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Pennsylvanian (Carboniferous) biotas and palaeoenvironments
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Macrofloral biostratigraphy of the Ottweiler Group in Saar-Lorraine and its consequences for Stephanian palynostratigraphy and geochronology[2]

(Figs 1–4; Tab. 1)

Abstract. A revised macrofloral biostratigraphy for the Stephanian Ottweiler Group of the Saar-Lorraine Coalfield places most of the succession in the upper Stephanian B Substage (*Alethopteris zeilleri* Zone). Only the Breitenbach Formation at the top of the Group indicates a position in the middle Stephanian C Substage (*Sphenophyllum angustifolium* Zone). These revised correlations now make the tonstein date for the Wahlschied Seam, one of the few reliable radiometric dates for the Stephanian Stage, compatible with the recently proposed Carboniferous time scales. It also explains the large time gap at the base of the Holz Conglomerate suggested by the radiometric dates. There is now little evidence that the palynological ST Zone extends lower than the Stephanian B Substage, and that there appears to be a gap in the palynological zonation between the lower Cantabrian and top of the Barruelian Substages.

Key words: Stephanian, macrofloras, biostratigraphy, correlations.

INTRODUCTION

The Saar-Lorraine Coalfield that straddles the Franco-German border near Saarbrücken and Metz has played a critical role in the development of Pennsylvanian (Upper Carboniferous) chronostratigraphy. For many years it was the only European coalfield that contained well-documented Westphalian and Stephanian strata, and so was central to ideas concerning the definition of the Westphalian–Stephanian boundary (Jongmans & Gothan, 1937). Subsequent work in northern Spain, however, showed that there was in fact a significant stratigraphical gap between the Westphalian and Stephanian successions in Saar-Lorraine, and resulted in the establishment of a new Cantabrian Substage to account for the missing time-

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interval (e.g. Wagner, 1964, 1966, 1969). This diverted attention away from Saar-Lorraine in the debate concerning the relationship between the Westphalian and Stephanian Stages.

Nevertheless, Saar-Lorraine has remained important for Pennsylvanian stratigraphical studies as it is reputedly the only European coalfield with a succession of well-preserved Barruelian ('Stephanian A'), Stephanian B and Stephanian C palynofloras. In what is still regarded as the standard Carboniferous palynostratigraphy (Clayton *et al.*, 1977), the Stephanian biozones were largely based on evidence from here. However, the importance of this palynostratigraphical scheme for determining chronostratigraphical correlations of Stephanian strata depends on the independent dating of the biozones within Saar-Lorraine. Faunal biostratigraphical evidence is mainly restricted to non-marine bivalves (e.g. Eagar, 1984, 2005) that are heavily influenced by facies and environment, and insects (e.g. Schneider *et al.*, 2005; Schneider & Werneburg, 2006) that have not been extensively recorded. So, at present, the only independent biostratigraphical guide to relating the palynozones to the chronostratigraphy is the macrofloras.

The Saar-Lorraine succession is also of critical importance in the development of a Carboniferous time scale, especially for the upper part of the interval. A tonstein in a coal known as the Wahlschied Seam has yielded one of the few radiometric dates that can be directly tied to the Stephanian Stage (Lippolt & Hess, 1985). However, this tonstein has traditionally been taken as in the Barruelian ('Stephanian A') Substage, which conflicts with the most recently proposed Carboniferous time scales (Menning *et al.*, 2000, 2004, 2006; Gradstein *et al.*, 2004). For this reason, also, an independent verification of the chronostratigraphical position of the Ottweiler Group coals is of wider importance.

The biostratigraphy of the underlying Asturian ('Westphalian D') macrofloras of Saar-Lorraine was reviewed by Cleal (1984), but that of the Stephanian macrofloras has not been properly evaluated in recent years. In this paper, I will examine the ranges of the macrofloral species in the Stephanian succession of Saar-Lorraine in the context of Wagner's (1984) Carboniferous macrofloral biostratigraphy, and then use this to see how it helps determine the positions of the boundaries between the substages of the Heerlen regional chronostratigraphy (Wagner, 1974).

