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RESULTS OF RENEWED PALAEOBOTANIC DATING OF LATE CARBONIFEROUS STRATA (NE BELGIAN CAMPINE BASIN)

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(18 figures and 4 tables)

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ABSTRACT. In this revision the Late Westphalian C and Westphalian D palaeobotanic subdivisions of Wagner (1966, 1979) Cleal (1997) and others were recognized and applied. Two diachronous discontinuities are demonstrated: an important one at the Westphalian C / D transition (the Symon unconformity) and one below the base of the Neeroeteren formation (the Neeroeteren unconformity). The Neeroeteren formation has a 'middle' to 'late' Late Westphalian D age. Within the earliest and latest realms of the Late Westphalian D other discontinuities are suspected as well; at the end of the 'early' Late Westphalian D and on top of the Neeroeteren formation. They were caused by intermitted pro- and retrograding and gradual northwardly shifting of (terminal) parts of alluvial fans. In the western and northwestern realms these fan deposits intermittently interfinger with limnic and floodplain sediments. Next to some initial Late Westphalian C sourcing from the north / northeast, local sediment supply during the Westphalian D predominantly came from eastern / southeastern areas. These fan sediments and accompanying discontinuities reflect the effects of the Late Malvernian (Late Westphalian C) and Leonese (Mid / Late Westphalian D) Variscan orogenic pulses. The palaeobotanic datings permitted correlations and comparisons with contemporaneous developments in the northeastern Netherlands.

KEYWORDS. Palaeobotany; Westphalian C; Westphalian D; discontinuities; Malvernian; Leonese; Campine basin.

1. Introduction

1.1 Well selection

To put the results of the palaeobotanic reviews of the Late Carboniferous strata of the KB 146 and KB 225 wells (Van Amerom & Van Tongeren, 2002) within a regional stratigraphic framework, three other wells in the eastern part of the Belgian Carboniferous Campine basin were investigated in a similar way: KB 113, KB 168 and KB 172. The results of the former palaeobotanic study of the KB 146 and KB 225 wells have been integrated in this paper. Occasionally reference is made to the palaeobotany of other wells, e. g: KB 117 (Piérart, 1958) and KB 169 (Dusar et al., 1987) but the palaeobotany of these wells has not been reviewed in detail (Fig. 1).

The selection of the new wells has been based predominantly on the presence of the Late Carboniferous Neeroeteren formation over the preceding Carboniferous sequence and on their relative proximity to the other boreholes as well as on their relatively large coverage and good documentation of the Carboniferous strata (Renier, 1942-1944, 1944; Dusar et al, 1986 and 1987). Moreover, in the KB 168 and KB 172 wells the presence of the Nibelung volcanic ash horizon fixes the lithostratigraphic base of the Upper Westphalian C (Upper Bolshovian; Fiebig & Groscurth, 1984). Also other overregional volcanic marker horizons are present in these two wells (e.g. the younger, Upper Westphalian C 'tonstein' Odin; Dusar et al, 1986; Dusar et al, 1987). This allows a good correlation between their lithostratigraphy and the actually presented chronostratigraphy.

Unfortunately such lithostratigraphic markers are absent in well KB 113; nor have they been found in well KB 146 (Dusar & Houlleberghs, 1981) and KB 225 (Dusar, 2002). In addition to its large amount of palaeobotanic data (Stockmans & Willière, 1975) the KB 113 well is located at the approximate southern end of the same seismic profile that runs over well KB 146 (line # 8012 Neeroeteren-Rotem survey; Fig 2). This provided some seismic control too (Van Tongeren, in prep.). The Carboniferous sequences of these wells have been completely cored and consist of Westphalian C and younger sediments only.

All studied wells are situated directly southwest of the Roer Valley graben area; i.e. within the eastern Carboniferous subbasin of the Belgian part of the Campine basin (Langenaeker, 2000; Van Adrichem Boogaert & Kouwe, 1993; Fig. 1).

In the studied region, most palaeobotanic literature and other geologic information date from the coal mining period in the previous century. This also holds for most information from the surrounding regions. To facilitate the comparability of this actual study with the majority of the available data, the authors decided to maintain the use of the older stratigraphic terminology as this is still commonly practiced in these parts of Europe. To further minimize confusion and for reasons of control and familiarity, the authors have also used the formerly practised palaeobotanic nomenclature; e.g. as used in Josten & Van Amerom (1999), Cleal (1978, 1984, and 1986) and by many other palaeobotanists. Hence recently proposed and / or official new species names (Laveine,

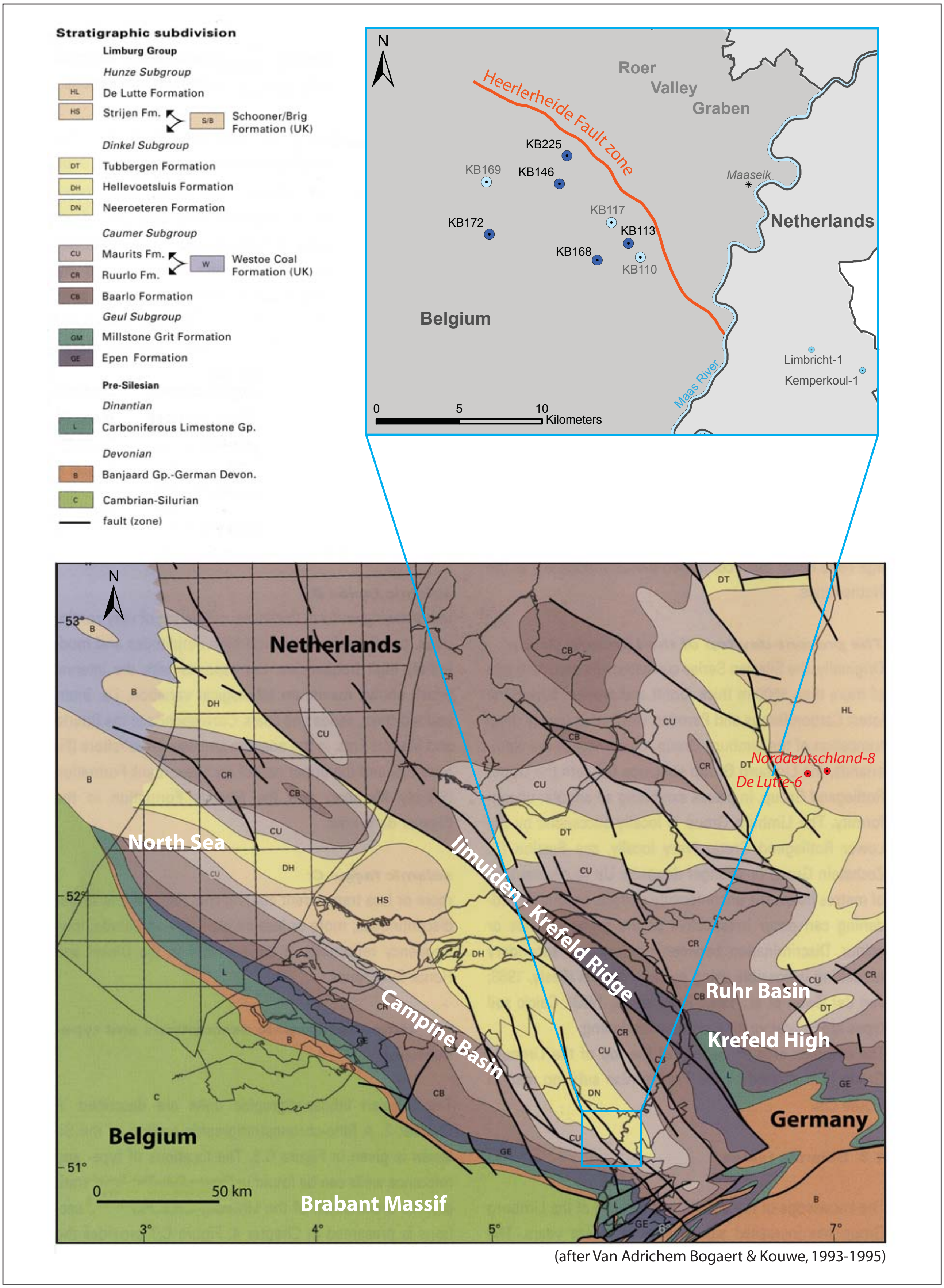

Figure 1. Regional position of the Campine basin (s.l.) plus its actual pré-Permian stratigraphic subdivision after Van Adrichem Boogaert & Kouwe (1993-1995) and the locations of the De Lutte-6 and Norddeutschland-8 wells. The intra-basinal position of the investigated area is shown by the in-zoomed area. The location of the studied wells (dark blue) other important wells (light blue) and the local, southern limit of the Roer Valley Graben (the Heerlerheide fault zone) are indicated.

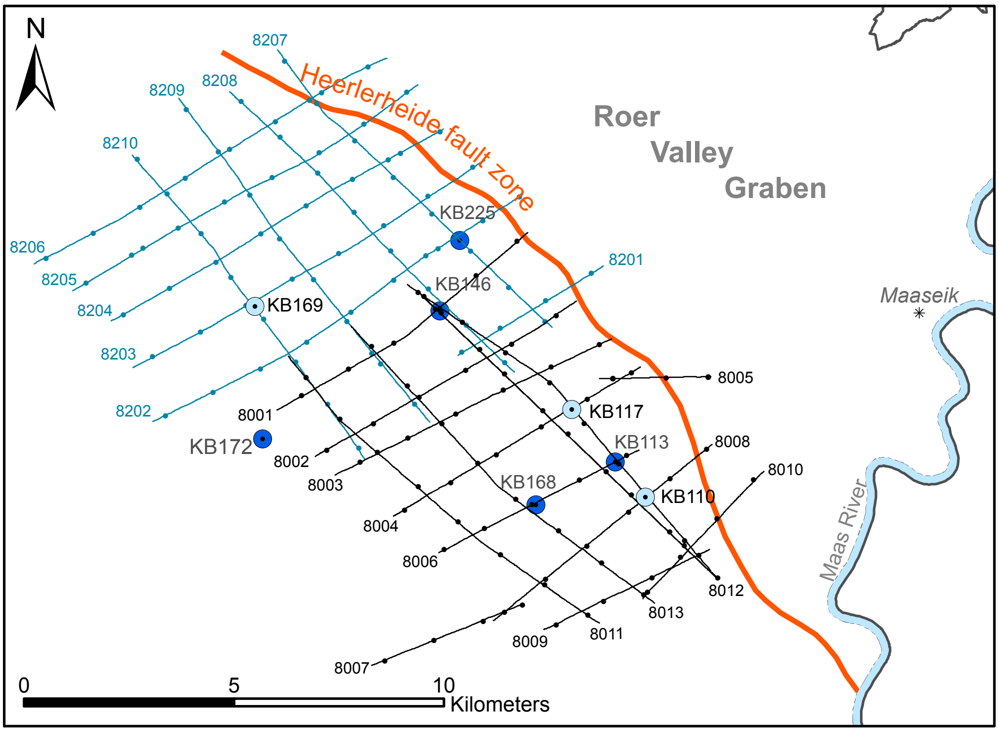

Figure 2. Position of the Neeroeteren-Rotem (black) and Meeuwen-Bree (blue) seismic survey-lines (Van Tongeren, 2004; Van Tongeren, in prep.) the studied (dark blue) and noted (light blue) Campine basin (s.s.) wells plus the Heerlerheide fault zone (top Carboniferous level).

pers. comm; 2006) - e.g. like *Laveinopteris tenuifolia, Macroneuropteris scheuchzeri* and *Karinopteris rubusta*, etc. - have remained in this study respectively: *Neuropteris tenuifolia, Neuropteris scheuchzeri* and *Mariopteris robusta,* etc.

1.2 Seismic sedimentary information

South and southwest of the investigated area the former coal-mining industry as well as the Belgian Geological Survey, over time have acquired ample data about age, stratigraphy, tectonism, etc, of the Upper Carboniferous and younger strata. Except for well KB 225 all studied wells were part of former coal exploration campaigns.

The re-interpretation of two recently reprocessed former seismic surveys (Neeroeteren-Rotem, 1980 & Meeuwen-Bree, 1982; Fig. 2; Van Amerom & Van Tongeren, 2003; Van Tongeren, 2004; Van Tongeren, in prep.) has been quite important in the understanding of the chronostratigraphic results of this study. Local Late Westphalian C and D sediments actually are interpreted to represent (distal) parts of alluvial fan sedimentation (Van Tongeren, in prep.). From their southeastern to northeastern sources these distal terminal fan deposits intermittently prograded as 'tips of sedimentary wedges' over each other and / or laterally over flat flood- and delta-plain deposits into roughly opposite directions. In this way local / regional discontinuities of varying importance were created. In the adjacent southeastern and eastern regions of Dutch Limburg and the German Aachen-Erkelenz Basin these fan deposits formed a Late Carboniferous palaeo-high which also influenced later, regional Permian and Early Mesozoic sedimentations (Van Tongeren 2004; Van Tongeren, in prep.).

In an earlier overregional study of the Carboniferous, Draxler & Edwards (1984) in a general way mentioned the occurrences of: "large alluvial fans stretching out from the mountains in the south and the northeast far into the flat plain"; the latter "flat plain" especially being present in "Holland" (meant is: the Netherlands) and the "southern North Sea" areas; so into the Campine basin sensu lato.

In his study of the Upper Carboniferous in northwest Germany, Schröder (1971) too, already mentioned the likeliness of northwardly prograding terminal (fluvial) fan related sediments ("ausgedehnte Schüttungsfächer") into the German northwestern part of the Carboniferous basin.

1.3 Palaeobotanic background

Over the last 30 years, detailed studies of Late Carboniferous fossil plants from both outcrop and core material have provided a large number of new stratigraphic data in western Europe.

Next to the work of Wagner (1979) in a rather general way, the palaeobotanic work of Josten (1991) and Josten & Van Amerom (1999) for the Ruhr basin and northwest Germany, the results of Laveine in the French Saar-Lorraine basin (1989) and northern France (1967) and in particular the studies of Cleal (e.g. 1978, 1984, 1997 and 2003) in various regions of the United Kingdom have been used in this paper. As was agreed upon at the 2nd congress on the 'Stratigraphy and Geology of the Carboniferous' in Heerlen 1935, the interpreted biostratigraphic subdivisions for the Carboniferous in this paper are based on palaeobotany.

Next to the important palaeobotanic publications above, the results of the palaeobotanic study of the 'De Lutte-6' well in the northeastern Netherlands also have been considered (Van Amerom, 1996; Pagnier & Van Tongeren, 1996). In this way the most relevant palaeobotanic documents to the chronostratigraphy of the

Carboniferous regions surrounding the Belgian part of the Campine basin have been taken into account at this study.

1.4 Stratigraphic background

1.4.1 General remarks

Generally, the chronostratigraphic subdivision of the Westphalian C and D is based on the determination of successive palaeobotanic biozones, involving the acme's of certain species and not 'first' or 'last' occurrences. In view of the sometimes rather limited material available, true acme determination was rarely possible. Occasional sampling gaps and / or lack of diagnostic fossils therefore, often caused the deduced chronostratigraphic boundaries to remain arbitrarily; estimated to commonly be in the order of maximally ca. twenty meters.

Note that the apparent ambiguity between the sometimes regionally varying stratigraphic ranges of certain time-diagnostically considered species - and so in their stratigraphic boundaries - may be caused by slight, but consistant changes of (sedimentary) facies. These generally limited range differences then are the result of rather subtle, but still important changes in the environmental conditions. This, unfortunately, is often combined with limited data as well.

An important (over)regional cause of some variations in stratigraphic ranges may be the (seismically) interpreted, intermittently occurring interchanges between somewhat higher (well-drained) grounds - as provided by the (terminal) fan systems - and lower flat (less well-drained) areas- as formed by the various (upper) floodplain sediments (Van Tongeren 2004; Van Tongeren, in prep.). Some encountered (limited) range-variations may be explained in this way (e.g. *Neuropteris dussartii*? *Dicksonites plueckenetii*?).

1.4.2 Westphalian C

The lithostratigraphic subdivision of the Westphalian C coal groups and the names of the Westphalian C volcanic marker horizons, are based on the terminology used in the German Ruhr area (Fiebig, 1971; Fiebig & Groscurth, 1984).

Chronostratigraphically, the Upper Westphalian C stage (Upper Bolsovian) is generally indicated by the *Paripteris liguaefolia* zone (megaflora; Wagner, 1979; Cleal 1997). In the lithostratigraphic sense of Fiebig & Groscurth (1984) however, this (large) biostratigraphic zone encompasses the about 'mid' Lower Westphalian C plus the Upper Westphalian C. The range of this zone therefore, lithostratigraphically starts somewhat earlier than the Upper Westphalian C.

In order to subdivide the Upper Westphalian C in the Carboniferous of South Wales, Cleal (1997) identified the '*Alethopteris serlii* subzone', within the *Paripteris linguaefolia* zone of Wagner (1979). The base of this subzone roughly coincides with the 'Cambriense Marine

Palaeobotanic subdivision for the Westphalian D

'late' Late Westph. D (including Neeroeteren formation s.l.)	— *Dicksonites plueckenetii* subzone	*Lobatopteris vestita* zone (Cleal, 1997)
'early' Late Westph. D	— *Lobatopteris micromiltonii* subzone	
'late' Early Westph. D		*Linopteris obliqua / bunburii* zone (Wagner, 1979 / Cleal, 1997)
'early' Early Westph. D		

Palaeobotanic subdivision for the Middle - Late Westphalian C (Upper Bolsovian)

'late' Late Westph. C	*Alethopteris serlii*	*Alethopteris serlii* subzone	*Paripteris linguaefolia* zone (Wagner, 1979; Cleal, 1997)
'middle' Late Westph. C	*Alethopteris serlii* + *Paripteris linguaefolia*		
'early' Late Westph. C			
------------------	Nibelung volcanic ash (±Top Marine Band) ------------------		
'late' Early Westph. C	*Alethopteris serlii* (limited till the most upper part) + *Paripteris linguaefolia*		

Former Westphalian D palaeobotanic subdivision (Cleal, 1978; 1984)

Late	Westphalian D	*Lobatopteris vestita* zone
Middle	Westpahlian D	*Lobatopteris micromiltonii* zone
Early	Westphalian D	*Linopteris bunburrii* zone

Figure 3. Actual palaeobotanic subdivision of the Westphalian C and Westphalian D (combined after Wagner, 1979 and Cleal, 1997) plus the former Westphalian D subdivision by Cleal (1978, 1984).

Band'; that is the equivalent to the 'Top Marine Band' known in the English Midlands and the western North Sea. In turn, the 'Top Marine Band' is considered the lithostratigraphic equivalent of the base of the 'Nibelung' coal group, in which the 'Nibelung' volcanic ash horizon occurs. This ash level commonly has been observed in both eastern Belgium, the southeastern Netherlands and the German Ruhr area (Pagnier & Van Tongeren, 1996). In the Belgian part of the Campine basin the base of the Nibelung coal group is commonly represented by a brackish horizon containing the ostracod *Geisina subarcuata* (Dusar et al, 1987). In this latter region therefore, the base of the *Alethopteris serlii* subzone (Cleal, 1997) may be taken to begin at this 'Nibelung' brackish / marine horizon.

Although present in both wells KB 172 and KB 168 (Dusar et al. 1987; Dusar et al. 1986) this brackish interval is not encountered everywhere in the Campine basin. For practical purposes therefore, the start of the *Alethopteris serlii* subzone (Cleal, 1997) regionally also may be taken to start some forty-five meters below the Nibelung volcanic ash level.

Although the species *Alethopteris serlii* continues into the Early Westphalian D (Laveine, 1989; Josten, 1991; Cleal, 1997) its acme is in the Upper Westphalian C. In following Cleal (1997) we consider the *Alethopteris serlii* subzone (Fig. 3) to palaeobotanically represent the Upper Westphalian C. In view of the above however, its exact upper boundary is not always sharp if no other criteria are present. Both the *Alethopteris serlii* subzone and the *Paripteris linguaefolia* zone end at the palaeobotanic start of the Early (or Lower) Westphalian D; that is at the beginning of the *Lobatopteris obliqua* zone (Wagner, 1979; Cleal et al, 2003) although this zone hardly shows distinctive macrofloras. Mind that *Paripteris linguaefolia* commonly already disappears quite before the true (litho)stratigraphic termination of the Westphalian C (Josten & Van Amerom, 1999; Cleal, 1984).

