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ON BROWN COAL RESOURCES IN THE LOWER RHINE EMBAYMENT (WEST GERMANY)

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ABSTRACT

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The Tertiary brown coal resources in the Lower Rhine Embayment amount to 55,000 million tons. The open-cast mining operations under way or at the planning stage ensure an annual production of 115-120 million tons over a period of the next 75 years. The brown coal mainly serves to generate electrical energy. At present about 150-250 m of overburden have to be removed to get at the brown coal. In future this may increase up to 500 m. The maximum thickness of the brown coal is about 100 m.

The brown coal beds provide data about:

- a basin-shaped subsidence of the embayment during the Miocene. No major block faulting occurred during the main period of peat accumulation.
- peat compaction. 100 m of brown coal (under an overburden of 500 m) might correspond to 250 m of peat.
- a Pre-Rhine river system during the main period of peat accumulation.
- the perennial effectiveness of some Palaeozoic structural elements.

INTRODUCTION

Regarding the contour lines of the base of the Tertiary, the North Sea Basin apparently ends in the Mid-Netherlands (Fig. 1). The adjacent structures –the Central Graben, the Peel Horst and the Lower Rhine Embayment– may perhaps be considered as marginal parts of the North Sea Basin, yet their history certainly deserves a description of its own (Fig. 2).

Concerning the Lower Rhine Embayment and the brown coal area (Fig. 3), the activities of the brown coal mining industry make a great quantity of information available. The interpretation is far from being complete.

SOME MINING ASPECTS

The total quantity of brown coal in the Lower Rhine Embayment amounts to about 55,000 million tons (Fig. 4). A detailed evaluation of the resources was given by HANNAK (1974). At the prevailing energy cost and the present state of opencast techniques the mining industry regards 35,000 million tons as economically minable. Some 9,000 million tons can be mined out of the operating open pits and those open pits which are now at the planning stage. The quantity of 9,000 million tons

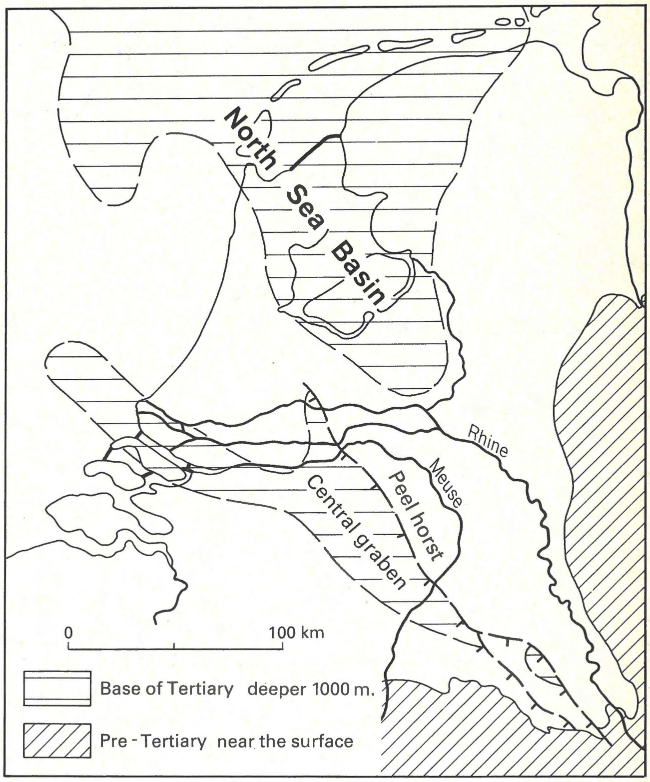

Fig. 1
The southern end of the North Sea Basin and adjacent structures, modified after Heybroek, 1974.

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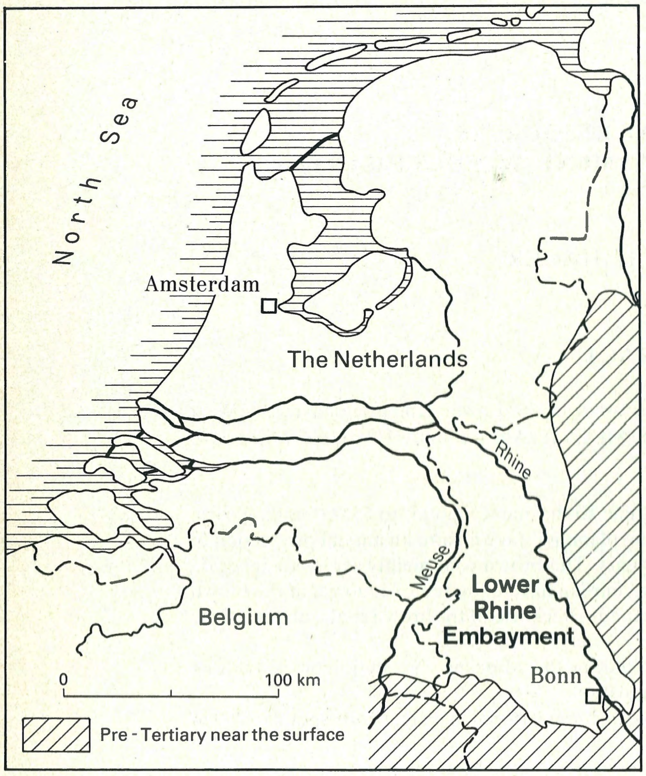

Fig. 2
The Netherlands and the Lower Rhine Embayment.

