

## Subsurface facies analysis of the Namurian and earliest Westphalian in the western part of the Campine Basin (N Belgium)

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### Abstract

Geophysical wireline logs from recent boreholes were used to unravel the sedimentary history of the Namurian and earliest Westphalian in the western part of the Campine Basin. The study comprises 4 wells with petrophysical data (Merksplas, Poederlee, DZH14, DZH15) and 1 corehole (Turnhout). Paleogeographical cartoons are presented for the studied interval together with some examples of the log-response of the sedimentary sequence.

The Pendleian is missing in the Campine Basin. The Namurian sedimentary sequence starts with Arnsbergian to Alportian basinal mudstones. These are followed by two turbidite-fronted delta sequences which prograded towards the north into the basin. From the late Yeadonian onwards, four successive shallow-water sheet-deltas developed. The upper part of the earliest Westphalian Ransart Member is formed by braided river deposits, situated underneath the Finefrau Nebenbank Marine Band. This succession corresponds very well to the Namurian sequence of a marginal part of the English Pennine Basin, the Gainsborough Trough, although the timing of the events is somewhat different.

### Introduction

The Campine Basin, comprising the largest coal basin in Belgium, is located to the north of the Caledonian Brabant Massif (Fig. 1). The northern limit, situated to the north of the Belgo-Dutch border, is formed by the Netherlands Central Graben and its southeastern extension, the Roer Valley or Roermond Graben (Geluk 1990). Sedimentation started in the Middle Devonian and lasted discontinuously till the end of the Westphalian. More than 3 kilometres of Upper Carboniferous sediments (Namurian to Westphalian D) were preserved in the eastern part of the basin. This area, corresponding to the mining district, is fairly well known from the collieries and the numerous coal

exploration wells. Moreover the Campine coalfield passes towards the east into the Dutch South-Limburg coalfield.

In the western part of the Campine Basin, data on the Paleozoic are scarce. After the initial 'coal rush' of the beginning of the century, one geological and hydrological reconnaissance well was drilled in the fifties (Turnhout) and two wells were drilled in the early sixties (Booischoot-geological reconnaissance and Heibaart-wildcat; Bless et al. 1976). The search for geothermal and subsurface gas storage reservoirs has renewed the interest in the western Campine during the last 15 years. This exploration was mainly focused on the karstified top of the Dinantian limestones. More than 15 wells, reaching the top of the Dinantian, were drilled

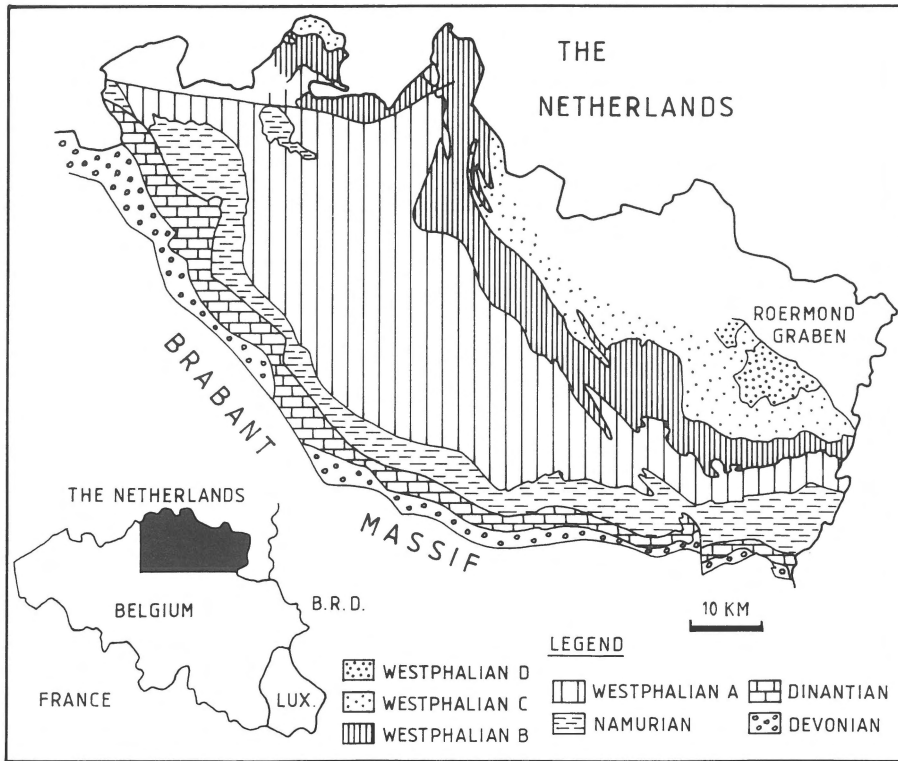


Fig. 1. Location map of the Campine Basin with schematic subcrop of upper Paleozoic below base Mesozoic.

by the Belgian Geological Survey and Distrigaz. The majority of these wells are situated on the Distrigaz subsurface gas storage site at Loenhout-Heibaart (Fig. 2).

