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PETROPHYSICAL STRATIGRAPHY OF THE NAMURIAN AND LOWERMOST WESTPHALIAN IN THE WESTERN PART OF THE CAMPINE BASIN.

by

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ABSTRACT

In the western part of the Campine Basin the Turnhout well (KB 120) constitutes the only cored borehole with a complete Namurian section. Some additional boreholes were geophysically logged in this area during the last 15 years. These logs can be used for a detailed stratigraphical interpretation of the Namurian and lowermost Westphalian in the West of the Campine Basin. The thickness of the Namurian varies between 240 m at Poederlee and 502 m at Turnhout. The early Westphalian Ransart member attains 56 m only in Poederlee, but 110 m in Turnhout and even 160 m further to the north in Meer. Thickness variations during the lower part of the Namurian are due to sedimentation on a paleorelief. For the upper Namurian and the Westphalian they are explained by tectonically driven differential subsidence.

KEY WORDS

Geophysical logs, Namurian, Stratigraphy, Campine Basin (Belgium).

1. INTRODUCTION

During the last decade, geological reconnaissance and research in the western part of the Campine Basin was focussed on the Dinantian limestones which form an important reservoir, prospected for geothermics and gas storage. Some interest for hydrocarbons arose from the Dinantian gas show in the Merksplas well (fig.1). A biostratigraphical review of the older Woensdrecht, Heibaart, Turnhout, Kessel and Booischot coreholes was given in Bless *et al.* (1976). A sedimentological, diagenetical and geochemical study of the Dinantian in these boreholes and in the Poederlee well (KB 170) is carried out by Ph. Muchez and co-authors (Muchez *et al.*, 1987, 1991 ; Muchez and Viaene, 1991). The structural outline of the top of the Dinantian in this area was dealt with by Dreesen *et al.* (1987). The overlying Namurian in the western Campine however, has received less attention. The only borehole with a completely cored Namurian section is the Turnhout well (KB 120) (Grosjean *et al.*,1955 ; Delmer, 1962). A model for the Namurian transgression in the Campine, based on the Woensdrecht, Turnhout, Heibaart and Wijvenheide wells is given in Bouckaert (1967).

The interest in the Dinantian is to a large extent explained by the economic reservoir potential of these karstified limestones in the Campine Basin. A number of new boreholes were drilled in the last 15 years by the Belgian Geological Survey and Distrigaz, exploring the karstified top of the Dinantian limestones. Some of these wells intersected hundreds of meters of overlying Silesian rocks. Cores are in most cases not available from the Namurian and Westphalian A, but a number of geophysical wireline logs were recorded in almost every well. An attempt has been made to use these logs for a stratigraphical interpretation of the Namurian and the early Westphalian Ransart member, delineated by the Sarnsbank and Finefrau Nebenbank Marine Bands (as defined by Paproth *et al.*, 1983) (tab.1). A similar correlation scheme between petrophysical logs and biostratigraphical data has already been presented for the Upper Cretaceous of the Campine Basin (Felder *et al.*, 1985).

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Location	Campine Basin nr (KB)	Distrigaz number (DZ)	Belg. Geol. Survey Archive nr	Year drilled	Lambert coordinates	Total depth (in m)	Top above MSL (in m)	Commissioned by
Turnhout	120	-	17E225	1953-55	X 190.573 Y 223.829	2706	30	City/ INICHAR BGS
Rijkevorsel (Heibaart)	143	DZH4	7E200	1980	X 174.617 Y 228.569	1356	27	Distrigaz
Meer	149	-	7E205	1980-81	X 177.378 Y 237.304	2515	13	BGS
Beerse (Merksplas 1)	165	-	17W265	1983	X 181.938 Y 225.856	1761	34	BGS
Poederlee	170	DZP1	30W371	1984	X 182.667 Y 212.654	1690	16	Distrigaz/ BGS
Rijkevorsel	202	DZH14	16E176	1989-90	X 175.610 Y 227.355	1408	32	Distrigaz/ BGS
St.-Lenaarts	203	DZH15	7E223	1990	X 172.063 Y 228.543	1390	28	Distrigaz/ BGS

Table 1. Overview of studied wells.