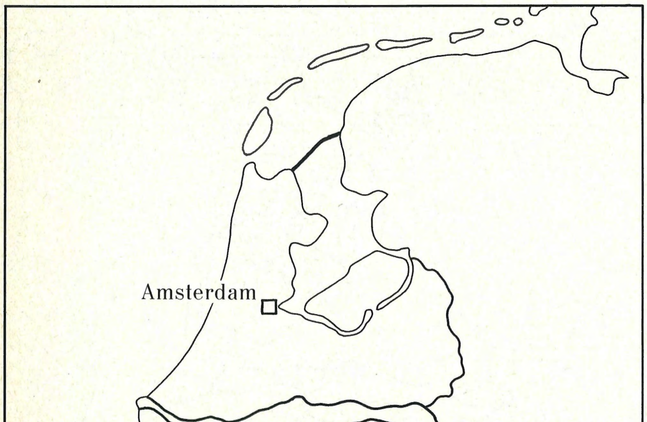

Fig. 3
Brown coal deposits in the Lower Rhine Embayment.

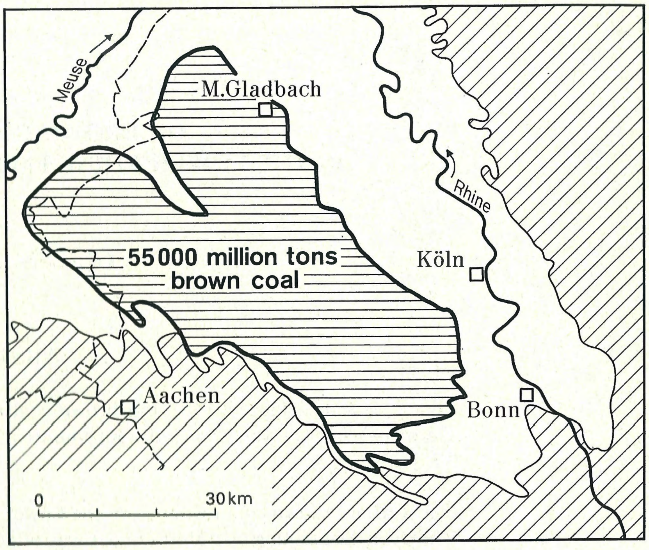

Fig. 4
Brown coal resources in the Lower Rhine Embayment.

will be sufficient to ensure an annual production of 115-120 million tons over a period of the next 75 years.

The brown coal in the Lower Rhine Embayment largely serves as raw material to generate energy. About one quarter of the total West German electrical energy is supplied by the brown coal mining industry. Some other large-scale applications are under study, for example the gasification of brown coal in connection with atomic power stations.

Although the brown coal resources are considerable, it might be desirable to encourage research in order to increase the energy output of brown coal. The easily minable parts of the resources have already been largely exploited. They were situated close to the surface. The overburden consisted of only 10-20 m gravel. At present about 150-250 m of overburden have to be removed to get at the brown coal beds. In future opencasts the overburden will attain 400-500 m. Fig. 5 presents isopachs of the overburden for that area where the total thickness of the brown coal beds exceeds 25 m.

The mining technique adopted at present is based on bucket wheel excavators digging 100,000 bank cubic meters per day. It may be added that the next machinery generation is already under construction. This will be able to handle 200,000 bank cubic meters of overburden or brown coal daily. It is clear that a bucket wheel excavator of this capacity cannot be operated economically unless the brown coal beds exceed a certain thickness.

There are many other items to be considered in the economic planning of brown coal mining operations. Each ton of brown coal mined requires the draining of 11 m³ of water from depths down to 500 m in order to dewater the open pits. To ensure stable slopes at a depth of 500 m the area of the opencast will have to be very large. This will inevitably pose serious problems concerning the resettlement of communities

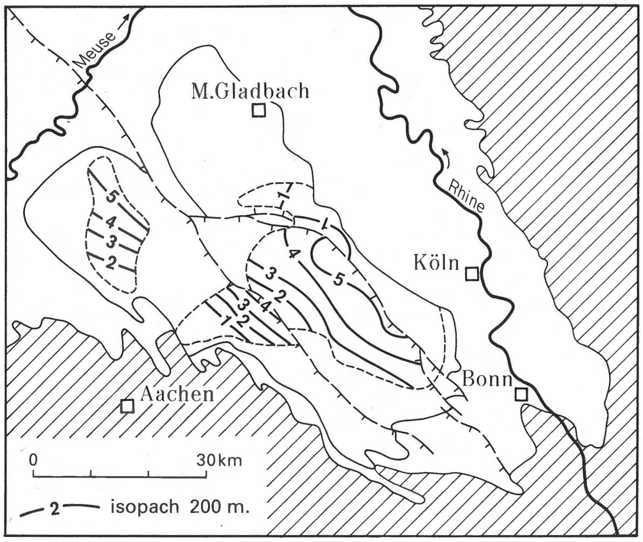

Fig. 5
Overburden within area of brown coal >25 m, modified after Hannak, 1974.