1.4.3 Westphalian D

In this paper the lithostratigraphic subdivision of the Westphalian D into a Lower and an Upper Westphalian D has been used according to the proposal of Pagnier & Van Tongeren (1996). Their proposed lithostratigraphic subdivision however, does not exactly match the actual combined palynological / macrofloral division by Cleal et al. (2003).

To be able to correlate more correctly to, and in line with the current palynologic criteria for the stratal subdivision of the Late Carboniferous, the actual divisional scheme by Cleal et al. (2003) subdivides the Westphalian D into two macrofloral zones only: the *Linopteris obliqua* zone (Wagner 1979) - or *Linopteris bunburii* zone (Cleal, 1997); different names, but both species and zones are considered identical - and the *Lobatopteris vestita* zone. They respectively represent the Early and the Late Westphalian D (Fig. 3). Previously however - e.g. in his 1978 and 1984 studies - Cleal applied a threefold macrofloral Westphalian D subdivision: an 'Early' (*Linopteris bunburii* zone) a 'Middle' (*Lobatopteris micromiltonii* zone) and a 'Late' Westphalian D (*Lobatopteris vestita* zone; Fig. 3). Using the latter subdivision, the proposed Lower / Upper Westphalian D lithostratigraphic boundary by Pagnier & Van Tongeren (1996) for the De Lutte-6 well in the northeastern Netherlands was situated within the 'Middle' Westphalian D; so somewhere within the *Lobatopteris micromiltonii* zone (Van Amerom, 1996; also see chapter 9 below).

In the actually used biostratigraphic scheme by Cleal (1997; Cleal et al, 2003) the former 'Middle' Westphalian D *Lobatopteris micromiltonii* zone has been incorporated as a separate subzone within the single Late Westphalian D *Lobatopteris vestita* zone (Fig. 3). In this way palaeobotanically an 'early' Late, and a 'late' Late Westphalian D have been created. These two epochs now correspond to two subzones: the (older) *Lobatopteris micromiltonii* subzone (formerly: zone) and the new, younger *Dicksonites plueckenetii* subzone.

In this new biostratigraphic scheme the Early Westphalian D is completely encompassed by the *Linopteris obliqua* zone (Cleal et al, 2003; Wagner, 1979). The zone is situated between the *Alethopteris serlii* (Late Westphalian C; Cleal, 1997) and the *Lobatopteris micromiltonii* subzones ('early' Late Westphalian D; Cleal, 1997).

Consequently, the proposed lithostratigraphic boundary between the Lower- and Upper Westphalian D by Van Tongeren & Pagnier (1996) does not correspond with the actually used Early and Late Westphalian D subdivision by Cleal (1997) and Cleal et al. (2003). Biostratigraphically it is now situated within the 'early' Late part of the Westphalian D.

Important remarks to the actually used biostratigraphic zonation (Cleal et al, 2003) are:

a) The base of the *Lobatopteris micromiltonii* subzone ('early' Late Westphalian D) theoretically(!) starts at the base of the acme of *Lobatopteris vestita*. Note however, that *Lobatopteris vestita* (generally) does not occur in the 'early' part of the *Lobatopteris vestita* zone (Cleal, 1997). A common presence of *Lobatopteris micromiltonii* therefore, is already considered confirmation of this subzone.

b) The start of the common presence of *Dicksonites plueckenetii* (the 'late' part of the Late Westphalian D) is regarded as the beginning of the second subzone. Note however, that the acme of this species occurs in the Cantabrian stage of the Stephanian period (Cleal et al, 2003).

In this paper the biostratigraphic subdivision of Cleal et al. (2003) has been applied. The paper also shortly addresses the regional stratigraphic implications of the interpreted subdivisions of the studied Carboniferous sequences.

2. Regional geologic setting

The Campine basin (sensu lato; s.l.) forms an elongated Upper Carboniferous sedimentary basin and is a part of the general chain of flexural foreland basins north of the Variscan orogenic thrust belt. This belt extends from southwest Wales and England, through northern France into central Germany and southwest Poland. Onshore the basin roughly runs between the actual northern subcrop edge of the Brabant Massif in mid-Belgium and the structural IJmuiden - Krefeld Ridge in the Netherlands (Fig. 1; Van Adrichem Boogaert & Kouwe, 1993 - 1995).

The Upper Carboniferous strata of northeast Belgium constitute the southeastern part of this Campine basin (s.l.). To minimise confusion, the Belgian part of the basin - in local literature commonly referred to as the ‘Campine basin’ - in this paper will be referred to as the Campine basin sensu stricto (s.s.).

To its east the Campine basin (s.s.) is structurally bound by the German Aachen - Erkelenz and Ruhr basins. To its south and west its actual edge is formed by the subcropping rocks of the Brabant Massif (Van Adrichem Boogaert & Kouwe, 1993-1995).

During the Westphalian C, D and the Stephanian, orogenic pulses and regional / local up-lifts occurred both

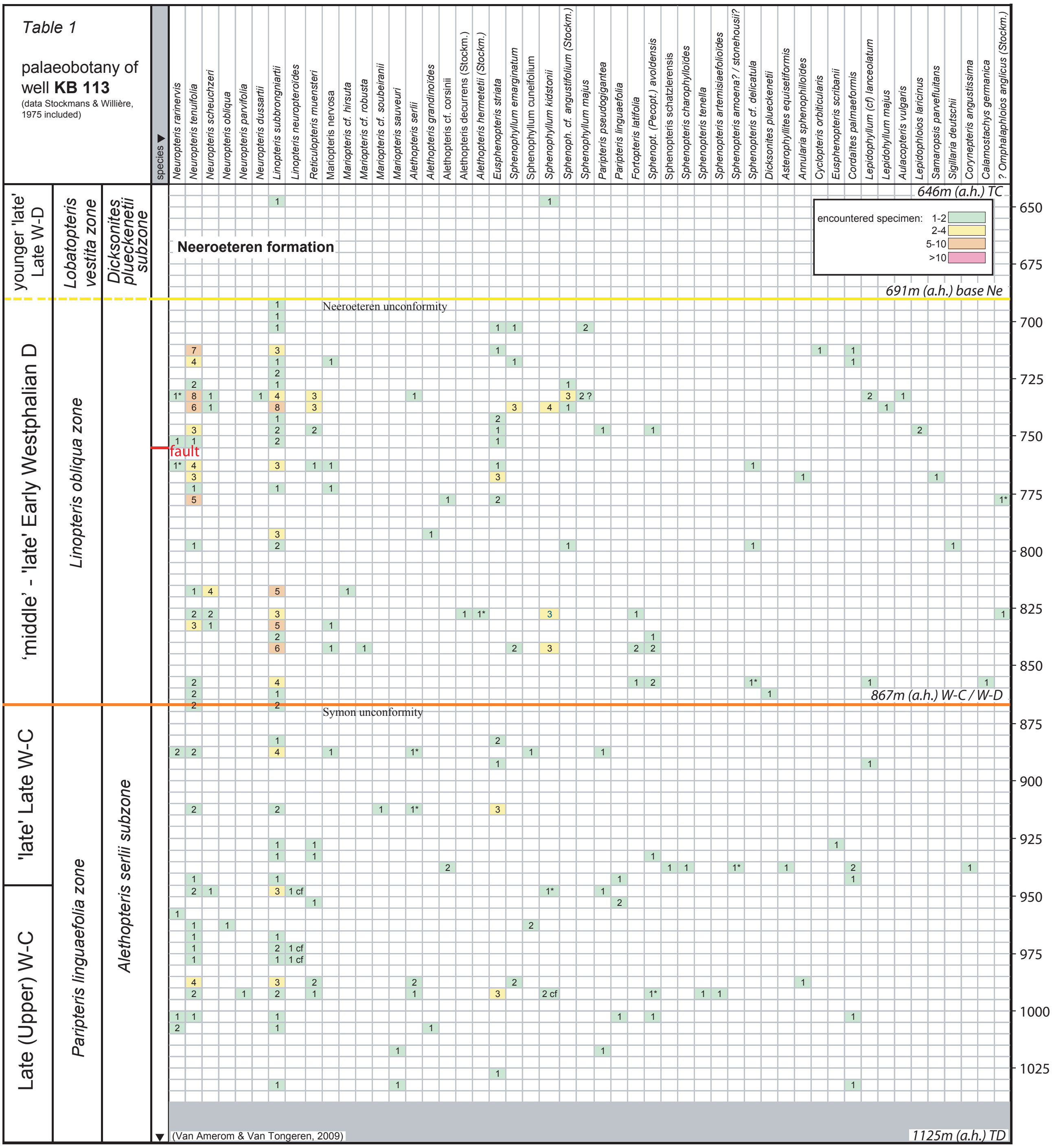

Table 1. Actual subdivision of available palaeobotanic sample material of well KB 113 in reference to the along hole depth. The actual W-C / W-D boundary position is at 867 m (orange line-level). The former boundary position was at 925 m (blue line-level; Van Tongeren & Van Amerom, 2003). The yellow line shows the level of the base Neeroeteren formation. The red line indicates an interpreted fault (after Renier, 1944). Shortened depth-range parts show in grey color. (Belgian Campine basin; after Van Tongeren & Van Amerom, 2005).

north and south of the Variscan orogenic mountain chain. In the southeastern Campine basin (s.l.) the intra Variscan, Malvernian tectonic events during the 'mid / late' Westphalian C have been relatively important (Wills, 1956; Kellaway, 1970; Bless et al, 1977). The effects of this orogenic 'hinterland folding' and partly uplifting phase, resulted in a gradual increase of the regional silt- and sandstone incursions. As transpressive and transtensive areas related to active shear zones became increasingly more pronounced too, it also caused changing subsidence rates and facies, as well as unconformities and increases of local diastems (Dreesen et al, 1995). The general source area of these depositions into the orogenic foreland basins - so including the Campine basin (s.l.) - was the intermitted uplifting of the Variscan Mountain chain to the south and (south)east (Bless et al, 1977).

After the following, tectonically more quiet period during the Early Westphalian D, tectonism picked up again in the Upper Westphalian D (Pagnier & Van Tongeren, 1996) with the Leonese tectonic pulses (Wagner, 1966). Moreover, in the course of these Late Westphalian C and Westphalian D events a gradual climatic shift occurred; from generally humid-tropical towards semi-arid conditions (Van der Zwan et al. 1993; Van de Laar & Van der Zwan, 1996).

3. Studied material

At well KB 113 (Table 1) the former listing of Stockmans & Willière (1975) has been compared to the collection of rock samples still present at the Belgian Geological Survey. The original core-description by Renier (1944) and most of its palaeobotanic samples were available for determination. Generally the palaeobotanic determinations of Stockmans & Willière (1975) proved very reliable. Only at very few occasions changing and updating was felt necessary.

The Belgian Geological Survey also provided sampled macrofossil material of the KB 168 and KB 172 wells. The (remaining) material of KB 168 (Table 2) however, was rather limited. Detailed descriptions of the coals, sedimentology and structural observations of the cored Carboniferous intervals of those wells were obtained from literature (i.e. Dusar et al. 1986; Dusar et al. 1987). The description of the KB 172 well included a listing of previously determined macroflora by Borremans (in: Dusar et al, 1987) with the corresponding approximate depths. Together with the additionally interpreted sample material this list has been incorporated into the study (Table 3). Note that the majority of the listed samples (Dusar et al. 1987) however, have not been verified by the authors. The former determinations of Borremans were simply taken to be correct. Neither the palaeobotanic data of well KB 172 nor those of well KB 168 have been used in detailed stratigraphic correlations before. Moreover, well KB 168 previously had only been investigated for its content of microfossils (ostracods, molluscs) and palynology (mega-, miospores); no macrofloral study had been carried out (Dusar et al, 1986).

The palaeobotanic sample-results of well KB 146 are presented in chapter 7 below, and in Table 4. As the cored strata of well KB 225 are very limited (4 m only) no table of this well is presented. Only a description of its macrofossil content is given below. The wells KB 117 and KB 169 only were reviewed by a consideration of their (limited) literature (Piérart, 1958; Stockmans & Willière, 1975; Dusart et al, 1987/1).

4. Palaeobotany of well KB 113

4.1 General

The top Carboniferous at this well is at a depth of 646 m. With a thickness of some 45 m the Neeroeteren formation has its base at ca. 691 m. Neither volcanic ash (marker) horizons nor faults have been described.
Predominantly based on the occurrences of both mega- and miospores Piérard (1958) already correlated the upper part of the strata below the Neeroeteren formation - being 'rich in *Superbisporites dentatus* and *Triletisporites tuberculatis* (megaspores)' - with the Du Souich and the d' Edouard series of the Pas-de Calais area in northern France ('early' / 'mid' Early Westphalian D; Laveine, 1967).

Also Stockmans & Willière (1975) appointed the top parts of the sequences below the Neeroeteren formation of the wells KB 113 and KB 117, to the Westphalian D. Dusar & Houlleberghs (1981) confirmed these conclusions and also extended them till a Westphalian D part in well KB 146 around 1069 m, some 45 m below the base of the Neeroeteren formation. Van Amerom & Van Tongeren (2003) too, attributed a large part of the strata below the Neeroeteren formation in this well to the later part of the Early Westphalian D.

4.2 Macrofaunal characterization of KB 113

Below the palaeobotanically sterile sediments of the Neeroeteren formation the sample revision revealed the macrofloral content of the Carboniferous sequence in KB 113 to be generally characterized by the following elements (Table 1):
a) *Neuropteris ovata* is absent; as well as *Neuropteris semireticulata*; *Lobatopteris vestita* and *Lobatopteris micromiltonii*.
b) Neuropteris dussartii occurs high in the sequence; only 1 sp. at 734 m. *Dicksonites plueckenetii* is present in the upper part too; 1 sp. at 860 m.
c) Linopteris subbrongniartii is remarkably well present throughout the whole sequence, as is *Neuropteris tenuifolia*.
d) Paripteris linguaefolia only occurs in the lower part of the well; till 944 m.
e) Alethopteris serlii occurs at low frequency throughout the sequence, but predominantly in the lower part. *Alethopteris grandinioides* rarely occurs; once in the upper part and once in the lower part of the section.
f) Reticulopteris muensteri and *Eusphenopteris striata* regularly occur within the sequence.

g) Neuropteris obliqua has been found only once at 964.50 m (according to Stockmans & Willière, 1975: *Neuropteris* gr. *obliqua*; according to Van Amerom and Josten [pers. comm. 2003]: a sound example of *Neuropteris obliqua*). *Neuropteris parvifolia* was found only twice; at ca. 818 m -according to Stockmans & Willière, 1975; actually this was not [!] confirmed by Van Amerom - and at ca. 992 m.

h) Mariopteris nervosa regularly occurs in the younger part of the sequence.

i) Sphenophyllum emarginatum and *Pecopteris avoldensis* occur predominantly in the upper half of the section. In this upper part *Lepidophyllidae* are occasionally present as well.

4.3 Discussion

4.3.1 Upper sequence part

Neuropteris ovata has not been found in this well, but despite its absence, the presence of a well preserved specimen of *Dicksonites plueckenetii* at about 860 m also indicates a Westphalian D age for the upper part of the sequence (Laveine, 1967, 1989; Wagner, 1979; Cleal, 1978, 1984; Josten, 1991; Josten & Van Amerom, 1999). The co-occurrence of *Alethopteris grandinioides* in this respect - although rare - supports this general age as does *Neuropteris dussartii* (see below) higher at ca. 734 m.

Moreover, typically Westphalian C characterizing elements like *Paripteris linguaefolia*, *Neuropteris parvifolia* and *Neuropteris obliqua*, clearly are absent in this part of the rock sequence.

Renier (1942-1944) originally determined a *Pecopteris miltonii* just above 757 m; a species generally attributed to indicate a Westphalian C age. In earlier studies however, this species has often been mistaken for *Pecopteris vestita* (Wagner, pers. comm.). Unfortunately this possibility could not be verified by the present authors, as no sample from this depth was present in their material. Neither do Stockmans and Willière mention a sample at this depth, nor have they observed such species in their review (1975). In regard too of the *Dicksonites plueckenetii* find at ca. 860 m, a misinterpretation by Renier (1942 – 1944) cannot be excluded. As the sample has not been (re)found however, no consequences were drawn. Renier (1942-1944) also considered *Linopteris obliqua* to occur abundantly in this well; predominantly in the upper part of the sequence. He nevertheless explicitly mentions his difficulties in distinguishing this species from *Linopteris neuropteroides* (Renier, 1944); a species currently recognized to (partly) represent *Linopteris subbrongniartii* (Laveine 1967). Neither the actual revision, nor the former one by Stockmans & Willière (1975) has revealed the presence of *Linopteris obliqua*; instead both revisions show many specimen of *Linopteris subbrongniartii* (Table 1). So Renier (1942 -1944) likely misinterpreted his findings here.

The occurrence of *Neuropteris dussartii* at 734 m appears both important and confusing. Commonly it is considered a typical Westphalian D species (Josten, 1991) indicating the 'middle' Westphalian D in the northwestern German wells (Josten & Van Amerom, 1999). In South Wales however, the species may already occur in the Late Westphalian C (Cleal, pers. written comm. 2005). Laveine (1967) indicates *Neuropteris dussartii* in the top of the d' Edouard coal group, so in the 'middle' Early Westphalian D of northern France. In his reviewing letter of 2005 to the authors however, he gives a somewhat extended range in that region; now also including the 'early' Early Westphalian D (Du Souich & d' Edouard coal groups; Laveine, pers. comm. 2005). The range of *Neuropteris dussartii* given by Josten & Van Amerom (1999) falls both within the later parts of the *Linopteris obliqua* zone (Wagner, 1979; Cleal et al, 2003) and the early part of the *Lobatopteris vestita* zone (so in the *Lobatopteris micromiltonii* subzone; Cleal, 1997; Cleal et al, 2003). This both joins and upwardly extends the range indicated by Laveine (2005) above.

The stratigraphic importance of *Dicksonites plueckenetii* has been firmly established (a.o. Wagner, 1979, Cleal, 1978, 1984). Generally it is considered a strong indicator for the 'latest' part of the Westphalian D; yet its acme is placed within the Stephanian (Laveine, 1989; Wagner, 1979). In northern France however, the species has also been noted to occur on an occasional base throughout the Early Westphalian D (Laveine, 1989). Cleal (1984) too, attributes the first occurrences of *Dicksonites plueckenetii* around the 'middle' Westphalian D. So in regard of both Laveine (1989) and Cleal (1984) *Dicksonites plueckenetii* may already occur incidentally in (the later part of?) the *Linopteris obliqua* zone (Wagner, 1979; Cleal et al, 2003).

In respect to the occurrences of both *Dicksonites plueckenetii* and *Neuropteris dussartii* above, the absence of *Lobatopteris micromiltonii* in the KB 113 well sequence is important; particularly as it has been found relatively often in the nearby well KB 168 and also occurs in well KB 172. Above the depth of 860 m the absence of *Lobatopteris micromiltonii* rather hints to a 'middle' to 'late' Early Westphalian D age. This age is supported by the single occurrence of *Alethopteris serlii* in this higher sequence part, versus its quite more frequent occurrences in the lower well section.

The find of *Dicksonites plueckenetii* at a quite lower level (126 m) than *Neuropteris dussartii* and also in regard of the absence of *Lobatopteris micromiltonii*, likely indicates a more 'late' Early Westphalian D age of the strata around the depth of ca. 734 m. This corroborates and joins the stratigraphic age realm inferred above.