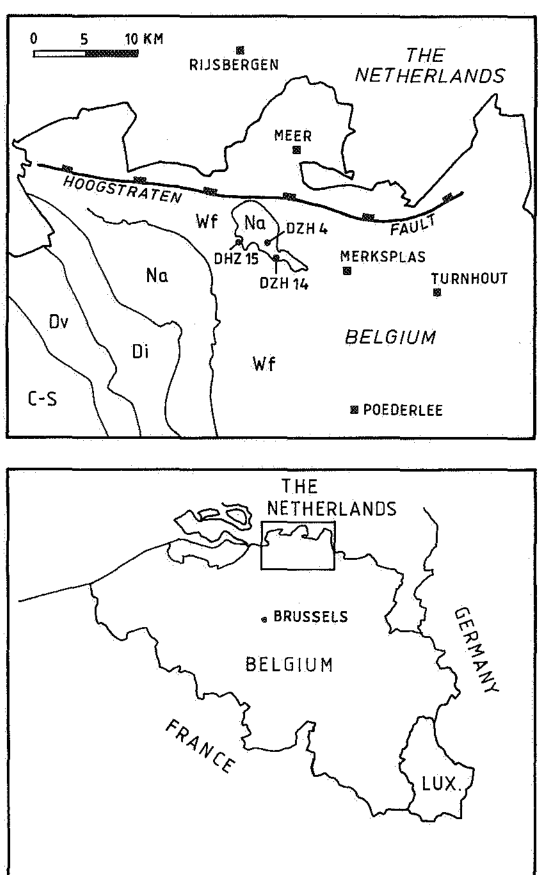

Figure 1. Location of the wells mentioned in the text. The Hoogstraten fault is indicated as well as the age of the Paleozoic subcrop (C-S : Cambro-Silurian ; Dv : Devonian ; Di : Dinantian, Na : Namurian : Wf : Westphalian);

2. GENERAL STRUCTURE AND STRATIGRAPHY

In the western part of the Campine Basin, rocks of Middle Devonian to Westphalian age subcrop underneath the base of the Upper Cretaceous. The general structural trend of the Devonian-Carboniferous sequence is NNW-SSE, as observed for the direction of strike and faults. An exception to this general rule is formed by the E-W striking listric-shaped Hoogstraten fault (Vandenberghe, 1982, 1984 ; Vandenberghe *et al.*, 1984) which divides the area in a southern part where mainly Westphalian A and older rocks subcrop and a northern part where also the younger Westphalian is preserved (fig.1). To the south of the Hoogstraten fault an elongated NNW-SSE trending structural high exists on which the Loenhout-Heibaart and Poederlee domal reefs were formed in the uppermost Viséan (Muchez and Langenaeker, 1990 ; Muchez *et al.*, 1991). Above

Horizon	Top	Bottom	Goniatites	Strat. Interpretation
1	1659.90	1660.60	*G. cf. subcrenatum*	base Ransart mbr. (G2) Sarnsbank M.B.
2	1668.22	1668.52	*G. crencellatum*	Yeadonian (G1) Hauptflöz M.B.
3	1773.25	1777.05	*G. ? sigma*	top Marsdenian (R2c2), base Yeadonian
4	1793.45	1795.10	*R. superbilingue* *Ht. divaricatus*	Marsdenian (R2c1)
5	1803.40	1813.30	*R. metabilingue* *R. bilingue*	Marsdenian (R2b)
6	1846.09	1848.03	*R. gracile* *Hd. ornatum*	Marsdenian (R2a)
7	2078.45	2106.60	*R. regularum*	Kinderscoutian (R1b2)
8	2113.00	2116.00	*R. aff. stubblefieldi* *H. moorei* *R. subreticulatum* *R. hodsoni* *R. nodosum*	Kinderscoutian (R1b)
9	2118.50	2120.00	*Homoceratoides sp.*	Kinderscoutian (R1a ?)
10	2122.30	2122.60	indeterminable	
11	2138.47	2138.52	indeterminable	
12	2141.80	2142.75	*Ht. prereticulatus*	Alportian (H2c)
13	2147.25	2151.30	*H. subglobosum* *H. aff. eostriolatum* *H. diadema* *H. beyrichianum*	Alportian-Chokierian (H2c/H1)
14	2152.50	2153.00	indeterminable	
16	2156.00	2160.00	*E. bisulcatum*	Arnsbergian (E2c)

Table 2. Goniatite data and stratigraphic interpretation from the Turnhout well (KB 120) (identification J. Bouckaert *in* Grosjean *et al.*, 1955). Stratigraphical interpretation based on Paproth *et al.* (1983).
(E) *Eumorphoceras* - (H) *Homoceras* - (Ht) *Homoceratoides* - (R) *Reticuloceras* - (Hd) *Hudsonoceras* - (G) *Gastrioceras*.

the Heibaart dome only a thin Namurian cover has been preserved.

