Geologie en Mijnbouw 66: 313–326 (1987)

Sedimentology, coalification pattern and paleogeography of the Campine-Brabant Basin during the Visean

Ph. Muchez[1, 2], W. Viaene[1], M. Wolf[3] & J. Bouckaert[4]
[1] *Katholieke Universiteit Leuven, Fysico-chemische Geologie, Celestijnenlaan 200 C, B-3030 Heverlee, Belgium;* [2] *Research assistant N.F.W.O.;* [3] *R.W.T.H. Aachen, Lochnerstrasse 4–20, D-5100 Aachen, Germany;* [4] *Geological Survey of Belgium, Jennerstraat 14, B-1040 Brussels, Belgium*

Received 9 February 1987; accepted in revised form 2 September 1987

Key words: Sedimentology, coalification, paleogeography, Campine-Brabant Basin,Carboniferous, block-faulting.

Abstract

During the Visean, four major lithological and biostratigraphical sequences formed in the Campine-Brabant Basin, north of the London-Brabant Massif. The Visean strata are mainly composed of carbonates. The first sequence was formed during the Early Moliniacian. At this time, the Heibaart area was a structural high. During the late Moliniacian, when the second sequence was formed, the whole Campine-Brabant Basin was characterized by carbonate sedimentation on a broad shallow shelf. The third sequence formed during the Livean. Sedimentation was restricted in the Turnhout and Halen area. In the Heibaart area, sediments were deposited in an environment with open water circulation. During the Early Warnantian the fourth sequence was formed. Reef mounds developed in the Poederlee-Heibaart area and probably also in the Turnhout area. The sediments penetrated by the Halen borehole were deposited alternately in an open and in a restricted environment. The thickness variations of the different sequences and the facies distribution indicate that synsedimentary faults were active in the Campine-Brabant Basin during the Visean. A comparison with the Upper Westphalian of the Campine-Brabant Basin, and with the Lower Carboniferous of northern England suggests a block-faulted structural framework for the Campine-Brabant Basin during the Visean.

The paleogeothermal gradient of the Visean and the Namurian-Westphalian A strata of the western zone of the Campine-Brabant Basin has been calculated. The coalification data at the top of the Visean confirm the existence of a fault zone near the London-Brabant Massif and of a shelf bordered to the north by a listric fault.

Introduction

The Visean of the Campine-Brabant Basin, north of the London-Brabant Massif, is known only from boreholes. Lithological descriptions have been given by Lohest et al. (1903), Stainier (1932), Delmer (1962) and Legrand (1964). Facies interpretations of the uppermost 20 m of the Visean strata of the Heibaart boreholes have been published by Bless et al. (1981) and of the Visean strata of the Booischot, Halen and Turnhout boreholes by Muchez et al. (1985). The top of the Dinantian has been

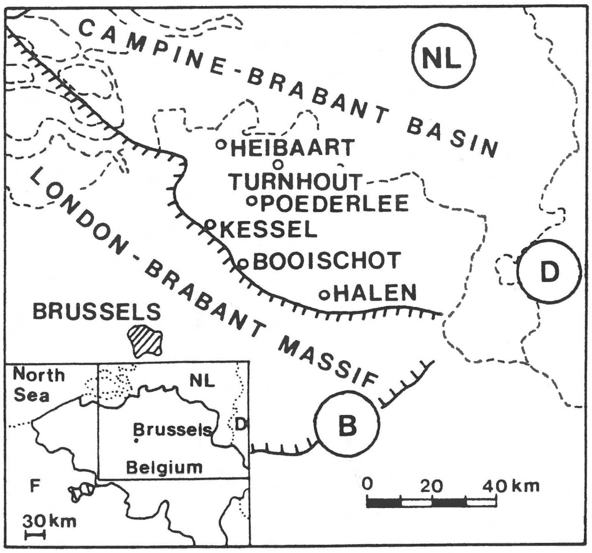
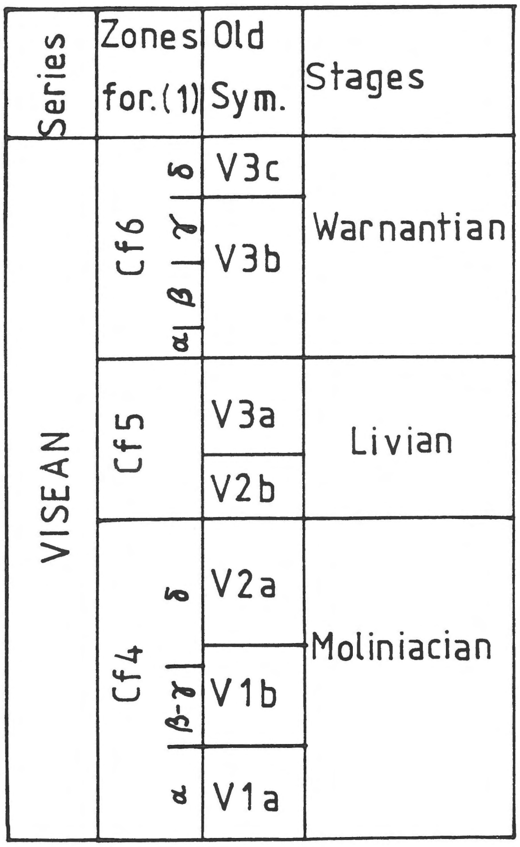


Fig. 1. Location of the boreholes, which are sediment petrographically investigated. The barbed lines mark the northern and southern border of the Dinantian strata.

extensively explored by seismic methods, and the karst paleogeography of the western zone of the Campine-Brabant Basin has been reconstructed (Dreesen et al. 1985; Vandenberghe et al. 1984). Detailed biostratigraphical investigations have been carried out by Conil (1964), Voglet (1970), Lederer (1973), Bouzet (1975), Longerstaey (1975) and Mamet et al. (1978). Lithological and biostratigraphical data of the Dinantian in the subsurface north of the London-Brabant Massif in Belgium, the Netherlands and the Federal Republic of Germany have been reviewed by Bless et al. (1976).

In this study, the sediment petrography of six boreholes was investigated (Booischot, Halen, Heibaart, Kessel, Poederlee and Turnhout; Fig. 1). The biostratigraphical data have been taken from Bless et al. (1976), and from Conil and Poty (1987, pers. comm.). Bless et al. (1976) based the stratigraphy on the subdivision of Demanet (1958). However, the old symbols indicated both formations and biozones (Paproth et al. 1983). Both the old and the new symbols are given here in order to improve readability. A review of the biostratigraphic and lithostratigraphic subdivision of the Dinantian in Belgium (Fig. 2) has been given by Paproth et al. (1983).