An age varying from the about 'middle' to 'late' Early Westphalian D therefore; or rather: a position ranging from the about 'middle' into the 'late' *Linopteris obliqua* zone (Cleal et al, 2003) seems a fair assumption for these upper KB 113 well strata below the Neeroeteren formation. Stockmans & Willière (1975) indicated here a Westphalian D; Van Tongeren & Van Amerom 2003 an Early Westphalian D.

This age is supported by the absence of specific Westphalian C species in this upper part of the sequence. The relatively abundant occurrences of *Linopteris* *subbrongniartii, Neuropteris tenuifolia* and to a lesser extend of *Reticulopteris muensteri* and *Eusphenopteris striata* in the upper part of the well, also support this age. The occasional co-presences of *Alethopteris serlii*, *Fortopteris* (*Mariopteris*) *latifolia*, *Pecopteris avoldensis* and more commonly of *Mariopteris nervosa* fit well too.

Below the base of the Neeroeteren formation, this about 'middle' – 'late' Early Westphalian D age would at least involve the next 169 m of Carboniferous strata. Hence the Westphalian C / D transition occurs below 860 m.

4.3.2 Lower sequence part

Typical Westphalian C specimens like *Paripteris linguaefolia*, *Neuropteris parvifolia*, and *Neuropteris obliqua* occur in the part of the Carboniferous sequence below ca. 940 m. Palaeobotanically they best fit within the 'early' to 'middle' Late Westphalian C. All three species disappear before the end of the Westphalian C (Laveine, 1989; Josten 1991; Van Amerom, 1996). The presence of *Alethopteris serlii* in this lower part of the sequence (5 spec.) below 860 m supports this age. Although in northwest Germany *Paripteris pseudogigantea* - next to its common occurrence until the later parts of the Westphalian C - also sporadically occurs around the 'middle' Westphalian D realm (Josten & Van Amerom, 1999) its occurrence at 888 m (1 spec.) most likely still indicates a Late Westphalian C. These 56 m of strata above the latest occurrence of *Paripteris linguaefolia* (at ca. 944 m) likely indicate the gradual change from about 'middle' into more 'late' Late Westphalian C strata.

The absence of both *Linopteris obliqua*, *Neuropteris ovata* and e.g. *Annularia stellata*, combined with the still relatively abundance of *Linopteris subbrongniartii* and regular occurrences of both *Neuropteris tenuifolia*, *Neuropteris rarinervis* and *Eusphenopteris striata*, also suggest a Late Westphalian C age (*Paripteris linguaefolia* zone, *Alethopteris serlii* subzone; Cleal, 1997).

Between 860 m (*Dicksonites plueckenetii*) and the youngest find of *Paripteridae* (*Paripteris pseudogigantea* at ca. 888 m) only 28 m of strata are maximally present in which the transition of the Westphalian C to D occurs. So less than 28 m should represent the 'latest' part of the Westphalian C, the 'early' Early Westphalian D and - possibly - a part of the 'middle' Early Westphalian D as well. As no condensed stratal sequences are present (Renier, 1942-'44, 1944) a stratigraphic discontinuity (hiatus) is present within this interval. These missing strata (latest Westphalian C and 'early' Early Westphalian D) due to the combined effects of non-sedimentation and erosion represent the Symon discontinuity (Wills, 1956; Kellaway, 1970).

A quick evaluation of the palaeobotanic findings of Stockmans and Willière (1975) at well KB 117 indicates this discontinuity also to be present in this well.

4.3.3 Westphalian C / D boundary

Van Tongeren & Van Amerom (2003) arbitrarily placed the level of the above indicated discontinuity gap - so between 'late' Late Westphalian C and 'middle' Early Westphalian D - at 925 m. Actually this level has been

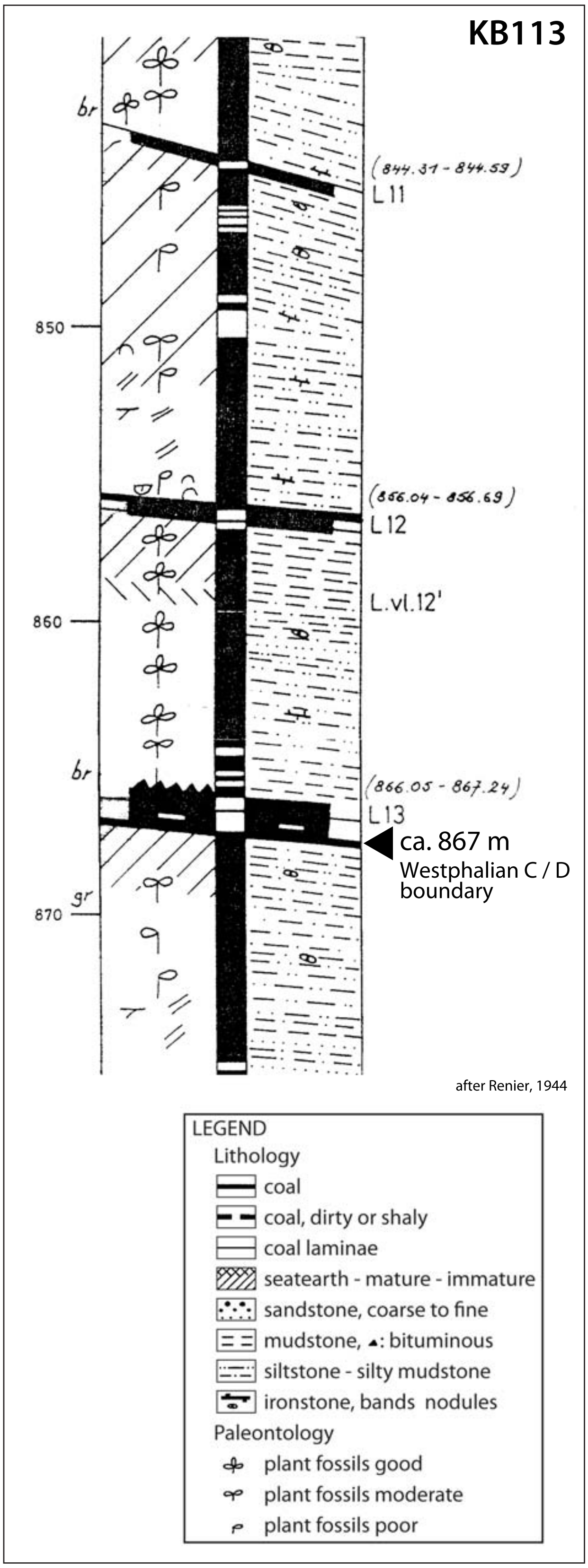

Figure 4. Inferred Westphalian C / D boundary at ca. 867 m in the KB 113 well (after Dusar, unpublished document).

slightly reset. The Westphalian C / D boundary now has been put - however still arbitrarily - at the base of the coal seam at 867 m (Fig. 4). Hence below the Neeroeteren formation about 176 m of (incomplete) Early Westphalian

D strata are present at this well. The complete Early Westphalian D thickness in the study area is not known. Note that the Early Westphalian D sediments at well KB 113 show a distal fluvial fan facies.

4.4 The KB 113 Neeroeteren formation

Palaeobotanically the Neeroeteren formation is considered to have a 'late' Late Westphalian D age (sensu Cleal, 1997) or lithostratigraphically, a late Upper Westphalian D age (sensu Pagnier & Van Tongeren, 1996) in all studied wells (see § 7.1.1 below). In view of the complete absence of 'early' Late Westphalian D strata in well KB 113 therefore, another discontinuity exists between the Neeroeteren formation and the 'late' Early Westphalian D strata below it (i.e. the Neeroeteren unconformity; Van Tongeren & Van Amerom 2003; Bertier et al, 2008). During this non-depositional time-gap some erosion occurred. The discontinuity at the base of this formation shows at the seismic section over the wells KB 113 and KB 146. It also shows the base of the Neeroeteren formation to be slightly older at well KB 113 than at well KB 146 (Van Tongeren & Van Amerom, 2003; Van Tongeren in prep.).

5. Palaeobotany of well KB 168

5.1 General

The top Carboniferous in this well is at a depth of ca. 653 m. The base of the 32 m thick Neeroeteren formation is at ca. 685 m. In the cored Carboniferous sequence the presences of some volcanic ash horizons provide important markers; two Nibelung ashes - at ca. 1142 m and 1141 m respectively - the Odin ash - at 1058 m - and a previously unknown(!) one - at 699 m. At the 875 m and 917 m levels small faults have been noted (Dusar et al, 1986).

5.2 Macrofloral characterisation of KB 168

Below the sterile Neeroeteren formation the macroflora of well KB 168 (Fig. 5; Table 2) is characterized by the following elements:

a) A fairly good presence of *Lobatopteris micromiltonii* (5 spec.) in the upper part of the well till 822 m.

b) The absences of both *Lobatopteris vestita* and of *Dicksonites plueckenetii*.

c) The occurrence of 1 specimen of *Neuropteris* (aff.) *ovata* at 700 m. The fair presences of both N*europteris tenuifolia* and *Neuropteris rarinervis* (particularly above 723 m). The rare occurrence of *Neuropteris semireticulata* and the absence of *Neuropteris parvifolia*.

d) The occasional presences of *Sphenophyllum zwickaviense* and *Sphenopteris bronnii* and the occasional occurrences of *Annularia stellata*, *Annularia spicata* and *Palmatopteris spinosa*.

e) The abundant presence of *Linopteris subbrongniartii* in the upper part of the well (in particular above 822 m) and the relatively limited presence of *Eusphenopteris striata* (5 spec; mainly above 744 m).

f) The absence of *Paripteridae*.

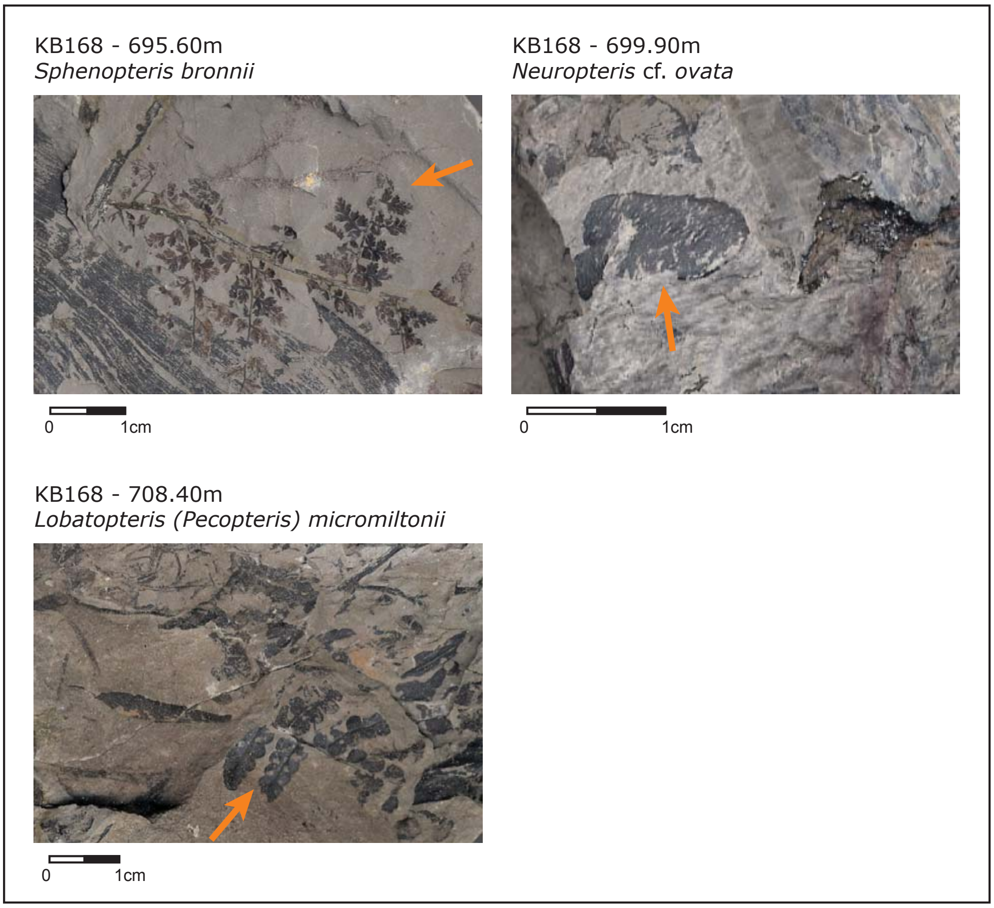

Figure 5. Some important macrofossils from the KB 168 well.

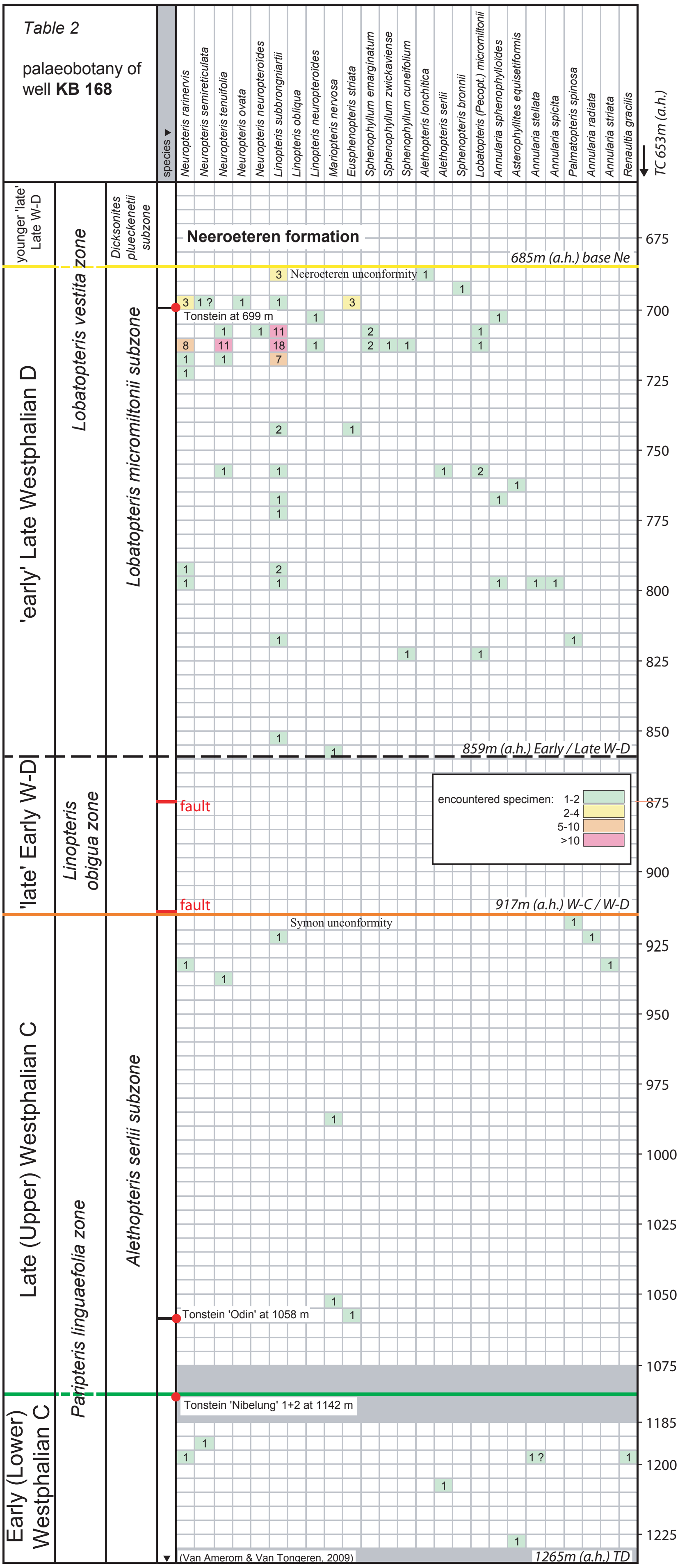

Table 2. Actual subdivision of available palaeobotanic sample material of well KB 168 in reference to the along hole depth. The orange line indicates the position of the actual W-C / W-D boundary at the fault level of 917 m (lower red line; Dusar et al, 1986). The upper red line indicates another fault at 875 m (after Dusar et al, 1986). The yellow line shows the base of the Neeroeteren formation. Grey depth-range parts have been shortened. Red dots indicate 'tonstein'-levels (volcanic ash layer). The Nibelung volcanic ash level is indicated by the green line at 1142 m. (Belgian Campine basin; after Van Tongeren & Van Amerom, 2005).

5.3 Discussion

5.3.1 Upper sequence part

The absence of both *Lobatopteris vestita* and *Dicksonites plueckenetii* - in conjunction with the frequent occurrences of *Lobatopteris micromiltonii* (5 spec.) - put the upper part of this rock sequence till a depth of 822 m within the *Lobatopteris micromiltonii* subzone of the *Lobatopteris vestita* zone ('early' Late Westphalian D; Cleal, 1997; Cleal et al, 2003).

The appearance of *Lobatopteris vestita* commonly only starts in the course of the *Lobatopteris micromiltonii* subzone (Cleal, 1997). As *Lobatopteris vestita* is rather common in the wells KB 146 (5 spec; Table 4) and KB 225 (3 spec; Van Amerom & Van Tongeren, 2002; Van Tongeren & Van Amerom, 2003) its absence in KB 168 strongly indicates a relatively 'early' position - so the 'older' part - within the *Lobatopteris micromiltonii* subzone. This 'early' Late Westphalian D age in the actual sense of Cleal (1997, Cleal et al, 2003) is also in line with the absence of *Dicksonites plueckenetii*. In the former sense of Cleal (1974, 1984, 1986) it biostratigraphically would have meant an 'early' (or 'older') position within the 'Middle' Westphalian D. In the lithostratigraphic sense of Pagnier & Van Tongeren (proposed; 1996) it means a position within the 'latest' Lower Westphalian D.

In age therefore, these strata succeed the 'middle' – 'late' Early Westphalian D dated sediments in the upper part of the nearby KB 113 well (chapter 4 above) quite nicely.

The Westphalian D age of this upper part of the KB 168 sequence is firmly supported by the presence of both *Neuropteris* (aff) *ovata*, *Sphenophyllum zwickaviense* (Zodrow, 1988) and *Sphenopteris bronnii* (Laveine, 1989). The presence of a specimen of *Annularia* cf. *spicata* at a depth of 801 m - a species that without 'cf.' is given an exclusive Middle Stephanian range (Josten & Van Amerom, 1999) - supports the Late Westphalian D range too; as does the occurrence of *Annularia stellata* (Josten, 1991; Josten & van Amerom, 1999; Cleal, 1984; Laveine, 1989).

The occurrence of the unknown volcanic ash horizon at ca. 699 m (Dusar et al, 1986) - obviously unknown in the German Ruhr area because of the absence of Westphalian D in that region - perfectly fits into this interpretation. This ash horizon may prove to be a precious marker within other 'early' Late Westphalian D strata either within, or near the Campine basin (s.l.).

5.3.2 Palaeobotanic remarks

Although the species *Neuropteris semireticulata* is commonly limited to the Westphalia C, yet its range extends into this part of the Westphalian D (Josten, 1962; Van Amerom, 1996). Note, that at the Dutch 'De Lutte-06' borehole (§ 9.2) it even occurs within the identical palaeobotanic time-frame. In the Saar-Loraine basin *Palmatopteris spinosa* sporadically occurs in the Upper Westphalian C until the Westphalian D boundary (Laveine, 1989). Also in the Upper Westphalian C of northwestern Germany the species is rare (Josten, 1991). Its presence at ca. 820 m in this borehole - still within the *Lobatopteris micromiltonii* subzone - implies a more extended range for this species. The other specimen observed just below the fault at ca. 920 m is taken to be situated within the Late Westphalian C (see below). The occurrence of *Neuropteris tenuifolia* does not contradict a Westphalian D age either. Josten (1991) mentions its quite common presence in the Westphalian D of northwestern Germany.