The stratigraphical subdivision of the Namurian and earliest Westphalian is mainly based on the occurrence of goniatite-bearing marine bands. These represent temporary marine incursions. The goniatites contained in the bands provide a possible age indication ; the rhythm of marine incursions also determines the lithological sequence and partly reflects sea level fluctuations. The scheme of the goniatite biozones as it is presently used was established for the British basins by Ramsbottom (1969, Ramsbotton *et al.*, 1978). This goniatite zonation is also applicable for the Upper Carboniferous of Belgium (Bouckaert, 1961, 1971). An overview of the biostratigraphical framework for the Namurian and Westphalian is provided by Paproth *et al.* (1983). A cyclical recurrence of marine bands has been described in greater detail for the Southern Belgian coal basins by Fiege and Van Leckwijck (1964).

The boundary between the Namurian and Westphalian is the Sarnsbank Marine Band, identified by the occurrence of the goniatite species *Gastrioceras subcrenatum.* This marker bed is easily traced on the wireline logs due to its high uranium content. The Namurian-Dinantian boundary is more problematic and will be dealt with in section 5.1.1.. A log correlation scheme covering this interval and related to Dinantian sedimentary environments has been provided for the Heibaart dome by Bless *et al.*(1981).

3. BIOSTRATIGRAPHICAL DATA

Some biostratigraphical data for the Namurian are available from two older boreholes in the western part of the Campine Basin (Bless *et al.*, 1976). The Namurian traversed in the Woensdrecht borehole (The Netherlands) was assigned an Alportian (H2) to Kinderscoutian (R1) age, based on macroflora. The Pendleian

(E1) to Chokierian (H1) then should be missing or condensed to the lowest 15 m of the Namurian section.

In the Namurian of the Turnhout borehole (KB 120), 15 goniatite-bearing levels were found. The stratigraphically important goniatites are listed in table 2. The only useful recent biostratigraphical data come from the Poederlee well (KB 170). A core was taken in this borehole between 1354.8 m and 1365.2 m which yielded *Donetzoceras sigma* (or *Gastrioceras* ? *sigma*) as well as *Reticuloceras superbilingue*. These goniatites either belong to the topmost Marsdenian or to the basal Yeadonian (Bouckaert *et al.*, 1987).

4. GEOPHYSICAL BOREHOLE LOGS

Recent exploration boreholes in the western Campine encompass Meer (KB 149), Merksplas (KB 165), Poederlee (KB 170) and a number of boreholes on the Loenhout-Heibaart gas storage site (location on fig. 1, tab. 1). Geophysical wireline logs were recorded in all wells. However a complete logging suite is not always available: some of these logs were recorded in production wells and are therefore discontinuous. Part of the logs were recorded in cased boreholes. These logs nevertheless provide valuable correlation data.

Two logged parameters, which were recorded in most wells, were used for the stratigraphical correlations : the natural gamma ray log and the sonic log. Both logs allow to differentiate sandstones and shales and are good indicators of marine bands which are generally enriched in uranium and have slow travel times (Schuster *in* Hedemann *et al.*, 1984). The typical log response for marker beds can be recognised over a major part of the original depositional basin, as has been demonstrated for the Westphalian by Schuster and Schmitz (1989).
The logs from the boreholes in which the Namurian and Westphalian A Ransart member were interpreted and correlated are shown in figure 2. A granulometric log was drawn for the Turnhout well (KB120) on the basis of the original description by Grosjean *et al.*-(1955). This log is comparable to the geophysical measurements from the other wells and can therefore be used for correlation purposes.