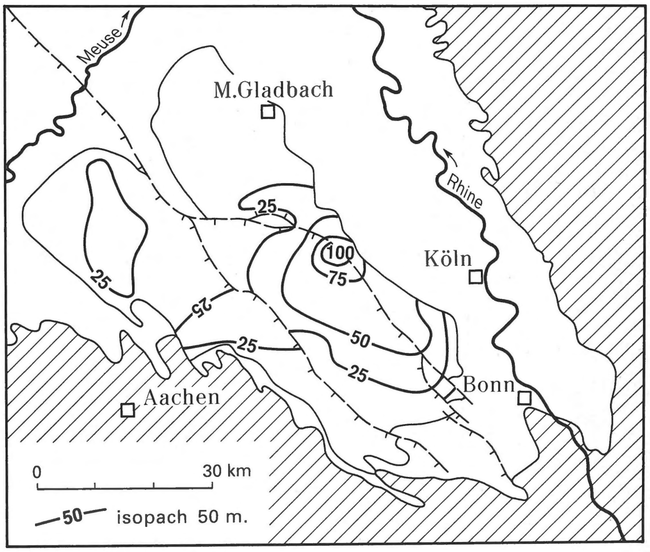

Fig. 6
Total thickness of brown coal, modified after Hannak, 1974.

and industries. For details concerning the planning of new opencasts and the quality of the brown coal, the interested reader may be referred to LEUSCHNER (1972) and KOTHEN & REICHENBACH (1974).

SOME GEOLOGICAL ASPECTS

Mining operations of this magnitude must be carefully calculated in advance. One calculation (out of many others that are needed) is the quantity of minable coal. In figure 6 the total thickness of the brown coal has been plotted.

From the beginning of modern brown coal mining in the Lower Rhine Embayment about 70 years ago, the discovery of brown coal beds up to 100 m thick was seen not only as a resource and a mining problem but also as a geological problem. An additional question was raised by the fact that the seam of 100 m thickness was free of any sandy or clayey intercalation.

The first attempts to solve this question were based on a few bore holes of doubtful reliability. Now data from more than 20,000 bore holes, about 10,000 geophysical well logs and the pollen analytical investigation of 60,000 samples are available. From these data one can infer some details about the cause of this unusual accumulation of peat.

Subsidence

Out of all the factors favouring peat accumulation, one may be considered as the most important: this is a rise of the groundwater level. Often, a rising groundwater level may be interpreted as being caused by local or regional subsidence.

In the Lower Rhine Embayment subsidence has played a major role since the Middle Oligocene. In fact a detailed record of subsidence can be found in the brown coal beds themselves.

During the period of the main peat accumulation in the Lower Rhine Embayment the general pattern of subsidence probably had a basin-like shape (Fig. 7). The maximum rate of subsidence apparently occurred close to the long axis of the embayment.

Figure 7, however, does not indicate the pattern of subsidence in the North-West nor does it show the amount of subsidence. These ommissions are the result of two difficulties:

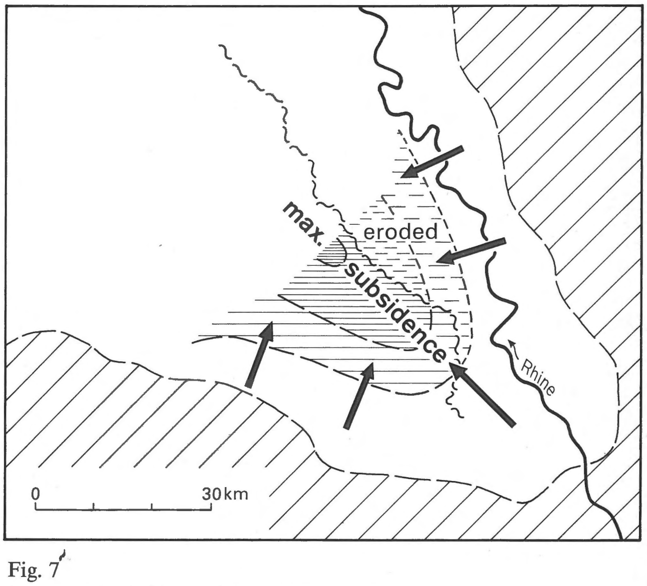

Fig. 7
Pattern of subsidence (main seam group).

