

RECENT EXPLORATION IN PRE-PERMIAN ROCKS AROUND THE BRABANT MASSIF IN BELGIUM, THE NETHERLANDS AND THE FEDERAL REPUBLIC OF GERMANY¹

M. J. M. BLESS², J. BOUCKAERT³ & E. PAPROTH⁴

ABSTRACT

Bless, M. J. M., J. Bouckaert & E. Paproth 1983 Recent exploration in Pre-Permian rocks around the Brabant Massif in Belgium, The Netherlands and the Federal Republic of Germany. In: J. P. H. Kaasschieter & T. J. A. Reijers (eds.): Petroleum geology of the southeastern North Sea and the adjacent onshore areas (The Hague, 1982) – Geol. Mijnbouw 62: 051-062.

The palaeogeographic evolution of NW Europe during the Pre-Permian has been controlled by three important orogenic periods since the Late Precambrian. Since the end of Cadomian times, a block-faulted platform seems to exist to the southwest of the Fenno-Scandian Shield: the Belgo-Dutch Platform. One of the main structural elements in this platform is the London-Brabant Massif that was uplifted by the Late Caledonian movements. The Brabant Massif and its surrounding areas form the best-known part of the Belgo-Dutch Platform.

Recent geological work in this area has focussed, e.g. on the extension of the allochthonous thrust-sheets south of the Brabant Massif (Dinant Nappes), the rapid lateral facies and thickness changes in the Devon-Dinantian carbonate deposits (e.g., in the St.-Ghislain and Visé-Puth areas, respectively south and east of the Brabant Massif), and the Upper Carboniferous (Silesian) coal deposits to the north and northeast. The present review is meant as a preliminary synthesis of the state of these exploration projects.

INTRODUCTION

The palaeogeographic evolution of NW Europe during the Pre-Permian has been controlled by three important orogenic periods since the late Precambrian (Fig. 1). These orogenic movements resulted in mountain belt development in the areas involved, which subsequently served as the principal sources of clastic sediments. Their influence on the main sedimentation pattern in Belgium, The Netherlands and NW Germany during the Cambro-Silurian and Devon-Carboniferous is discussed briefly.

Early Cambrian (Late Devillian) deposits in the Brabant Massif and Ardennes suggest a main clastic supply from the north, where a Cadomian mountain belt might have existed. During the Cambrian, the influence of this northern source area diminished rapidly, whereas the originally subordinate

supply of clastic material from the south became more and more important, especially during the Ordovician and Silurian. Uplift and erosion of the southern (Rocroi) and eastern (Stavelot-Venn) Ardennes in late Ordovician and Silurian

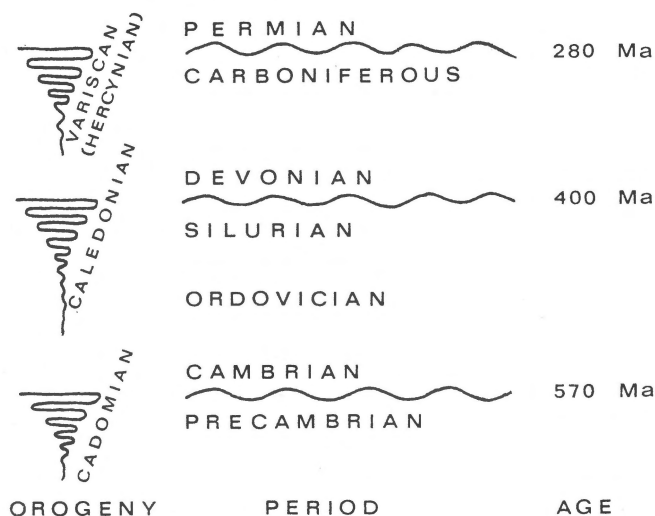


Fig. 1 Palaeozoic time-scale and main orogenic periods in Europe.

¹ Manuscript received: 1983-01-13

² Natuurhistorisch Museum Maastricht, Bosquetplein 6-7, 6211 KJ Maastricht, The Netherlands

³ Geological Survey of Belgium, Jennerstraat 13, 1040 Brussels, Belgium.

⁴ Geologisches Landesamt Nordrhein-Westfalen, De Greiffstrasse 195, 415 Krefeld, Federal Republic of Germany.

times can be deduced from, amongst others, the frequent occurrence of reworked Ordovician acritarchs in the Silurian deposits of the Condros area. Presumably, these acritarchs were derived from the Rocroi and Stavelot-Venn regions, where Silurian strata are absent by erosion. Such reworked Ordovician acritarchs have not (yet) been reported from strata of the same age in the Brabant Massif.

Practically everywhere in NW Europe important gaps in the sediment record occur around the Silurian-Devonian boundary. Only some basins further to the south and east (e.g., Normandy and Brittany in western France; Czechoslovakia and Poland) were not affected by the Caledonian movements and there, deposition was more or less continuous from Silurian into Devonian.

The Caledonian orogeny remodelled completely the structural-depositional framework of NW Europe (Fig. 2.). Three main depositional areas can be distinguished for the Devonian-Carboniferous:

- The Caledonian fold belt running from Norway into Great Britain (with Devonian Old Red Sandstone deposits as well as Caledonian trends of basins and highs, lateron followed by Carboniferous sedimentation),
- The Cornwall-Rhenish basins (with epicontinental shale-dominated deposits in the Devonian, and a 'foredeep' setting in the Carboniferous),
- The Belgo-Dutch Platform (that could be considered as a micro-craton, originally belonging to the Fenno-Scandian Shield and East-European Platform).

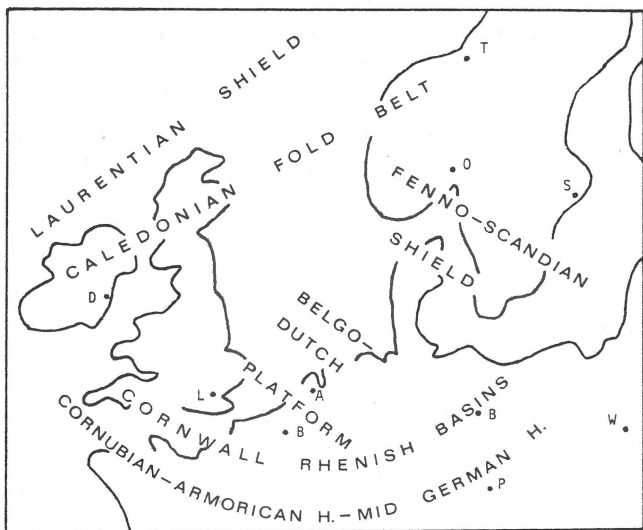


Fig. 2
Main tectonic framework of NW Europe for the Devonian-Carboniferous period. By the end of Carboniferous time, the Cornubian-Armorican-Mid German Highs as well as large parts of the Cornwall-Rhenish basins had been incorporated in the Variscan Mountain Belt.

These depositional settings were bordered to the north by the Laurentian and Fenno-Scandian Shields, and to the south by the Cornubian-Armorican and Mid German Highs. The latter two (as well as large parts of the Cornwall-Rhenish basins) became incorporated in the mobile Variscan belt, starting from the late Devonian.

The main (SW-NE trending) Caledonian fold belt runs from Ireland through northern England and Scotland to Norway. Several narrow secondary branches are known. One follows the southern border of the Fenno-Scandian Shield and East European Platform. A second one is located in the possibly allochthonous Ardennes (Stavelot-Venn, Serpont, Rocroi and Givonne) and a third one is found in the Condros zone. Presumably, these secondary branches follow generally WNW-ESE trending weakness zones in between more stable Pre-Cambrian blocks. The Caledonian deformation in the Belgo-Dutch Platform may have been limited to block-faulting and perhaps locally very low-grade metamorphism.

During the Devonian period, vast amounts of siliciclastic Old Red Sandstone sediments were derived from the Caledonian fold belt. These accumulated in rapidly subsiding, non-marine, fault-bounded basins with igneous activity along fault-lines (Ireland, Great Britain, Orcadian basin NE of Scotland in the North Sea, Norway). Frequent unconformities in these more than several thousand meters thick successions record phases of repeated tectonic activity.

Since the early Carboniferous, the relief of the Caledonian fold belt was degraded to a large extent. Marine incursions reached far to the north into Ireland, Scotland and the Central North Sea. From those times onward, the sedimentation patterns on the Caledonian fold belt became comparable to those of the Belgo-Dutch Platform because of the similar relief conditions in both areas. Furthermore, the SW-NE trend of these basins revealed the Caledonian origin.