Series	Zones for.(1)		Old Sym.	Stages
VISEAN	Cf6	δ	V3c	Warnantian
		γ	V3b	
		β		
		α		
	Cf5		V3a	Livian
			V2b	
	Cf4	δ	V2a	Moliniacian
		β-γ	V1b	
		α	V1a	

Fig. 2. Stratigraphic subdivision of the Visean (after Paproth et al., 1983). (1) foraminifers; Sym.: symbols.

We integrate facies relationships and coalification data in the form of paleogeographical reconstructions for different periods of the Visean.

Facies patterns of the Visean

The Visean strata are divided into four lithostratigraphical megasequences. Biostratigraphical data (Bless et al. 1976) indicate that the first sequence formed during the Early Moliniacian, the second during the Late Moliniacian, the third during the Livian and the fourth during the Early Warnantian. Table 1 lists the thicknesses of the units as found in the different boreholes.

Facies pattern of the Lower Moliniacian

Lower Moliniacian (Cf4α, β, γ) strata are encountered in the boreholes of Booischot, Halen, Kessel and Turnhout. Four areas with different depositional settings are distinguished:

- In the Heibaart area, several wells were drilled. One of these (Heibaart 1 + 1-bis) reached the Silurian. Lower Moliniacian sediments are not intersected or are very thin and detrital in character. We conclude that this area formed a structural high during the Early Moliniacian.
- Lithologically, the upper part of the Lower Moliniacian in the boreholes of Booischot and Kessel (Fig. 3) consists of dolomicrosparites, calcareous sandstones and sandy bioclastic wackestones and packstones. The sandy wackestones and packstones are interpreted as having been deposited in a shallow lagoon because of the low biotic diversity, indicating a restricted environment (Wright, 1986). The presence of irregular fenestrae and desiccation cracks in a few horizons suggests an intertidal setting (Shinn, 1983). The presence of paleosols (Fig. 5) at the top of the Lower Moliniacian strata indicates that they were occasionally subaerially exposed (Legrand, 1964).
- The fauna (crinoids, brachiopods and forams) in the packstones and grainstones of the Halen borehole (Fig. 3) suggest sedimentation in an open marine environment. The different stages in the micritization of the bioclasts and ooliths (coated grains) indicate an organic origin of the peloids (Bathurst, 1975). The peloids are sometimes grouped into grapestones which are characteristic of a shallow depositional environment, where there is no appreciable current activity and where the bottom is stable (Purdy, 1963). However, the water turbulence and circulation rates were high enough to limit the accumulation of mud. The use of micritic envelopes in paleobathymetric studies has been questioned by Friedman et al. (1971). However, the bioclasts and ooliths of the Lower Moliniacian strata are so intensively micritized that a shallow water deposition environment is more probable than a deep water one. A depth range between intertidal and 25 m is inferred as that is the present day zone of active micritization (Perkins & Halsey, 1971).
- In the area of the Turnhout borehole (Fig. 4) a thick sequence of algal boundstones with minor bioclastic wackestones to grainstones intercalations was deposited. The algal boundstones are similar to the loferites as described by Flügel (1982, p. 225). They were formed by non-calca-

Table 1. Thickness of the biostratigraphical and lithological sequences of the Visean of the different boreholes.

borehole / sequence	Booischot	Halen	Heibaart (DzH1 and He1+1-bis)	Kessel	Poederlee	Turnhout
Lower Warnantian (Cf6α, β,)	n.p.	155	> 142 m	n.p.	> 145 m	53 m
reworked	n.p.	20 m	n.p.	n.p.	/	23 m
Livian (Cf5)		n.p.	42 m			n.p.
Upper Moliniacian (Cf4δ)	> 131 m	94 m	125 m	> 29 m	/	> 10 m
Lower Moliniacian (Cf4α, β,)	64 m	110 m	0-32 m	> 82 m	/	> 417 m

-·-·-·-	erosion surface
-------	end of borehole
······	biostratigraphical dating problems
n.p.	not present