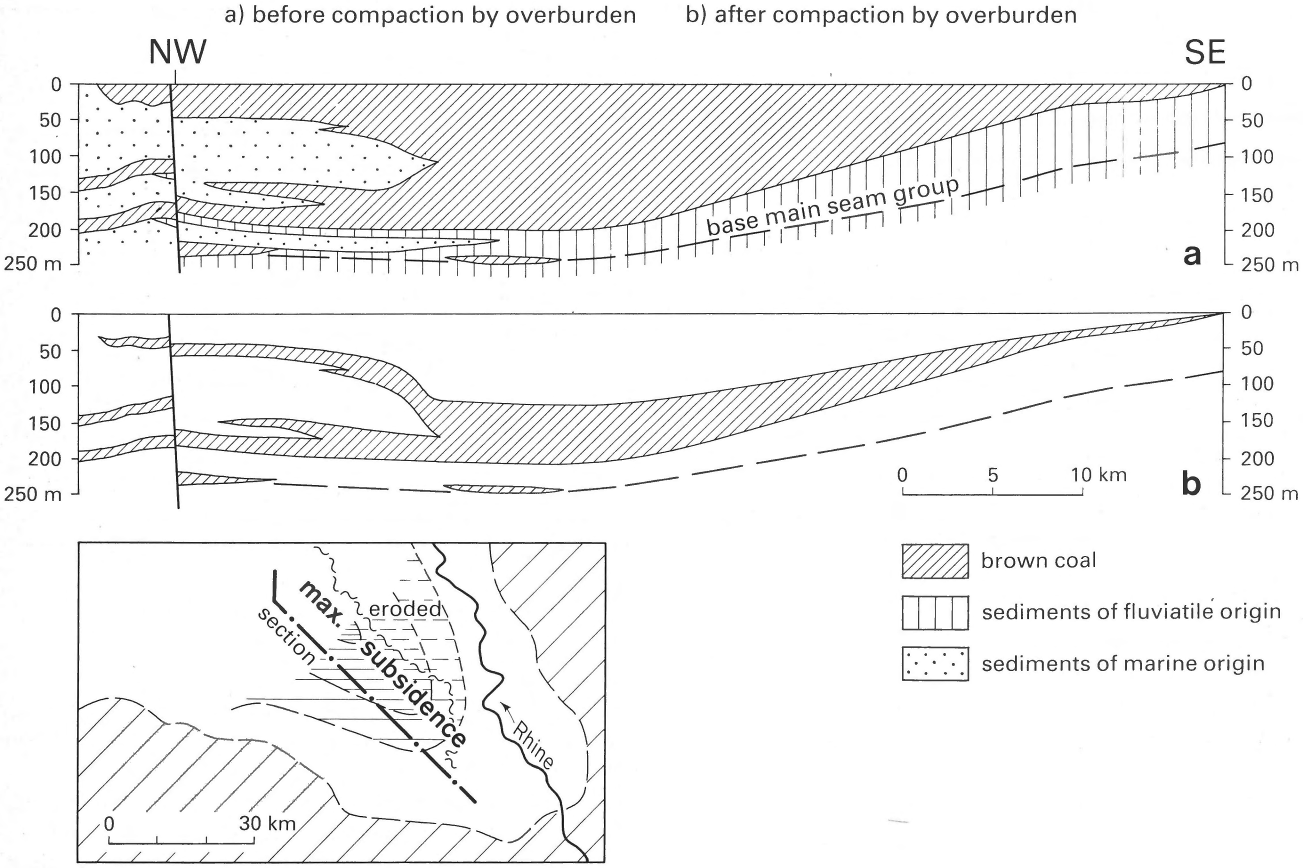

Fig. 8
NW – SE sections of the main seam group, modified after Gliese, 1977.

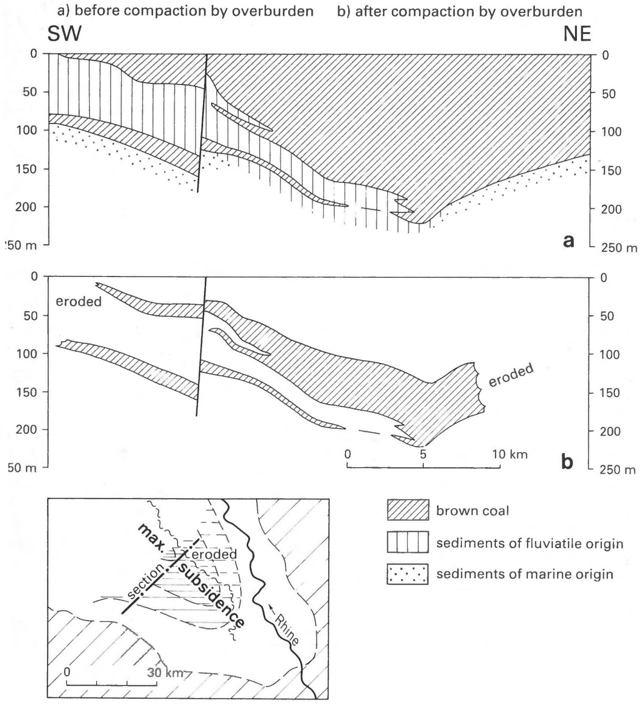

Fig. 9
SW – NE sections of the main seam group, modified after Gliese, 1977.

- The brown coal beds split in western and northern directions; in other words: here the thickness of the brown coal itself cannot serve directly as an indication of subsidence.
- During its geological history the peat was subjected to compaction, the thickness of the brown coal is not identical with the previous thickness of the peat and the previous rate of subsidence.

Peat compaction

Both phenomena –the splitting of seams and the compaction of peat– may be gathered from figures 8 and 9.

The section in Fig. 8 runs roughly parallel to the axis of the basin-like pattern of subsidence. The upper section reveals an increase of peat thickness from Southeast to Northwest up to the point where the seam splitting intervenes. The splitting was caused by marine sedimentation.

The lower section in figure 8 shows the present thickness of the seams. Peat was converted to brown coal in a diagenetic