The Cornwall-Rhenish basins formed a complex chain of several, as yet ill-defined, quickly subsiding epicontinental to open marine basins in between the Belgo-Dutch Platform to the north and the Cornubian-Armorican and Mid German Highs to the south. Rapid subsidence was marked by extremely thick siliciclastic deposits. Igneous activity occurred along several faultlines, e.g. in SW England and in the Rhenish Massif. Local shoals with a cover of shelf carbonates occurred since the Middle Devonian. The clastic sediments in these basins came from the north (Caledonian fold belt, Belgo-Dutch Platform) and from the south (Cornubian-Armorican and Mid German Highs). Palynological evidence illustrates that the Early Devonian deposits in the possibly allochthonous Ardennes were derived from various sources (e.g., Brabant Massif, Stavelot-Venn and Rocroi). A continuous northward shift of the main basin axes and gradual incorporation of the southern borders of these basins into the Variscan belt, was presumably followed by eventual uplift and rapid denudation since the late Famennian.

The Belgo-Dutch Platform, extending from northern France into NW Germany, is interpreted as a micro-craton. It

was probably already consolidated in Pre-Cambrian (Cadmian?) times. At the latest during the Caledonian movements, the area was broken up into a complex mosaic of tilted blocks with strong, partly en-echelon, WNW-ESE trending faults or faults-zones, which are crossed by generally weak, possibly undulating NE-SW directed lineations (Figs. 3 and 4). The Belgo-Dutch Platform is marked by a relatively low-grade Caledonian metamorphism (possibly of late Ordovician age as most isotopic age determinations indicate a main metamorphic event some 440-450 Ma ago; FROST ET AL., 1981). Caledonian metamorphism and igneous (intrusive) activity may have been restricted to some of the WNW-ESE directed weakness zones. Variscan deformation was largely limited to repeated rejuvenation of upwarp and subsidence along existing fault-zones. Only along the southern borders of the Belgo-Dutch Platform, which are now partly incorporated in e.g. the Dinant Nappe, Variscan folding and thrusting occurred.

Repeated rejuvenation of these fault zones did not only take place during the Devonian-Carboniferous, but also later. This is evident from the remarkable parallelism between, e.g. the Carboniferous and Jurassic-Early Cretaceous sedimentation patterns in the area north of the Brabant Massif (BLESS ET AL., 1980). It may be of interest to observe that also SW-NE directed Caledonide faults in the main Caledonian fold belt

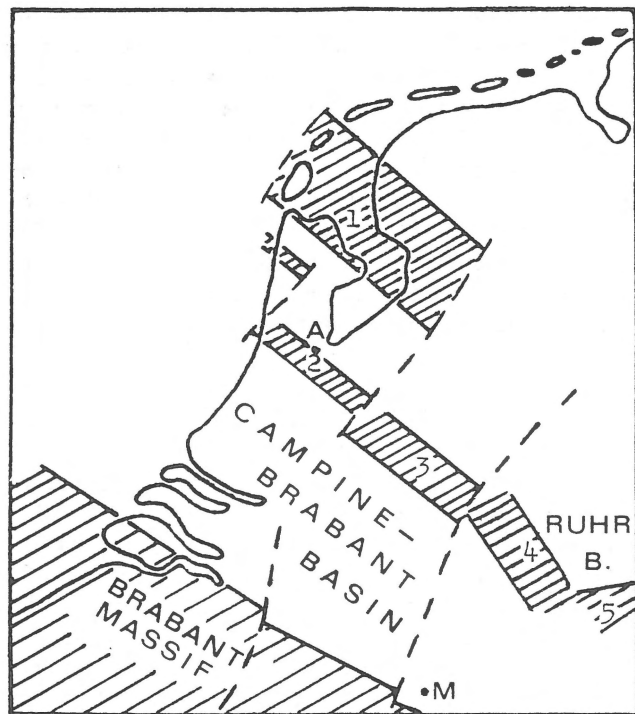


Fig. 3
Tentative diagrammatic reconstruction of the main Devonian-Carboniferous structural elements in The Netherlands and neighbouring parts of Belgium and the Federal Republic of Germany. Highs are hatched, lows are shown in white. 1 = Texel-IJsselmeer High, 2 = Zandvoort High, 3 = Maasbommel High, 4 = Krefeld High, 5 = Rhenish Massif.

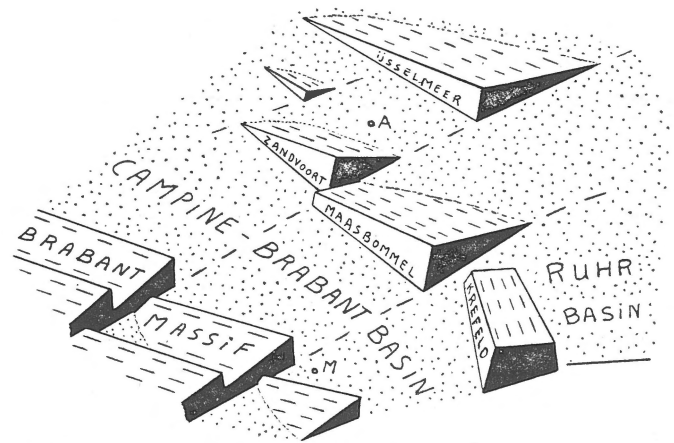


Fig. 4
Conceptual model of the main structural elements during the Devonian-Carboniferous, showing asymmetrically tilted blocks and basinal areas (stippled).

between Scotland and Norway were rejuvenated in late Jurassic/early Cretaceous times (JOHNSON & DINGWALL, 1981).

Indications for a mild, late Caledonian (late Silurian) metamorphism in the Belgo-Dutch Platform are virtually absent, except for a weakness zone between the platform and the southern border of the Fenno-Scandian Shield (boreholes Flensburg and Westerland in northernmost part of Federal Republic of Germany; FROST ET AL., 1981). However, the frequent occurrence of relatively well-preserved acritarchs (reworked from late Silurian strata from the north) into the Lower Devonian (Gedinnian, Siegenian and Emsian) of Belgium (VANGUESTAINE, 1979; STEEMANS, 1981) suggests that at least part of the Silurian graptolite shales of the Belgo-Dutch Platform were practically not affected by Caledonian metamorphism.

The sedimentary history of the Belgo-Dutch Platform during Devonian-Carboniferous times has been summarized in figure 5. This strongly idealized scheme is not representative for the complete range of depositional environments on the platform. Graben areas frequently contain more siliciclastic sediments, whereas the sequence on the highs may be rather incomplete.

During the Early Devonian, the Belgo-Dutch Platform separated the non-marine (Old Red Sandstone) facies in the British-Norwegian Caledonian fold belt from the epicontinental (perimarine to marine) setting in the Cornwall-Rhenish basins. An infill of Early Devonian Old Red Sandstone sediments is likely for some of the grabens on this platform. Otherwise, erosion of Cambro-Silurian deposits from at least the higher parts of the platform provided the bulk of the Lower Devonian in the Cornwall-Rhenish basins, particularly in the Ardennes and Rhenish Massif.

During the transgressions of the Eifelian-Frasnian period, the Belgo-Dutch Platform was characterized by the occurrence of widespread carbonate deposition on shoals, whereas some of the WNW-ESE directed grabens may have been filled with siliciclastics derived from local highs or from the Caledo-

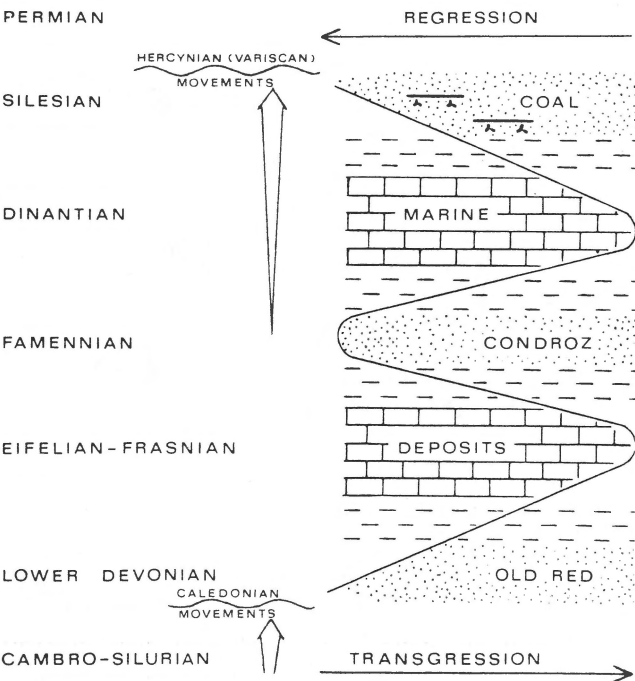


Fig. 5
Simplified sedimentary history of the Belgo-Dutch Platform during the Devonian-Carboniferous.

nian fold belt to the north. These incursions reached into the Central North Sea area, where Middle Devonian marine limestones were found in the Argyll borehole (DEEGAN & SCULL, 1977). Another series of transgressions started at the end of the Devonian ('Strunian' or 'Etroeungt') and reached their acme during the late Dinantian. These transgressions cover the Belgo-Dutch Platform as well as an important part of the then largely eroded Caledonian fold belt, where carbonates were deposited on shoals. Paralic to non-marine environments, locally with swamp vegetations, prevailed in northern Great Britain and in the central to northern North Sea region. Dark marine limestones and clayey sediments accumulated in the more basinal areas. The mainly siliciclastic Late Carboniferous succession shows a progressive diminishing of marine influence. The principal source area for the siliciclastics on the Belgo-Dutch Platform is seen in the Variscan belt to the south. This belt gradually extended northwards and eventually incorporated large parts of the former Cornwall-Rhenish basins. Sedimentation was essentially rhythmic. Typical Namurian rhythms consist of a thin marine shale at the base, passing through siltstone into non-marine sandstone. Westphalian rhythms or cyclothems show an ideal upward succession of seat earth-coal-(marine) shale-siltstone-sandstone. Some of the marine shales in these Namurian and Westphalian rhythms have been recognised throughout NW Europe. Marine bands and coals are practically absent in the youngest Carboniferous (latest Westphalian and Stephanian) deposits, which are frequently red-coloured on the Belgo-Dutch Platform.