GEOLOGICAL BACKGROUND

The Saar-Lorraine Coalfield was formed in an intramontane basin about 150 km south of the Variscan Foredeep (Fig. 1). The depression was formed between the Saxothuringian and Rhenohercynian Zones of the Variscan Mountains, and was infilled with a thick succession of clastic sediment eroded from the surrounding uplands. The result was a Pennsylvanian-aged coal-bearing succession up to 6,000 m thick (Schäfer, 2005). The succession was subsequently (in Permian times) folded into a broad thrusted monocline known as the Saarbrücken Anticline (Kneuper, 1964). Exposure of the succession within the main part of the coalfield is limited to the northern limb of the Saarbrücken Anticline in the eastern (German) part of the

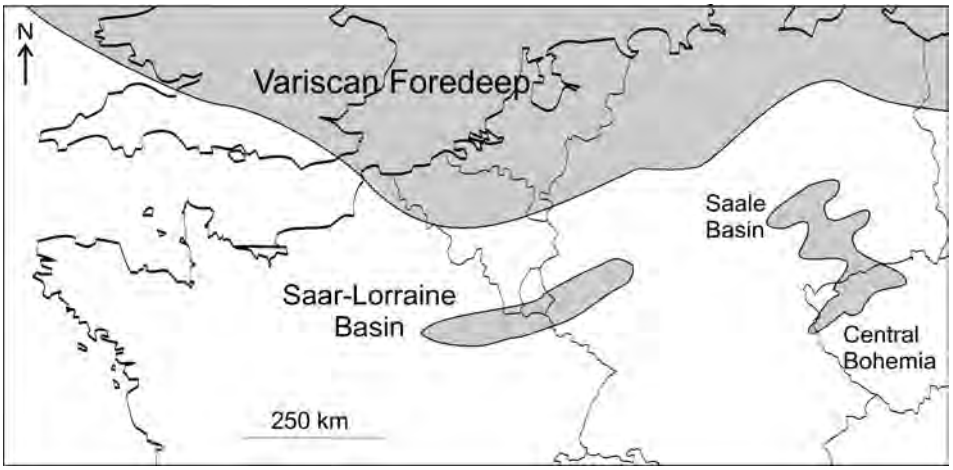

Fig. 1. Location of the principle Pennsylvanian-aged intramontane basins in central Europe, including Saar-Lorraine. Relative positions of the basins is based on Opluštil (2004)

coalfield, and even here outcrop is mostly limited to artificial exposures due to overlying superficial deposits (although there are a few exposures of these strata in the easternmost part of the Saar-Lorraine Basin, in neighbouring Rhineland-Palatinate, e.g. at Königsberg near Wolfstein and Lemberg near Bad Kreuznach). The western and southern parts of the coalfield are overlain by a thick succession of Upper Permian to Jurassic sedimentary rocks. Nevertheless, there is a detailed record of the Pennsylvanian stratigraphy here resulting from the extensive underground exploitation of the coal reserves during the 19th and 20th centuries.

The Pennsylvanian succession is divided into the Saarbrücken and Ottweiler Groups. The former represents the Westphalian-aged mainly-grey coal-bearing succession that contains most of the economically-viable seams within the coalfield, and ranges from (?)Langsettian to latest Asturian in age (Weingart, 1976; Cleal, 1984). It is overlain by the mainly red-bed succession of the Ottweiler Group, the base of which is marked by the Holz Conglomerate.

The Ottweiler Group consists mainly of oxidised alluvial sandstones and mudstones (Weingart, 1961; Kneuper & Schönenberg, 1962; Schönenberg & Kneuper, 1964) deposited under conditions of relatively low water table. Periodically, however, water tables became higher resulting in grey intervals with coals, or even the development of widespread lacustrine conditions with non-marine bivalve and conchostracan faunas. These grey and lacustrine layers form distinctive horizons within the succession and have been used to divide the succession into four formations (Fig. 2).

MACROFLORA RECORD

Diverse macrofloras have only been well-documented from four stratigraphical levels in the Ottweiler Group: from the roof-shales of the Wahlschied, Schwalbach, Reisbach and Grenzkohle seams (Fig. 2). A fifth macroflora has been reported by Boersma (1973) from the upper Heusweiller Formation, but has never been properly described or illustrated. Drawing up a conventional stratigraphical range chart for the succession would thus give a misleadingly stepped-appearance (e.g. Germer & Kneuper, 1967, 1970; Germer & Engel, 1986). Instead, the distribution of the species has been shown in a tabular form (see Table 1). Only those morphotaxa that are likely to be of biostratigraphical significance are listed, mostly of the foliage,