5. THE NAMURIAN AND LOWERMOST WESTPHALIAN IN THE WESTERN CAMPINE BASIN.

5.1. Namurian

5.1.1. Pendleian to Alportian

The Pendleian (E1) apparently is missing in the Campine Basin as well as in the other Belgian basins (Bouckaert and Higgins, 1963 ; Bouckaert, 1967 ; Paproth *et al.*, 1983).
Recently however the Pendleian was reported with some reservation for the St.-Ghislain borehole by Delmer (1988) as there was no apparent time break between Viséan and Namurian at Mont des Groseillers in Blaton (Bouckaert *et al.*, 1961). However, these localities are located in the central part of the "Auge hennuyère", a rapidly and more continuously subsiding part of the Namur Synclinorium to the South of the Brabant Massif. The oldest recognised Namurian in the western Campine is of Upper Arnsbergian (E2c) age as was proven by the presence of *E. bisulcatus* at 2160 m in the Turnhout well (determinations by Bouckaert *in* Grosjean *et al.*, 1955 ; Delmer, 1962, 1963).

In the same well, the marine band between 2147.25 m and 2151.30 m contained *H. subglobosum, H. diadema* and *H. beyrichianum*, which are assigned to the Chokierian (H1) (horizon 13, tab.2). *H.* aff. *eostriolatum* was also recognised at this horizon, as well as in the overlying marine band at 2141.80-2142.75 m. At the latter horizon this species occurred together with *Ht. prereticulatus*. This association points to the Upper Alportian (H2c) biozone.

This reduced Arnsbergian to Alportian sequence is formed by an alternation of ampelitic shales (black organic-rich pyritic shales which, when subject to alteration, turn into light coloured to violaceous porous fissile shales) with silicified limestones corresponding to the high radio-active basal Namurian "hot shales" as recognised on the geophysical logs of the other boreholes. A Schlumberger Faciolog which was calculated for the Paleozoic of the Merksplas well confirms this correlation (Vandenberghe *et al.*, 1984).

The recognition of the Dinantian-Silesian boundary which is normally based on biostratigraphical criteria is not always obvious in the studied wells. Although the Viséan mainly consists of massive limestone beds, some Namurian type hot shales are intercalated in the top part, either produced by post-burial endokarstic dissolution and weathering or superficial karstification or by synsedimentary clays. In the basal Namurian, silicified limestone beds occur between the radioactive shales. These transition beds are marked by a strong

	KB 120	KB 170	KB 165	KB 202	KB 203	KB 143	KB 149
Base Cretaceous	1000	773	1005	991	987	1003	1186
Finefrau Nebenbank M.B.	1550	1203	1214	1000	991		2075
Finebrau b M.B.	1579	1221	1246	1024	1009		
Violette M.B.	1606	1248	1274	1047	1030		
Sarnsbank M.B.	1660	1266	1297	1066	1050		2235
Schieferbank M.B.	1690	1300	1329	1093	1086		
Hauptflöz M.B.	1719	1319	1361	1118	1099	1022	
Nivoie M.B.	1777	1358	1400	1156	1137	1048	
Base Marsdenian	1848	1384	1441	1180	1161	1072	
Base Kinderscoutian	2138	1496	1614	1310	1325	1237	
Top Dinantian	2162	1521	1630	1319	1330	1240	

Table 3. Depth location (in m) of important marker beds in the studied boreholes. Turnhout (KB 120), Poederlee (KB 170), Merksplas (KB 165), DZH14 (KB 202), DZH15 (KB 203), DZH4 (KB 143), Meer (KB 149).

diagenetic alteration and by an ongoing karstification and a paleorelief formation of the top Viséan. The top Dinantian could nevertheless be recognised in all the wells on the basis of the sonic log readings or the dipmeter which shows a typical drape pattern of the basal Namurian on the Viséan paleorelief (Vandenberghe *et al.*, 1986). In Turnhout the boundary was set at 2162 m by Grosjean *et al.* (1955), which remarkably fits the top Dinantian as established in Merksplas on the basis of petrophysical data. So at Merksplas and Poederlee the boundary is included in the high gamma ray interval (fig. 2). In the Loenhout-Heibaart area however, the hot shales are strongly reduced in thickness (tab. 4) , therefore here the Dinantian-Silesian boundary simply coincides with the top of the massive limestones.

5.1.2. Kinderscoutian

At Turnhout the Kinderscoutian was proven by the presence of several goniatites from the R1b biozone at the 2113 to 2116 m marine band (horizon 8, tab. 2). The upper part of the Kinderscoutian in the Turnhout and Poederlee wells is formed by massive sandstone bodies, which are reminiscent of the "Grès d'Andenne" from the Southern Belgian basin (Van Leckwijck and Ancion, 1947). At Merksplas and the Loenhout-Heibaart wells these sandstone units are absent except for a thin sandstone bed in Merksplas and DZH4 (fig. 2).