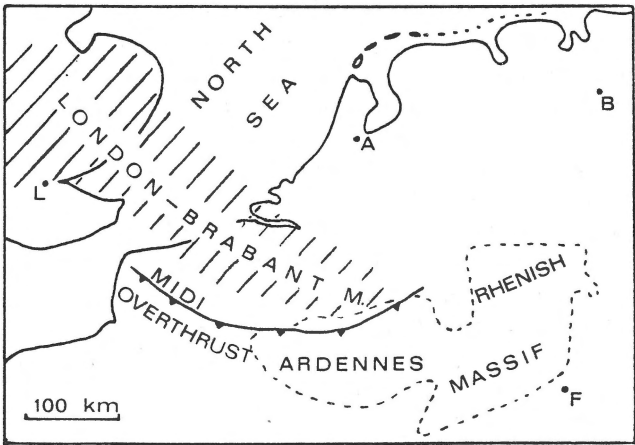


Fig. 6
Location of the London-Brabant Massif in relation to the Midi Overthrust and the outcropping Pre-Permian deposits of the Ardennes and Rhenish Massif.

One of the best known portions of the Belgo-Dutch Platform is the Brabant Massif and its surrounding areas (Fig. 6), where Palaeozoic rocks are known from outcrops (Ardennes, Rhenish Massif) or from relatively shallow depths in north-western France, Belgium, the southern Netherlands and NW Germany. The geological history of this area is representative for the Belgo-Dutch Platform as a whole.

Recent exploration efforts have focussed on, e.g., the extension of the allochthonous thrust-sheets south of the Brabant Massif (Dinant Nappes), the rapid lateral facies and thickness changes in the Devonian-Dinantian carbonate deposits (e.g. in the Visé-Puth area east of the Brabant Massif), and the Upper Carboniferous (Silesian) coal deposits to the north and northeast of the Brabant Massif. None of these projects is finished as yet. Therefore, this report is merely an interim inventory of the data obtained.

DINANT NAPPES

The northern front of the Variscan or Hercynian deformation in Belgium and adjacent parts of northern France and the Federal Republic of Germany is formed by a major thrust-fault complex, called 'Faille du Midi' or 'Grande Faille' in northern France and southwestern Belgium, 'Chariage du Condroz' in central Belgium, and 'Faille eifelienne' or 'Aachener Ueberschiebung' in the east (Fig. 7). For the sake of simplicity, this thrust-fault complex is called henceforth the Midi Overthrust.

The Midi Overthrust and frontal imbrications separate the allochthonous deposits which are outcropping in the Dinant Synclinorium to the south from the (partly underlying) autochthonous rocks which are outcropping in the Namur Synclinorium to the north. These underlying autochthonous rocks may be much younger (e.g., Late Carboniferous) than

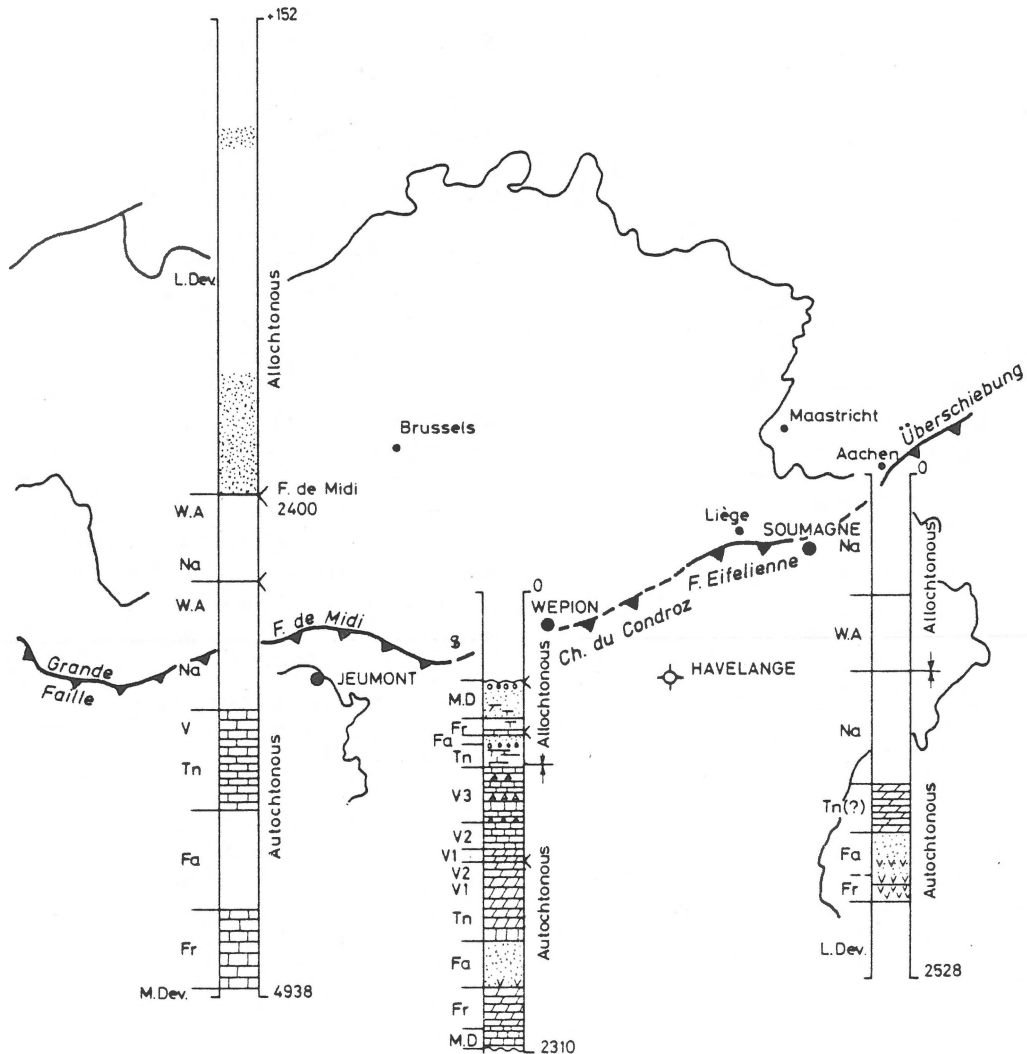


Fig. 7
Location of the Midi Overthrust in northern France, Belgium and the Aachen area of the Federal Republic of Germany.

the immediately overlying allochthonous deposits (e.g., Early Devonian) as observed in coal-mines and boreholes.

As far back as 1913, FOURMARIER suggested that the autochthonous coal-bearing Upper Carboniferous of the Namur Synclinorium might extend southwards below the Dinant Synclinorium into at least the Dinant region (Fig. 8). This would mean that in fact the Dinant Synclinorium might be a large-scale tectonic nappe structure. This idea seems to have been abandoned or neglected by later authors, but since 1963 this working hypothesis has been revived because of the results of several seismic surveys and boreholes.

Tectonic nappes occur in many places of the external zones of the Variscan belt in Europe, although their size is less spectacular than that of the Alpine thrust-sheets. One of the first attempts to investigate the southward extension of the Midi Overthrust was made by the Belgian Geological Survey in 1953 at Wépion, south of the city of Namur (GRAULICH, 1961). In 1963, a seismic survey by a consortium of oil

companies demonstrated the continuation of the Dinantian and Eifelian-Frasnian carbonates below the Midi Overthrust over a distance of some 40 km to the south in northern France. This distance is a minimum, since it was controlled by the length of the seismic lines. Subsequently, the seismic interpretation was confirmed by the Jeumont borehole (CLEMENT, 1963), where not only coal-bearing Late Carboniferous and Dinantian but also Eifelian-Frasnian carbonates occur below the overlying Lower Devonian (Fig. 9). Later on, a seismic reflector, presumably representing the Midi Overthrust, was detected in the Condroz-Famenne region of southern Belgium by several seismic surveys (Shell in 1965, Belgian Geological Survey in 1976-1978) (BLESS ET AL., 1977b). Recently, a similar reflector below the Cambro-Ordovician rocks of the Stavelot-Venn Massif, southeast of Aachen in the Federal Republic of Germany, was recognized by MEISSNER ET AL., (1981).