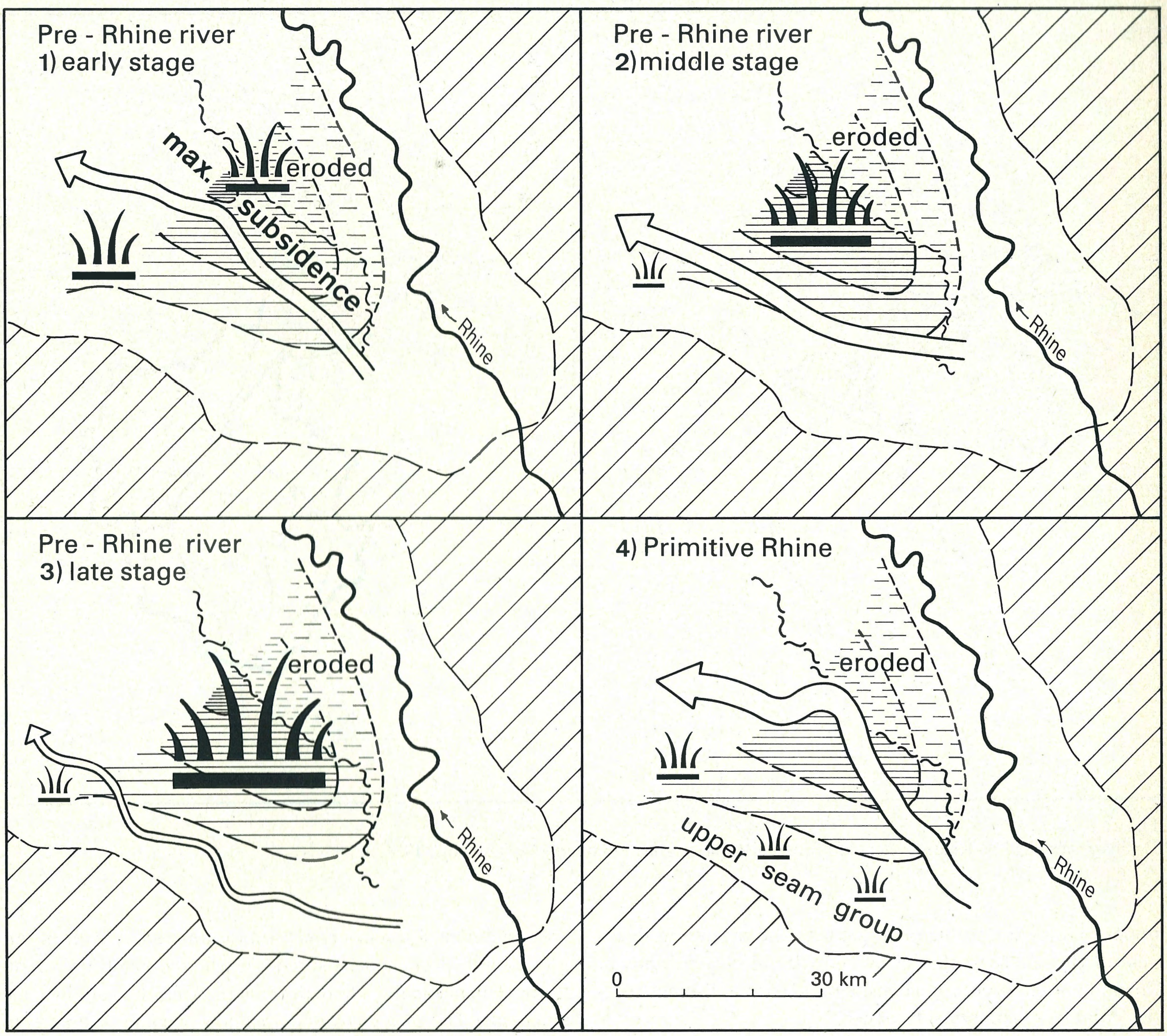

Fig. 10
Pre-Rhine river stages during deposition of the main seam group and Primitive Rhine (end of main peat accumulation).

process which is not yet completely understood.

It seems reasonable to assume that in the Lower Rhine Embayment the compaction ratio of Miocene peat to present-day brown coal may reach a value of 2.5:1. In other words, a 100 m brown coal bed was formed from a peat bed of about 250 m (a detailed study about peat compaction in the Lower Rhine Embayment is in preparation).

Fig. 9 gives a section in a direction perpendicular to Fig. 8. The upper part demonstrates the peat thickness at the same point of geological time as Fig. 8, that is to say when the main peat deposition had terminated, but no overburden had yet been placed on top of the peat.

In figure 9 seam-splitting mainly occurs by sediments of fluviatile origin. The lower section shows the present-day thickness of the brown coal seams.

From figures 8 and 9 it may be seen that seam splitting at least partially accounts for the remarkable difference between the total brown coal resources and the quantity which may be considered as minable.

Fluviatile sedimentation

If one compares the upper part of Fig. 9 with the pattern of subsidence, it may be noticed that the maximum thickness of the peat deposit apparently coincides with the maximum subsidence. The fluviatile sediments increase in thickness in the