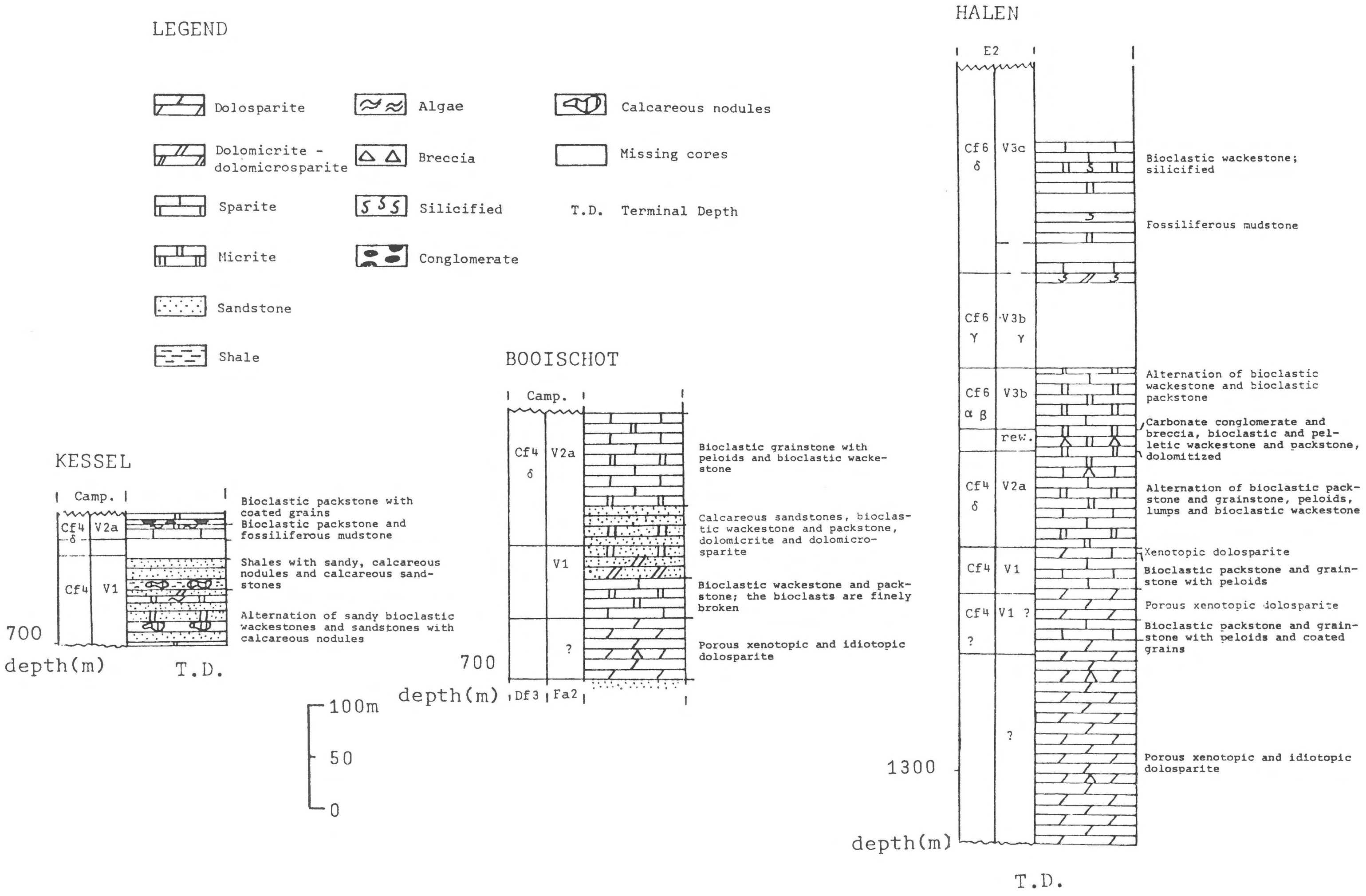


Fig. 3. Lithological logs of the boreholes Kessel, Booischot and Halen.

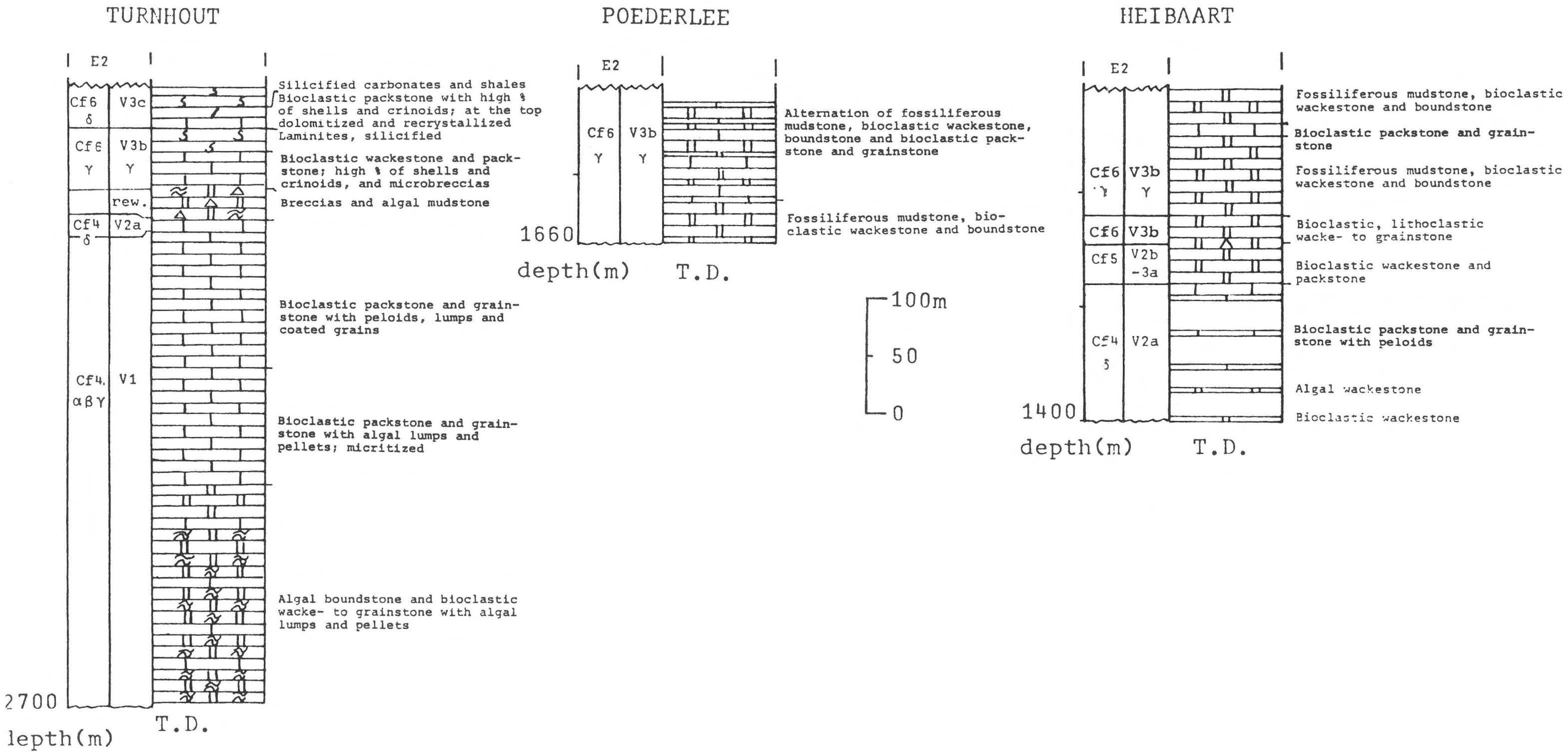


Fig. 4. Lithological logs of the boreholes Turnhout, Poederlee and Heibaart. Legend see figure 3.

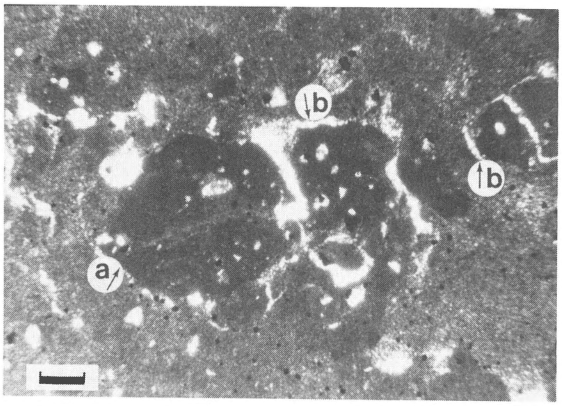


Fig. 5. Thin section photomicrograph of the paleosol in the Booischot borehole at a depth of 585 m. The calcrete glaebules (a), in a microsparitic matrix, contain and are surrounded by spar-filled cracks (b). Scale bar is 240 μm.