These investigations suggest a minimum areal extension of

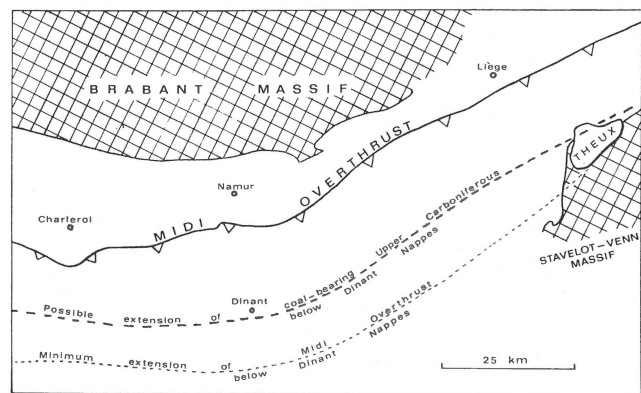


Fig. 8 Possible extension of autochthonous coal-bearing Upper Carboniferous strata and suggested minimum extension of Midi Overthrust according to Fourmarier (1913).

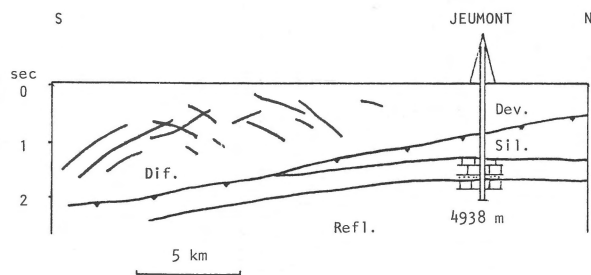


Fig. 9 Seismic profile 415 through Jeumont borehole (northern France; for location see figure 7), showing diffractions above the Midi Overthrust (MO) and strong reflectors representing the top of the Dinantian and the top of the Frasnian carbonates below the thrust plane (after Clement, 1963).

the Midi Overthrust of 175 x 40 km (Fig. 10), but it is believed that this overthrust extended southwards far beyond the area studied thus far.

One fascinating problem is that of the nature and age of the rocks immediately below the Midi Overthrust. Those immediately above the thrust plane consist of thrust-faulted and folded Lower Devonian to Cambrian. Those below the thrust plane seem to be approximately flat-lying but affected by block-faulting and large updoming structures of unknown origin. These latter features may have deformed the Midi Overthrust and the overlying Dinant Nappes as has been observed in the Famenne region. The age of the youngest deposits below the thrust plane is dependant of the displacement along the same.

FOURMARIER (1913) already speculated on the possibility that Upper Carboniferous below the Midi Overthrust might occur south of Dinant, i.e. at a distance of some 20-25 km south of the outcrop of this thrust. However, it could equally be that large parts of the Dinant Nappes rest directly upon Cambro-Silurian or even Precambrian basement. This problem may (partly) be resolved by deep boreholes. In 1980, the Belgian Geological Survey had started a deep boring in the Famenne region at Porcheresse-Havelange (Fig. 11), where the presumed Midi Overthrust has been traced by a seismic survey at a depth of about 1.6 seconds (about 4650 m). At the end of June, 1982, this borehole reached a depth of 3150 m, where Lower Devonian reddish sandstones and shales occurred. Probably even more challenging is the proposal by WALTER (1982) for a deep test hole penetrating the Cambro-Ordovician of the Stavelot-Venn Massif, southeast of Aachen, in the Federal Republic of Germany, where a seismic survey detected a flat-lying reflector – presumably representing the

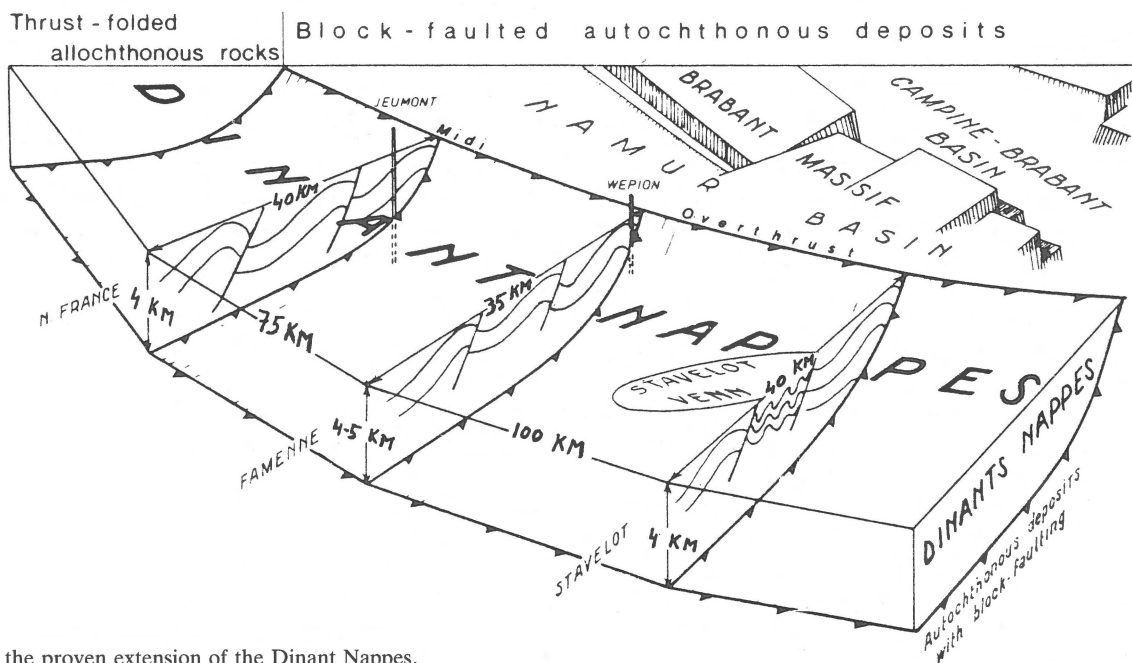


Fig. 10 Cartoon showing the proven extension of the Dinant Nappes.

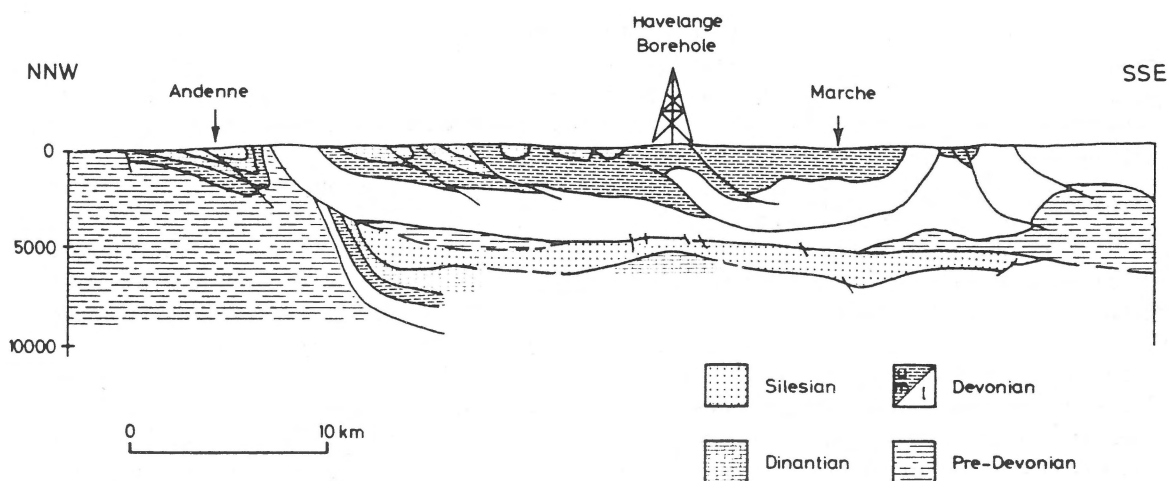


Fig. 11

Generalised structural profile through the Havelange borehole showing thrust-folded allochthonous rocks in the Dinant Nappes and frontal imbrications, as well as presumed existence of (coal-bearing?) Silesian deposits in the autochthonous sequence below the Midi Overthrust. For location of Havelange borehole see figure 7 (section slightly modified after Graulich, 1980).

Midi Overthrust – at a depth of 1.2 seconds (about 3-4 km). Several working models were suggested which present alternative solutions for the possible age of the rocks below this seismic discontinuity surface.