Four of the recent wells (Merksplas-KB165, Poederlee-KB170, DZH14-KB202, DZH15-KB203) intersected the complete Namurian and the earliest Westphalian Ransart Member (defined by Paproth et al. 1983). These boreholes, together with the completely cored Turnhout well (KB120), served as the basis for the present study. Since no cores were taken in the recent wells, the sedimentary facies analysis had to be based on geophysical borehole data and the regional geological evidence (Langenaeker & Dusar in press). It is clear that a detailed sedimentological analysis is impossible without the study of core material or outcrops. An assessment of the larger-scale sedimentological units and facies, however, can be carried out on the basis of the wireline logs. The key for establishing the sedimentological picture of the Namurian in the

western Campine, was the extensively studied Millstone Grit in the Pennine Basin of northern England (Collinson 1988).

#### Geophysical logs and facies analysis

Well logs are a widely documented tool for subsurface facies analysis (Cant 1984, Selley 1985, Visher 1990, and many other authors). In this study only two petrophysical properties as measured by the logs were used: the natural radioactivity and the travel times for acoustic waves. These two, recorded in the gamma ray and sonic logs, were available in all the wells and very well suitable for the Namurian sand/shale sequence. Resistivity logs were not recorded in all the wells and therefore not integrated in the present study.

Marine bands, which form the basis for the stratigraphical subdivision of the Silesian, i.e. the Upper Carboniferous, in northwest Europe, are also

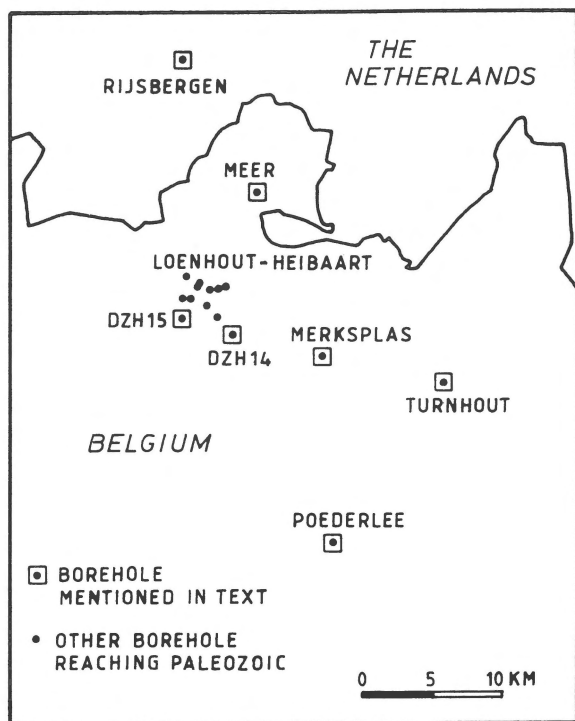


Fig. 2. Location of the most important wells in the western Campine (Turnhout: KB120, Meer: KB149, Merksplas: KB165, Poederlee: KB170, DZH14: KB202, DZH15: KB203). KB numbers are the well numbers for the Campine Basin according to the Belgian Geological Survey and are also used on Fig. 4.

recognised on the logs due to their high gamma ray/slow sonic travel time response (Hedemann et al. 1984, Schuster & Schmitz 1989). Some of the logs were discontinuous because of casing interference and discontinuous logging runs. Although in some cases the logs were run during well completion, they nevertheless provide valuable geological data.

The log data from the more recent wells were compared with the Turnhout cored section. No logs were available from the latter well, drilled in 1953–55. In this case the original core description by Grosjean et al. (1955) as emended by Bouckaert and published by Delmer (1962) was used to construct a granulometric log. This schematic grain size log was used for facies analysis and correlation purposes because of its resemblance to gamma ray/sonic logs in a sand-shale sequence.

### Deltaic sedimentation

The majority of the Namurian and early Westphalian sediments in the Campine Basin were formed in delta-related environments. This is also the case for the Silesian Pennine Basin in northern England. The Gainsborough Through at the southern margin of this basin was studied by Steele (1988) on the basis of subsurface data. This author recognised a number of prograding delta sequences which filled up the basin during the Namurian. Several different deltaic depositional environments were distinguished, each with its own typical log-response, based on a comparison between borehole and outcrop data. Similar environments can be recognised in the western Campine Basin.

Two different styles of deltaic progradation were described by Collinson (1988); these are also applicable in the western Campine. The first type are turbidite-fronted deeper-water sequences. These start with basal mudstones and distal to proximal turbidites. Some of the sandstones in the proximal turbidites can be up to a few tens of metres thick in the Pennine Basin and represent submarine channels through which the turbidite material was distributed into the basin. Higher up in the sequence, fairly thick coarsening-upward units of mainly siltstone can be recognised. These represent the slope deposits of the prograding delta. Sometimes thick sandstones occur between these siltstones, which correspond to the turbidite feeder channels. The top of the sequence is in most cases formed by sandy material which was deposited during floods into the distributary channels of the delta system (Collinson 1968a, 1968b, 1988, McCabe 1977). The finer grained sandstones and siltstones on the delta plain are interdistributary sediments.