5.1.3. Marsdenian

The presence of *R. gracile* and *Hd. ornatum* at the 1846.09 to 1848.03 m marine band marks the base of the Marsdenian (R2a) in Turnhout (horizon 6, tab. 2). Higher up, at the 1803.40-1813.30 m horizon *R. bilingue* and *R. metabilingue* were recognised (horizon 5, tab. 2). These goniatites correspond to the R2b biozone. *R. superbilingue* (R2c) was interpreted at the 1793.45-1795.10 m marine band (horizon 4, tab. 2).

The Marsdenian was generally found to be less sandy than the Kinderscoutian or younger Yeadonian. One thin sandstone bed could be correlated between Turnhout and Poederlee however (fig. 2).

5.1.4. Yeadonian

The base of the Yeadonian is formed by the Nivoie Marine Band (Paproth *et al.*,1983). This marker bed was probably found in the Turnhout well at the 1773-.25-1777.05 m horizon. Here the problematic goniatite species *D. sigma* was interpreted (=*Gastrioceras* ? *sigma* in the original interpretation). Although this

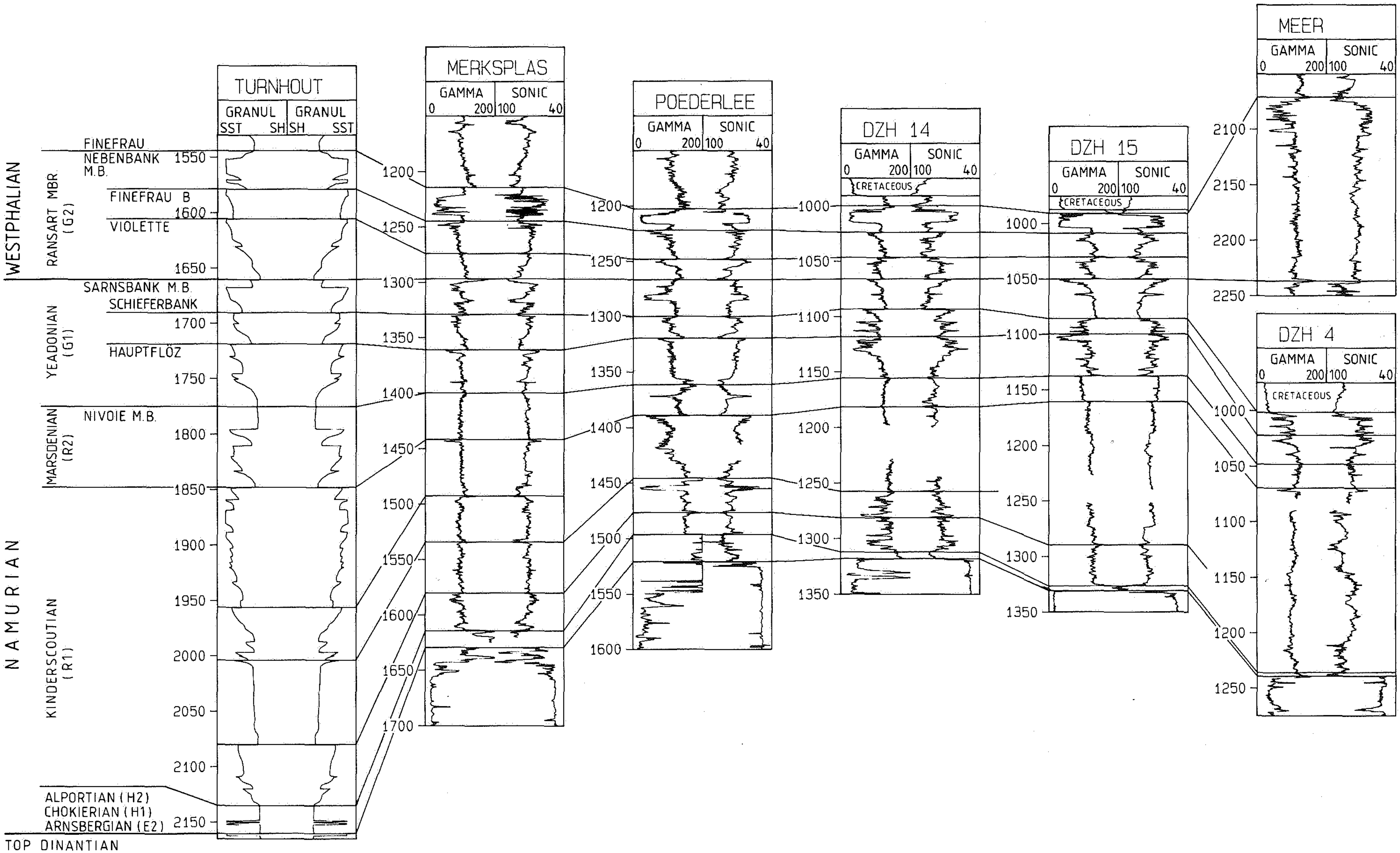

Figure 2. Log correlations for the Namurian and lowermost Westphalian in the Western Campine. See text for detailed explanation (Turnhout well ; SST : sandstone, SH : shale)

goniatite has been assigned to the R2c2 biozone (Paproth *et al.*, 1983), the Marsdenian-Yeadonian boundary is kept at this level for practical correlation purposes. The marine band can be traced through all the boreholes at the top of one of the few fining upward sequences in the Namurian of the western Campine Basin. An exception to this is the DZH15 well, where the marine band occurs at the top of a coarsening upward sequence (fig. 2).
The biostratigraphical data for the Namurian-Westphalian transition beds in the Turnhout well are confusing. In the original interpretation of Bouckaert in Grosjean *et al.*(1955), the Hauptflöz Marine Band was interpreted at 1668 m and the Sarnsbank Marine Band at 1660 m (horizons 2 and 1, tab. 2). These two marker beds are generally much further apart with in between also the Schieferbank Marine Band as shown for the Namurian in the South Limburg area (Kimpe *et al.*,1978). The goniatite fossils are poorly preserved at these levels and therefore do not allow an unequivocal determination. The Turnhout data were revised in Delmer (1962, 1963). Here the 1660 m and 1668 m levels are interpreted as Schieferbank and Hauptflöz while Sarnsbank was situated at the 1550 m level. The initial interpretation of *G. crencellatum* was confirmed for the 1668 m level, but *G. crenulatum* was interpreted at 1660 m instead of previously *G.