Whatever the outcome of the above investigations, there is little doubt that the Dinant Nappes show all the characteristics of typical thin-skinned fold-and-thrust belts. Nearly always, such nappe structures are broken up into several smaller, but interrelated sheets (see, also BLESS ET AL., 1977a). Therefore, the term Dinant Nappes is preferred over the term Dinant Nappe.

In thin-skinned, fold-and-thrust belts a wedge-shaped form of the deposits before the deformation is common and is more or less preserved in the eventual fold-and-thrust belt (CHAPPLE, 1978). The thickest part of the wedge is found at the back end from where the thrust originated, whereas the frontal portions are much thinner. These differences in thickness of the original sedimentary wedge are enhanced by structural shortening during the folding and thrusting process. This strong shortening of the wedge explains how the front may only have been moved over a few (tens) of kilometers, whereas at the same time the rear end has travelled some 100-200 km.

VISÉ-PUTH STRUCTURE

Multi-disciplinary, international co-operation since 1976 resulted in several working models serving as a basis for the hydrocarbon plays in the Pre-Permian rocks on the Belgo-Dutch Platform. One model postulates the existence of a small basin, east of the Brabant Massif, in the Visé-Puth area (Fig. 12) with a relatively thick Devon-Dinantian sequence with possibly intercalated evaporites. This hypothesis has been tested by a gravity and magnetic survey in 1979 and two years later by two shallow boreholes (Heugem-1/1a and Kastanjelaan-2) near Maastricht.

The Pre-Permian surface in the Maastricht area has long been enigmatic. The only relevant borehole in that area (Kastanjelaan-1) had been drilled in 1929. It penetrated Pre-Permian rocks at 203 m depth. However, their age was disputed by many geologists, who claimed Cambro-Silurian (e.g., PATIJN, 1963), Dinantian (e.g., TESCH, 1924) or Late Carboniferous (e.g., LEGRAND, 1968). Finally, foraminifera in the silicified limestone sequence between 203 and 330 m proved a late Dinantian (Visean) age (BLESS ET AL., 1976).

Another uncertainty was the eastern extension of the Brabant Massif. Whatever the suggested age of the Pre-Permian surface below Maastricht, all the available information seemed to indicate the presence of a gradual eastward plunging nose of Cambro-Silurian rocks with Devon-Carboniferous deposits along its northern and southern flanks in which coal had been mined in South Limburg and the Liège

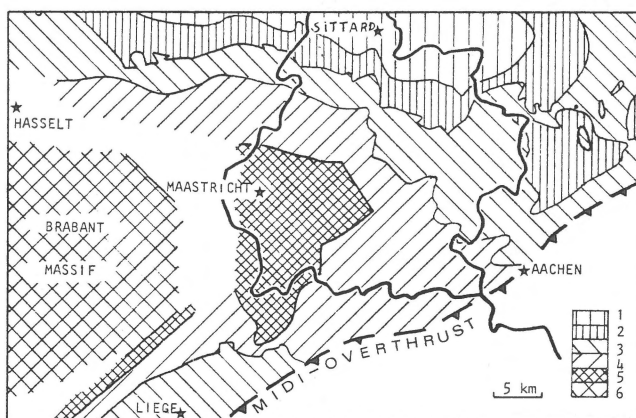


Fig. 12
Pre-Permian surface around Maastricht with uplifted Dinantian (= Visé-Puth Structure). 1 = Westphalian C-D; 2 = Westphalian B; 3 = Westphalian A; 4 = Namurian; 5 = Devono-Dinantian; 6 = Cambro-Silurian.

coalfields, respectively. However, the position of this supposed spur in the subsurface coincides with a negative Bouguer gravity anomaly which might contradict its existence. This fact was even more surprising since a 353 m borehole (Hermalle-sous-Argenteau), some 15 km south of Maastricht, had discovered Cambro-Silurian rocks at only 338 m depth at the position of a gravity high (KIMPE ET AL., 1978).

This contradictory evidence was studied in 1979 by a magnetic and gravity study of the area by the joint geological surveys of Belgium, The Netherlands and the Federal Republic of Germany in 1979 (BLESS ET AL., 1980), which confirmed the presence of the gravity low near Maastricht (Fig. 13). It was concluded that the Devono-Dinantian deposits below Maastricht might be much thicker than those known in the Hermalle-sous-Argenteau borehole (Fig. 14). Moreover, it was suggested that evaporites might be intercalated in such a

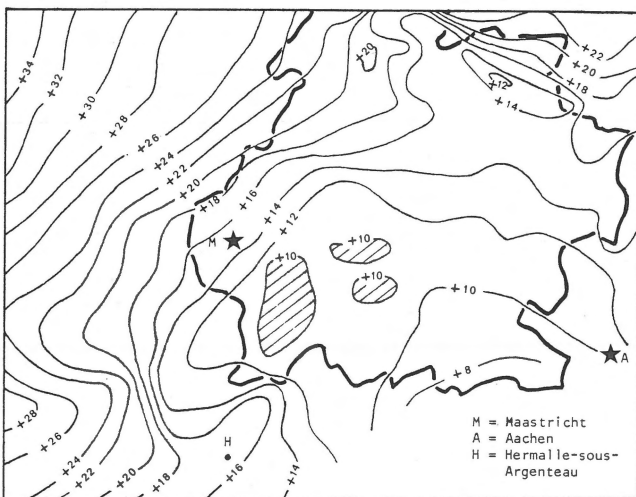


Fig. 13
Residual gravity map of South Limburg (from Bless et al., 1980). Values in mgal. The presence of the gravity low southeast of Maastricht, and of the gravity high at Hermalle-sous-Argenteau has been confirmed (see figure 14).

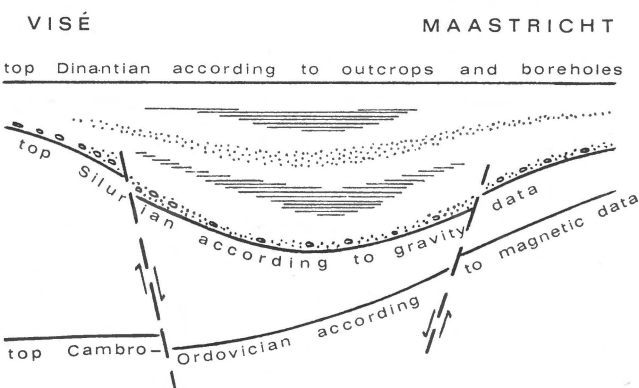


Fig. 14
Schematic working model of cross-section of Visé-Puth Structure, based on geological and geophysical interpretation (from Bless et al., 1980).

thick Devono-Dinantian rock sequence (BLESS ET AL., 1980, 1980a).

In 1981, these ideas were confirmed by two 500 m holes (Kastanjelaan-2 and Heugem-1/1a) around Maastricht (BLESS ET AL., 1981a). These holes proved the existence of a very thick Devono-Dinantian succession below Maastricht, presumably more complete than the one observed in Hermalle-sous-Argenteau (Figs. 15 and 16). Also, some thin (up to 3 cm thick) lenses of anhydrite and calcite pseudomorphs after anhydrite have been recognized in the Middle Viséan carbonates of the Heugem borehole.

The investigations on the Visé-Puth structure have left many problems unsolved:

- The total thickness of the Devono-Dinantian deposits below Maastricht is still unknown. Data available suggest that this area was subjected to rapid downwarp during this timespan. In a later phase, however, uplift must have taken place as can be deduced from the present Pre-Permian surface (Fig. 12). The age of this inversion has still to be determined.
- The possible presence of rock salt at the position of the gravity low southeast of Maastricht has been suggested, but needs to be confirmed by future drilling.
- The carbonates immediately below the present Pre-Permian surface have been affected by severe leaching and silicification processes (GÖKDAG, 1982). Presumably, these processes took place after the Carboniferous and before the Late Cretaceous, since reworked fragments of silicified Dinantian carbonates occur in the overlying Upper Cretaceous.

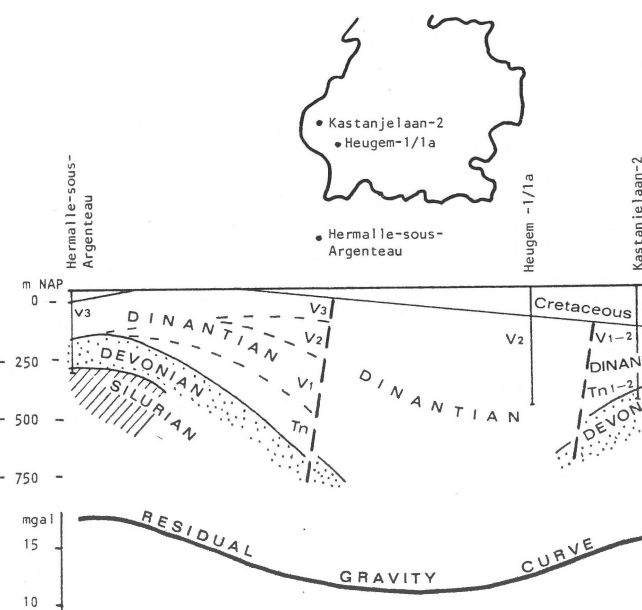


Fig. 15
Schematic cross-section between boreholes Hermalle-sous-Argenteau, Heugem and Kastanjelaan, compared with residual gravity curve. Note the strong resemblance with the working model of figure 14.