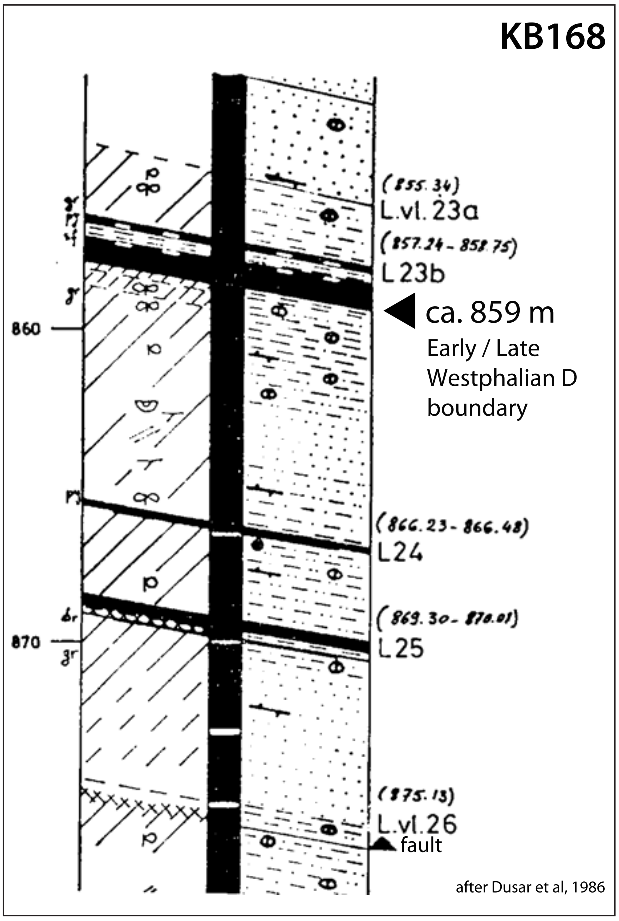

Figure 6. Inferred Early / Late Westphalian D boundary at ca. 859 m in the KB 168 well (after Dusar et al, 1986); for lithology see fig. 4.

The absence of *Alethopteris serlii* from 822 – 917 m may largely indicate a downward grading into the 'later' Early Westphalian D for this part of the sequence. Despite the relatively limited macrofloral data available and in view of the apparent lack of specific 'middle' – 'late' Westphalian C plant fossils (e.g. *Neuropteris parvifolia*, *Paripteris linguaefolia*, etc.) the strata between 917 m and 822 m have been interpreted to represent a grading between the (underlying) 'late' Early Westphalian D part (*Linopteris obliqua* zone; Wagner, 1979; Cleal et al, 2003) into (overlying) 'early' Late Westphalian D strata (*Lobatopteris micromiltonii* subzone, Cleal, 1997); so including the strata in between the two small normal faults at 875 m and 917 m.

The transient boundary between the Early and Late Westphalian D is likely situated someplace between 822 m (first occurrence of *Lobatopteris micromiltonii*) and the highest fault level at 875 m, where a 'late' Early Westphalian D age is already likely. This boundary may be placed - again arbitrarily - at the base of the 'dirty' coal seam at the depth of ca. 859 m (Fig. 6); so within the top part of a relatively large stretch (> 20 m) of extensively rooted, sandy sediments.

5.3.3 Lower sequence part

At 1058 m the presence of the 'Odin' volcanic horizon proves an 'early' Upper Westphalian C age. (Fiebig & Groscurth, 1984). However, specific 'early' and 'middle' Late Westphalian C palaeobotanic species that are relatively common in some other wells - e.g. like *Paripteris linguaefolia*, *Fortopteris latifolia* and *Neuropteris parvifolia* - seem absent in this one. Note that *Paripteris linguaefolia* likewise is absent above the Odin volcanic ash position in well KB 172 (see below) but that it does occurs in the 'middle' part of the interpreted Late Westphalian C part of well KB 113, in which well no volcanic ashes occur. Neither *Neuropteris semireticulata* nor *Neuropteris obliqua* were noted.

Nevertheless in this lower sequence part, single specimen of *Annularia stellata, Annularia radiata* and *Palmatopteris spinosa* were found between ca. 935 m and ca. 920 m. The earliest occurrences of *Annularia radiata* start within the later parts of the Westphalian C and Cleal (1984) mentions the base of *Annularia stellata* to be one of the signs of approaching the base of the Westphalian D. In northern France too, its occurrence starts in the 'late' Upper Westphalian C (Laveine, 1989). In northwest Germany however, Josten and Van Amerom (1999) have observed the species to begin only in the course of the Early Westphalian D.

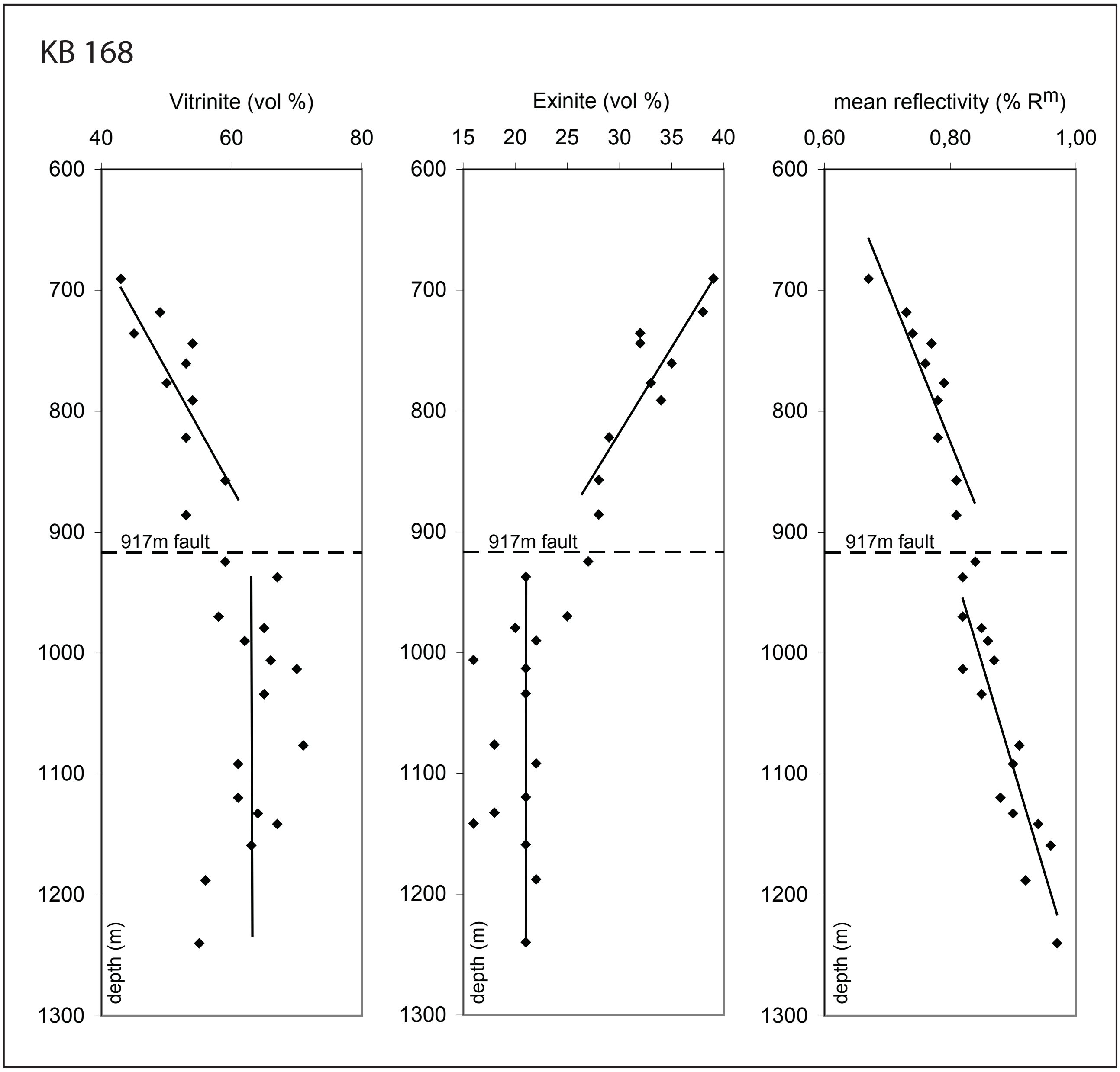

Figure 7. Coal quality (vol. % vitrinite / exinite) and coalification (%R^{mean}) graphs plus the 917 m-fault position at well KB 168 (data from Dusar et al, 1986).

As in this well these occurrences - including *Palmatopteris spinosa* at ca. 920 m - still hint to a Westphalian C age, it is likely that the Westphalian C / D boundary position lies above 920 m. Also single occurrences of respectively *Mariopteris nervosa* and *Linopteris subbrongniartii* were observed in these strata. Somewhat deeper single specimens of both *Neuropteris rarinervis* and *Neuropteris tenuifolia* are present, corroborating the Westphalian C age.
Despite the absence of *Paripteris linguaefolia*, *Fortopteris latifolia* and *Neuropteris parvifolia* species, a 'late' Upper Westphalian C age is concluded for the upper part of the rock sequence above tonstein Odin in this well, till at least 920 m.

5.3.4 Westphalian C / D boundary.
Interestingly the coal quality graphs, like coalification (% Rm) maceral development and others of well KB 168, show trend deviations between roughly 900 m and 935 m (Dusar et al, 1986; Fig. 7); so around the fault at 917 m. The throw of this fault has been described as quite limited. This points to a serious change in depositional and coal forming conditions. In conjunction with the palaeobotanic reasoning above, the Westphalian C / D boundary in this well has been put at the 917 m fault level (Fig. 8). This implies an Early Westphalian D thickness of at least 58 m (917 m and 875 m fault-throws unknown) and an 'early' Late Westphalian D part of ca. 174 m in this well.

Downwards from this fault - until the Nibelung volcanic ash horizon at 1142 m - the strata of KB 168 lithostratigraphically are assigned to the Upper Westphalian C.

Compared to the Upper Westphalian C thickness of some 400 m in the adjoining Dutch south-Limburg area (Krans et al, 1986) and of over 460 m in the German Ruhr area more to the northeast (Fiebig & Groscurth, 1984) the amount of some 225 m of Upper Westphalian C strata in well KB 168 - even considering some cut-away by normal faulting - is quite limited. Although in regard of its volcanic ash levels much of the 'early' Upper Westphalian C strata (in time) seems present, only some 84 m occur between the Nibelung and Odin ashes. This is quite less than the about 120 m or more that may be deduced at the Dutch Kemperkoul well (Pagnier & Van Tongeren, 1996; Fig. 1) but more than at well KB 172 (chapter 6 below). The 'late' Upper Westphalian C above the Odin ash level in well KB 168, shows a thickness of over 141 m (some tens of meters? 'limited fault throw', Dusar et al, 1986).

The Early Westphalian D thickness in this well minimally reaches some 58 m plus likely a few tens of meters, due to the 917 and 875 m fault throws. At the nearby well KB 113 the Early Westphalian D thickness is ca. 176 m ànd is incomplete. As both wells are only just over 2 km apart, any completeness of the Early Westphalian D strata at well KB 168 in very unlikely and only 'late' Early Westphalian D strata seem present. Moreover, some stratal thinning occurs too, and is quite in line with the regional seismic interpretations of Late Westphalian C and Early Westphalian D terminal fan developments (Van Tongeren, 2004; Van Tongeren in prep.).

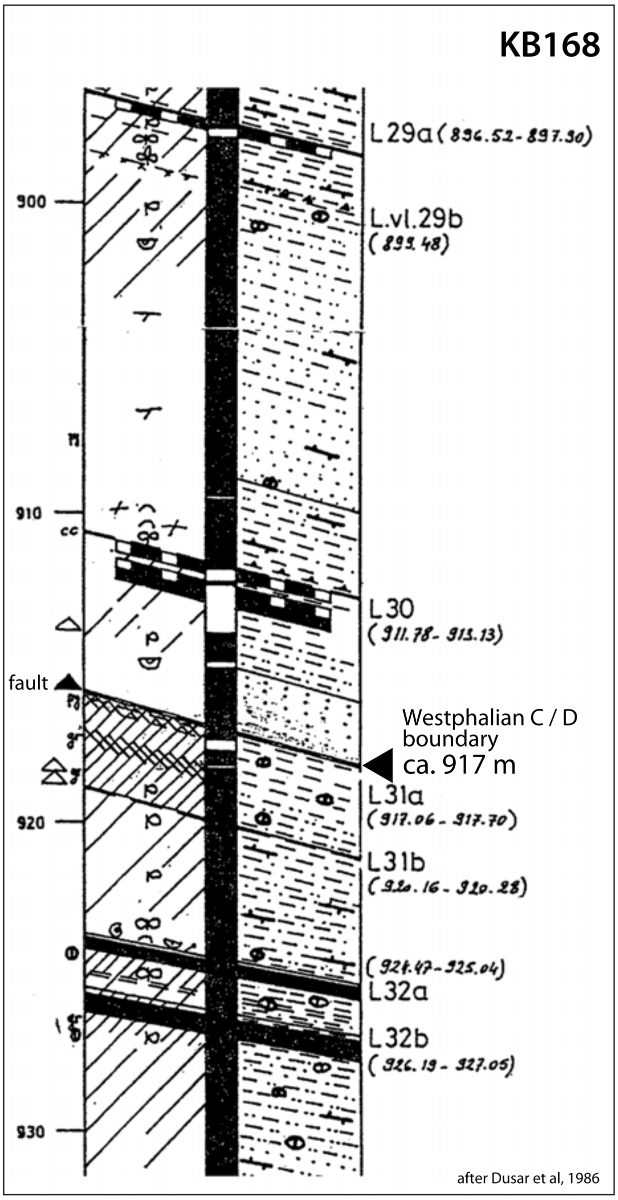

Figure 8. Inferred Westpalian C / D boundary at the 917 m-fault position in well KB 168 (after Dusar et al, 1986); for lithology see fig. 4.

This palaeobotanic interpretation of well KB 168 therefore indicates the largely absence of both the 'early' and 'middle' Early Westphalian D and likely some 'latest' Westphalian C; i.e. the Symon discontinuity (Kellaway, 1970). Note that the top 60 m of Westphalian D sediments below the Neeroeteren formation in this well show a more distal facies than the earlier part (Dusar et al, 1986/3).

5.4 The KB 168 Neeroeteren formation

No macrofossils have been found in the sandstones of the Neeroeteren formation in this well. In view of the determined age of this formation in well KB 146 (see chapter 7 below) in well 168 its age is considered a 'late' Late Westphalian D too (*Lobatopteris vestita* subzone; Cleal 1997).

At well KB 146 the species *Lobatopteris vestita* and *Dicksonites plueckenetii* both occur far before the base of the Neeroeteren formation. They are absent in well KB 168. Hence at least the 'later' part of the 'early' Late Westphalian D (Cleal, 1997) is missing in well KB 168 and probably also an earlier part of the 'late' Late Westphalian D. A discontinuity between the Neeroeteren formation and its underlying strata therefore is also concluded for this well; i.e. the Neeroeteren unconformity.

6. Palaeobotany of well KB 172

6.1 General

The Carboniferous sandstones of the Neeroeteren formation in this well start at 832 m. This formation is present till 957 m. So its thickness is some 125 m.

In this well too, a number of important volcanic reference horizons is present: the Hagen ashes (1 and 4) at ca. 1489 m and 1477 m respectively, Kobold (?) at 1427 m, Nibelung at ca. 1350 m and Odin at ca. 1282 m. This implies at least a Lower Westphalian C age for the part of the sequence below the Nibelung level and a definite Upper Westphalian C age for the 68 m thick series till the Odin ash level (Fiebig & Groscurth, 1984).

6.2 Macrofloral characterisation of KB 172

Below the sterile sediments of the Neeroeteren formation the palaeobotanical content of well KB 172 is characterized in the following way (Fig. 9; Table 3):

a) The presence of *Lobatopteris micromiltonii* (2 spec.) in the top of the sequence.

b) The absence of both *Lobatopteris vestita* and *Dicksonites plueckenetii*.

c) The rare presence of *Linopteris obliqua* in the higher and approximate middle parts of the sequence.

d) The occurrence of both *Linopteris subbrongniartii* and *Linopteris neuropteroides* from the Kobold(?) ash-level upwards. *Linopteris subbrongniartii* is still present in the top part of the sequence, whereas *Linopteris neuropteroides* only occurs till about mid-section (ca. 85 m above the Odin level).

e) The occasional presence of *Paripteris linguaefolia* in the middle part of the sequence; mostly between the Odin and Nibelung marker horizons and - more rarely - somewhat lower till about the Kobold(?) volcanic ash level. Note that - like in well KB 168 - the species does not show above the Odin ash level. Also *Paripteris pseudogigantea* regularly occurs in the middle part of the sequence and is present till some 140 m above the Odin level. *Paripteris* (*Neuropteris*) *lunata* is frequently present at one level only (some 25 m below the Nibelung level, so within the 'latest' Lower Westphalian C).

f) *Alethopteris serlii* frequently occurs from a little above the Kobold (?) volcanic ash level (1427 m) till about the top central part of the sequence.

g) *Annularia sphenophylloides* commonly occurs in the upper half of the sequence, as does more occasionally *Annularia radiata*. Neither *Annularia stellata* nor *Annularia spicata* have been found.

Figure 9. Some important macrofossils from the KB 172 well.