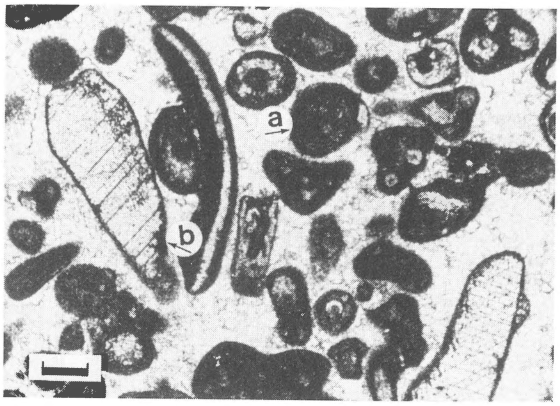


Fig. 6. Thin section photomicrograph of a bioclastic grainstone (Turnhout borehole 2324 m). Note intensive micritization of the forams (a) and the crinoids (b). Scale bar is 240 μm.

reous blue-green algae (Schizophyta) and green algae (Chlorophyta). Aitken (1967) proposed to designate this group of algae as *cryptalgal.* The boundstones in the Turnhout borehole are planar-laminated, typical for *cryptalgalaminates* which are formed in intertidal (Pratt & James, 1982) or very shallow (<5 m) subtidal waters (Gebelein, 1976). Paleogeographically, the loferites of the Northern Limestone Alps occurred on flats near the margin of a shelf that were influenced by the tidal action (Zankl, 1971). A similar position is suggested for the Turnhout area which is 25 km north of the London-Brabant Massif. The boundstone facies gradually passes upwards into packstones and grainstones with an open marine fauna, peloids, lumps and coated grains (Fig. 6). This facies change reflects a transition from a sedimentary environment near the margin of a shelf to one subject to subtidal conditions on a shallow, open shelf.

Facies pattern of the Upper Moliniacian

Upper Moliniacian (Cf4δ) strata are found in the boreholes of Booischot, Halen, Heibaart, Kessel and Turnhout. During the Late Moliniacian, bioclastic packstones and grainstones with peloids, lumps and coated grains were deposited (Figs. 3 and 4). The open marine fauna, the lumps and the coated grains indicate that sedimentation occurred on a shallow, open marine shelf. In the Booischot and Halen boreholes the bioclastic packstones and grainstones alternate with bioclastic wackestones. These wackestones have low biotic diversity indicating sedimentation in a restricted environment. The reduced thickness of the Upper Moliniacian in the Turnhout borehole (Table 1) is noteworthy, and may be due to erosion at the end of the Late Moliniacian or during the Livian. However, it is not clear whether this was subaerial or submarine erosion.

Facies pattern of the Livian and of the reworked sequences

Carbonates of Livian age are found in the Heibaart borehole. By contrast the boreholes of Halen and Turnhout contain the so-called reworked sequence (Bless et al. 1976) with mixed biota and breccia fragments. In the Heibaart borehole, the bioclastic wackestones and packstones of this stage contain a rich fauna and were deposited on a shelf at a depth below significant wave activity (Muchez et al., in press). The reworked sequence in the Halen borehole contains beside a Livian fauna also fragments with a Moliniacian fauna. This implies that during the Livian, Moliniacian fragments were eroded in the Campine-Brabant Basin and deposited in the Halen area. In the Turnhout borehole, the reworked sequence is characterized by foraminifera of Moliniacian to Early Warnantian age. This indicates that the reworking occurred during the Early Warnantian. The absence of unequivocal Livian strata indicates little sedimentation in the Turnhout area during this stage.

The carbonate clasts in the upper part of the Livian strata in the Halen and Heibaart boreholes (Figs. 3 and 4) are well-rounded and some are surrounded by a marine, radiaxial cement. Their wide lateral distribution suggests an epeirogenic origin for these breccias (Bless et al. 1976).

Facies pattern of the Lower Warnantian

Lower Warnantian (Cf6α, β, γ) strata are found in the boreholes of Halen, Heibaart, Poederlee and Turnhout. Three areas that have different facies, are recognized:

- In the Halen area (Fig. 3) the alternation of bioclastic packstones with an open marine fauna and bioclastic wackestones with a low diversity in the fauna indicates a cyclic change of open and restricted environments.
- The fossiliferous mudstones, bioclastic wackestones and boundstones found in the Poederlee (1658–1535 m) and the Heibaart (1224–1106 m) boreholes (Fig. 4) are interpreted as a reef mound facies (Muchez et al., in press). The same facies occurs in the Warnantian (Asbian and Brigantian age) of Derbyshire and North Staffordshire (Prentice, 1951; Orme, 1970) and at the eastern extension of the Campine-Brabant Basin (Muchez & Peeters, 1986). Interconnected stromatactoid structures (Fig. 7), typical components of many Paleozoic reefs (Pratt, 1982 and Tsien, 1985) are commonly found. Geopetal infillings in gastropods and brachiopods dip at about 6°, while the stratification and some stromatactoid have dips of about 34°. This points to sedimentation on a depositional slope with a dip of ca 28°. The core of the reef mound encountered in the Heibaart borehole is 74 m thick (1224–1150 m) and is surrounded by very clayey, laminated limestones and bioclastic grainstones (Bless et al. 1981, boreholes DzH2 and DzH4). The absence of cycles in the reef mound at Heibaart, the thick reef core and the listric fault, bordering the shelf of the Campine-Brabant Basin just to the north of the Heibaart area (Vandenberghe, 1984) indicate that the reef mound grew at the margin of a shelf. However, a cyclic change of the sedimentation environment has been recognized in the Poederlee area. The evolution in one cycle from boundstones via bioclastic packstones to grainstones was interpreted by Wilson (1975, p. 369) as a change from a depositional environment be-

Fig. 7. Etched slab showing interconnected stromatactoid cavities (a; Heibaart borehole 1138,8 m).

neath the wave base into an accumulation of bioclastic debris at the wave base. Similar cycles occur in shelf sediments in the Warnantian strata of Great Britain. This feature of the Poederlee area and its position, 20 km south of the listric fault lead to the conclusion that the reef mound in this area developed on a shelf.

- The Lower Warnantian strata in the area of the Turnhout borehole show a considerably reduced thickness compared with the strata of the other two areas. The accumulation of brachiopods and crinoids and the occurrence of cryptalgal microbreccias (Fig. 4) are interpreted as reef-associated sediments (brèches périrécifal of Mamet et al. 1978).

Paleogeographical reconstructions for the Visean

The paleogeographical reconstructions are based on the facies and thickness patterns of each sequence.

During the Early Moliniacian an east-west trending fault zone probably existed near the London-Brabant Massif which separated the Booischot-Kessel area from the Heibaart area (Fig. 8A). In the Booischot-Kessel area 60 to 80 m of sandy carbonates were deposited. However, in the Heibaart area further to the north, no or little sedimentation took place. In the Halen and Turnhout areas several hundred metres of carbonates were deposited. This contrasts with the Heibaart area which formed a high. A north-south fault was the boundary between the Heibaart and the two other areas. In the vicinity of the Turnhout borehole, strong subsidence favoured the sedimentation of more than 400 m of shallow water carbonates during the Early Moliniacian. This subsidence explains why there is an upward change from intertidal to subtidal deposites, representing a deepening sequence, in the Turnhout area. By contrast, in the Booischot and Kessel areas an upward change from subtidal to continental sedimentation occurred, forming a shoaling sequence. The structure contour map (Dreesen et al. 1985) of the top of the Dinantian carbonates based on seismic measurements shows a north-south fault zone between the Turnhout and the Heibaart-Poederlee areas. This map does not cover the Booischot-Kessel area and gives no evidence for the east-west fault zone near the London-Brabant Massif.