The second type of deltaic progradation sequences were formed by sheet deltas. The lower part consists of a coarsening-upward sequence of mudstones and siltstones. These are the prodelta deposits which pass up into a complex of mouth bars, distributary channels and finer interdistributary deposits as crevasse splays, overbank deposits or lake sediments (Collinson 1988, Elliott 1978, Okolo 1983). Sometimes marshes developed between the distributaries on the delta plain.

Coals or seat-earths were described in the upper part of the Namurian in the eastern part of the Campine Basin (Delmer 1963) and in the South-Limburg area (Kimpe 1961, Kimpe et al. 1978), but seem absent in the western Campine. The oldest described seat-earth in the Turnhout well occurs in the upper part of the Ransart Member, in the interdistributary deposits underneath the Finefrau Nebenbank sandstone (Grosjean et al. 1955).

The major difference between the Campine and Pennine basins is that in the depocentre of the latter, deep-marine conditions existed while in the Campine clastics were deposited in a shallow-marine shelf sea (Ziegler 1990). Water depths during the early Namurian were probably between 50 and a few hundreds of metres in the western Campine, as can be inferred from the thickness of the delta slope deposits which were interpreted on the logs.

### Interpretation of depositional history

The following will deal with the depositional history of the Namurian and earliest Westphalian in the western Campine Basin. Every major sedimentary sequence will be illustrated by geophysical log-examples. Paleogeographical cartoons for each sequence have been constructed (Fig. 4). The subdivision of the early Silesian (Fig. 8) is based on the goniatite faunas from marine bands (Bouckaert 1961, 1971, Ramsbottom 1969, Ramsbottom et al. 1978, Paproth et al. 1983). The stratigraphical framework in the studied wells was elucidated by Langenaeker and Dusar (in press), integrating log-correlations and biostratigraphical data.

#### *Pendleian to Alportian*

No hard proof has been found yet for the presence of Pendleian sediments in the Campine or for that matter in the other Belgian basins (Bouckaert & Higgins 1963, Paproth et al. 1983). The oldest identified Namurian onlapping on the Brabant Massif in the western Campine Basin is of late Arnsbergian age ('E2c'; Grosjean et al. 1955 (emended by Bouckaert), Delmer 1962, 1963). The lithology of

the condensed Arnsbergian to Alportian section consists of goniatite-bearing 'ampelites' (black organic-rich pyritic shales which, when subject to alteration, turn into light coloured to violaceous porous fissile shales) and silicified limestones and dolomites. The dark-grey or black basinal shales were deposited out of suspension in anoxic water conditions. These shales alternate with thin carbonate beds. The sequence has undergone extensive diagenesis, intensified at the contact between the Visean and Namurian. This is illustrated by the silicification of the thin limestones as well as part of the shales (Muechez 1988).

The thickness of the Arnsbergian to Alportian sequence varies between 24 m at Turnhout and only a few metres at Loenhout-Heibaart. The Heibaart area, which developed as a domal reef structure during the late Visean (Muechez et al. 1990) remained a topographically higher area at the onset of the Namurian transgression. This uplifted carbonate platform was flooded only during the Chokierian or Alportian. The latter is clearly not the case for the Poederlee dome which is also interpreted as a late Visean reef structure (Muechez et al. 1990) but where the basinal Arnsbergian-Alportian shale sequence is more than 20 m thick. The distinction between both late Visean shoals is that Heibaart is also underlain by a domal structure in the lower Paleozoic, while such a structure could not be recognised in Poederlee. Tectonic block-faulting mechanisms thus may interact with subsidence and influence sedimentation rates (Muechez & Langenaeker 1990).

The Arnsbergian to Alportian sequence is very distinctive on the geophysical logs because of the very high gamma ray and low sonic readings. The high radioactivity of these shales is due to the presence of uranium, confirmed by spectral gamma ray logs, which is related to the organic material (Legend 1957). Some examples of the log-response of these 'hot shales' are shown in Fig. 3.

The basin was frequently in contact with the open marine environment during this period as shown by the goniatite-bearing marine bands which were identified at the Turnhout corehole. Goniatite assemblages generally point to a thanatocoenosis from wind-driven and current-trans-