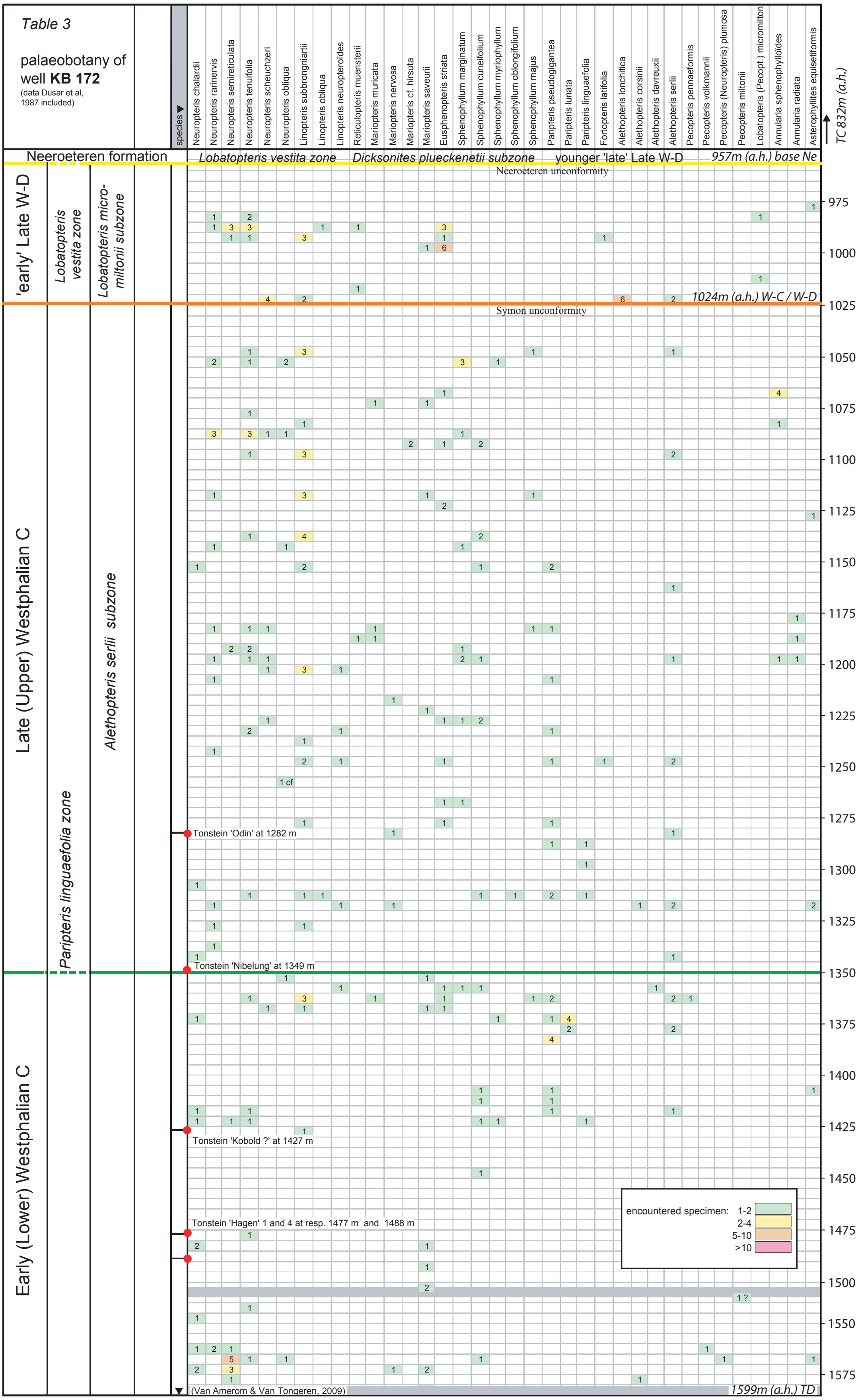

Table 3. Actual subdivision of available palaeobotanical sample material and published data by Dusar et al. (1987) of well KB 172, in reference to the along hole depth. The orange line indicates the position of the actual W-C / W-D boundary at 1023 m. The yellow line shows the base of the Neeroeteren formation. Grey depth-range parts have been shortened. Red dots indicate 'tonstein'-levels (volcanic ash layer). The Nibelung volcanic ash level is indicated by the green line at 1349 m. (Belgian Campine basin; after Van Tongeren & Van Amerom, 2005).

h) Neuropteris ovata is absent too. *Neuropteris rarinervis* occurs in relative abundance above the Upper / Lower Westphalian C boundary; it has been far less frequently found below. *Neuropteris* (cf.) *parvifolia* has been found only once, roughly in the middle of the sequence. *Neuropteris scheuchzeri* is frequent within the upper part and throughout the whole sequence *Neuropteris tenuifolia* frequently occurs, albeit most abundantly in the upper half. *Neuropteris obliqua* is relatively rare in the lower, but occurs somewhat more in the upper sequence part. *Neuropteris semireticulata* intermittently occurs throughout the whole sequence. *Neuropteris chalardii* is rather regularly present downwards from below the Odin ash level; above this level it becomes rare.

i) *Alethopteris lonchitica* has only been (abundantly) identified at one level in the top part of the sequence. *Alethopteris* cf. *corsinii* only rarely occurs in the lower sequence part. *Alethopteris davreuxii* has only been observed once in the lower part.

j) *Eusphenopteris striata* is common throughout the whole sequence from the top down. It occurs till a little below the Nibelung ash level.

k) *Reticulopteris muensteri* only occurs thrice in the upper half of the sequence.

l) Fortopteris (*Mariopteris*) *latifolia* is rarely present in the higher and approximate middle parts, whereas *Mariopteris saveurii* more commonly occurs throughout the complete sequence; albeit more frequently in the lower part. *Mariopteris muricata* shows uncommonly in the lower part, as does *Mariopteris nervosa*. *Mariopteris* cf. *hirsuta* has been spotted at one level in the upper sequence part only.

m) Pecopteris pennaeformis, *Pecopteris miltonii*, *Pecopteris (Neuropteris) plumosa* and *Pecopteris* cf. *volkmannii* are only rarely present and occur in the lower parts of the sequence.

n) Sphenophyllum cuneifolium occurs rather regularly, but not in the more upper part of the sequence. It is most frequent in the middle and upper middle parts. *Sphenophyllum majus* is somewhat less frequent, but also mostly present in the upper middle part. For *Sphenophyllum emarginatum* this goes too, although it occurs much more frequently. *Sphenophyllum myriophyllum* is only occasionally present throughout the sequence; in the most upper part it is lacking. *Sphenophyllum zwickaviense* is absent.

o) Asterophyllites equisetiformis occurs infrequently but intermittently throughout the whole sequence.

6.3 Discussion

6.3.1 Upper sequence part

Lobatopteris micromiltonii was observed just below the base of the Neeroeteren formation: one specimen at ca. 984 m and one 'cf' specimen at 1016 m. It is characteristic for the 'early' Late Westphalian D (*Lobatopteris micromiltonii* subzone; *Lobatopteris vestita* zone; Cleal, 1997) and does not occur in the Westphalian C. Also *Linopteris obliqua* is present in the well: at 989 m and 1312 m. Although the species may already infrequently occur in the 'late' Upper Westphalian C (Wagner, 1979; Laveine, 1989; Josten 1991) it most frequently occurs in the Early Westphalian D, for which it is considered characteristic (*Linopteris obliqua* zone; Cleal et al, 2003; Josten & Van Amerom, 1999; Laveine, 1989; Wagner, 1979 & 1984; Lyons, 1979).

The occurrences of *Lobatopteris micromiltonii* at ca. 984 m and in particular the (cf.) one at 1016 m, combined with the youngest occurrence of *Linopteris obliqua* at 989 m, are interpreted to biostratigraphically reflect a gradual transition between the late Early and the early Late Westphalian D in the stratal sequence around 1016 m and below.

The transient boundary between the ('late') Early- and ('early') Late Westphalian D sensu Cleal (1997) has been - arbitrarily - put at the base of the coal seam at ca. 987 m (Fig. 10); so in between both finds of *Lobatopteris micromiltonii*. In the lithostratigraphic sense of Pagnier & Van Tongeren (1996) these strata all are situated within the 'late' Lower Westphalian D.

6.3.2 Lower sequence part

Besides the base of *Annularia stellata*, Cleal (1984) also indicates the top of the *Paripteridae* range, as a first event indicating the approach of the base of the Westphalian D.

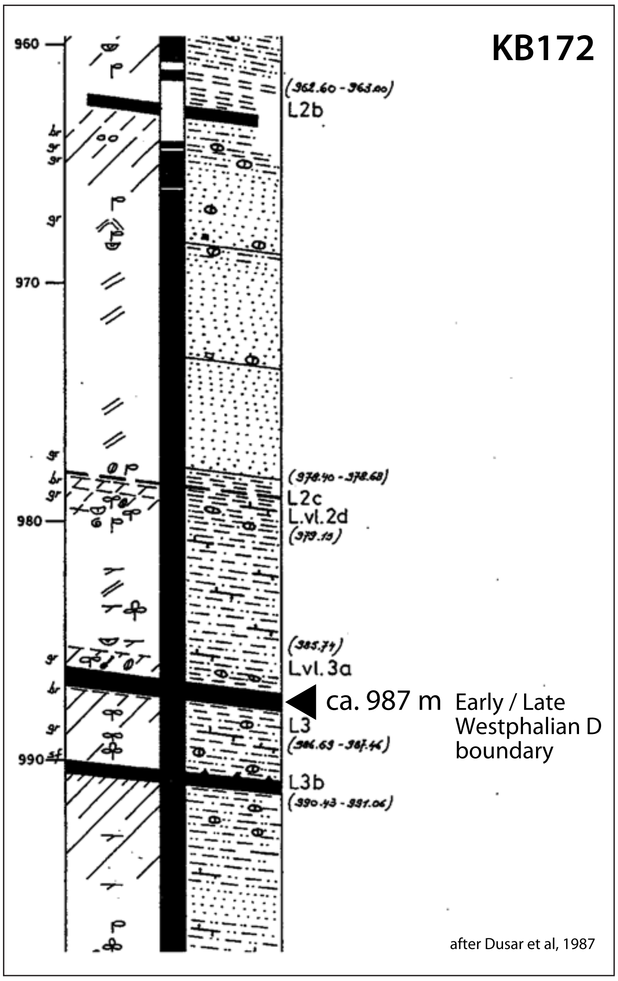

Figure 10. Inferred Early / Late Westpalian D boundary at ca. 987 m in the KB 172 well (after Dusar et al, 1987/3); for lithology see fig. 4.

In well KB 172, the youngest occurrence of *Paripteridae* is at about 1152 m (Dusar et al, 1987). *Annularia stellata* has not been identified. *Paripteris pseudogigantea* occurs till some 197 m above the Nibelung ash horizon; so till ca. 128 m above the Odin ash level. *Paripteris linguaefolia* has only been found in the Upper Westphalian C strata below the Odin horizon and *Paripteris* (*Neuropteris*) *lunata* some 25 m deep in the Lower Westphalian C sequence part at one level only. In this way the time-span of *Paripteridae* occurrences in the KB 172 well clearly falls within the range of the *Paripteris linguaefolia* zone of Wagner (1979).

Although Josten & Van Amerom (1999) indicate very rare occurrences of both *Paripteris pseudogigantea*, *Paripteris gigantea* and a *Paripteris* cf. *linguaefolia* in the Lower Westphalian D of northwest Germany, the *Paripteridae* commonly do not occur beyond the Westphalian C for which they are considered characteristic (Laveine, 1967, 1989; Wagner 1979; Josten 1991; Van Amerom, 1996; Cleal, 1984, 1997). The top of the Westphalian C in well KB 172 therefore should be above 1152 m.

The abundant presence of *Alethopteris serlii* throughout the upper and middle parts of the KB 172 sequence is important. Moreover - and in accordance to Cleal (1997) - the base of *Alethopteris serlii* in KB 172 coincides almost exactly with the base of *Linopteris subbrongniartii*.

According to the listing of Borremans (Dusar et al, 1987) the first occurrences of both *Alethopteris serlii* and *Linopteris subbrongniartii* already start some 75 to 80 m below the Nibelung ash level; so doubtlessly within the later part of the Lower Westphalian C. Both species are also commonly present in the part below the Odin ash level, so within the 'early' part of the lithostratigraphic Upper Westphalian C (Fiebig & Groscurth, 1984). The presence of *Alethopteris serlii* therefore, is quite in agreement too with the observations of Cleal (1997). The base of the *Alethopteris serlii* subzone (Cleal, 1997) is taken at the Nibelung ash level (§ 1.4.2).

The youngest presences of both *Alethopteris serlii* and *Linopteris subbrongniartii* in well KB 172 respectively occur at ca. 320 m and 360 m above the Nibelung ash level. For the Campine basin the two species are expected to occur within - or at least rather close to - the established ranges of both Laveine (1989) in northern France and Josten & Van Amerom (1999) in northwest Germany. In both regions the top range of rather frequent occurrences was established to run until the 'middle' of the Westphalian D. Hence in view of the last occurrence of *Alethopteris serlii* in particular and combined with the presence of *Lobatopteris micromiltonii* (cf.) just above this disappearance level, the base of the Early Westphalian D in well KB 172 too, lies below this youngest occurrence of *Alethopteris serlii*; so below ca. 1018 m.

6.3.3 Palaeobotanic remarks

Both Josten (1991) and Laveine (1967) put the top range of *Neuropteris semireticulata* exclusively within the Upper Westphalian C. Most abundantly it occurs somewhat before the 'later' part of the Lower Westphalian C. Notwithstanding, *Neuropteris semireticulata* has also been reported from within the *Lobatopteris micromiltonii* realm (now 'early' Late Westphalian D) in the northeastern Netherlands (Van Amerom, 1996). In well KB 172 four (4) specimen were found a few meters below *Lobatopteris micromiltonii* in the material available to the authors (Table 3). The last occurrence of *Neuropteris semireticulata* is roughly at 988 m; about 300 m above the Odin volcanic ash level. In this well KB 172 therefore the top presences of *Neuropteris semireticulata* likewise occur till into the *Lobatopteris micromiltonii* realm of the Westphalian D.

Josten & Van Amerom (1999) exclusively position *Linopteris obliqua* within the Lower Westphalian D. The species has not been found in the Westphalian C of the Ruhr area but only in boreholes in northwestern Germany (Josten, 1991; Josten & Van Amerom (1999). Its occurrence between the Odin and Nibelung horizons in well KB 172, confirms its occasional downward extension into the middle part of the Upper Westphalian C conform Laveine (1989).

6.3.4 Westphalian C / D boundary.

In well KB 172 *Neuropteris obliqua* occurs occasionally from ca. 1053 m downwards. In the Ruhr area the species only reaches till the late Lower Westphalian C; so below the Nibelung level (Josten, 1991). In northern France however, its occurrence has been established until the top of the Westphalian C (Laveine, 1967). So this species too, is considered characteristic for the Westphalian C. In conjunction with the above (§ 6.3.2) the Westphalian C / D transition therefore should be situated somewhere between 1018 m and 1053 m. In view of the overall palaeobotanic development of the borehole, the Westphalian C / D boundary has been - again arbitrarily - placed at the base of the coal seam at 1024 m (Fig. 11; Dusar et al, 1987).

This implies an Upper Westphalian C thickness of some 336 m in this well, of which about 258 m between the Odin tonstein and the Westphalian C / D boundary. Compared to the estimated thicknesses in both the Ruhr and the adjacent Dutch south-Limburg areas, this anew indicates stratal thinning in western directions. In regard of the transition boundary between Early and Late Westphalian D at 989 m, only a maximum of 35 m Early Wesphalian D strata has remained in this well. The Late Westphalian D here only has a thickness of about 32 m. The thickness of the complete Westphalian D therefore is limited to 67 m.

Below the Neeroeteren formation e.g. *Sphenophyllum cuneifolium* and *Sphenophyllum majus* are absent in the top sequence of this well, whereas they are quite regularly present in the deeper well parts. Considering their ranges in the northeastern Netherlands (Van Amerom, 1996) and northwestern Germany (Josten & Van Amerom, 1999) - till just into the base of the 'late' Late Westphalian D (*Lobatopteris micromiltonii* subzone; Cleal, 1996) - and their absence from the transition realm of the Early – Late Westphalian D sediments here, most of the Early Westphalian D must be absent (in time). Its very limited

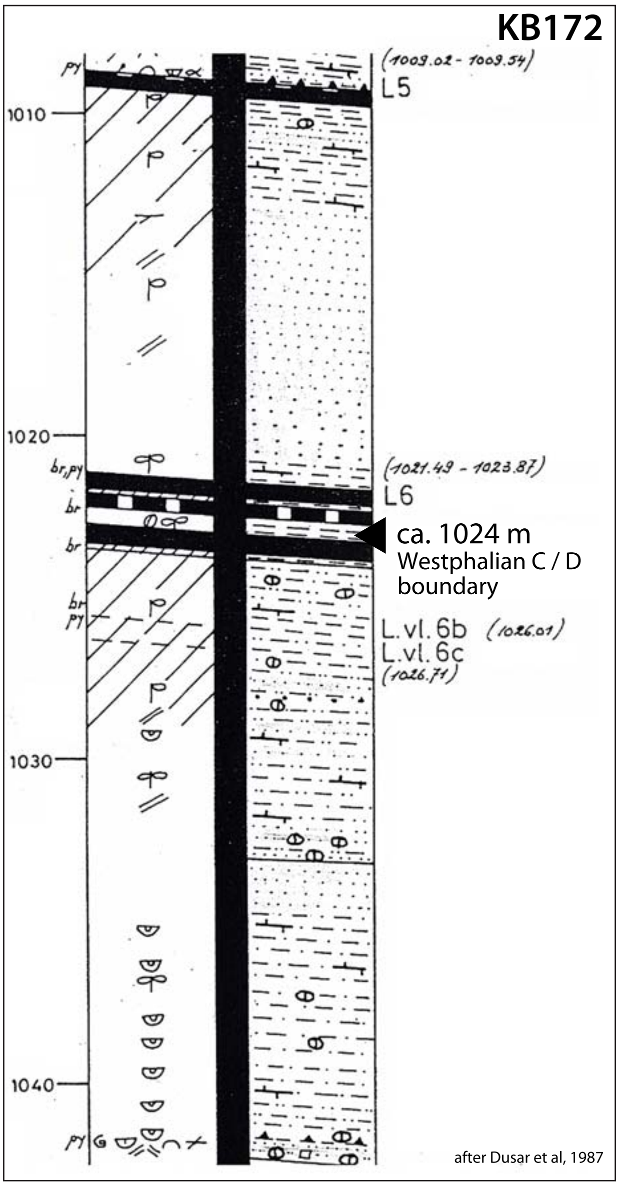

Figure 11. Inferred Westphalian C / D boundary at ca. 1024 m in well KB 172 (after Dusar et al, 1987/3); for lithology see fig. 4.

remaining stratal thickness corroborates this; i.e. the Symon discontinuity. Note that the Westphalian D facies below the Neeroeteren formation in this well have a somewhat more proximal sedimentary facies than the identically positioned sediments at the wells KB 168 and KB 146 (Dusar et al, 1987/3).

6.4 The KB 172 Neeroeteren formation

No macrofossils have been found in the Neeroeteren formation of this well. The age of this formation therefore has been assumed to be equal to that of this formation in well KB 146 (§ 7.2.3 below) so, around the middle part of the 'late' Late Westphalian D age (*Dicksonites plueckenetii* subzone; *Lobatopteris vestita zone*; Cleal, 1997).

Note that where the *Dicksonites plueckenetii* subzone in well KB 146 continues for almost 200 m below the Neeroeteren formation and begins above the Symon discontinuity (§ 7.2.5 and § 7.2.7) these subzone strata are completely absent in well KB 172. Hence in well KB 172 both a later part of the 'early' Late Westphalian D (*Lobatopteris micromiltonii* subzone; Cleal, 1997) seems lacking as well as the earlier part of the 'late' Late Westphalian D. Although being (partly) caused by the general westward thinning, this also demonstrates the timewisely quite important discontinuity below the Neeroeteren formation here (i.e. the Neeroeteren unconformity). Moreover, at this location it is possible that the Neeroeteren unconformity consists of the conjunction of several smaller discontinuities.

7. Palaeobotany of well KB 146

7.1 General

The top Carboniferous in well KB 146 starts at a depth of ca. 730 m with the sandstones of the Neeroeteren formation. This formation has a thickness here of some 294 m and runs to a depth of 1024 m.

The macroflora of well KB 146 has originally been determined by Houllebergh (in Dusar & Houlleberghs, 1981). Revision of sample material occurred in 2002 and 2003 by Van Amerom (Van Amerom & Van Tongeren, 2002; Van Tongeren & Van Amerom, 2003).

In contrast to the other investigated wells, within the Neeroeteren formation at well KB 146 indeed some identifiable plant fossils were found at various depths. Their quantity however, remains limited (Table 4).

7.2 Macrofloral characterisation of well KB 146

7.2.1 General

Most of Houlleberghs' work (Dusar & Houlleberghs, 1981) proved quite valid and reliable; only few new determinations differ from the original ones. For instance *Neuropteris obliqua* (Houlleberghs) at 840 m and between 1096 - 1099 m likely is a mistake; possibly *Linopteris obliqua* was meant. At a few places too, *Linopteris neuropteroides* (Houlleberghs) was changed into *Linopteris subbrongniartii* by Van Amerom.

7.2.2 Macrofloral characterisation of the Neeroeteren formation

In well KB 146 the macroflora of the Neeroeteren formation is characterised by the following elements (Fig. 12; Table 4):

a) The presence of *Neuropteris* (aff.) *ovata* (2 spec.) and the fair presence of *Neuropteris scheuchzeri*.

b) The (semi-)regular occurrence of *Neuropteris rarinervis* and the occasional presence of *Neuropteris tenuifolia*.

c) The occurrence of *Dicksonites plueckenetii* (?; 1 spec.) and the occasional presence of *Linopteris subbrongniartii*, *Eusphenopteris striata*, *Annularia sphenophylloides* and *Mariopteris muricata*.

d) The presence of *Eusphenopteris nummuriana, Sphenophyllum cuneifolium* and the fair occurrences of *Reticulopteris muensteri* (4 spec.) and *Sphenophyllum emarginatum* (4 spec.).

e) The presence of *Lepidodendron obovatum* and a species of *Cantheliophorus*.

f) The apparent absence of *Lobatopteris vestita*.