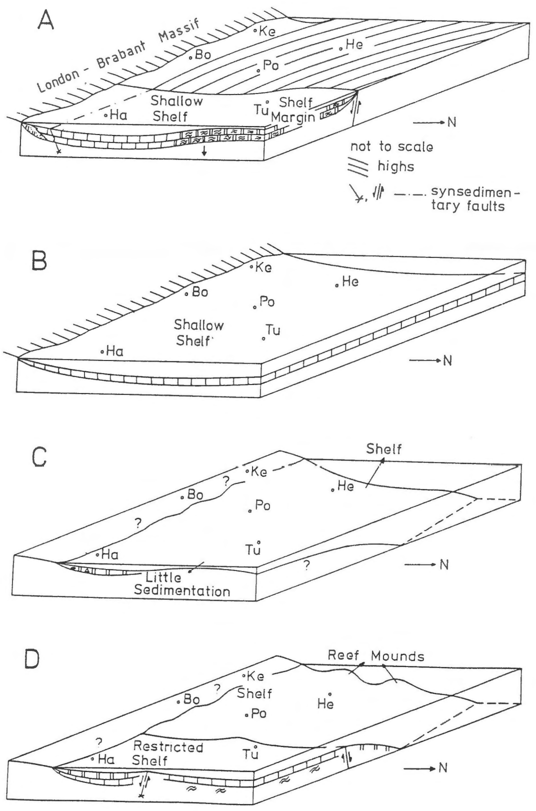


Fig. 8. Paleogeographical reconstructions: (A) Early Moliniacian; (B) Late Moliniacian; (C) Livian; (D) Early Warnantian. Lithological legend see Fig. 3.

During the Late Moliniacian, sedimentation took place on a broad, shallow, open marine shelf (Fig. 8B) to give a uniform thickness and facies distribution except in the Turnhout area where erosion occurred in the next stage. During the Livian open shelf sediments formed in the Heibaart area (Fig. 8C). In the Halen area, eroded fragments of the Moliniacian age were deposited and little sedimentation occurred in the Turnhout area. The carbonate clasts in the upper part of the Livian strata in the Halen and Heibaart areas indicate the large-scale movements in the Campine-Brabant Basin.

As already mentioned in the discussion of the facies patterns three different realms existed during the Early Warnantian (Fig. 8D). Strong subsidence occurred in the Poederlee-Heibaart area (>140 m sediments) where reef mounds developed in a shelf setting. In the Halen area a thick sequence of carbonates was deposited under alternating open marine and restricted conditions. In the third area (Turnhout) slow subsidence prevailed. The thickness and facies variation between the three different facies realms can be explained by synsedimentary fault activity.

Bless et al. (1980) suggested on the basis of isopach maps and seismic profiles that the Campine-Brabant Basin was a block-faulted basin during the Westphalian. However, seismic methods only exceptionally show reflectors in the Dinantian (Vandenberghe et al. 1986). No accurate isopach maps can be constructed. The dome-like blocks, limited by faults and elongated narrow depressions, of the top of the Dinantian (Vandenberghe et al., 1984; Dreesen et al., 1985) show a preferential rectangular pattern, suggesting a relationship with block-faulting (Vandenberghe et al. 1986). The variations in facies and thickness of the Visean of the Campine-Brabant Basin can also be explained by block-faulting that was already active during the Visean. The domains were sparated by east-west and north-south zones, that are interpreted as faults. A tilt-block structural framework has recently been applied by Grayson & Oldham (1987) for the Lower Carboniferous of northern England, which forms the lateral extension of the Campine-Brabant Basin. The north-south and east-west trending synsedimentary faults postulated for the Visean of the Campine-Brabant Basin are similar to the trends of the 'blocks' and 'basins' in northern England (Grayson & Oldham, 1987).

Paleogeothermal gradient and the coalification pattern of the carboniferous of the Campine-Brabant Basin

The maximum vitrinite reflectance ($\bar{R}$max) has been measured for carbonates, shales and sandstones from seven boreholes (Booischot, Halen, Heibaart, Kessel, Poederlee, Rillaar and Turnhout) and for samples from outcrop in the Visé area. In addition to Visean strata, Namurian and Westphalian strata have also been analyzed.

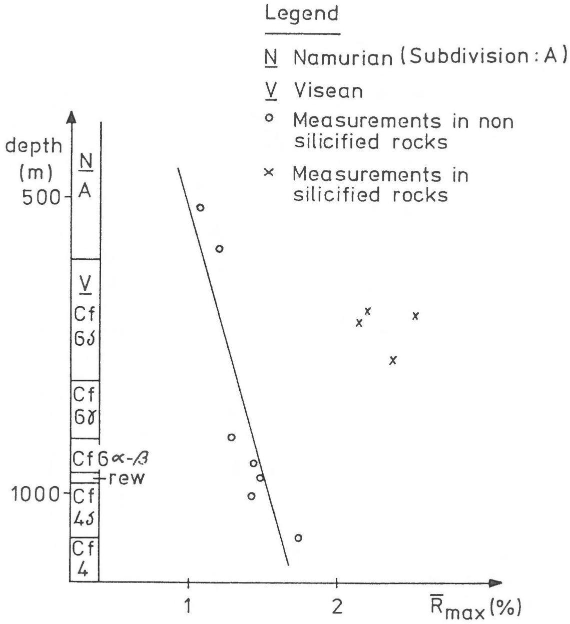


Fig. 9. Coalification diagram: Halen borehole.

Coalification data

The coalification data are summarized in Table 2 and Figs. 9, 10 and 11.

A maximum vitrinite reflectance of 0.95% was measured on vitrinites occurring in a karst at a depth of 477 m in the Booischot borehole. This reflectance of 0.95% is lower than the values established for the Rillaar and Halen boreholes which are located further to the east and is therefore a reasonable minimum value for $\bar{R}$max at the top of the Visean.