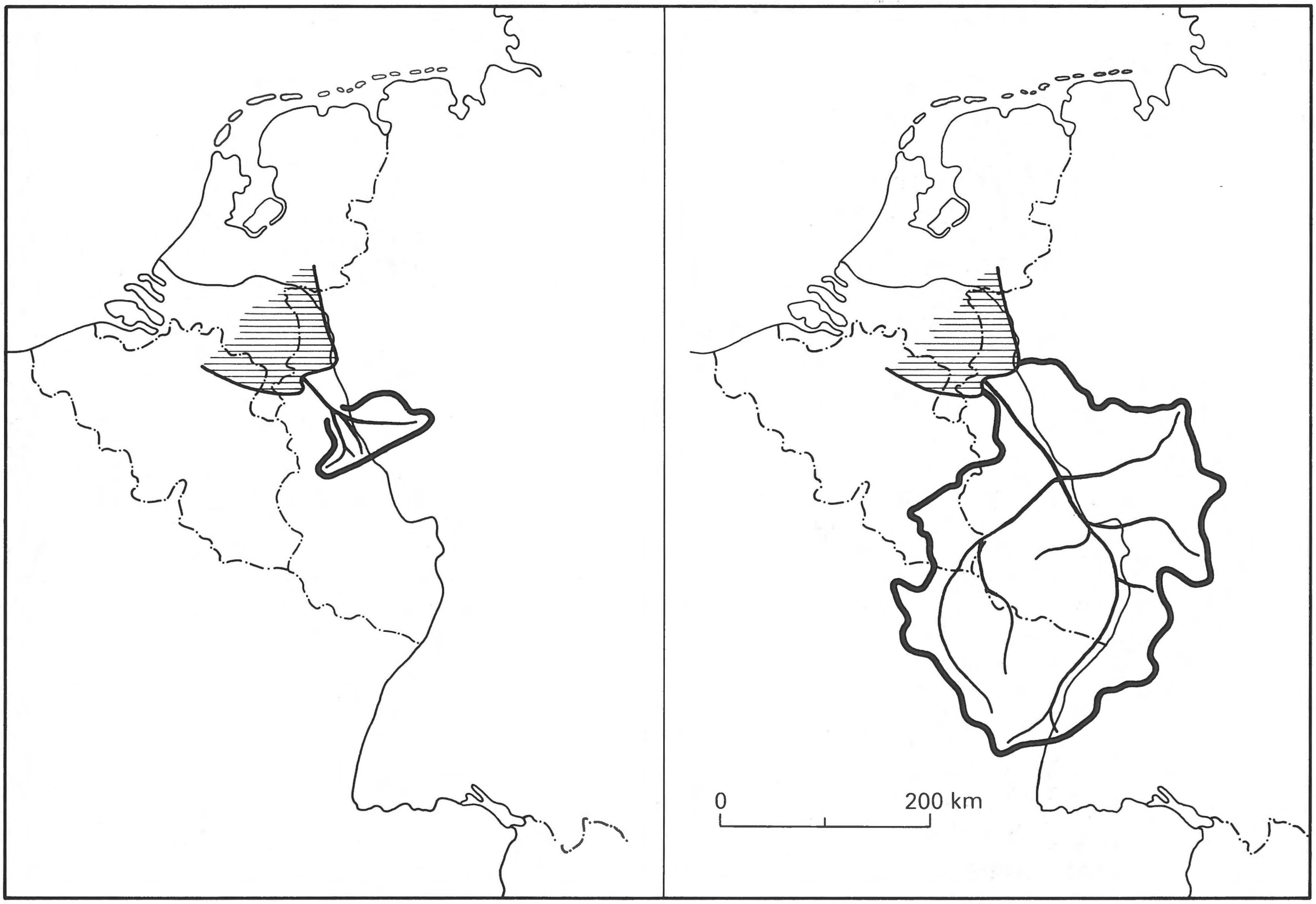

Fig. 11
Drainage area of Pre-Rhine (left) and Primitive Rhine (right), modified after Quitzow, 1974.

opposite direction to the peat deposit. The maximum thickness of the sandy to silty clays and silty to clayey sands of fluviatile origin occurs at a considerable lateral distance from the point of maximum subsidence.

The process of fluviatile sedimentation was obviously not governed by the rate of subsidence. The increase of the fluviatile sediments was caused by a continuous displacement of the drainage system –a minor river which can reasonably be named the Pre-Rhine System– in a southwestern direction. During the early stage of peat deposition this river flowed through the embayment on a course close to the area of maximum subsidence (Fig. 10). If one observes the peat deposition from its early stage to its middle and late stage one can see that the Pre-Rhine altered its course more and more towards the Southwest. The area of undisturbed and uninterrupted peat accumulation enlarged correspondingly.

During the early stage the river separated two peat bogs of about similar size. During the late stage the river surrounded the eastern peat bog which had considerably enlarged and covered most of the southern embayment.

The fourth part of Fig. 10 looks like a restitution of the early stage of peat deposition, but the contrary is true. In the central area peat deposition has now been terminated. A river of far greater transport capacity spreads clastic sediments on top of the peat, in particular where the peat thickness had attained its maximum. The former swamp area now becomes submerged and converted into a landscape dominated by rivers and lakes.

Subsidence and compaction of the thick peat cushion combined to make the surface subside much faster than before.

Peat was deposited again at places where the peat accumulation had been hampered by the previous fluviatile sedimentation, as had been the case in the western part of the embayment. Here the compaction of peat was negligible and the rising of the groundwater level was determined by the rate of subsidence only.

The conversion of the Lower Rhine Embayment from a peat accumulation area into a landscape dominated by clastic sedimentation has been interpreted as the consequence of the origin of the primitive Rhine, that is the river system cutting through the Slate Mountains from the Upper Rhine Graben to the Lower Rhine Embayment (QUITZOW, 1974).

The character of the Pre-Rhine System can be deduced from its drainage area. It was probably restricted to the northern slope of the Slate Mountains (Fig. 11). The primitive