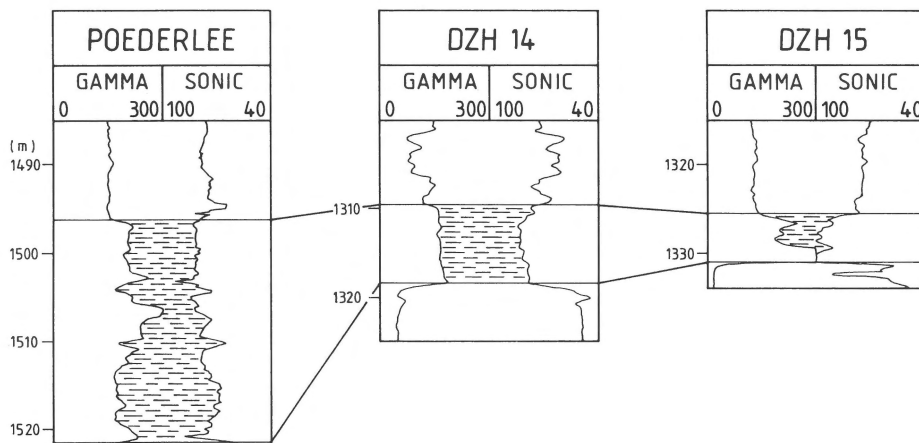


Fig. 3. Log examples of the basal Namurian 'hot shales'. Note the extremely high gamma ray values of these shales. Gamma ray is in API units and sonic in microsec/ft.

ported floating life-communities. The paleogeographical cartoon (Fig. 4A) shows the basal area and the Heibaart shoal during the Arnsbergian-Alportian. The margin of the basin was situated not far to the southwest, in the direction of the London-Brabant Massif, where the late Visean limestones probably emerged above sea-level. The position of the landmass to the southwest of the studied area is confirmed by seismic data which show a gradual thinning of the Namurian in that direction. It can furthermore be inferred from the presence of paleosols, identified by Muchez and Viaene (1987) in the Booischot well, the presence of sandy sediments in the Dinantian of the same well and of the Kessel well (Legrand 1964), both situated at the southwestern margin of the Campine Basin, and the strong thickness reduction of the Dinantian on the London-Brabant Massif (Bless et al. 1980). (Booischot and Kessel are situated respectively 21 km SSW and 16 km WSW of Poederlee.)

#### *Kinderscoutian*

The lower part of the Kinderscoutian consists of basal mudstones and siltstones which were deposited out of suspension. These are much less carbonaceous and have a much lower gamma ray response when compared to the underlying sequence. The fine-grained sediments are mixed with

coarser siltstones and sandstones, which are particularly well-developed at well DZH14 in the Heibaart area. Somewhat coarser sediments were also found in the Merksplas and Turnhout wells. The mixture of this material with some marine fossiliferous horizons at Turnhout confirms the basal setting of these deposits.

The coarser material is interpreted as distal turbidites thrown into the basin along feeder channels in the delta slope and basin floor and deposited on laterally shifting lobes (Collinson, 1988). This interpretation is mainly based on the log response of these sediments, which is shown on Fig. 5, and which corresponds very well to the turbiditic log facies described in the Gainsborough Trough by Steele (1988). Only a few metres of core in this facies were taken in well DZH14. The core was situated in between the more important sandstones, which are up to 3 m thick. The cored section was not sufficient to confirm the turbiditic nature of the sediments but also did not contradict this interpretation. These sediments were deposited on a shelf rather than in a deep basin. This does not exclude the presence of turbidites since a water depth of only 50 m is believed to be sufficient for their formation (Stow 1986). The paleogeographical cartoon with a delta plain and slope situated to the southwest of the studied area is shown on Fig. 4B.