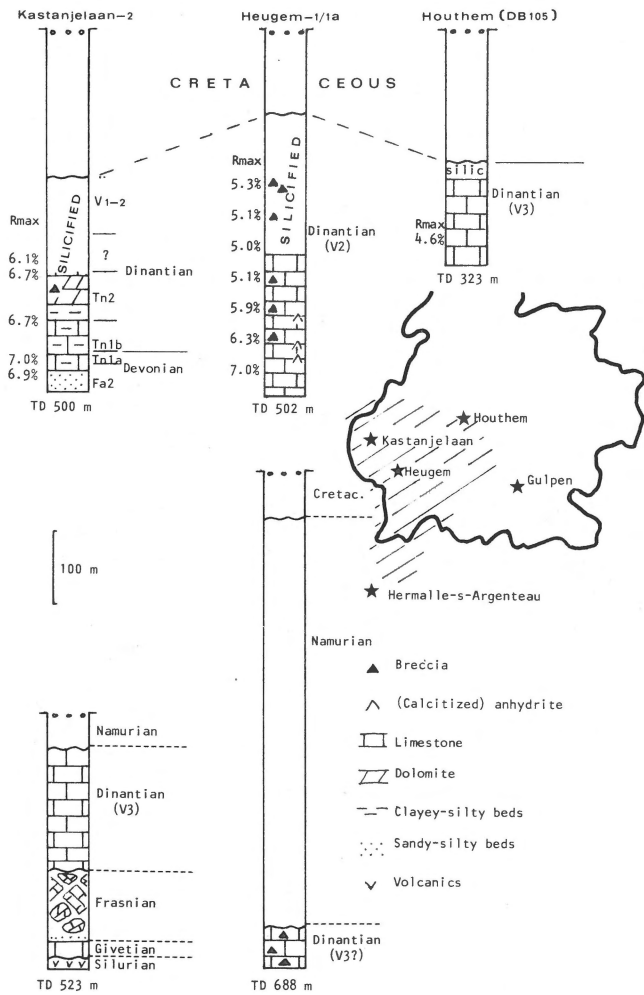


Fig. 16 Boreholes in the Dinantian rocks within and around the Visé-Puth Structure. Note the silicified top of the Dinantian carbonate sequence in boreholes where the Namurian deposits were eroded away before deposition of the Upper Cretaceous. Also note the high rank of coalification measured in the holes Kastanjelaan, Heugem and Houthem.

- The suggestion that the Devono-Dinantian rocks below Maastricht were deeply buried below an extremely thick cover of Upper Carboniferous cannot be confirmed. The thickness of the Upper Carboniferous can be estimated at approx. 2000-3000m from the deposits now occurring in the Liège and Sittard areas and from palaeogeographic considerations. However, such an overburden does not correspond to the very high rank of coalification (vitrinite reflectance values between 5 and 7% Rmax in the boreholes Heugem and Kastanjelaan; WOLF, 1982). As the Visé-Puth area corresponds today to a temperature low (geothermal gradient about 2.5°/100 m), it is suggested that the high reflectance values have been caused by a relatively short-lived heat-flow. The presence of a gravity low in this area seems to exclude an intrusive magmatic body at relatively shallow depth, but the heat flow could have been related to the inversion movements which affected this area.

- An unsolved problem is the extension of the Visé-Puth Basin to the north. Comparison with the Dinantian carbonate deposits on the northern flanks of the Wales-London Massif in Great Britain suggests the, yet untested possibility of a basin with a predominance of clays or dark limestones (calclutites) in the central portions of the former Campine-Brabant Basin.

Rapid changes in thickness and facies of Devonian and Dinantian deposits can be postulated for the Visé-Puth area, as they are also known to occur elsewhere in northern Europe. A spectacular example is shown by the comparison of the boreholes Jeumont and St.-Ghislain (Fig. 17). In the thick Dinantian sequence of St.-Ghislain several massive evaporite intercalations (anhydrite and subordinate gypsum) are present, with a total thickness of almost 900 m. This certainly demonstrates a more varied depositional setting than the often cited but too simple one with the Dinantian only subdivided into Carboniferous limestone (or 'Kohlenkalk') and Kulm.

Rock salt, supposedly occurring southeast of Maastricht, has not yet been recognized. However, the presence of thick rock salt sequences in the Dinantian of Nova Scotia (SE Canada; HACQUEBARD, 1972) suggests that these may occur as well in northern Europe, as these two areas belonged to the

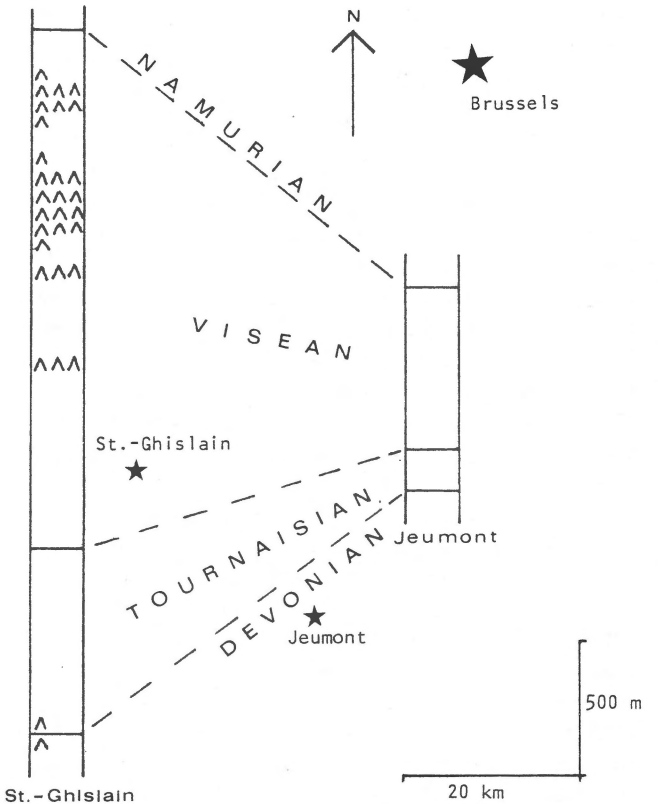


Fig. 17 Thickness variation of the Dinantian deposits between the boreholes Jeumont and St.-Ghislain, south of Brussels. The occurrence of the anhydrite intercalations in St.-Ghislain is also indicated.

same sedimentation belt during the Dinantian. Restricted environments with evaporite deposition have also been described from the Devonian of northern Europe. Anhydrite and gypsum have been discovered in the North Sea (Argyll borehole: DEEGAN & SCULL, 1977), Belgium (Tournai borehole: VAN TASSEL, 1961; Leuze borehole: LEGRAND, 1981; Soumagne borehole: GRAULICH, 1977; Wépion borehole: DREESEN & THOREZ, 1982), France (Normandy: PONCET, 1967; Annapes borehole: BLESS ET AL., 1980b), Poland (DADLEZ, 1978) and the Baltic region (SOKORIN ET AL., 1981). It could be worthwhile to test the possible occurrence of such restricted environments also on the northern flanks of the Brabant Massif in Devonian times.

UPPER CARBONIFEROUS COAL DEPOSITS

Since 1970, there has been a renewed exploration interest for coal in the Upper Carboniferous basins northeast of the Brabant Massif (Fig. 18). It started in the German Ruhr coal mining district, where up to the end of 1981, some 350 boreholes were drilled with a total length of over 400 000 m (average depth about 1200 m). This campaign also included the shooting of some 1200 km of seismic profiles as well as 185 km² of three-dimensional seismic. These efforts, and a detailed revision of colliery data, yielded a completely new structural model for the Carboniferous rocks in this area (BORNEMANN 1980; DROZDZEWski, 1980; KAULLFUSS, 1980; KUNZ, 1980; WREDE, 1980).

In 1979, the Kempense Steenkoolmijnen and the Belgian Geological Survey started investigations in the northeastern part of the Belgian Campine coal-mining area, where up to the end of 1981 about 84 km of seismic profiles had been shot, which were complemented with fifteen boreholes. Renewed exploration for coal in The Netherlands started only at the end of 1981 with a seismic survey in South Limburg, north of the former (in 1974 completely abandoned) coal-mining area. Several 1000-1500 m holes will be drilled from 1983 onward. The Geological Survey of the Netherlands proposes to extend the search for coal in The Netherlands to northern Limburg and to the area around the Gelria concession (BLESS & DE VOOGD, 1980; BLESS, 1981).