$\bar{R}$max at the top of the Visean in the Halen borehole is estimated at 1.18% (Fig. 9). In silicified sediments, the reflectance of vitrinite is high (2.14%–2.52% $\bar{R}$max) compared with the maximum reflectance of samples at a greater depth in the same borehole (1.29%–1.74% $\bar{R}$max). This is the result of the oxidation of the vitrinite (= inertinite) by ground waters, which were also responsible for the intense silicification of the carbonates

Table 2. Coalification data (R̄max) of the Carboniferous of the Campine-Brabant Basin, n = number of analysis; s = standard deviation.

Borehole	Depth (m)	Age	R̄max (%)	n	s	Occurrence of vitrinites
Booischot	477	Cf4δ	0.95	37	0.06	in karsts
Booischot	513	Cf4δ	2.36	29	0.06	oxidized, in limestone
Booischot	541	Cf4δ	2.45	26	0.26	oxidized, in limestone
Booischot	628	Cf4	2.12	58	0.26	oxidized, in limestone
Booischot	643	Cf4	1.43	25	0.06	in limestone
Halen	520	NamA	1.05	1	–	in siltstone, cuttings
Halen	590	NamA	1.20	2	–	in siltstone, cuttings
Halen	690	Cf6δ	2.20	8	0.39	silicified limestone, cuttings
Halen	698	Cf6δ	2.52	11	0.09	in silicified limestone
Halen	707	Cf6δ	2.14	10	0.41	in silicified limestone
Halen	773	Cf6δ	2.37	11	0.25	in silicified limestone
Halen	907	Cf6α, β	1.29	2	–	in limestone
Halen	951	Cf6α, β	1.45	23	0.07	in limestone
Halen	976	rew.	1.49	2	–	in limestone
Halen	1004	Cf4δ	1.43	59	0.09	in limestone
Halen	1075	Cf4	1.74	58	0.08	in limestone
Kessel	500	Camp	0.73	15	0.07	in chalk
Kessel	573	Camp	1.37	5	0.09	in chalk
Kessel	622	Cf4	1.39	18	0.06	oxidized (?), in limestone
Kessel	690	Cf4	2.45	9	0.15	oxidized, in limestone
Heibaart	1047	Nam	2.81	22	0.09	in shale
Heibaart	1097	Nam	2.89	28	0.07	in shale
Heibaart	1129	Cf6	2.79	50	0.08	in karst
Heibaart	1352	Cf4δ	3.23	2	–	in limestone
Poederlee	1466.8	Nam	2.84	53	0.09	in shale
Poederlee	1489	Nam	2.50	80	0.09	in shale
Rillaar	371.5	Cf4δ/Cf5	1.10	66	0.09	in limestone
Turnhout*	1100	Westph.A2	1.95	27	0.12	in sandstone
Turnhout*	1192.3	Westph.A1	1.94	35	0.11	in sandstone
Turnhout*	1700	NamC	2.14	25	0.16	in siltstone
Turnhout*	1800.5	NamB	2.45	20	0.27	in silty shale
Turnhout*	1991	NamB	2.87	25	0.45	in shale
Turnhout	2063	NamB	2.64	33	0.13	in shale
Turnhout*	2096.05	NamB	4.2	50	0.33	in siltstone
Turnhout	2134	NamB	2.81	3	–	in shale
Turnhout	2163	Cf6	3.37	100	0.14	in silicified shale
Turnhout	2170	Cf6	3.59	7	0.03	in silicified limestone
Turnhout	2196	Cf6	3.69	45	0.13	in limestone
Turnhout	2213	Cf6	4.34	62	0.19	in silicified limestone
Visé area		Cf6	1.11	7	0.05	in limestone
Visé area		Cf6	1.13	8	0.03	in shale
Visé area		Cf6	1.22	6	0.06	in shale
Woensdrecht**	1167	NamA	2.52	25	0.23	in shale

* Data taken from report by M. Wolf for the Belgian Geological Survey (1982).

** Data taken from Bless et al. 1976.

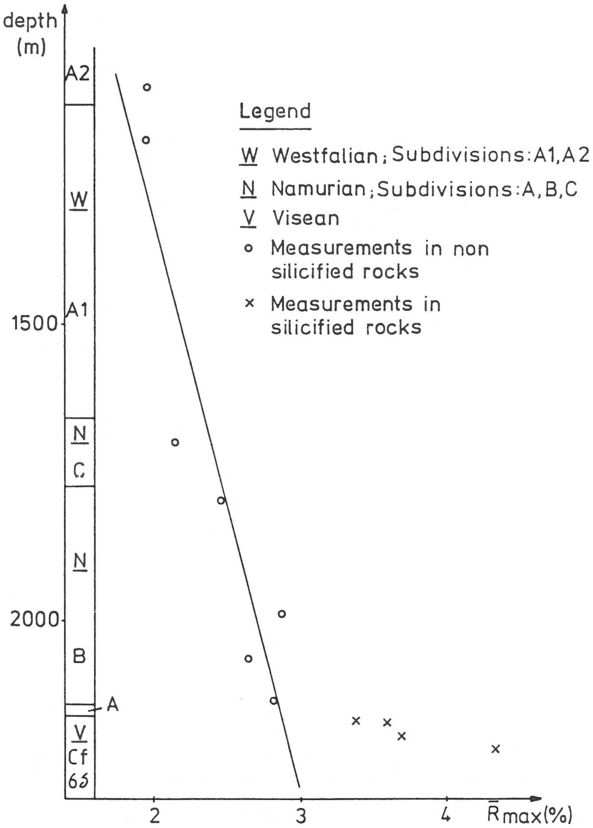


Fig. 10. Coalification diagram: Turnhout borehole.

(Laschet, 1984). If the silicified samples are taken into account, the maximum reflectance is independent of the depth (Fig. 9). However, there is a very good linear correlation between the two parameters when the silicified carbonates are excluded. The reflectance gradient for the Visean, based on this linear correlation, is 0.12%/100 m (Fig. 9). It is impossible to convert this reflectance gradient into a true geothermal gradient because the burial history of the Campine-Brabant Basin from the Late Westphalian to the Cretaceous (using Lopatin's method, in Waples, 1980) is not known.

R̄max values for the Visean strata of the Kessel borehole are very high, indicating oxidation of the vitrinite (= inertinites). Original R̄max values were obtained from a detrital vitrinite population probably of pre-Mesozoic age that occurs in a Campanian sample. This sample has a maximum reflectance of 0.73% (Table 2). This value is comparable with the coaliffication values for other boreholes near the Brabant Massif.