This turbidite-fronted delta prograded towards

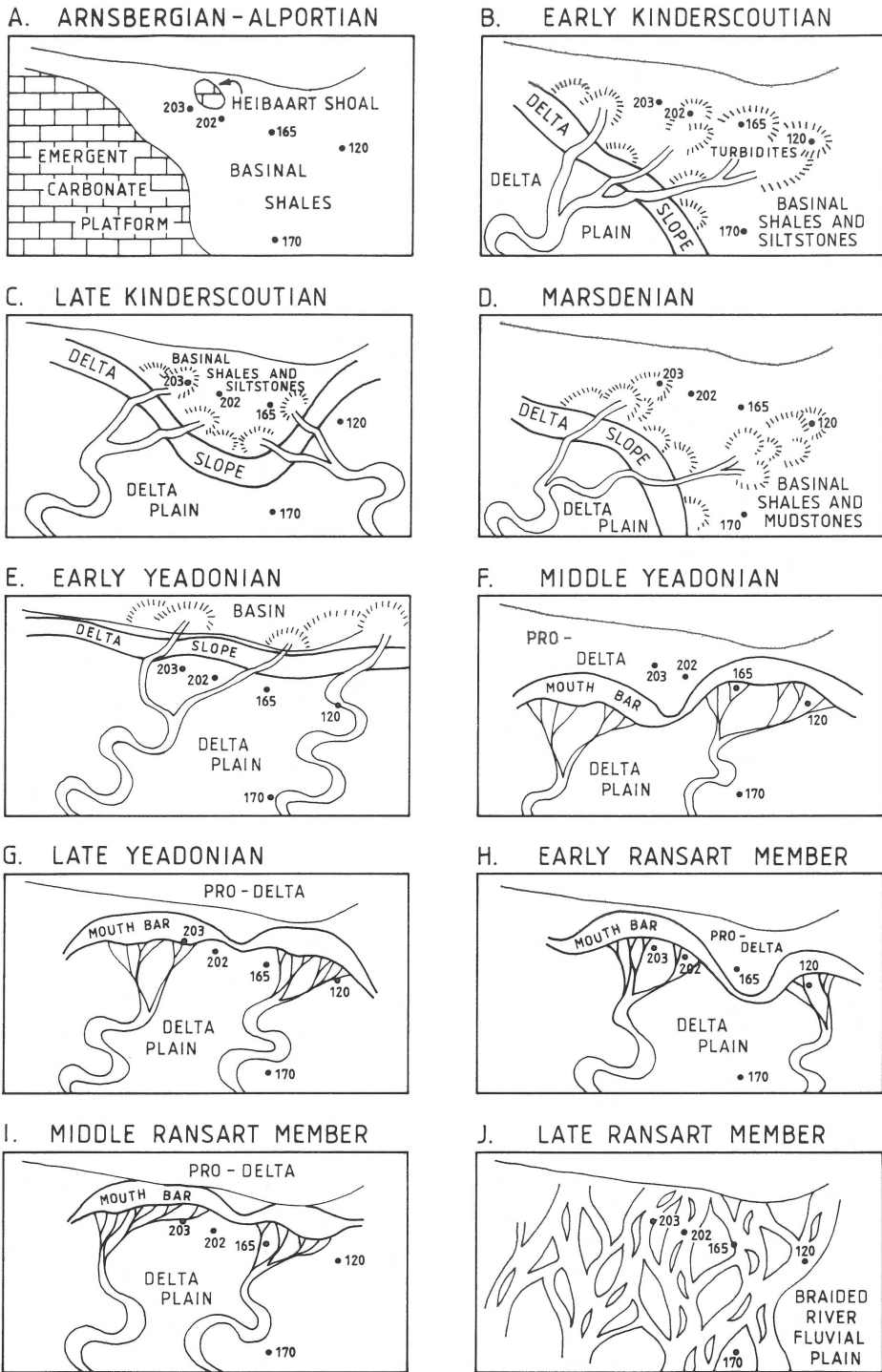


Fig. 4. Paleogeographic cartoons for the Namurian and the Ransart Member in the western Campine. Curved line at the top of each cartoon is the trace of the Hoogstraten fault. Carbonates of platform and shoal shown in A are pre-Namurian. The meandering nature of the rivers is conjectural and not derived from the sediments. The location of the five studied wells is indicated (120: Turnhout, 165: Merksplas, 170: Poederlee, 202: DZH14, 203: DZH15).

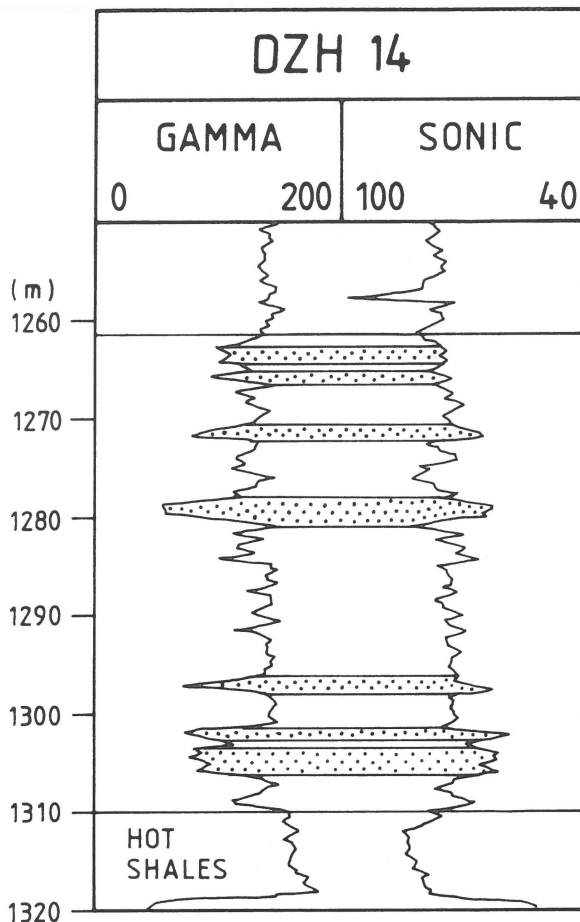


Fig. 5. Sandy distal turbidites (stippled) in the Kinderscoutian of well DZH14. Hot shales are basal Namurian. Gamma ray is in API units and sonic in microsec/ft.

the north during the Kinderscoutian. The lack of slope or delta top deposits at Merksplas and in the Loenhout area shows that the delta did not reach these regions. The coarser material at DZH15 is part of a turbidite lobe. The delta top deposits at Poederlee are only 7 m thick with a minor distributary channel sandstone. At Turnhout, the top of the Kinderscoutian consists of about 40 m of sand-dominated sediments which are probably stacked channels. The thickest individual sandbody is 15 m thick. A paleogeographical cartoon of the late Kinderscoutian is shown on Fig. 4C.