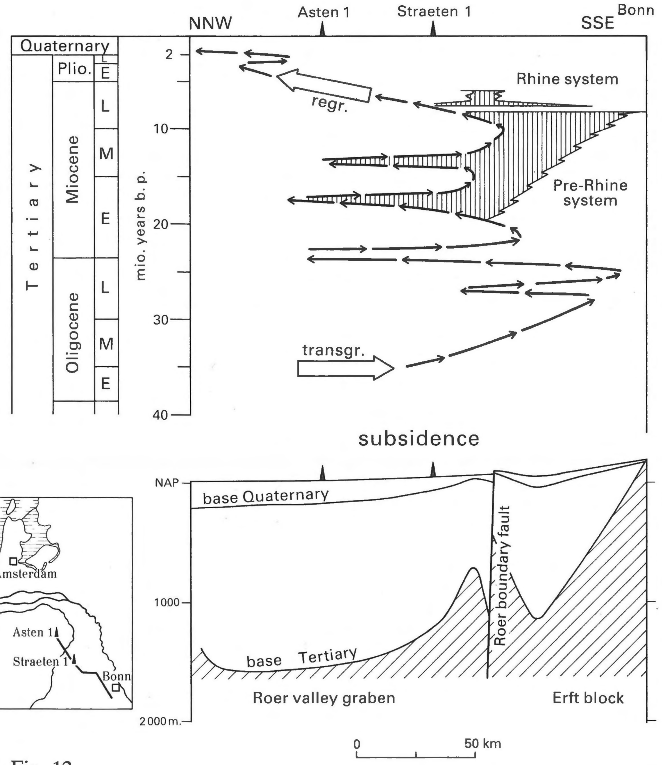

Fig. 12
Peat deposition, shifting of coast line and subsidence in relation to the absolute time scale.

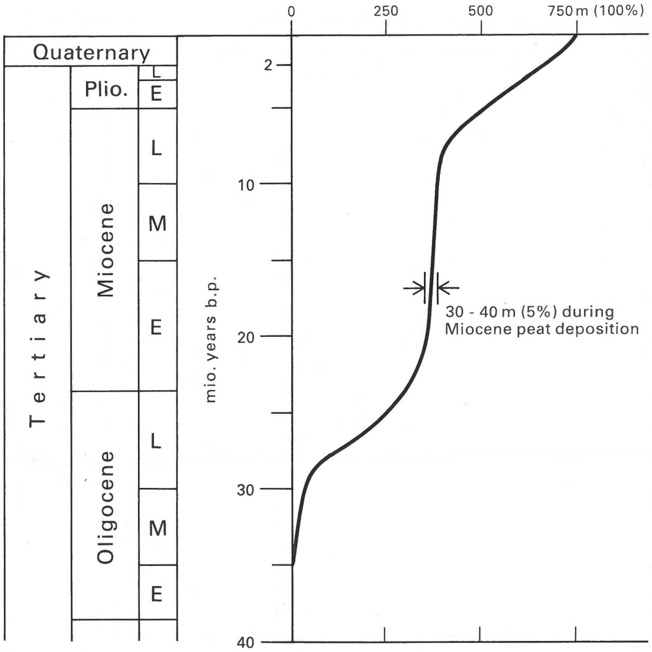

Fig. 13
Fault activity in relation to the absolute time scale.

Rhine already drained a large area south of the Slate Mountains (Fig. 11).

Marine sedimentation

Figure 12 is a condensed presentation of what is known or believed to be known about peat deposition and the simultaneous occurrence of fluviatile and marine sedimentation in the Lower Rhine Embayment. The upper section shows the latest interpretation of data related to the peat accumulation, the shifting of the coast line and the geological time scale in million years before present.

A long-standing agreement exists concerning the start of the main peat deposition in the Early Miocene (for a detailed discussion see GLIESE, 1971). A similar accord may perhaps be assumed if one says: the peat accumulation ended in the Late Miocene. A recent correlation of data from the wells Asten 1 (ZAGWIJN, 1967) and Straeten 1 (FABIAN, 1958) provides some hints that peat deposition continued for a considerable period during the Late Miocene. It does not seem unlikely that an interval of only 6 to 7 million years exists between the present time and the end of the peat deposition. It should be emphasized, however, that this interpretation has not so far been agreed upon by Dutch specialists concerned with the Asten well.

For an interval of approximately 25-28 million years the coast line of the North Sea shifted within the Lower Rhine Embayment. The lateral shift of the coast ranged up to 100 km. The sea constantly maintained a high groundwater level in the low land behind the coast. This of course improved the conditions for peat accumulation. Invasions of the sea apparently did not lead to heavy erosion of peat but to interruptions of peat deposition only. A receding of the sea was immediately followed by peat deposition.

The lower section (Fig. 12) is a simple plot of the thickness

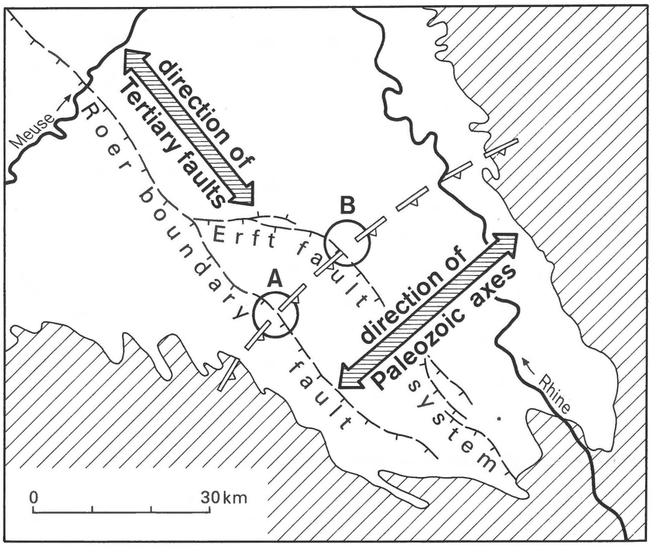

Fig. 14
Directions of Tertiary faults and Palaeozoic axes.