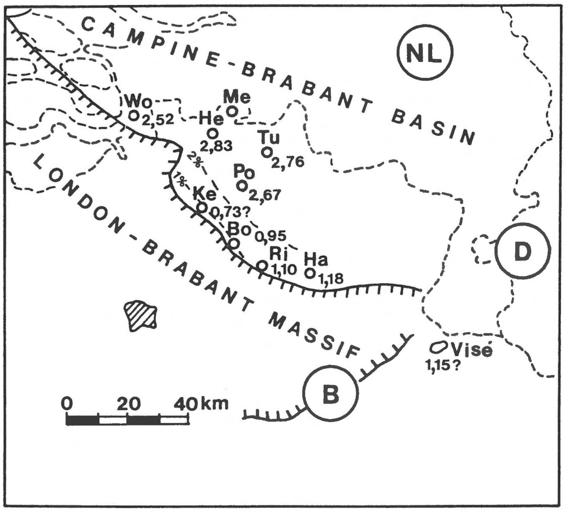


Fig. 11. R̄max (%) at the top of the Visean strata (isoreflectance; Bo: Booischot; Ha: Halen; He: Heibaart; Ke: Kessel; Me: Meer; Po: Poederlee; Ri: Rillaar; Tu: Turnhout; Wo: Woensdrecht).

The estimated R̄max values for the top part of the Visean in the boreholes of Heibaart, Poederlee, Rillaar and Woensdrecht (after Bless et al. 1976) are respectively 2.83%, 2.67%, 1.10% and 2.52%.

For the Turnhout borehole, R̄max at the top of the Visean is estimated at 2.76%. The Upper Warnantian strata are silicified and show a high maximum reflectance (3.37%–4.34% R̄max) compared with non-silicified rocks at the same depth range (2.64%–2.81% R̄max). As at Halen, the abnormally high values are not used in the calculation of the paleogeothermal gradient. The reflectance gradient for the Namurian-Westphalian A is 0.10%/100 m (Fig. 10). The organic matter content in the Lower Visean carbonates of the boreholes of Turnhout and Heibaart is too low to obtain reliable reflectance measurements.

Discussion of the results

The reflectance gradients, determined for the boreholes of Halen and Turnhout are similar to the gradient for the Namurian and Lower Westphalian of the eastern zone of the Campine-Brabant Basin (0.10%/100 m; Table 3). Wolf (1972) measured similar values for the Namurian of the 'Rheinische Schiefergebirge', namely 0.11%/100 m.

In he Poederlee and Turnhout boreholes the Visean is covered by 753 m and 1162 m of Upper Carboniferous strata respectively. The estimated amounts of erosion of the Carboniferous cover are similar at the two locations and therefore the difference in thickness now observed was originally present. Pillement (1982) concluded that the main coalification in the Campine-Brabant Basin occurred during the Late Carboniferous. Nevertheless, the vitrinite reflectance indices are nearly the same at the top of the Visean for both boreholes, which suggests that the heat flow at Poederlee was somewhat higher than at Turnhout. Areal variations in paleogeothermal gradients also characterized the eastern part of the Campine-Brabant Basin during the Late Carboniferous (Dusar 1987, pers. comm.).

Relation between the paleogeographical reconstructions and the coalification pattern at the top of the Visean

Near the London-Brabant Massif a rapid increase of the $\bar{R}$max values from south to north is observed (Fig. 11). This points to high differential subsidence which in turn indicates post-Visean fault activity, parallel to and near the London-Brabant Massif. This activity corresponds with he E-W fault zone in the paleogeographical reconstructions for the Visean. The fact that this coalification pattern occurs at the top Visean implies a reactivation of the fault system during the Late Carboniferous. Investigations by the Geological Survey of Belgium on the Upper Carboniferous confirm this reactivation of faults (Dusar 1987, pers. comm.).

The very high $\bar{R}$max value encountered by the Meer borehole (3.36% at the top of the Namurian; Dusar 1987, pers. comm.) indicates a considerable accumulation of sediments in the area. This change in $\bar{R}$max can be explained by the listric fault recognized by Vandenberghe (1984). This fault bordered the shelf of the Campine-Brabant Basin.

Table 3. Reflectance gradients (expressed as % $\bar{R}$max/100 m) for the Campine-Brabant Basin (Tu: Turnhout borehole; Ha: Halen borehole; western zone: this study, central and eastern zone: after Pillement, 1982).

Stratigraphy		Western zone		Central zone	Eastern zone
stage	horizon	TU	HA		
Westphalian	Maurage				
	Eisden			0,035	0,035
	Quaregnon			0,06	0,065
	n° 75			0,13	0,13
	Wasserfall				0,10
Namurian		0,10			0,10
Visean			0,12		

Conclusion

On the basis of sediment petrographical and biostratigraphical data for the Visean strata, paleogeographical reconstructions of the Campine-Brabant Basin were made. Coalification data provide supporting evidence for the paleogeographical reconstructions.

The development of synsedimentary faults has been deduced from the thickness variations between different areas, from the facies distribution and from the coalification pattern. The faults can best be explained by block-faulting. This system was active not only during the Upper Carboniferous but already during the Visean.

Acknowledgements

We thank Dr. M. Dusar for stimulating discussions and for providing us with coalification data. We are grateful to Prof. Dr. N. Vandenberghe for his helpful comments on an earlier version of this paper and to Prof. Dr. R. Conil, Dr. E. Poty and Mr. M. Laloux for their personal data on the biostratigraphy of the Campine-Brabant Basin. We also thank the reviewers for their constructive comments which greatly improved the manuscript. Mr. C. Moldenaers and Ms. A. Van Espen are thanked for their technical assistance.

References

Aitken, J.D. 1967 Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta – J. Sediment. Petrol., 37: 1163–1178

Bathurst, R.G.C. 1975 Carbonate sediments and their diagenesis – Developments in sedimentology, 12, Elsevier, Amsterdam: 658 pp

Bless, M.J.M. 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. et al. 1980 Pre-Permian depositional environments around the Brabant Massif in Belgium, the Netherlands and Germany – Sediment. Geology 27: 1–81

Bless, M.J.M., P. Boonen, M. Dusar & P. Soille 1981 Microfossils and depositional environment of late Dinantian carbonates at Heibaart (northern Belgium) – Ann. Soc. Géol. Belg., 104: 135–165

Bouzet, Ph. 1975 Étude biostratigraphique du sondage de Halen. Essai de classification des Tournayellidae – Mém. Licence, Instit. Géol. Univ. Cath. Louvain, unpubl.: 63 pp

Conil, R. 1964 Interprétation micropaléontologique de quelques sondages de Campine. Note préliminaire – Bull. Soc. belge Géol. Pal. Hydr., 72: 123–136

Delmer, A. 1962 Coupes des sondages du Basin Houiller du Nord de la Belgique. Sondage de Turnhout (n 120) – Ann. Mines Belg., 2: 101–138

Demanet, F. 1958 Contribution à l'étude du Dinantien de la Belgique – Mém. Inst. Roy. Hist. Nat. Belg., 141: 5–152