* cf. *subcrenatum*. As in Vandenberghe *et al.* (1988), we accept the more plausible original interpretation of Sarnsbank at 1660 m based on a comparison with the topmost Namurian in the eastern part of the Campine Basin and the South Limburg area. The lower 1668 m marine band is probably already part of the Sarnsbank marine incursion. The most likely position of the Schieferbank and Hauptflöz horizons in the Turnhout well is at approximately 1690 m and 1719 m respectively.

A widely known sandstone generally occurs under Sarnsbank, which was also described in the Pennine basin (Rough Rock sandstone *in* Bristow ; 1988, Collinson, 1988). In the western Campine a similar sandstone is situated at the top of a coarsening-upward sequence and the log response is generally less "blocky" than that of the overlying Finefrau Nebenbank sandstone (see section 5.2.).

5.2. Ransart Member (Westphalian A)

The easiest to correlate log event in the Silesian of this area is the Finefrau Nebenbank Marine Band overlying a massive sandstone with a typical "blocky" log response. This marine band forms the base of the Floriffoux member and the top of the G2 goniatite biozone. Finefrau Nebenbank is situated in the Turnhout well at the 1550 m level, where no goniatites were described but other fossils are indicative for the weakly marine environment in this band. This horizon could without any problems be traced in the Merksplas, Poederlee, DZH14 and DZH15 wells. In the other wells of the Loenhout area, close to the crest of the Heibaart dome, it is removed by the Pre-Cretaceous erosion.

Between the Finefrau Nebenbank and Sarnsbank Marine Bands, three depositional cycles can be identified in the western Campine. The top of the middle cycle is formed by the Finefrau b (=Geitling 2=St.--Nicholas) marine influenced band ; the top of the lower cycle probably corresponds to the Violette (=Kreftenscheer 2) marine influenced band as interpreted in the eastern part of the Campine Basin (Delmer, 1963) and in the South Limburg area (Kimpe, 1961).

6. LOCAL PALEOGEOGRAPHICAL IMPLICATIONS

A summary of the depth locations of the most important Namurian and early Westphalian marker beds in the studied boreholes is given in table 3. The depths are as measured in the well and thus not corrected to vertical depth in the deviated wells (Poederlee,DZH14,DZH15). Table 4 lists the thickness for the Ransart member and the Namurian subdivisions in the seven wells. These data are corrected for the effects of deviation.