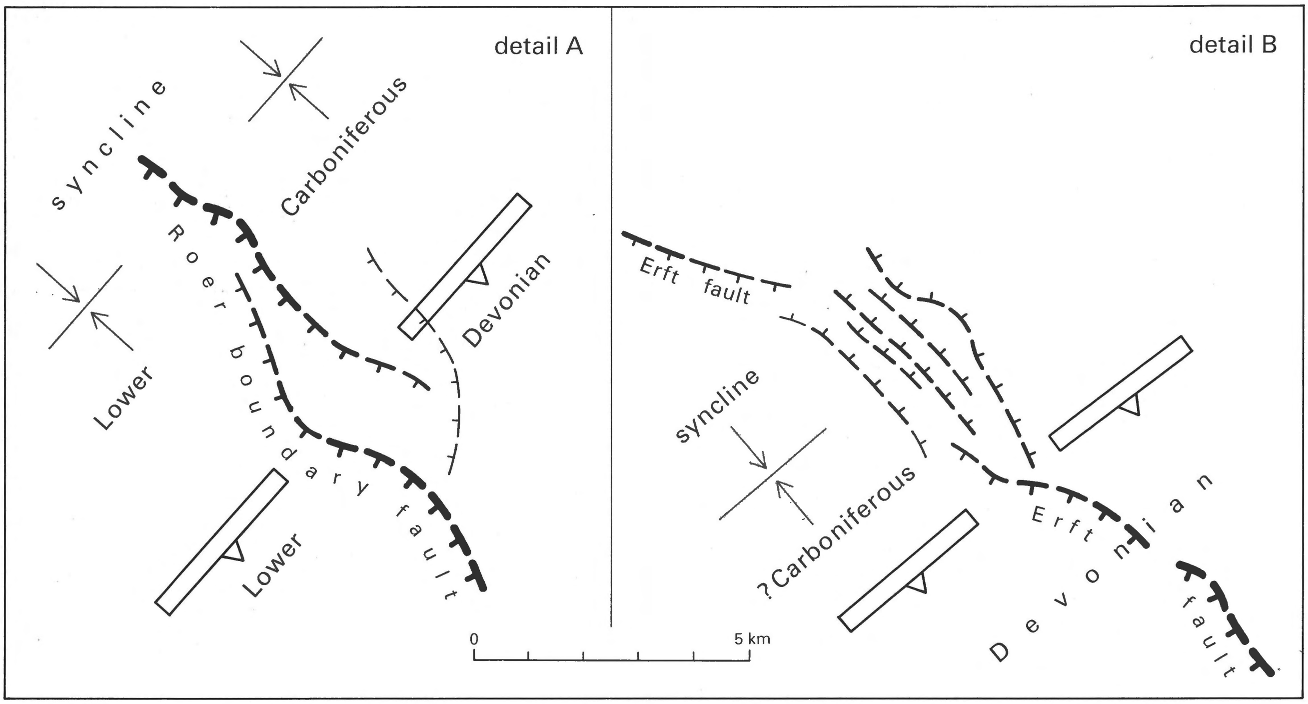

Fig. 15
Pattern of faults:
A: Roer boundary fault system between Niederzier and Oberzier (left).
B: Erft fault system between Bedburg and Bergheim (right).

of the Tertiary and the Quaternary. It may be seen that subsidence differed considerably. In figure 12 the lower and the upper section Asten 1 – Bonn were combined in order to demonstrate that the configuration of the permanently shifting coast line does not show any close relation to the pattern of subsidence. This impression could be confirmed by detailed observations in the brown coal area.

It therefore seems reasonable to assume that the shape and the shift of the coast line were determined by other influences which have not yet been investigated in detail.

From figure 12 it can be deduced that the origin of the primitive Rhine and the start of the final marine regression occurred almost simultaneously. Whether or not these events were interrelated, they terminated the period of wide-spread peat deposition (Hauptflözgruppe) in the Lower Rhine Embayment.

Timing of faults

In figure 13 the vertical displacement of the Roer or Peel boundary fault has been plotted against time. During the period of main peat deposition the activity of this fault was insignificant. This observation also holds true for most of the other major faults within the brown coal area.

From Fig. 13 it appears that fault activity was considerable before and particularly after peat accumulation (see also AHORNER, 1968). Activity of the faults and block tilting induced the present-day differences in overburden thickness of up to 500 m. An uplift of blocks led to large-scale erosion of brown coal in the East.

Fault pattern

The fault pattern in the Lower Rhine Embayment has given rise to various interpretations (for example: CLOOS, 1939; KNETSCH, 1954; TEICHMÜLLER, 1974; and HOYER, 1978).

The mapping of faults in the opencasts and their vicinity has provided new details. A fault which is apparently homogeneous in a scale of 1:500,000, may prove to be a variety of faults in a more detailed scale. Here it must suffice to mention two examples.

Below the unconsolidated Tertiary cover an overthrust of Variscan origin may be supposed to cross the embayment from Southwest to Northeast. The Tertiary fault lines are interrupted where they meet the overthrust below (Fig. 14, details A and B).

In figure 15, detail A, the Variscan overthrust has placed Lower Devonian on top of Lower Carboniferous. The interruption of the Roer boundary fault may apparently be understood to be a kind of a code-sign for the overthurst below.

In figure 15, detail B, the interruption of the Erft fault is more pronounced. The interruption appears as a gap, within which the Erft fault has been replaced by parallel antithetic faults and block tilting.

In our opinion, the interruption of the Erft fault may be interpreted as a code element of the overthrust already mentioned and a Carboniferous syncline within the immediate vicinity of the overthrust. If this interpretation is correct, it would confirm a perennial effectiveness of Variscan structures in the base of the Tertiary up to the present time.

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