Table 4. Actual subdivision of available palaeobotanical sample material of well KB 146 in reference to the along hole depth. The orange line indicates the position of the actual W-C / W-D boundary at 1222 m. The former W-C / W-D boundary was at the blue 1240 m line-level (Van Tongeren & Van Amerom, 2003). The yellow line shows the base of the Neeroeteren formation. The red line indicates an interpreted fault (after Dusar & Houlleberghs, 1981). Grey depth-range parts have been shortened. (Belgian Campine basin; after Van Tongeren & Van Amerom, 2005).

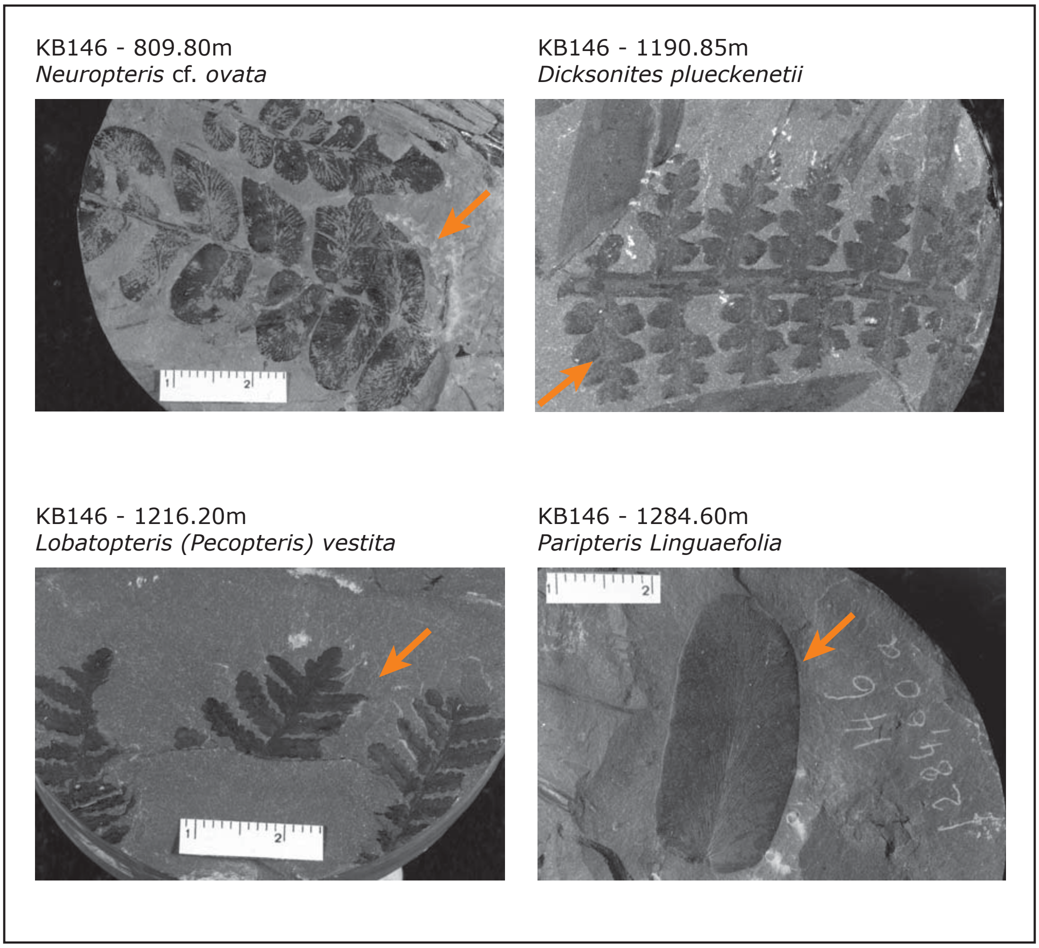

Figure 12. Some important macrofossils from the KB 146 well.

7.2.3 Age of the Neeroeteren formation

The single specimen of *Dicksonites plueckenetii* (?) as well as the find of *Neuropteris* aff. *ovata* (2 spec; these determinations were also personally confirmed by K-H. Josten, 2002) in conjunction with the stratigraphic position of this formation (§ 7.2.5 below) indicate a general 'late' Late Westphalian D age for this formation ((*Lobatopteris vestita* zone; *Dicksonites plueckenetii* subzone; Cleal, 1997; Cleal et al, 2003; Van Amerom & Van Tongeren, 2002; Van Tongeren & Van Amerom, 2003). Although *Dicksonites plueckenetii* has its acme in the Cantabrian (Early Stephanian; Laveine, 1989; Wagner, 1979) the ranges of most other co-occurring species remain limited to the Westphalian.

So the occurrences of *Neuropteris scheuchzeri* (3 spec.) *Mariopteris muricata* (1 spec.) and other species with a strong Westphalian affinity as well as the lack of specific palaeobotanic elements that might indicate a younger age, clearly prevent any younger age assignment. The occurrence of *Neuropteris tenuifolia* (1 spec.) may seem remarkable, but the species also occurs in the Westphalian D of northwest Germany where it covers an about identical range as *Mariopteris muricata*. In the eastern Campine basin both species apparently show a somewhat more extended range than is common. *Neuropteris rarinervis* in northwest Germany - as *Neuropteris rarinervis* var. *attenuata* - is present over almost the complete Westphalian D; so stratigraphically, in northwestern Germany it ranges quite further than in the Saar-Lotharingen realm (Josten & Van Amerom, 1999). This also is the case in northeastern Belgium. *Reticulopteris muensteri* too, has been found up till high in the Westphalian D (Van Amerom, 1996; Josten & Van Amerom, 1999).

7.2.4 Age of the Neeroeteren formation in other wells

Seismic information demonstrates the base of the prograding sandstones of the Neeroeteren formation at well KB 113 to be somewhat older than in well KB 146. This means that the basal deposits of the Neeroeteren formation (mid-alluvial fan sediments; Dreesen et al, 1995; Van Tongeren, 2004) run slightly diachronously into the basin. Indications of incisive erosion of Neeroeteren sediments into the underlying Westphalian D strata are present as well (Van Tongeren & Van Amerom, 2003; Van Tongeren, in prep.). Notwithstanding this slight diachronism however, and considering the age of the strata immediately below the formation in this well (see below) the palaeobotanic age of the base of the Neeroeteren formation has been taken to represent a 'late' Late Westphalian D age at all studied localities. The age of its base in this well KB 146 probably varies between a middle and late position within the *Dicksonites plueckenetii* subzone (Cleal, 1997).

7.2.5 Macrofloral characterisation of the sequence below the Neeroeteren formation (Table 4)

a) Below the base of the Neeroeteren formation (ca. 1024 m) *Dicksonites plueckenetii* rather commonly occurs (3 species) in conjunction with a relatively high abundance of *Lobatopteris vestita* (5 species) over a stratal length of some 190 m (Van Amerom & Van Tongeren 2002). *Lobatopteris micromiltonii* is absent.

b) Mariopteris muricata, and *Mariopteris nervosa* are sparsely present in the upper sequence part. *Mariopteris (*cf) *hirsuta* has once been found in the middle part. Other *Mariopteridae* (e.g. *Mariopteris robusta*, *Mariopteris souberanii* [cf], *Mariopteris andraeana* and *Mariopteris sauveurii*) successively but sparsely occur in the lower sequence part.

c) Eusphenopteris striata is fairly present in the upper sequence part, but scarcely occurs in the lower part.

d) Neuropteris rarinervis occurs quite regular in the lower part of the sequence but becomes more occasional in the upper part. *Neuropteris tenuifolia* is regularly present in both the lower and middle parts (semi-abundant) of the sequence. *Neuropteris ovata* is absent.

e) Alethopteris serlii has only sparsely been found at one place in the more upper sequence part. Single presences of *Alethopteris decurrens* and *Alethopteris* cf. *nortensis* are present in the higher middle part of the sequence.

f) Palmatoleptis spinosa (cf) is rare; it showed once in the lower realm of the middle part of the sequence.

g) Linopteris subbrongniartii occurs only from the middle part of the sequence upwards; at places it is (semi-) abundant too.

h) Paripteris linguaefolia is abundant, but only present in the lower part of the sequence. *Paripteris pseudogigantea* is absent.

i) Fortopteris latifolia appears absent.

j) Sphenophyllum cuneifolium as well as *Sphenopteris bronii* (cf.) are rare in the lower part. S*phenophyllum emarginatum* is absent.

k) Pecopteris miltonii sparsely occurs in the lower part of the sequence.

l) Asterophyllites charaeformis has been noted rarely in the lower part; *Asterophyllitus equisetiformis* in both the lower and middle parts and *Asterophyllites sphenophylloides* (cf.) in the upper middle part of the sequence.

m) Annularia sphenophylloides is rarely present in the upper sequence part. *Annularia stellata* is absent.

7.2.6 Upper sequence part

In regard of the relatively common occurrences of both *Lobatopteris vestita* (5 spec.) and *Dicksonites plueckenetii* (3 spec.) the upper sequence part of well KB 146 clearly shows a 'late' Late Westphalian D age (*Lobatopteris vestita* zone; *Dicksonites plueckenetii* subzone; Cleal, 1997). The eldest occurrence of *Dicksonites plueckenetii* is at ca. 1191 m and of *Lobatopteris vestita* at ca. 1216 m (Van Tongeren & Van Amerom, 2003). So for at least some 183 m, the sediments below the Neeroeteren formation show an 'identical' palaeobotanic age as the sediments of this formation.

This age is generally supported by the presence of *Eusphenopteris striata* and - to a somewhat lesser extent - by the common and sometimes evenly abundant occurrences of *Linopteris subbrongniartii*.

Remarkable is the absence of *Lobatopteris micromiltonii*. In general this species is still often present within the lower part of the *Dicksonites plueckenetii* subzone (Cleal, 1984 & 1997; Laveine, 1989). Considering too, that the occurrence of *Lobatopteris vestita* only starts in the course of the *Lobatopteris micromiltonii* subzone (Cleal, 1997) at first sight the shown floral content of this stratal part seems to indicate a position towards the more middle part of the *Dicksonites plueckenetii* subzone. Dusar & Houlleberghs (1981) however, mention a *Pecopteris miltonii*(?) at ca. 1179 m. In former studies this species has often been confused with *Lobatopteris* (formerly: *Pecopteris*) *micromiltonii* (Wagner, pers. comm.). In view of the occurrences of both *Dicksonites plueckenetii* and *Lobatopteris vestita* below this depth, a similar mistake probably happened at this well. This likely means that the stratal realm below and around ca. 1179 m may be dated a little younger; more in the earlier parts of the 'late' Late Westphalian D. The possible occurrence of *Linopteris obliqua* in this sequence realm (see § 7.2.1 above) supports this age, as does the presence of *Alethopteris serlii*.

Seismic evidence indicates a discontinuity at the base of the Neeroeteren formation (Van Tongeren, 2004; Van Tongeren, in prep.). Considering the about 200 m of preceding strata in this well with a palaeobotanic age starting in the earlier part of the *Dicksonites plueckenetii* subzone (Cleal, 1997) the Neeroeteren formation likely belongs to the middle / upper parts of this subzone. This is supported by the inferred age of the strata overlying this formation (see § 8.2). Hence the overall age of the Neeroeteren formation is in the middle / later time parts of the 'late' Late Westphalian D.

7.2.7 Lower sequence part

A typical species for the Westphalian C - *Paripteris linguaefolia* - is abundantly present at some depths in the more lower stratal sequence of well KB 146. Its youngest appearance is between 1246 and 1249 m. Note however, that the *Paripteris linguaefolia* mentioned at ca. 1196 m by Dusar & Houlleberghs (1981) is considered incorrect by the authors. At 1251 m Dusar & Houlleberghs (1981) identified another typical Westphalian C species: *Neuropteris parvifolia*. Also in the interval between 1291 m and 1258 m the latter species is often mentioned. At places, e.g. at 1236 m and 1261 m, *Neuropteris* cf. *obliqua* has been encountered too. All three species generally disappear before the end of the Westphalian C (Wagner, 1979).

7.3 Westphalian C / D boundary

In view of the above, the Westphalian C / D transition should occur someplace between the 1246 m / 1236 m realm with the last occurrences of *Paripteris linguaefolia* and *Neuropteris* cf. *obliqua* and the first occurrence of

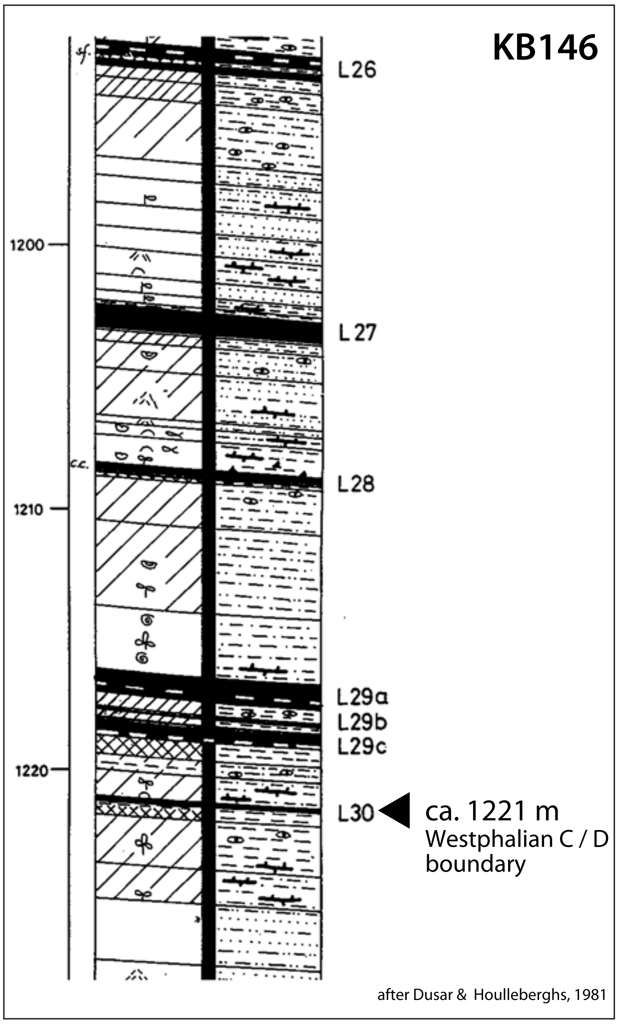

Figure 13. Inferred Westphalian C / D boundary at ca. 1221 m in well KB 146 (after Dusar & Houlleberghs, 1981); for lithology see fig. 4.

Lobatopteris vestita at 1216 m. So within a stratal interval of some 20 m. The Westphalian C / D boundary has been arbitrarily placed around 1221 m, just below a series of compiled coal seams and mature soil / seatearth formation (Fig. 13).

This means that the actual top of the Upper Westphalian C (top of the *Alethopteris serlii* subzone; Cleal, 1997) the Early Westphalian D (*Linopteris obliqua zone*; Wagner, 1979; Cleal et al, 2003) as well as (most of ?) the 'early' Late Westphalian D (*Lobatopteris micromiltonii*; Cleal, 1997) are absent here (Van Amerom & Van Tongeren, 2002; Van Tongeren & Van Amerom, 2003). Like at well KB 172, this large discontinuity - i.e. the Symon discontinuity - may be composed of various merged discontinuities too.

Due to lack of macrofloral resolution, the discontinuity directly present below the sandstones of the Neeroeteren formation - inferred in the other wells, in seismics (Van Tongeren, 2004; Van Tongeren, in prep.) and demonstrated by diagenetic studies (Bertier et al, 2008) - in this well cannot (yet) be palaeobotanically demonstrated. However, the abrupt lithologic contrast between the proximal sediments of this formation and the preceding, more distal deposits (197 m) certainly supports a discontinuity (i.e. the Neeroeteren unconformity). Timewise however, this hiatus is more limited here. It likely involves some 'middle' realm of the 'late' Late Westphalian D.

Note that the first 60 m of Westphalian D deposits in this well show a distal sedimentary facies before changing into more proximal (Dusar & Houlleberghs, 1981).

8. Palaeobotany of the wells KB 169 and KB 225

8.1 General

Well KB 169 is located in the northwest corner of the studied area (Fig.1) ca. 2 km north of well KB 172. Top Carboniferous of the well is at 1090 m and the well ended at 1371 m within a fault zone; probably belonging to the fault zone described below. The Neeroeteren formation in this well (i.e. its type of sandstones) is absent. The facies of its cored Carboniferous sediments predominantly consist of silty clay- / clayey siltstones, at places intercalated by thin claystones (pond segments) small (0.5 to 4 m) fine-grained sandstones and many thin, often impure coal seams (Dusar et al, 1987/1).

The surface position of the well is quite close and just south to the northeast-striking, fault-related antiformal ridge that largely limits the northwestern extension of the Neeroeteren formation. Over the fault zone and nearby areas facial changes occur between regionally more common floodplain deposits and terminal parts of alluvial fan sediments (Van Tongeren, in prep.).

New for the Campine basin in this well is the a-typical, small volcanic ash drilled at about 1244 m, tentatively interpreted to be the possible equivalent of either the Siegfried, or the Parcifal 'Graupen-Kristall' tonstein of the Ruhr area (Upper Westphalian C; Dusar et al, 1987/1). In the northwestern German Ruhr area the distance between the Odin and Parcifal volcanic ashes averages in the order of 85 m, and between the Odin and the Siegfried ashes about 160 m (Fiebig & Groscurth, 1984). Might this volcanic ash at well KB 169 indeed represent either the Parcifal or Siegfried one, the 'late Upper Westphalian C' thickness at this location comes in the order of at least (see below) 179 m or even 254 m.

Well KB 225 is situated on the structural 'Bree High', about 2 km north of well KB 146 (Fig. 1). It just penetrated some 15 m of Carboniferous strata, of which only the last 4 m were cored (from 567 – 571 m). The top of the Carboniferous is at 556 m (Dusar, 2002) and its lithology consists of shales and siltstones with a small, very fine-grained sandstone intercalation. Neither Neeroeteren formation-like sandstones nor coals are present (Dusar, 2002). The Carboniferous of this well seems to overlie the Neeroeteren formation (Van Tongeren, 2004; Van Tongeren, in prep.).

8.2 Palaeobotany of well KB 169

In well KB 169 *Paripteris linguaefolia* (typically Westphalian C; Wagner, 1979; Laveine, 1989; Cleal,

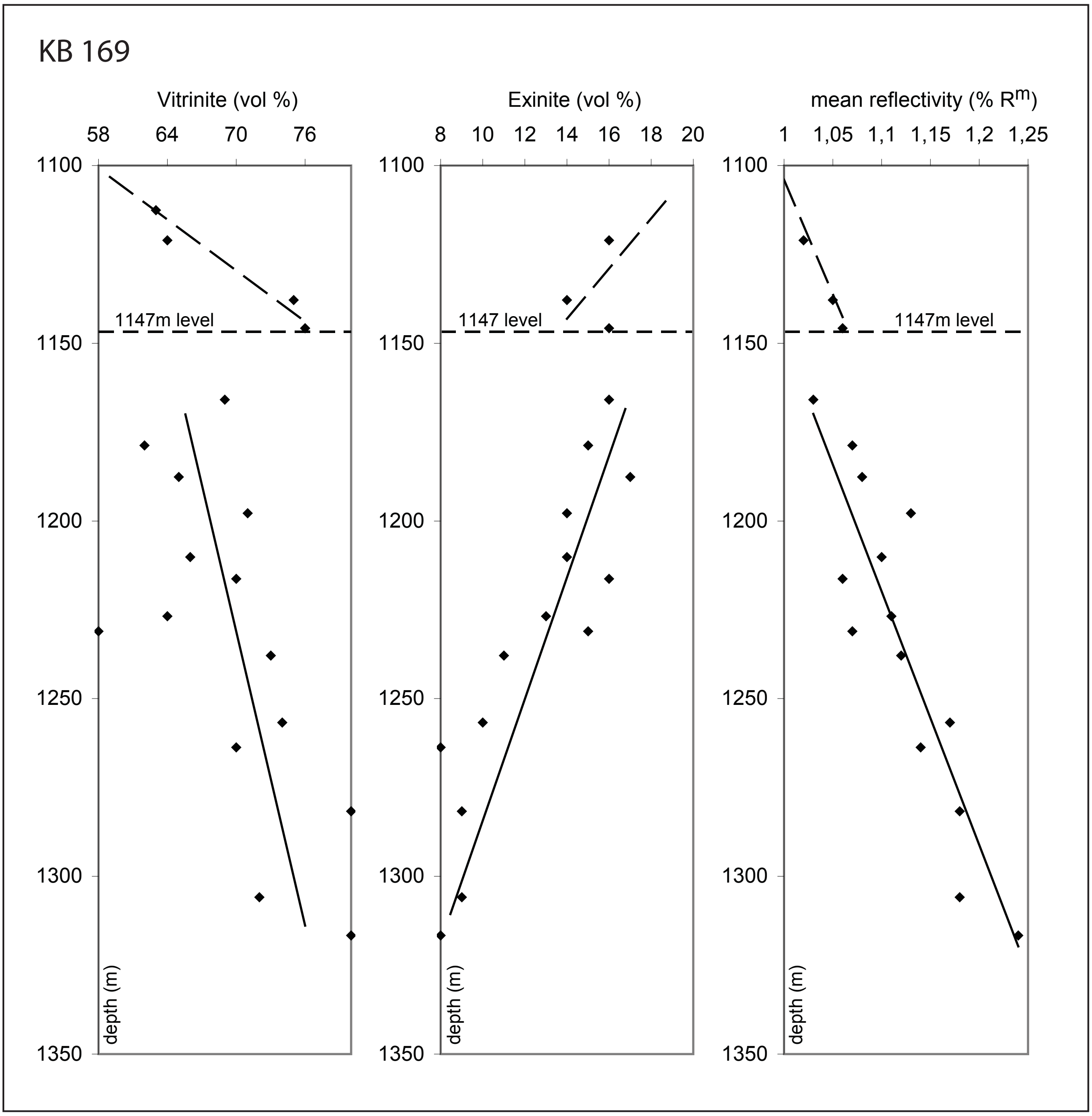

Figure 14. Coal quality (vol. % vitrinite / exinite) and coalification (%R^{mean}) graphs of well KB 169 (data from Dusar et al, 1987/1).