### *Marsdenian*

During this stage, a second turbidite-fronted delta started to prograde from the area to the southwest of the studied wells. In these wells the Marsdenian consists of basal sediments with strong marine influences towards the top. The sediments are generally fine-grained except for some turbiditic material at Turnhout and DZH15 and a thin (1 m) sandstone bed at Poederlee. The thickness of the Marsdenian is limited when compared to the Kinderscoutian and Yeadonian. It varies between 71 m in Turnhout and less than 25 m in the Loenhout area. The thickness of the Kinderscoutian varies between 290 m in Turnhout and 104 m in Poederlee, while the Yeadonian has a thickness of 117 m in Turnhout and 85 m in the Loenhout area (Lange-naecker & Duser in press). This reduced thickness is partly explained by the basal setting of Marsdenian sedimentation in the studied area. The paleogeographical cartoon is shown on Fig. 4D.

### *Yeadonian*

The sedimentological environment changes into a delta slope setting and further into a delta plain environment during the early Yeadonian. The delta top sediments have a limited thickness at Turnhout, Poederlee and Merksplas. In the Loenhout area they consist of more than 30 m of distributary channel sandstones, interdistributary deposits and a number of minor coarsening upward cycles, probably formed by delta-lobe shifting. Fig. 4E shows the paleogeography during the early Yeadonian.

As in the Pennine Basin (Collinson 1988, Steele 1988), these turbidite-fronted deltas constitute the major basin fill. The Marsdenian-early Yeadonian delta clearly overstepped the Kinderscoutian delta and prograded much further to the north. These deeper-water deltas are followed by a number of shallow-water sheet deltas which repeatedly prograded towards the north and northeast. The log-response corresponds to deltaic cycles which start with a lower coarsening-upward part frequently having at the basis a marine or marine-influenced band (Fig. 6). These are the pro-delta deposits.

The delta plain consists of a mixture of mouth bar deposits, crevasse splays, finer-grained interdistributary lake and overbank deposits and also sand-filled distributary channels. Four of such sheet deltas could be differentiated in the western part of the Campine Basin between the base Yeadonian and the top of the Ransart Member.

The first two sheet delta sequences form the remaining part of the Yeadonian. Delta I did not reach the Loenhout area where finer-grained pro-delta deposits were deposited (Fig. 4F). The second delta prograded over the whole of the studied area (Fig. 4G). The thickness of these deltaic cycles is generally 20 to 30 metres.

#### *Ransart Member (earliest Westphalian A)*

Two other sheet delta sequences were recognised in the early Westphalian A sediments. Again the first of these two did not prograde very far to the north as indicated by the lack of delta-plain deposits in Merksplas (Fig. 4H). The last sheet delta was correlated through all the wells. The paleogeographical cartoon is shown in Fig. 4I.

The repeated progradation recorded in the sheet deltas is interrupted by the best marker bed for log-correlation purposes in the western Campine: the Finefrau Nebenbank Marine Band, corresponding to a eustatic sea-level rise. The eustatic nature of this and other similar transgressions is inferred from the very widespread occurrence of the marine bands throughout northwestern Europe (Read 1991). The widespread sandstone in the upper part of the Ransart Member, above Finefrau b and underlying Finefrau Nebenbank, is a 10 to 20 m-thick, sheet-like channel sandstone resembling the Rough Rock Sandstone in the Pennine Basin (Collinson 1988, Bristow 1988). The latter, however, is situated under the Sarnsbank (*Gastrioceras subcrenatum*) rather than the Finefrau Nebenbank Marine Band (*Gastrioceras listeri*). Both sheet-like channel sandstones were formed on fluvial plains, dominated by a large number of broad and shallow braided rivers (Bristow 1988). A schematic paleogeographical cartoon for the western Campine is given in Fig. 4J and a few examples