The Meer well (KB149) in the western Campine shows a different picture for the Silesian sedimentary history (Vandenberghe *et al.*, 1988). This borehole was not integrated in the larger part of the study because the Namurian section was neither logged nor cored. The Finefrau Nebenbank and Sarnsbank Marine Bands were identified at 2075 m and 2235 m respectively. The resulting thickness of the Ransart member is thus 160 m at Meer.

The 278 m of Namurian traversed in the well are all of Yeadonian age (Vandenberghe *et al.*, 1988). This would imply a strong thickness increase towards the north of at least the youngest Namurian. These observations are compatible with the results of the Dutch Rijsbergen well where a thick Namurian sequence was found (Van Wijhe and Bless, 1974). The Namurian thickness increase from the studied boreholes towards the Meer and Rijsbergen wells was interpreted by Vandenberghe (1982, 1984) to be discontinuous at the Hoogstraten listric growth fault (fig. 1).

Important thickness variations also exist within the studied area. The total thickness of the Namurian in Turnhout is more than the double of that in DZH14. The Namurian and earliest Westphalian on the dome structures of Loenhout-Heibaart and Poederlee are clearly reduced in comparison with Merksplas and certainly Turnhout. This thickness reduction can be

	KB 120	KB 170	KB 165	KB 202	KB 203	KB 143	KB 149
Ransart member	110	56	83	64	58		160
Yeadonian	117	86	103	86	85		> 278
Marsdenian	71	26	41	23	24	24	
Kinderscoutian	290	104	173	124	164	165	
Alportian Chokierian Arnsbergian	24	24	16	9	4	3	
Total Namurian	502	240	333	242	277		

Table 4. Vertical thickness (in m) of the Ransart member and the Namurian subdivisions in the studied boreholes. Turnhout (KB 120), Poederlee (KB 170), Merksplas (KB 165), DZH14 (KB 202), DZH15 (KB 203), DZH4 (KB 143), Meer (KB 149).

partly explained by the existence of a Dinantian paleorelief during the early Namurian. Dreesen *et al.*(1987) also supposed small-scale sagging phenomena during the Namurian in structural trenches affecting the underlying Dinantian. Ongoing karstification of these Dinantian limestones was seen as the agent responsible for local subsidence increases. This assumption remainshypothetical. The major controlling factor however is a tectonically driven differential subsidence throughout the Namurian and the Lower Westphalian A. This is proven by the consistent thickness reduction of almost all stratigraphical intervals in the Loenhout and Poederlee area (tab. 4). A similar mechanism was invoked to explain thickness and facies variations in the Viséan of the western Campine (Muchez and Langenaeker, 1990). A filling up of sedimentation space on a paleorelief would have a marked influence on the lowermost part of the Namurian only.

The latter effect can be observed in the thickness differences of the Arnsbergian to Alportian hot shale sequence. These mudstones, which were formed by the accumulation of organic-rich clayey material, are 24 m thick at Turnhout and only a few metres on the crest of the Heibaart dome. An anomalous situation exists at the Poederlee dome were the sequence attains the same thickness as in Turnhout. The base of these shales becomes progressively younger when climbing on the Heibaart structure. The same was the case towards the marginal parts of the Campine basin as illustrated by the dutch Woensdrecht borehole where the oldest found Namurian is of Alportian or even Kinderscoutian age.

Paleogeographical reconstructions for these stratigraphic intervals show a transition from basinal mudstones to turbidite-fronted delta sequences and shallow-water sheet-deltas (Langenaeker and Dusar, 1992).

7. CONCLUSIONS

The geophysical wireline logs which were recorded in the exploration wells of the Western Campine Basin are useful tools for a stratigraphical interpretation of the Namurian and Westphalian A, even when no cores or biostratigraphical data are available. A log-stratigraphical framework has been established which can be used as a reference for the interpretation of other or new wells.

Important thickness variations in the Namurian and lowermost Westphalian Ransart member exist in the studied area. The influence of the Dinantian Poederlee and Heibaart domes on the observed thicknesses is obvious. To a large extent however, tectonically driven differential subsidence has controlled the sedimentation in the early Silesian estern Campine Basin as had already been described for the Dinantian (Muchez and Langenaeker, 1990).

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