1997) occurs downwards below ca. 1165 m. The youngest occurrence of *Alethopteris serlii* at ca. 1147 m is only some 16 m higher. *Neuropteris obliqua* was found till ca. 1153 m. *Neuropteris rarinervis* is abundantly present between ca. 1152 - 1156 m, but has its youngest occurrences at ca. 1095 and 1100 m. So till a depth of about 1153 m an Upper Westphalian C age in this well is certain and even may be maintained till around 1147 m.

In the remaining 57 m of younger Carboniferous sediments the encountered species - a.o. *Annularia radiata*, *Annularia sphenophylloides*, *Calamites cisti*, *Linopteris subbrongniartii*, *Mariopteris nervosa*, *Mariopteris sauveuri*, *Neuropteris rarinervis / attenuata*, *Paripteris pseudogigantea* and *Reticulopteris muensteri* (Dusar et al, 1987) - commonly also occur in the Westphalian D (a.o. Josten & Van Amerom, 1999).

Coal reflectivity (%R^m) and other coal quality graphs of this well (Fig. 14) indicate a possible break around ca. 1147 m (Dusar et al, 1987). Therefore, the Symon discontinuity may be present in the uppermost part of this well too. For confirmation however, a detailed palaeobotanic re-assessment is necessary.

8.3 Palaeobotany of KB 225

Remarkable are the three (3) findings of well preserved specimen of *Lobatopteris vestita* (Fig. 15) in this well. Also *Calamites suckowii* and *Cordaites principales* occur. Neither *Dicksonites plueckenetii* nor *Lobatopteris*

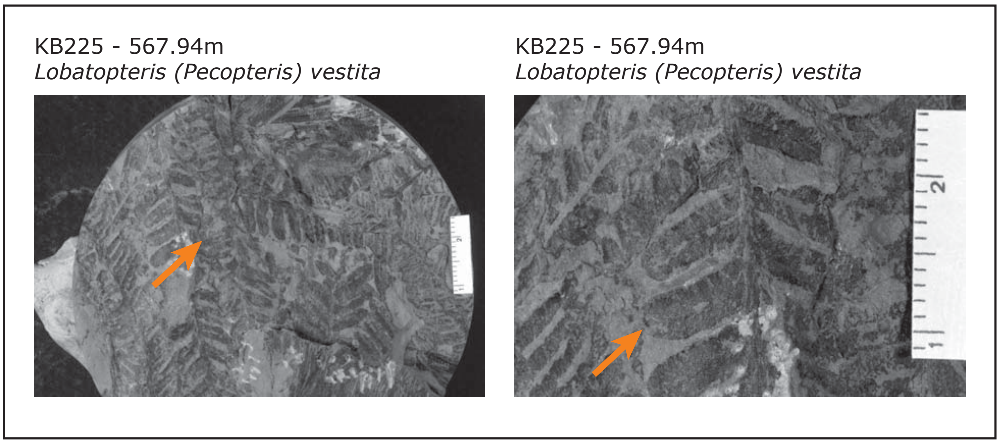

Figure 15. *Lobatopteris vestita* specimen (at ca. 568 m) from well KB 225.

micromiltonii were encountered. This points to a 'late' Late Westphalian D age (*Lobatopteris vestita* zone; *Dicksonites Plueckenetii* subzone; Cleal, 1997).

Lobatopteris vestita however, ranges well into the Early Stephanian (Cantabrian; Cleal, 1978 & 1997; Cleal et al, 2003) and also the youngest ranges of the other macrofossils surpass the top of the Westphalian D. Hence a younger, Cantabrian age may be possible too.

In view of the commonly rather late appearance of *Lobatopteris vestita* within the *Lobatopteris vestita* zone (Cleal, 1997) and the lack of specific fossils truly indicating a younger age, the Carboniferous strata of well KB 225 - tentatively - are interpreted to still have a 'late(st)' Late Westphalian D age.

Seismically - at places - a discontinuity is present between the top of the Neeroeteren formation and its overlying Carboniferous sediments (Van Tongeren, 2004; Van Tongeren in prep.). Note too, that the floral assemblages from the top Carboniferous of the De Lutte # 6 well in the northeastern Netherlands (§ 9.2 below) practically show identical floral compositions; both in its latest Westphalian D and its Stephanian strata (e.g: *Lobatopteris vestita*; *Calamites sp.* and *Cordaites principalis*; Van Amerom, 1996).

9. Interpretation and discussion

9.1 Late Variscan tectonism, unconformities and depositional shifting.

In well KB 113 the thickness of the upper part of the late Upper Westphalian C strata – here defined as "from the Odin tonstein upwards" - is unknown. In well KB 168 this part is over 141 m, and in well KB 172 some 258 m. Hence, going west/northwestwardly from well KB 168 to well KB 172, the thickness of the later part of the *Alethopteris serlii* subzone (Cleal, 1997) increases. This is corroborated by the 'late Westphalian C' thickness(es) of at least 179 or 254 m (+ possibly ca. 50 m?) at well KB 169 more to the northwest. In regard to the increasing west/northwestern thickness trend, the latter figures even suggest a preferred correlation of the 'new' tonstein in this well with the Siegfried one in the Ruhr area. Mind that in well KB 172 - although possibly a coincidence - *Paripteris liguaefolia* is not present above the Odin tonstein. In the wells KB 113 and KB 146 no tonsteins were encountered, but their Late Westphalian C thicknesses above the latest presence of *Paripteris liguaefolia* are some 77 m and ca. 25 / 30 m only. So tentatively, particularly in the western and northwestern realms more 'late' Westphalian C appears to be present than in the southeast and east.

Into the same direction - now starting from well KB 113 - the Westphalian D ages of the strata above the discontinuity at the Westphalian C / D transition change from 'middle' / 'late' Early Westphalian D, via a 'late' Early / 'early' Late Westphalian D (well KB 168) into a limited 'latest' Early / 'early' Late Westphalian D (well KB 172). Hence the hiatus migrates in time and is gradually younging into this direction. The distal terminal / fluvial fan sediments (seismic interpretation; Van Tongeren, 2004; Van Tongeren, in prep.) so clearly demonstrate an important prograding component towards the west/northwest over the remaining parts of the Late Westphalian C; hence over the transitional Westphalian C / D unconformity level.

Going in turn northeastwardly from well KB 172 to well KB 146, the thickness of the *Alethopteris serlii* subzone (Cleal, 1997) quickly decreases; the top of this subzone being absent in the latter well. The ages of the overlying Westphalian D strata now change respectively from 'late' Early / 'early' Late Westphalian D into the (beginning of?) the 'late' Late Westphalian D. Hence the gap of the hiatus northeastwardly increases in time; its top younging into the same direction, while its base now gets older. Contrarily to the retrograding time trend one might expect in regard to the former direction, instead a prograding time component of the fan sediments occurs to the northeast. Moreover, this happens while the first 60 m of the KB 146 sediments show a retrograding sedimentary facies[1] (Dusar & Houlleberghs, 1981). In combination with the initially more distal facies of these eastern fan sediments, the increase in time-gap by the diverging ages of the strata below and above the discontnuity is interpreted as a northwardly shift of these deposits. This also hints to

1 determined from sedimentary logs published in the indicated reference(s).

the existence of another hiatus sometime during the 'late' Early / 'earliest' Late Westphalian D realm and a local merging of this hiatus with the larger (regional?) disconformity.

Going northwestwardly from well KB 113 towards well KB 146, the age of the overlying sediments changes from a 'middle' Early Westphalian D into (the beginning of?) the 'late' Late Westphalian D. Moreover - when defined as: 'the stratal thickness with common *Alethopteris serlii* showings above the latest *Paripteris linguaefolia*' - the top part of their underlying *Alethopteris serlii* subzones may slightly decrease too. In well KB 113 this part is ca. 77 m and in well KB 146 it maximally seems some 30 m. And defined in this way, it also may be (almost?) absent in well KB 169. So the time-gap into this direction particularly increases by the younging of the overlying sediments. Note that at the western well KB 172 in this way, some 260 m of upper *Alethopteris serlii* subzone appear present. In conjunction with the above this equally shows the gradual northwardly shifting and the western / northwestern extensions of these (terminal) fan deposits.

The erosive Late Westphalian C thickness and age variations below its confining discontinuity plus the succeeding Westphalian D terminal fan deposits, reflect the Late Westphalian C / 'early' Early Westphalian D compressive uplifting / tilting phases of the late Malvernian Variscan orogenic phase (Wills, 1956; Kellaway, 1970; Bless et al, 1977). Particularly in the more north/ northeastern and eastern parts of the studied area. Contemporaneous and following erosional / denudational processes created the (time base of the) unconformity here, while successive terminal and distal fan cycles gradually filled-up and transgressed the (local) lower (synformal) parts (Van Tongeren, in prep.). Uplifts along the Heerlerheide and related eastern fault systems may well have played an important part at these movements.

In the southeast of the studied area these uplifts apparently happened as well, probably however, to a relatively lesser extend and / or more gradually. During these times the utmost western and northwestern realms quite longer remained depositional (floodplain) areas.

The above is well corroborated by the thickness variations of the Westphalian D strata confined between the underlying unconformity and the overlying Neeroeteren formation. The remaining Westphalian D strata in well KB 172 only leave some 67 m for the combined ('late') Early Westphalian D and the 'early' Late Westphalian D sediments. In regard to the > 232 m in well KB 168, this proves the still serious, overall (north) westwardly thinning of the Westphalian D distal fan sediments mentioned above. For the 'early' Late Westphalian D only, these figures respectively are: 30 m (well KB 172) versus 174 m (well KB 168).

Interestingly however, singularly for the 'late' Early Westphalian D these figures respectively become 67 m (well KB 172) versus > 58 m (well KB 168). These less / non-diverging values likely mean that the Early Westphalian D terminal fan strata generally stopped their westwardly thinning, while coming to an end within this trajectory; laterally and intermittently interfingering with contemporaneous floodplain sediments. Mind that the Early Westphalian D sediments at well KB 113 (Renier, 1944) are interpreted to already have a rather distal fan facies (Van Tongeren, in prep).

In general overview; these Early Westphalian D sediments were succeeded by more prograding 'early' Late Westphalian D terminal fan sediments - still present in the west/northwestern realm (wells KB 168 and KB

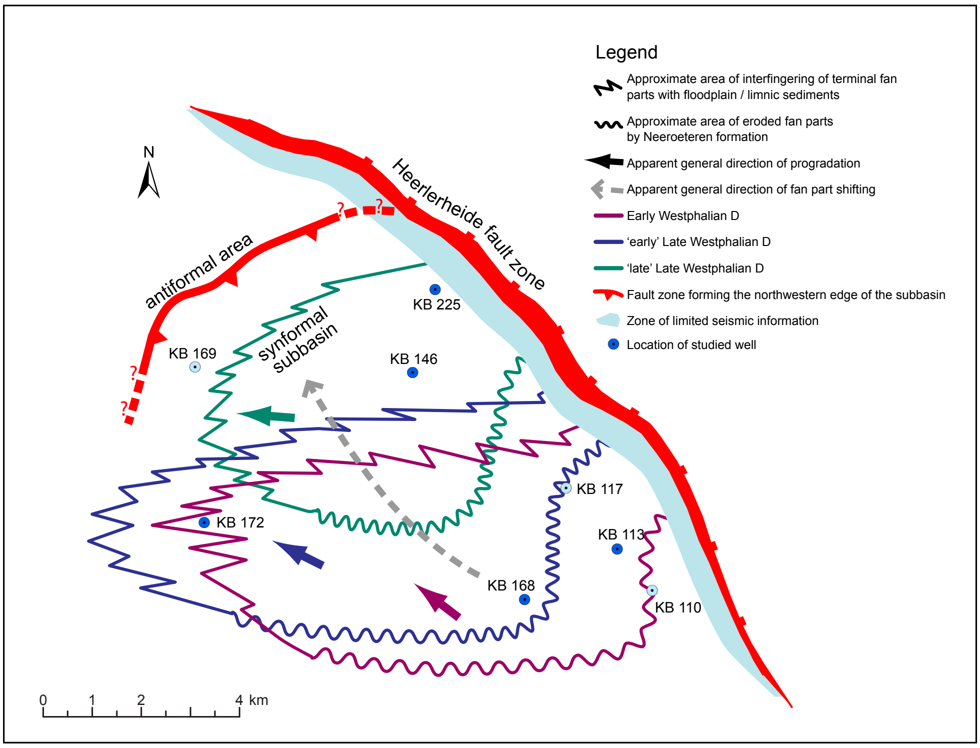

Figure 16. Schematic indication of pro- / retrogradation and shift directions of 'middle' Early / 'late' Late Westphalian D terminal fan-lobe sediments over the Symon unconformity level before their partial erosion by, and the subsequent deposition of the mid-alluvial fan sediments from the Neeroeteren formation. Note the fan-limiting fault-related antiformal and synformal subbasin areas (Van Tongeren, 2004; Van Tongeren, in prep.).

172) - that were simultaneously shifting northwardly and in turn were succeeded by another retro- / prograding cycle of 'late' Late Westphalian D strata; actually still remaining in the north/northeast (well KB 146; Fig. 16).

A serious discontinuity at, or near the base of the Westphalian D is also present in many regions of the United Kingdom and in the southern North Sea region (Van Amerom & Van Tongeren, 2002); particularly adjacent to contemporaneous landmasses. It is rather widespread and diachronous, representing the erosional / non-depositional effects caused by Late Westphalian C, Malvernian tectonic pulses and is known as the Symon unconformity (Wills, 1956; Kellaway, 1970; Bless et al, 1977; Tubb et al, 1986; Dreesen et al, 1995).

In the eastern part of the Campine basin (s.s.) the Symon discontinuity is present in all studied wells that drilled these Westphalian C / D strata. Palaeobotanically it is situated within the stratigraphic realm of the Late Westphalian C / Early Westphalian D transition period and generally comprises either a serious part of, or the complete Early Westphalian D. At places additionally missing parts of Late Westphalian C and / or 'early' Late Westphalian D strata alter its time-gap.

After the Late Malvernian tilting in the northern, northeastern and eastern realms and the following period of tectonic relaxation - areal relevelling by denudation and in-fill through (terminal fan) deposition - the succeeding deposition of the sandstones of the more proximal Neeroeteren formation during the 'late' Late Westphalian D, expresses new rises of the eastern and southeastern hinterlands as well as an overall increase of depositional gradients (Dreesen et al, 1995).

Palaebotanically the Neeroeteren formation sediments have been placed in the middle to later parts of the

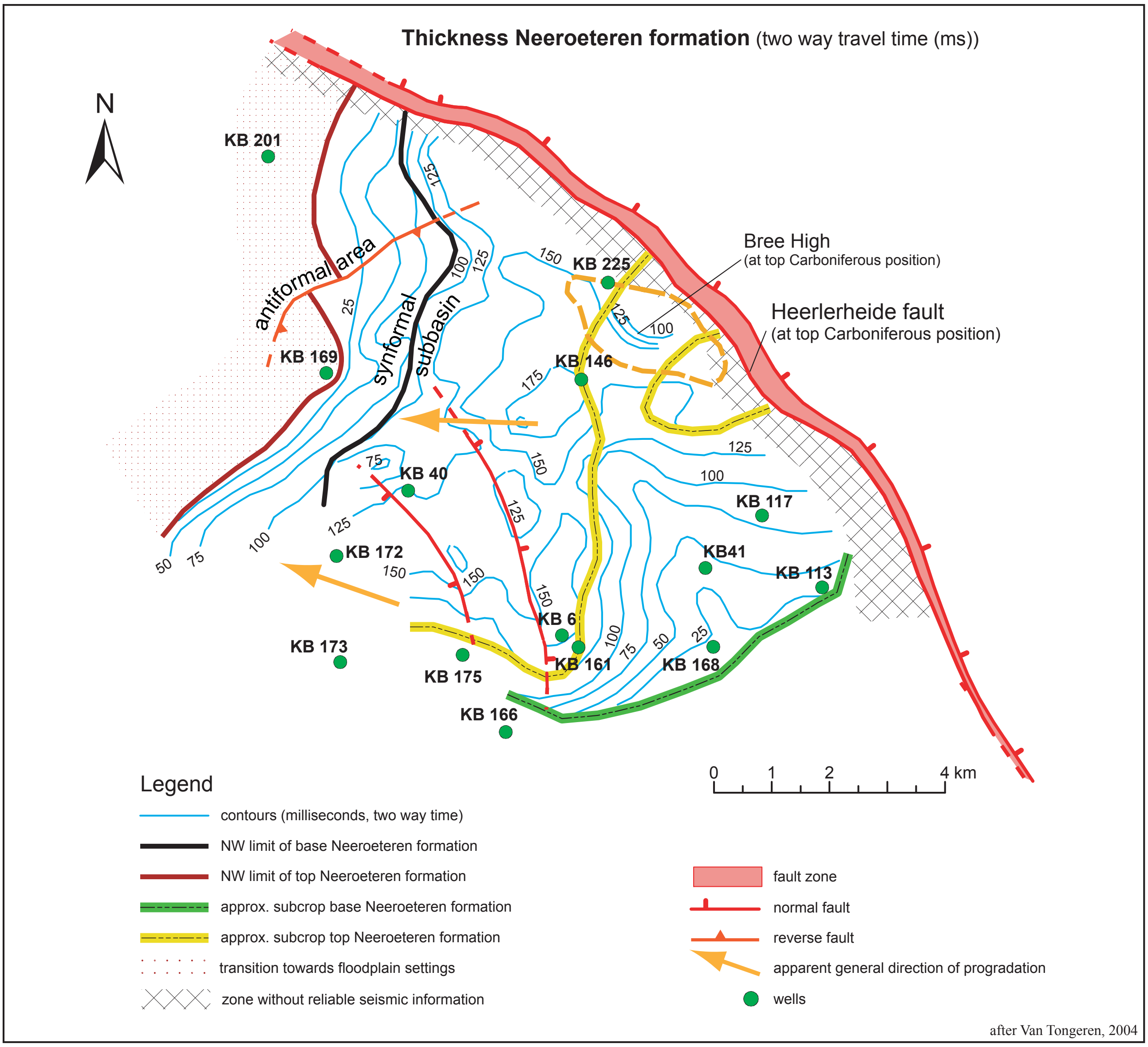

Figure 17. Two-way traveltime contour map of the thickness (ms) of the Neeroeteren formation suggesting rather eastern to southeastern source areas. In the synformal, and partly over the antiformal areas, changes occur toward distal terminal fan and finally limnic / floodplain sediments. In the southeastern and southern areas the formation subcrops against the eroded top Carboniferous level (Saalian unconformity).