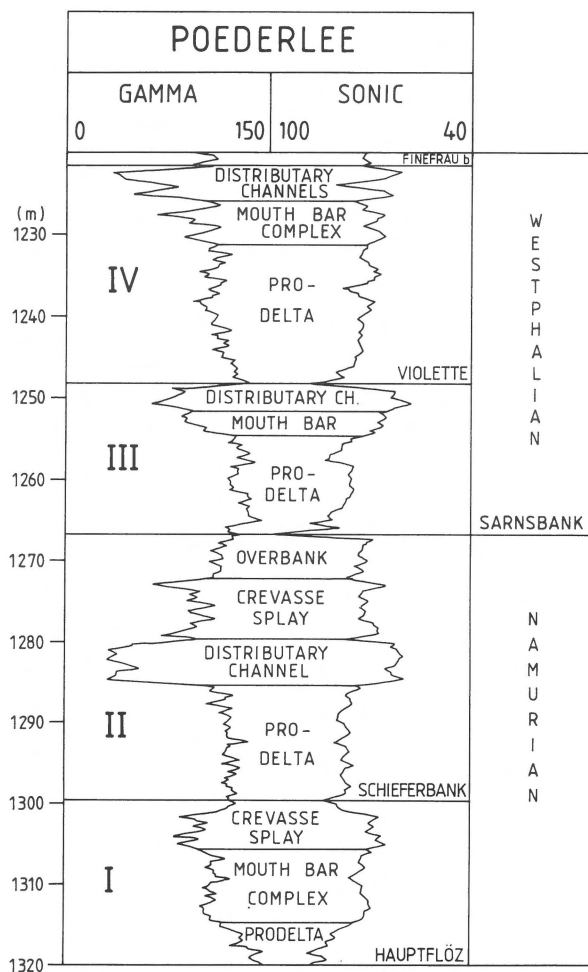


Fig. 6. Yeadonian and lowermost Westphalian sheet delta sequences (I-IV) in the Poederlee well. Gamma ray is in API units and sonic in microsec/ft.

of the log-response of the sandstone are shown in Fig. 7. A paleogeographical reconstruction for this stratigraphical interval was presented for the South-Limburg area by Bless (1973).

The classical development of Coal Measures on a delta plain environment starts above this marine band, in the Westphalian A Floriffoux Member.

#### Discussion

The sedimentology of the Namurian in the western part of the Campine Basin is summarized in Fig. 8. This succession of turbidite-fronted deltas and

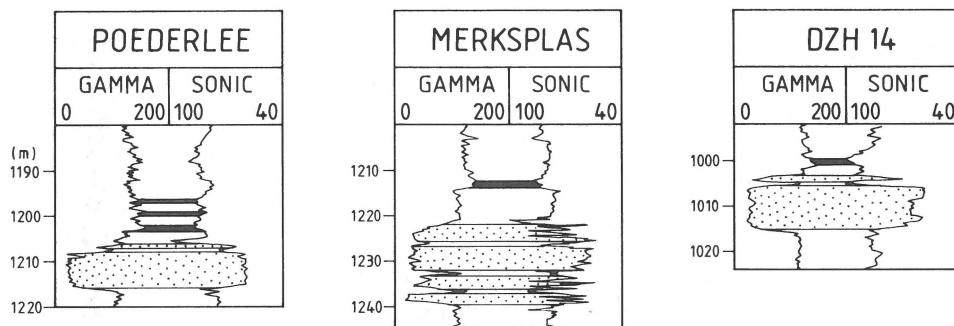


Fig. 7. Examples of the Finefrau Nebenbank Marine Band with underlying sandstone (stippled). Black bands indicate acme phase of marine incursion. Gamma ray is in API units and sonic in microsec/ft.

shallow-water sheet deltas corresponds very well to the Namurian sequence in the Gainsborough Trough as described by Steele (1988). The timing of the basin-fill is different however. The hot shales in the Gainsborough Trough are of Pendleian age while those in the Campine are somewhat younger (Arnsbergian to Alportian). An anoxic sedimentation environment as explanation for the hot, organic-rich shales is proposed by a number of authors (Steele 1988, Read 1991).

Restricted basinal conditions existed in between uplifted shoals composed of karstified Visean carbonates. The turbidite-fronted deltas are of Arnsbergian to Alportian age in the Gainsborough Trough in contrast to the Kinderscoutian to early Yeadonian age in the western Campine. The sheet deltas started during the Kinderscoutian in the Gainsborough Trough but only during the Yeadonian in the western Campine. This shows that in the western part of the Campine Basin near the Lond-Brabant Massif the filling up of the sedimentation space occurred much later than in the marginal parts of the Pennine Basin. Marshes as proven by seat-earths or coal seams only developed during the Westphalian in this part of the Campine Basin, in contrast to the eastern part where they are also recorded from the late Namurian.

The Namurian sediments in the studied area were mainly derived from the emerged London-Brabant Massif although the rising Variscan mountains to the south also partly sourced the sedimentation (Ziegler 1990). The depocentre of the basin was situated not far to the north of the studied

area as illustrated by the thick Namurian sequence in the Dutch Rijsbergen well (Van Wijhe & Bless 1974) and the more than 278 m thick Yeadonian in the Meer well (Fig. 2; Vandenberghe et al. 1988). The thickness increase towards the north is apparently discontinuous over the Hoogstraten fault as described by Vandenberghe (1982, 1984). Also in the eastern part of the Campine Basin, the Namurian attains a greater thickness. Almost 700 m of Namurian strata were found in the Wijvenheide borehole (43 km SE of Poederlee; Delmer 1963). This all shows that the studied area is situated in a marginal part of the Namurian basin to the north of the Brabant Massif. The thickness reduction towards the west and southwest in the studied area suggests that the border of the sedimentation area at the end of the Namurian was situated only a few tens of kilometres to the west or southwest of the Merksplas-Turnhout region. The Poederlee and Loenhout-Heibaart domes are extraordinary settings in the basin since they represent Dinantian reefal build-ups on tectonically controlled intra-basinal highs. The thickness of the Namurian strata in these areas is therefore not relevant for the overall trends in the basin since the local Dinantian topography influenced the sedimentation.