Seismic and borehole exploration of the coal-bearing Upper Carboniferous commonly consists of two phases. The first one is a regional survey that serves to understand the main geological features in the subsurface as well as the regional trends in number and thickness of coal seams and coal-bearing strata. The need for such a regional picture is demonstrated by the variations in the Upper Westphalian A successions between northeastern Belgium (Campine) and the Ruhr district in the Federal Republic of Germany (Fig. 19). The second, more detailed stage of reconnaissance consists of a dense grid of closely spaced seismic lines and boreholes. This phase should reveal the nature and size of small tectonic units as well as the local variations in thickness

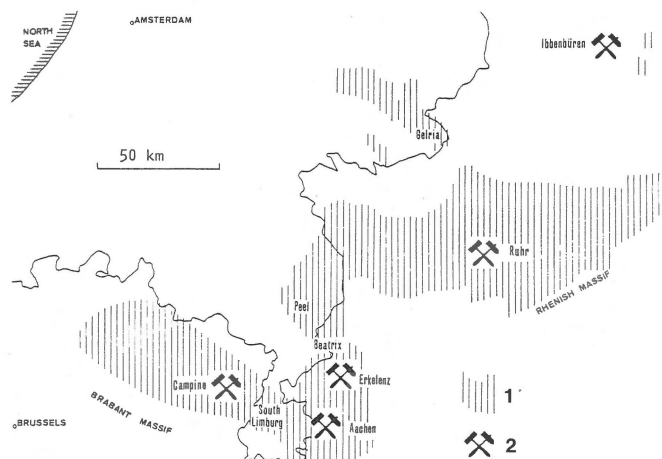


Fig. 18

Coal-bearing Upper Carboniferous deposits at less than 1000 m below the surface in Belgium, The Netherlands and the Federal Republic of Germany. 1 = Coal measures outcrop and subcrop with less than 1000 m overburden; 2 = Coal mining district.

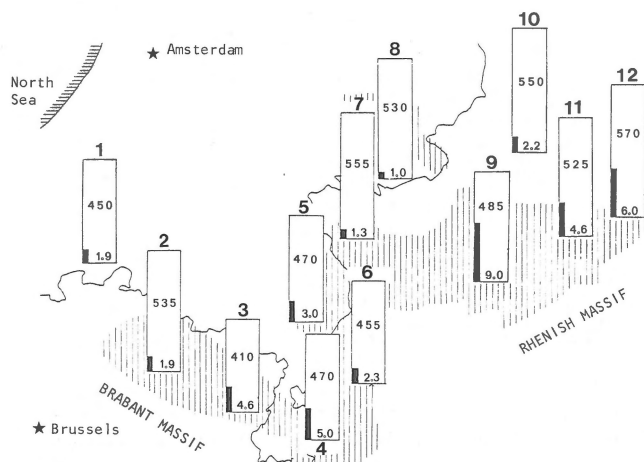


Fig. 19

Variation in thickness (in m, upper part of columns) and total coal thickness (in percentages of the total thickness, lower part of columns) of the Upper Westphalian A of Belgium, The Netherlands and the Federal Republic of Germany. 1 = Rijsbergen-1; 2 = W-Campine; 3 = E-Campine; 4 = Loverich-3; 5 = 132 borehole; 6 = Hohenbusch; 7 = Uedem-1; 8 = Zeddam-1; 9 = Bonifacius; 10 = Münsterland-1; 11 = Werne-22; 12 = Linnefeld-1.

and other properties of coal seams and coal-bearing rocks.

The initial phase of coal exploration by the Belgian Geological Survey in the Campine region was confined to the Neeroeteren-Rotem area, north of the coal mining concession of the Kempense Steenkoolmijnen. Only one borehole (No. 146, Neerglabbeek) was drilled, but it yielded a wealth of information, showing, for example, the presence of no less than 13 coal seams with a minimum thickness of one meter (maximum thickness more than 3 m) within the 627 m sequence of Upper Westphalian C and Lower Westphalian D (DUSAR & HOULLEBERGHS, 1981). Probably even more important is the presence of an almost 300 m thick sequence of the so-

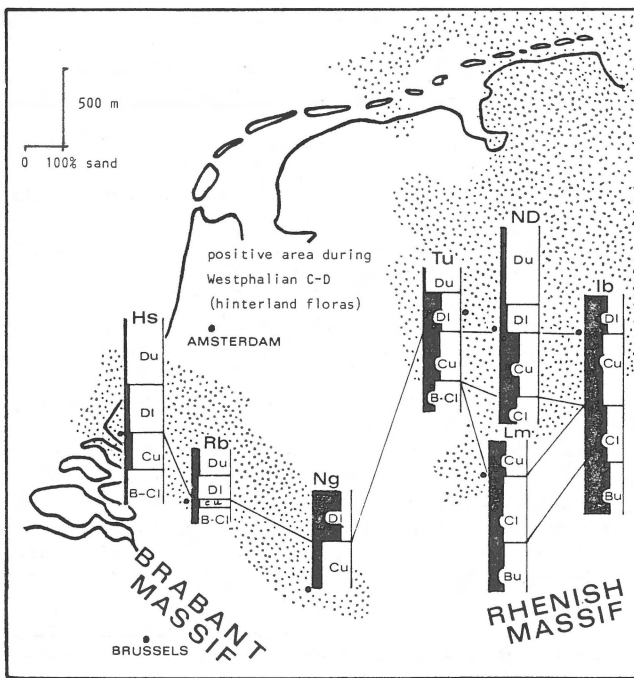


Fig. 20
Average sandstone percentages in Upper Westphalian B, Lower and Upper Westphalian C, and Lower and Upper Westphalian D in boreholes Hellevoetsluis (Hs), Rijsbergen (Rb), Neerglabbeek (Ng), Tubbergen-8 (Tu), Nord-Deutschland-8 (ND), Ibbenbüren (Ib) and Lippemulde (Lm). The stippled areas indicate the present distribution of Westphalian C-D deposits in northern Belgium, The Netherlands and northwestern Germany.

called Neeroeteren Sandstones in the Lower Westphalian D (between 730 and 1060 m). This sequence consists of a number of up to 65 m thick coarse-grained sandstone beds which are separated by silty shales and coal seams. The white-grey, feldspar-rich sandstones show a relatively high porosity (average porosity 18%), notwithstanding the frequent occurrence of diagenetic vermicular kaolinite. However, the permeability of these sandstones is relatively low (usually below 50 mD). The porosity values in the Neerglabbeek borehole match those observed for the Neeroeteren Sandstones in another borehole (No. 113), with a porosity of 18.7% (RENIER, 1945). This means that the Neeroeteren Sandstones represent a potential reservoir for hydrocarbons. It is expected that they extend to the northeast below the Roer Valley Graben or the Central Netherlands Graben, whereas a change towards more clay/silt-dominated deposits has been observed in western directions (boreholes Rijsbergen-1 and Hellevoetsluis; Fig. 20, VAN WIJHE & BLESS, 1974).

REFERENCES

Bless, M. J. M. 1981 Scenario voor een exploratie naar steenkool in Nederland; programma eerste fase – Tijdschrift TH Aken 23 (1): 3-13.