Dicksonites Plueckenetii subzone (Cleal, 1997). Hence their palaeobotanic age is a - slightly varying - 'late' Late Westphalian D over the whole area. Combined with the varying ages of the sediments below the base of this formation - from 'mid' / 'late' Early Westphalian D (well KB 113) via 'early' Late (wells KB 168 and KB 172) to (middle) 'late' Late Westphalian D (well KB 146) - this defines the hiatus and diachronism of the underlying Neeroeteren unconformity (Van Tongeren, 2004; Bertier et al; 2008; Van Tongeren, in prep.). Note that at well KB 146 - at least paleobotanically - the hiatus cannot properly be defined (as yet). It (actually) is rather local and its time-gap clearly decreases into northeastern / eastern directions.

The new period of increased tectonic activity during the Middle / Late Westphalian D and represented by the Neeroeteren formation, is known as the Late Variscan, Leonese tectonic phase (Wagner, 1966; also see § 9.2).

In their ages the combined stratal suites of the Westphalian D sediments confined between the Symon and Neeroeteren unconformities, reflect an overall rather complete successive stratigraphic sequence. During most of this time-span therefore, sedimentation probably had occurred rather continuously over a larger (south/ southeastern) part of the area. Hence the succeeding orogenic pulse(s) must have caused the erosive removal of much / all of any remaining 'late' Early to 'mid' Late Westphalian D deposits in particularly the more southern and southeastern realms (i.e. at the KB 113 and KB 168 well areas and beyond). This happened before and at the early start of the depositions of the Neeroeteren formation (Figs. 16 & 17).

Representing the most proximal event, the Neeroeteren formation as well as its (age) related more distal fan sediments in / around the area likely prograded further west- / northwestwardly than any preceeding terminal fan sediments. The corresponding uplifts particularly happened around and east / northeast of well KB 146 and demonstrate the regional influences of the Leonese tectonic phase (Wagner, 1966). Both the Malvernian and Leonese tectonic events reflect the predominantly north- and northwestwardly directed compressional build-ups and gradual prograding of the Variscan orogeny.

In view of the general, steadily ongoing south/ southeastern Variscan uplifts - which also continued at later stages (e.g. the Saalian orogenic and erosive phases) - it is quite likely that the remaining Neeroeteren formation sediments within the studied area, only represent the northerly remaining parts of a much larger and initially more south- / southeastwardly extended alluvial fan system. This likely holds for the elder (terminal) fan remains as well (Figs 16 & 17).

Another, still younger discontinuity - locally displaying both on and off-lapping seismic reflection configurations against the reflector(s) representing the top of the Neeroeteren formation - also indicates varying post-Neeroeteren formation time-gaps and diachronism. Seismic facies of these overlying sediments both hint to generally east- / southeastwardly prograding floodplains and a renewed intermittent retrograding of terminal distal fans (Van Tongeren, 2004; Van Tongeren, in prep.). This seems a renewed period of tectonic relaxation. Although in well KB 225 likely sediments were drilled above this younger discontinuity level, the resolution of the palaeobotanic data (as yet) also proves insufficient to define a hiatus. The authors therefore maintain a 'latest' Westphalian D age to be the most likely for the Carboniferous strata in well KB 225.

9.2 Correlation of ages and tectonics with the De Lutte-6 well

To correlate our palaeobotanic findings in the Campine basin, the actual Westphalian D biostratigraphic scheme by Cleal (1997) and Cleal et al. (2003) has been applied to the published palaeobotanic listing of the De Lutte-6 well in the northeastern Netherlands (Van Amerom, 1996; Fig. 1). The former biozone boundaries in this well had been partly concluded by applying the (now dated) biostratigraphic scheme of Cleal (1984) in regard and conjunction to lithofacies development and large-scale sedimentary trends. Note that the biozone boundaries used by Van Amerom (1996) do not (always) match the lithostratigraphic member subdivision by Pagnier & Van Tongeren (1996). Both subdivisions are given in Fig. 18. Note too, that this well was deviated; correlations between along hole (ah) and true vertical depths (tvd) are given in figure 18. Where deemed appropriate the true vertical depth is noted in this text.

For the actual correlations also this time a combination of the palaeobotanic results and large-scale sedimentologic trends has been applied at establishing the important new time-boundaries.

Using this combination, a biostratigraphic Early Westphalian D age is concluded for the De Lutte-6 well part between ca. 3113 m – ca. 2815 m (ah). This confirms the original age given by Van Amerom (1996); its upper biozone boundary (ca. 2815 m) separating the 'Early' and 'Middle' Westphalian D sensu Cleal (1984). Hence also the actually interpreted sequence with an Early Westphalian D age covers the top of the lithostratigraphic member I and the lower / middle parts of member II.

The Late Westphalian D sequence sensu Cleal (1997) is actually interpreted between ca. 2815 m (ah) and the (also formerly interpreted) Stephanian base at ca. 2352 m (ah). It subsequently covers the remainder of the lithostratigraphic member II, as well as the members III - VI.

The 'true' stratigraphic thickness of the Early Westphalian D in this well is some 250 m. For the Late Westphalian D a minimum of about 380 m must be taken (presence of some small normal faults). The complete Westphalian D thickness at this well therefore, stratigraphically comprises a minimum of some 630 m.

Contrarily to the original subdivisional boundary between Middle and Late Westphalian D at ca. 2575 m (ah) by Van Amerom (1996) the actual subdivision of the Late Westphalian D into its 'early' and 'late' parts sensu Cleal (1997) has been tentatively put at the boundary

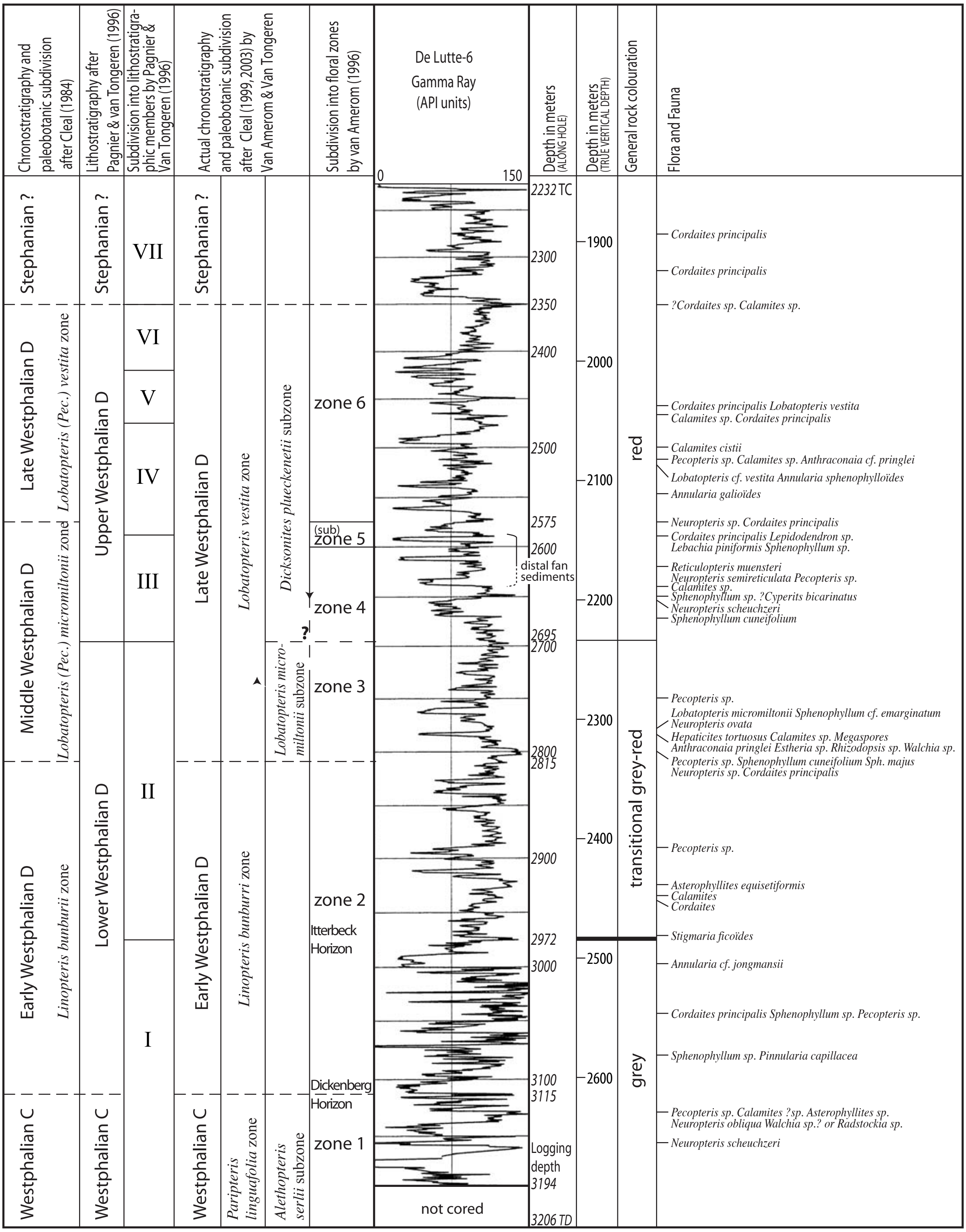

Figure 18. Original palaeobotanic, sedimentologic and biozonal subdivisions of the De Lutte-6 well (northeastern Netherlands) combined with the actual palaeobotanical subdivision (after Van Amerom, 1996 and Pagnier & Van Tongeren, 1996) plus plant-fossil indications, gamma-ray log, along hole and true vertical depths.

between the members IV and V at 2475 m (ah). So at a true depth of about 2050 m. This deviation from the original classification has been made with particular notice to the 'cf' indication of the *Lobatopteris vestita* specimen (2) around the 2518 m (ah) level and the still relatively frequent occurrences of *Lobatopteris micromiltonii* (3). Note that the 'cf' indication lacks at the *Lobatopteris vestita* specimen at the younger 2461 / 2460 m (ah) level and that *Lobatopteris micromiltonii* here has not been found.

Hence the 'early' Late and 'late' Late Westphalian D parts respectively have minimal statigraphic thicknesses of 275 m and 105 m. Note too however, that *Dicksonites Plueckenetii* has not been found in this well and that above the last specimen of *Lobatopteris vestita* (2461 m / 2460 m ah; ca. 2040 m tvd) no further stratigraphically decisive plant fossils have been noted.

Hence the inferred 'late' Late Westphalian D in the northeastern Netherlands is quite thinner than the almost 500 m at well KB 146 in the Belgian Campine basin. Even more so, if (a part of) the sediments overlying the Neeroeteren formation should be included (see § 8.2). Timewise, the deposits of well KB 146 correlate with the sedimentary members V and VI in the De Lutte-6 well.

Member V has been described as being progradational; its sediments represent fine-grained, stacked floodplain sequences, upwardly grading into sandstones of a minor ephemeral channel complex. Various calcic soils are developed (one real calcrete) but no ferralitic ones (laterites) are present. The sediments of this series have been interpreted to have an intra-basin, relatively near-source origin and to have resulted from a small phase of 'renewed' regional tectonic activity (Pagnier & Van Tongeren, 1996). Note that the more mature calcic soils in particular (outstandingly high gamma-ray peaks) indicate considerable times of soil formation and non-deposition.

Member VI - the topmost Westphalian D sediments in this well - represents a retrogradational trend. It predominantly consists of red silty claystones (floodplain fines) with some minor sandstones at its base (minor channels and sheetfloods).

The top sand bodies of member V and the sands at the base of member VI combined together, constitute a minor ephemeral stacked channel complex that forms the transition between these two members. The member-boundary has been put at the turn-over from the on overall coarsening-up (i.e. prograding) series into the generally fining-up (i.e. retrograding) sedimentary parts (Fig. 18).

Member VI represents a period of tectonic relaxation. Its top is overlain by a very well developed soil horizon, considered to represent the (unconformal) base of the Stephanian period (Pagnier & Van Tongeren, 1996).

Particularly considering the actually inferred ages, together with the member subdivision and the (times represented by the) soil formations, the sandstones of the Campine (s.s.) Neeroeteren formation are best correlated with the ephemeral cannel complex at the member V – VI transition.

Although the relatively small phase of tectonic activity deduced at member V only shows intra-basin effects, the depositional timing of the resulting sediments corresponds well with the age of the Neeroeteren formation. Both are caused by a renewed, (later) Leonese tectonic pulse of faulting and uplifts. In regard however to its sedimentary 'effects' in both regions, the activity of this tectonic phase clearly appears to diminish towards the north.

Hence the 'late' Late Westphalian D sediments directly below the Neeroeteren formation in well KB 146 correlate with the elder sediments of member V at the De Lutte-6 well.

The 'late' Late Westphalian D sediments in both regions clearly reflect different sedimentary styles. The northern sheetflood plains and serious soil developments versus the alluvial fan / dirty coal deposits to the south, quite well show the distinctions in proximity, drainage and possibly even microclimatic conditions between the two areas.

In the De Lutte-6 well the silty floodplain deposits, (minor) channels and sheetflood sediments of member IV represent an aggrading sedimentary system, indicating a period of tectonic relaxation and peneplainisation. Next to a few ferralitic ones, in particular calcic soils are present.

The intermittently stacked sedimentary series of the underlying member III show a progressive coarsening. The entire member reflects a prograding, distal fluvial fan megasequence (Pagnier & Van Tongeren, 1996). Its deposits include sheetflood conglomerates interpreted as distinct toes of alluvial fans - of which three at least are sourced from outside the basin (Van der Meer & Pagnier, 1996). Also ephemeral braided channels and sheetfloods with interbedded fines are present, as well as calcic and ferralitic soils (both mature and immature). Member III has been interpreted to indicate a period of renewed and intensifying tectonic activity that must have steepened reliefs and topographic gradients (uplifted areas, probably fault scarps); the regional start of the Leonese tectonic phase. The timing of this Leonese pulse and the later one at member V / VI transition (see above) corresponds well with the Mid / Late Westphalian D timing of Wagner (1966).

Particularly the lower, early sediments of this member III are to be correlated with the 'early' Late Westphalian D sedimentary distal fan deposits just below the Neeroeteren formation in the KB 168 and KB 172 wells in the Campine basin (s.s.). Of the remaining middle and upper sedimentary parts of member III and member IV, their Campine basin (s.s.) counterparts must have been either (largely) eroded or not have been deposited at all. This too hints to another period of erosion in the eastern Campine basin (s.s.) during the Late Westphalian D at which - particularly in the southern and western realms of the study area - the resulting discontinuity must have merged with the Neeroeteren unconformity.

Member II in the De Lutte-6 well has been interpreted to represent a relaxation phase after the tectonic phase(s) which invoked the deposition of the regional sandstones of the Tubbergen formation. Deposition of this formation started in the course of the Early Westphalian C; its top part having an Early Westphalian D age (Pagnier & Van Tongeren, 1996; Van Tongeren, 1996). The formation shows the effects of the Late Variscan, Malvernian tectonic pulses (Wills, 1956; Kellaway, 1970; Bless et al, 1977).

Above the last stacked channels of this formation (ca. 2974 m ah) the member II sediments mainly reflect overbank deposits frequently intercalated with small crevasse-type sands and minor channel sandstones. In these predominantly silty and sandy claystones of mixed coloration (varying palaeo-groundwater levels) both ferralitic and even immature calcic soils start to develop (Pagnier & Van Tongeren, 1996).

The ‘middle’ / ‘late’ Early Westphalian D dated sediments of well KB 113 generally correlate with the sedimentary part of member II above the Tubbergen formation. This fits with the regionally interpreted, overall relaxation phase at the De Lutte-6 well. The presence of the Symon unconformity above the Tubbergen formation has not been ascertained. Considering the clear change in sedimentary style however, combined with the meters-thick, heavily rooted soil development over the top of this formation (the 2969 m – 2976 m ah interval; Pagnier & Van Tongeren, 1996) a discontinuity at this location is quite likely. Moreover, the start of the Tubbergen formation sediments in general appears rather time-equivalent to the intermittent beginning of the Kemperkoul member (‘middle’ Early / Late Westphalian C; Van Tongeren, in prep.) in the eastern Campine basin (s.s.).

10. Conclusions

a) This palaeobotanic study shows the Westphalian C and D subdivisions of the stratal sequences drilled at the wells KB 113, KB 146, KB 168, KB 172 and KB 225 in the Belgian part of the Campine basin (s.s.).

b) Some plant-fossils appear to stratigraphically range somewhat further than sometimes generally considered. Among those are *Neuropteris tenuifolia*, *Mariopteris muricata, Paripteris gigantea, Neuropteris semireticulata* and *Reticulopteris muensteri* (also see Van Amerom, 1996).

c) The palaeobotanic Late Westphalian C and Westphalian D zones of Wagner (1966, 1979) and Cleal (1997) were recognized and (co-)applied in both local and regional correlations and palaeogeographic reconstructions.

d) In this way the prograding, retrograding, and northwardly shifting of the various Westphalian D fan-part sequences as well as their partial erosion and the presence of two important discontinuities - the Symon and Neeroeteren unconformities - have been demonstrated.

e) Both unconformities prove diachronous and the local (terminal) fan sediment supply predominantly came from east/southeastern and eastern sources.

f) On sedimentary / seismic grounds other discontinuities are suspected around the ‘early’ to ‘late’ Late Westphalian D transition (former Middle Westphalian D; Cleal, 1984) and over the top of the Neeroeteren formation.

g) The Symon unconformity occurs over the Westphalian C / D transition period and has an over-regional occurrence. It (co-)represents the effects of the Late Malvernian Varistic orogenic phase(s); particularly during the Late Westphalian C.

h) The Neeroeteren unconformity is the local Late Westphalian D result of tectonic pulses from the succeeding Leonese Variscan orogenic phase(s) occurring during the Middle / Late Westphalian D.

i) The sedimentary differences of the resulting sediments from these two tectonic periods - distal, fluvial / terminal fans versus proximal mid-alluvial fan deposits - reflect the intermittency of the (local) north/northwestwardly progradation of the Variscan orogene.

i) The age of the Neeroeteren formation is in the (middle to later parts of the) ‘late’ Late Westphalian D. In this study the sediments underlying this formation all have older, varying Westphalian D ages.

j) The sediments of well KB 225 are considered to have a ‘latest’ Late Westphalian D age. A slightly younger (Cantabrian) age however, cannot be excluded. They do not seem to be part of the Neeroeteren formation (Dusar, 2002) and may disconformably overlie this formation (Van Tongeren, in prep;)

k) The palaeobotanic subdivision of Cleal (1997) could well be applied to the palaeobotanic results of the De Lutte-6 well (northeastern Netherlands; Van Amerom, 1996). In combination with the lithostratgraphic subdivision (Pagnier & Van Tongeren, 1996) its Late Carboniferous sediments are correlated with the eastern Campine Basin (s.s.) strata in this study.

l) This correlation demonstrates both the close matching of (over)regional tectonic events in time as well as the general differences in geologic development between both areas in terms of proximity, drainage and possibly climatic conditions.

m) The occurrences of regional / local discontinuities as concluded in this palaeobotanic study - combined with the regional seismic evaluations (Van Tongeren & Van Amerom, 2003; Van Tongeren, 2004; Van Tongeren, in prep.) - are quite in line with the model of Clevis et al. (2004) about the combined effects of episodic tectonism and sealevel fluctuations in foreland basins.

11. Acknowledgements

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