## Conclusions

The Namurian basin-fill history in the western part of the Campine Basin corresponds very well to the sequence of the marginal Gainsborough Trough in

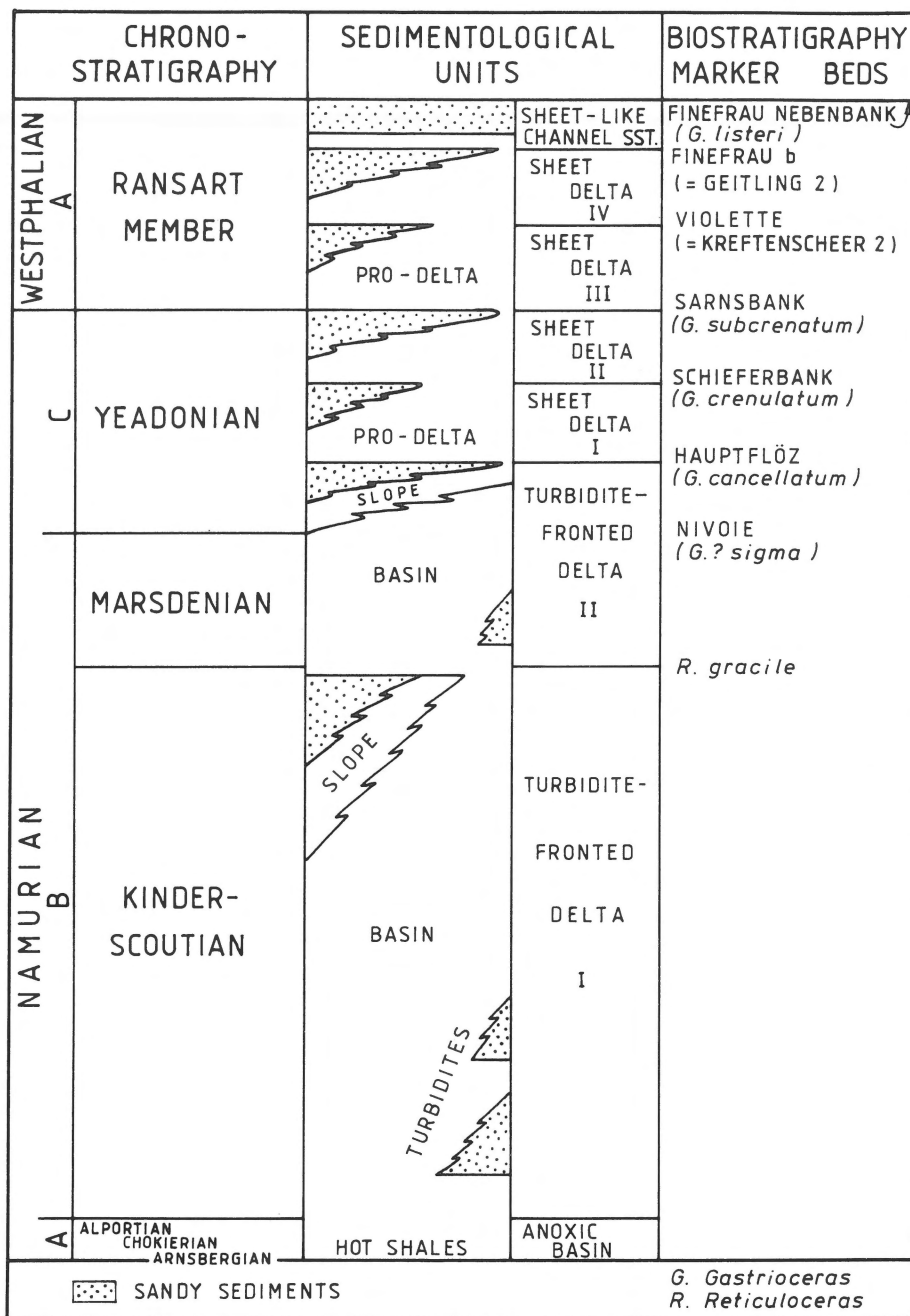


Fig. 8. Summary of the Namurian and earliest Westphalian sedimentological history in the western Campine.

the English Pennine Basin. The latter, which was a deeper basin, was nevertheless filled up much earlier in the Namurian.

A number of major sedimentary sequences could be correlated between the studied wells in

the western Campine. A basinal anoxic deposition period is followed by a major basin-fill period consisting of two turbidite-fronted deeper-water deltas. From the Yeadonian onwards, a succession of shallow-water sheet deltas developed in the west-

ern Campine. The Finefrau Nebenbank sandstone, an areally extensive braided river sediment deposited on top of this sequence, announced the development of extensive coal deposits during the remaining part of the Westphalian.

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