der Senckenbergischen Naturforschenden Gesellschaft *38*(3): 253–289.

MANTEN, A. A. 1958. Facies en ouderdom der zuidoostnederlandse bruinkool. Grondboor en Hamer, Nieuwe reeks, no. 4.

PANNEKOEK, A. J., e.a. 1956. Geologische geschiedenis van Nederland. 's Gravenhage.

PELTZ, W. und H. W. QUITZOW. 1954. Die Bruchtektonik des Braunkohlengebietes der Ville nach neueren Bohrergebnissen. Geol. Jb. Hannover, B. *69*: 293–302.

POTONIÉ, R. 1948. Stand der mikropaläontologischen Tertiärstratigraphie. Zeitschr. deutsch. geol. Ges. *100*: 366–378.

——— 1951. Revision stratigraphisch wichtiger Sporomorphen des mitteleuropäischen Tertiärs. Palaeontographica, Stuttgart, *91*, Abt. B.: 131–151.

——— 1956*a*. Die Behandlung der Sporae dispersae und der fossilen Pflanzen überhaupt nach dem Internationalen Code der Botanischen Nomenklatur. Pal. Zeitschr. *30*, no. 1/2: 69–87.

——— 1956*b*. Die stratigraphische Inkongruität der Organe des Pflanzenkörpers. Pal. Zeitschr. *30*, no. 1/2: 88–94.

——— und H. VENITZ. 1934. Zur Mikrobotanik des miocänen Humodils der niederrheinischen Bucht. Arbeiten aus dem Institut für Paläobotanik und Petrographie der Brennsteine, Preuss. geol. L.A. Berlin. *5*: 5–54.

——— P. W. THOMSON und F. THIERGART. 1950. Zur Nomenklatur und Klassifikation der neogenen Sporomorphae. Geol. Jahrb. Hannover, *65*: 35–69.

QUITZOW, H. W. 1952. Über das geologische Alter der jüngeren Braunkohlenablagerungen und den stratigraphischen Wert pflanzlicher Reste. Zeitschr. deutsch. geol. Ges. Hannover, *104*: 354–378.

——— 1955. Die Sedimentationsrhythmen der jüngeren Braunkohlenformation. Neues Jb. Geol. Paläont. Stuttgart. H. *4/5*: 173–185.

REIN, U. 1950*a*. Die Bedeutung der Flözeingliederung für den rheinischen Braunkohlenbergbau und ihre Anwendung in der Praxis. Braunkohle, Wärme und Energie, Jahrg. 1950, H. *5/6*: 72–78.

——— 1950*b*. Die Anwendung der Pollenfeinstratigraphie in der Praxis des rheinischen Braunkohlenbergbaues. Geol. Jahrb. Hannover. *65*: 127–144.

——— 1956. Pollenanalytische Untersuchungen an mitteleuropäischen Braunkohlenvorkommen des Miocäns. Grana Palynologica, Stockholm. *1*, nr. 2: 108–114.

SARGENT, C. E. 1921. Manual of the trees of North America. London.

THIERGART, F. 1940. Die Mikropaläontologie als Pollenanalyse im Dienst der Braunkohlenforschung. F. Enke Verlag, Stuttgart.

——— 1949. Die Sciadopityszone und der Sciadopitys-Vorstoss in der niederrheinischen Braunkohle. Braunkohle, Wärme und Energie, Jahrg. *1949*: 153–156.

——— 1950. Pollenfloren aus den tertiären Braunkohlen vom Niederrhein. Geol. Jb. Hannover. *65*: 81–106.

THOMSON, P. W. 1949. Alttertiäre Elemente in der Pollenflora der rheinischen Braunkohle und einige stratigraphisch wichtige Pollenformen derselben. Palaeontographica, Stuttgart. *90*, Abt. B: 94–98.

——— 1950*a*. Grundsätzliches zur tertiären Pollen- und Sporenmikrostratigraphie auf Grund einer Untersuchung des Hauptflözes der rheinischen Braunkohle in Liblar, Neurath, Fortuna und Brühl. Geol. Jb. Hannover. *65*: 113–126.

——— 1950*b*. Die Sukzession der Moortypen und Pflanzenvereine im Hauptflöz der rheinischen Braunkohle. Proceedings 7th Intern. Botan. Congres, Stockholm, *1950*: 575.

——— 1950*c*. Aufbereitung von Sporomorphen in Braun- und Steinkohlen. Proceedings 7th Intern. Botan. Congress, Stockholm, *1950*: 887

——— 1950*d*. Die Entstehung von Kohlenflözen auf Grund von paläontologischen Untersuchungen des Hauptflözes der rheinischen Braunkohlen. Braunkohle, Düsseldorf. *2*: 39–49.

——— 1951. Die Sukzession der Pflanzenvereine und Moortypen im Hauptflöz der rheinischen Braunkohle mit einer Übersicht über die Vegetationsentwicklung im Tertiär Mitteleuropas. Bericht über das Geobotanische Forschungsinstitut Rübel, Zürich, *1952*: 81–87.

——— 1954. Der Fazieswechsel im Hauptflöz der rheinischen Braunkohle im Gebiet der Grube Fortuna. Geol. Jb. *69*: 329–338.

——— 1956. Die Braunkohlenmoore des jüngeren Tertiärs und ihre Ablagerungen. Geol. Rundschau, Stuttgart *45*: H. 1: 62-70

——— und U. REIN, 1950. Mikropaläontologische Untersuchung eines Standardprofils der rheinischen Braunkohle in der Grube Liblar/Bezirk Köln. Geol. Jb. Hannover. *65*: 107–112.

——— und H. GREBE, 1951. Zur Gliederung des tertiären Deckgebirges der rheinischen Braunkohle im südlichen und mittleren Teil der Ville-Scholle und der Erft-Scholle auf mikropaläontologischer Grundlage. Braunkohle, Wärme und Energie, Jahrg. 1952, H. *7/8*: 131–134.

——— und H. PFLUG. 1952. Zur feinstratigraphischen Untersuchung von Braunkohlenflözen. Geol. Jahrb. Hannover. *66*: 559–575.

——— und ———. 1953. Pollen und Sporen des mitteleuropäischen Tertiärs. Palaeontographica, Stuttgart. *94*, Abt. B.: 1–138.

TRAVERSE, A. 1957. The nomenclatural problem of plant microfossil species belonging to extant genera. Micropaleontology *3*, nr.3: 255–258.

WEYLAND, H. 1934. Beiträge zur Kenntnis der rheinischen Tertiärflora I. Floren aus den Kieseloölith- und Braunkohlenschichten der Niederrheinischen Bucht. Abh. preuss. geol. L.A., Berlin. N.F., H. 161.

WÖLK, E. 1935. Eine neue geologische Untersuchung des niederrheinischen Hauptbraunkohlenflözes. Braunkohle, Halle/Saale. *36*, H. 46/47.

——— 1936. Mächtigkeit, Gliederung und Entstehung des niederrheinischen Hauptbraunkohlenflözes. Braunkohle, Halle/Saale. *35*, H. 12/13.