- Bless, M. J. M., P. Boonen et al. 1981a Microfossils and depositional environment of late Dinantian carbonates at Heibaart (northern Belgium) – *Ann. Soc. Géol. Belg.* 104: 135-165.
- Bless, M. J. M., P. Boonen et al. 1981b Preliminary report on Lower Tertiary-Upper Cretaceous and Dinantian-Famennian rocks in the boreholes Heugem-1/1a and Kastanjelaan-2 (Maastricht, The Netherlands) – *Meded. Rijks Geol. Dienst* 35 (15): 333-415.
- Bless, M. J. M., W. Bosum et al. 1980 Geophysikalische Untersuchungen am Ost-Rand des Brabanters Massivs in Belgien, den Niederlanden und der Bundesrepublik Deutschland – *Meded. Rijks Geol. Dienst* 32 (17): 313-343.
- Bless, M. J. M., J. Bouckaert et al. 1976 Dinantian rocks in the subsurface north of the Brabant and Ardenno-Rhenish Massifs in Belgium, The Netherlands and the Federal Republic of Germany – *Meded. Rijks Geol. Dienst* N.S. 27 (3): 81-195.
- Bless, M. J. M., J. Bouckaert et al. 1977a Paleogeography of Upper Westphalian deposits in NW Europe with reference to the Westphalian C north of the mobile Variscan belt – *Meded. Rijks Geol. Dienst* N.S. 28 (5): 101-127.
- Bless, M. J. M., J. Bouckaert et al. 1977b Y A-t-il des hydrocarbures dans le Pré-Permien de l'Europe occidentale? – *Serv. Géol. Belg. Prof. Pap.* 148: 1-58.
- Bless, M. J. M., J. Bouckaert et al. 1980a Evaporites anté-silésiennes sur la bordure orientale du massif du Brabant et dans le Fossé rhénan: une hypothèse – *Hommage à Léon Calémbert*, Ed. Georges Thon, Liège: 23-32.
- Bless, M. J. M., J. Bouckaert et al. 1980b Pre-Permian sedimentation in NW Europe: Pre-Permian depositional environments around the Brabant Massif in Belgium, The Netherlands and Germany – *Sediment. Geol.* 27 (1): 1-81.
- Bless, M. J. M., R. Conil et al. 1980 Stratigraphy and thickness variations of some Strunio-Dinantian deposits around the Brabant Massif – *Meded. Rijks Geol. Dienst* 32 (8): 56-65.
- Bless, M. J. M. & N. Voogd 1980 Exploration for coal in The Netherlands – *Meded. Rijks Geol. Dienst* 33 (3): 17-32.
- Bornemann, O. 1980 Tiefentektonik der Lippe- und Lüdinghausener Hauptmulde – *Beiträge zur Tiefentektonik des Ruhrkarbons. Geol. Landesamt Nordrhein-Westfalen Krefeld*: 173-191.
- Bouckaert, J., M. Duser & Van de Velde 1981 Exploration for coal in the Neeroeteren-Rotem area (Campine coalfield of the Campine-Brabant Basin NE. Belgium): preliminary results of a seismic survey carried out in December 1980-January 1981 – *Ann. Soc. Géol. Belg.* 104: 281-289.
- Chapple, W. M. 1978 Mechanics of thin-skinned fold-and-thrust belts – *Geol. Soc. Am. Bull.* 89: 1189-1198.
- Clement, J. 1963 Résultats préliminaires de campagnes géophysiques de reconnaissance dans les permis de recherches 'Arras et Avesnes' de l'Association Shell Française – P.C.R.B. – SAFREB. Objectifs du forage profond Jeumont-Marpent No. 1. – *Ann. Soc. Géol. Nord* 83: 237-241.
- Dadlez, R. 1978 Podpermiskie kompleksy skalne w strefie Koszalin-Shajnice – *Kwart. Geol.* 22 (2): 269-301.
- Deegan, C. E. & B. J. Scull 1977 A standard lithostratigraphic nomenclature for the Central and Northern North Sea – *Inst. Geol. Sci. Rep.* 77/25, Bull. 1.
- Dreesen, R. & J. Thorez 1982 Upper Devonian sediments in the Ardenno-Rhenish area; sedimentology and geochemistry – *Publ. Nat. Hist. Genootschap Limburg* 32 (1-4): 8-15.
- Drozdewski, G. 1980 Tiefentektonik der Emscher- und Essener Hauptmulde im mittleren Ruhrgebiet – *Beiträge zur Tiefentektonik des Ruhrkarbons. Geol. Landesamt Nordrhein-Westfalen Krefeld*: 45-83.
- Duser M. & E. Houleberghs 1981 De steenkool verkenningsboring van Neerglabbeek (Boring 146 van het Kempens Bekken) – *Ann. Mines Belg.* 1981 (11): 913-1003.
- Duser, M. 1982 Exploration for coal in the Belgian Campine – *Publ.*

- Nat. Hist. Genootschap Limburg 32 (1-4): 27-39.
- Fourmarier, P. 1913 Les phénomènes de charriage dans le bassin de Sambre-Meuse et le prolongement du terrain houiller sous la faille du Midi dans le Hainaut – *Ann. Soc. Géol. Belg.* 40: B192-B235.
- Frost, R. T. C., F. J. Fitch & J. A. Miller 1981 The age and nature of the crystalline basement of the North Sea Basin. In: L. V. Illing & D. C. Hobson (eds.): *Petroleum Geology of the Continental Shelf of North-West Europe* – Instit. Pet. London: 43-57.
- Gökdag, H. 1982 Some diagenetic aspects and origin of porosity in the Dinantian (Early Carboniferous) carbonates in the wells Heugem-1a and Kastanjelaan-2 (Maastricht, The Netherlands) – *Publ. Nat. Hist. Genootschap Limburg* 32 (1-4): 50-53.
- Graulich, J. M. 1961 Le sondage de Wépion – *Mém. Expl. Cartes Géol. Min. Belg.* 2: 1-102.
- 1977 Le sondage de Soumagne – *Serv. Géol. Belg. Prof. Pap.* 139: 1-55.
- Hacquebard, P. A. 1972 The Carboniferous of Eastern Canada – C.R. septième Congr. Intern. Strat. Géol. Carbonifère Krefeld 1971, 1: 69-90.
- Johnson, R. J. & R. G. Dingwall 1981 The Caledonides: their influence on the stratigraphy of the North-West European Continental Shelf. In: L. V. Illing & D. C. Hobson (eds.): *Petroleum Geology of the Continental Shelf of North-West Europe* – Instit. Pet. London: 85-97.
- Kaullfuss, R. 1980 Résultats de recherches récentes sur la structure géologique des gites de houille de la Ruhr – *Rev. Institut. français Pétrol.* 35 (2): 377-386.
- Kimpe, W. F. M., M. J. M. Bless et al. 1978 Palaeozoic deposits east of the Brabant Massif in Belgium and the Netherlands – *Meded. Rijks Geol. Dienst* 30 (2): 37-102.
- Kunz, E. 1980 Tiefentektonik der Emscher- und Essener Hauptmulde im östlichen Ruhrgebiet – *Beiträge zur Tiefentektonik des Ruhrkarbons. Geol. Landesamt Nordrhein-Westfalen Krefeld*: 85-134.
- Legrand, R. 1968 Le Massif de Brabant – *Mém. Cartes Géol. Min. Belg.* 9: 1-148.
- 1981 Les 'logs' des sondages de Tournai et de Vieux-Leuze – *Serv. Géol. Belg. Prof. Pap.* 180:1-2.
- Meissner, R., H. Bartelsen & H. Murawski 1981 Thin-skinned tectonics in the northern Rhenish Massif, Germany – *Nature* 290 (5805): 399-401.
- Patijn, R. J. H. 1963 Het Carboon in de ondergrond van Nederland en de oorsprong van het Massief van Brabant – *Geol. Mijnbouw* 42: 341-349.
- Poncet, J. 1967 Le Dévonien de la Basse-Normandie – *Intern. Symp. Devonian System Calgary 1967*, 1: 137-142.
- Sorokin, V. S., L. A. Ljarskaja et al. 1981 Devon i Karbon pribaltiki – *SINATNE, Riga*: 1-502.
- Stemans, Ph. 1981 Etude stratigraphique des spores dans les couches de transition 'Gedinnien-Siegenien' à Nonceveux et à Spa (Belgique) – *Ann. Soc. Géol. Belg.* 104 (1): 41-59.
- Tassel, R. van 1961 Anhydrite, célestine et barytine du Givétien au sondage de Tournai – *Bull. Soc. belge Géol. Paléontol. Hydrol.* 69: 351-361.
- Tesch, P. 1924 Verslag over de onderzoekingen der Rijksopsporing van Delfstoffen gedurende het tijdvak 1920-1923: 1-29.
- Thorez, J. & M. J. M. Bless 1977 On the possible origin of the Lower Westphalian D Neeroeteren Sandstone (Campine, Belgium) – *Meded. Rijks Geol. Dienst N.S.* 28 (5): 128-134.
- Vandenbergh, N. 1982 Carboniferous north of the Brabant Massif in the area of Heibaart, Turnhout and Meer; seismics and boreholes – *Publ. Nat. Hist. Genootschap Limburg* 32 (1-4): 24-26.
- Vandenbergh, N. & J. Bouckaert, 1980 Geologische beschouwingen van geothermische mogelijkheden in Noord-België – *Serv. Géol. Belg. Prof. Pap.* 168: 1-21.
- Vanguetaine, M. 1979 Remaniements d'acritarchs dans le Siegenien et l'Emsien (Dévonien inférieur) du synclinorium de Dinant (Belgique) – *Ann. Soc. Géol. Belg.* 101: 243-267.
- Walter, R. 1982 Europe-1: proposal for a deep test-hole through the Stavelot-Venn Anticline, Federal Republic of Germany – *Publ. Nat. Hist. Genootschap Limburg* 32 (1-4): 59-62.
- Wolf, M. 1982 Coalification pattern in the Visé-Puth area around Maastricht (The Netherlands) – *Publ. Nat. Hist. Genootschap Limburg* 32 (1-4): 48-49.
- Wrede, V. 1980 Tiefentektonik der Bochumer Hauptmulde im östlichen Ruhrgebiet – *Beiträge zur Tiefentektonik des Ruhrkarbons. Geol. Landesamt Nordrhein-Westfalen Krefeld*: 135-171.