Dreesen, R., J. Bouckaert, M. Dusar, P. Soille & N. Vandenberghe 1985 Collapse structures at the Dinantian-Silesian contact in the subsurface of the Campine Basin, north of the Brabant Massif (North Belgium) – Dixième Congr. Internat. Stratigr. Géol. Carbonifère, Madrid, 1983, 2: 7–14

Flügel, E. 1982 Microfacies analysis of limestones – Springer, New York: 633pp

Friedman, G.M., C.D. Gebelein & J.E. Sanders 1971 Micrite envelopes of carbonate grains are not exclusively of photosynthetic algal origin – Sedimentology, 16: 89–96

Gebelein, C.D. 1976 Open marine subtidal and intertidal stromatolites (Florida, the Bahamas and Bermuda) – In: Walter, M.R. (ed.): Stromatolites – Elsevier, Amsterdam: 381–388

Grayson, R.F. & L. Oldham 1987 A New Structural Framework for the Northern British Dinantian as a Basis for Oil, Gas, and Mineral Exploration – In: Miller, J., A.E. Adams & V.P. Wright (eds): European Dinantian Environments, John Wiley & Sons Ltd, New York: 33–59

Laschet, C. 1984 On the origin of cherts – Facies 10: 257–290

Lederer, F. 1973 Révision micropaléontologique du Viséen de quelques sondages profonds du Basin de la Campine – Mém. Licence, Instit. Géol. Univ. Louvain, unpubl.: 60 pp

Legrand, R. 1964 Coupe résumée du forage de Booischot (province d'Anvers) – Bull. Soc. belge Géol. Pal. Hydr., 72: 407–409

Lohest, M., A. Habets & H. Forir 1903 Étude géologique des sondages exécutés en Campine et dans les régions avoisinantes – Ann. Soc. Géol. Belg., 30: M101–M677

Longerstaey, P.J. 1975 Le Dinantien du sondage de Turnhout. Corrélations avec la Province Centrale d'Angleterre – Mém. Licence, Instit. Géol. Univ. Cath. Louvain, unpubl.: 44 pp

Mamet, B., G. Mortelmans & A. Roux 1978 Algues Viséennes du sondage de Turnhout (Campine, Belgique) – Ann. Soc. Géol. Belg., 101: 351–383

Muchez, Ph., J. Bouckaert & W. Viaene 1985 Sedimentological evolution of the Campine-Brabant Basin during the Visean – In: Rosell, J., C. Remacha & M. Zamorano (eds): Abstracts of the 6th European Regional Meeting of the I.A.S.: 618–621

Muchez, Ph. & C. Peeters 1986 The occurrence of a cryptalgal reef structure in the Upper Visean of the Visé area (the Richelle Quarries) – Ann. Soc. Géol. Belg., 109: 573–577

Muchez, Ph., R. Conil, W. Viaene, J. Bouckaert & E. Poty in press. Sedimentology and biostratigraphy of he Visean carbonates of the Heibaart (DzH1) borehole (northern Belgium) – Ann. Soc. Géol. Belg.

Orme, G.R. 1970 The D2-P1 'reefs' and associated limestones of the Pin-Dale Bradwell Moor area of Derbyshire – Compte Rendu 6e Congrès Intern. Strat. Géol. Carbonif., Sheffield 1967, 3: 1242–1262

Paproth, E., R. Conil et al. 1983 Bio- and lithostratigraphic subdivision of the Dinantian in Belgium, a review – Ann. Soc. Géol. Belg., 106: 185–239

Perkins, R.D. & S.D. Halsey 1971 Geological significance of microboring fungi and algae in Carolina shelf sediments – J. Sediment. Petrol., 41: 843–853

Pillement, Ph. 1982 La houillification des formations carbonifères en Belgique. Sa place dans l'histoire sédimentaire et structurale Varisque – Thèse doctorale, Univ. de Droit, d'Economie et des Sciences d'Aix, Marseille, unpubl.: 220 pp

Pratt, B.R. 1982 Stromatolitic framework of carbonate mudmounds – J. Sediment. Petrol., 52: 1203–1227

Pratt, B.R. & N.P. James 1982 Cryptalgal metazoan bioherms of Early Ordovician age in the St. George Group, western Newfoundland – Sedimentology, 29: 543–569

Prentice, J.E. 1951 The Carboniferous limestone of the Manifold Valley region, North Staffordshire – Quart. J. Geol. Soc. Lond., 106: 171–209

Purdy, E.G. 1963 Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentary facies – J. Geol., 71: 472–497

Shinn, E.A. 1983 Birdseyes, fenestrae, shrinkage pores and loferites: a reevaluation – J. Sediment. Petrol., 53: 619–628

Stainier, X. 1932 Le sondage de Kessel-les-Lierre – Bull. Soc. belge Géol. Pal. Hydr., 42: 43–59

Tsien, H.H. 1985 Origin of stromatactis – a replacement of colonial microbial accretions – In: Toomey, D.F. & M.H. Nitecki (eds): Paleoalgology, contemporary research and applications – Springer, New York: 274–289

Vandenberghe, N. 1984 The subsurface geology of the Meer area in North Belgium, and its significance for the occurrence of hydrocarbons – J. Petrol. Geology, 7: 55–66

Vandenberghe, N., M. Dusar, R. Dreesen & J. Bouckaert 1984 Recent subsurface data on the Dinantian in North Belgium – Abstract of the European Dinantian Environments – 1st meeting in Manchester: 85–87

Vandenberghe, N., E. Poggiagliolmi & G. Watts 1986 Offset-dependent seismic amplitudes from karst limestone in northern Belgium – First break, 4 (5): 9–27

Voglet, G. 1970 Contribution à l'étude du sondage de Booischot – Mém. Licence, Instit. Géol. Univ. Cath. Louvain, unpubl.: 44 pp

Waples, D.W. 1980 Time and temperature in petroleum formation: application of Lopatin's method to petroleum exploration – Am. Assoc. Petrol. Geol. Bull., 64: 916–926

Wilson, J.L. 1975 Carbonate facies in geologic history. Springer, New York: 471 pp

Wolf, M. 1972 Beziehungen zwischen Inkohlung und Geotektonik im nördlichen Rheinischen Schiefergebirge – N. Jahrb. Geol. Paläont. Abh., 141 (2): 222–257

Wright, V.P. 986 Facies sequences on a carbonate ramp: the Carboniferous Limestone of South Wales – Sedimentology, 33: 221–241

Zankl, H. 1971 Upper Triassic carbonate facies in the northern Limestone Alps – In: Müller, G. (ed.): Sedimentology of parts of Central Europe – Guidbook VIII Int. Sed. Congr.: 147–185