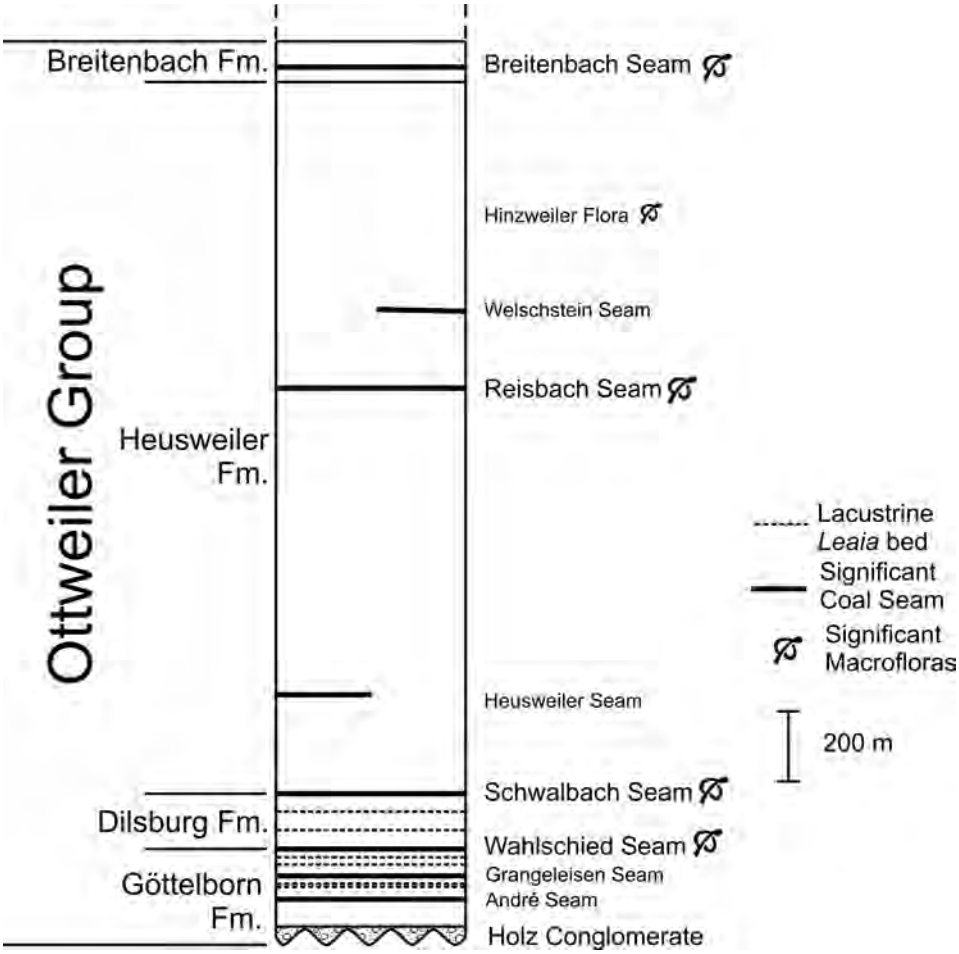

Fig. 2. Generalised succession of the Ottweiler Group, showing levels of major coals, lacustrine horizons and macrofloras. Based on data from Kneuper & Schönenberg (1962), Schönenberg & Kneuper (1964) and Schäfer (2005)

except for the lycophytes where the stem morphotaxa are given (see Cleal, 2005 for a brief discussion on the logic behind this selection).

The distribution of the macrofloral species is partly based on my observations on the extensive palaeobotanical collections in the Zentrum für Biodokumentation des Saarlandes, Saarbrücken (formerly the collection of the Saarbrücken Bergingenieurschule, von der Heydt). However, I have also supplemented this with data culled from the literature, especially where the records are illustrated (Hemmer, 1920; Bertrand, 1930; Corsin, 1951; Guthörl, 1943, 1953; Doubinger, 1956; Germer *et al.*, 1966, 1968; Germer, 1971; Doubinger & Germer, 1971a,b, 1972, 1974, 1975a,b; Boermsa, 1973, 1978; Germer & Doubinger, 1975; Alvarez-Ramis *et al.*, 1978; Brousmiche, 1983; Germer & Engel, 1986; Laveine, 1989).

BIOSTRATIGRAPHY

Most of the taxa listed in Table 1 are long ranging and thus of little biostratigraphical significance. However, in all four assemblages there are a few taxa whose overlapping ranges do give some useful biostratigraphical information (Fig. 3).

Wahlschied and Schwalbach Seams. Although these coals are separated by some 150 m of clastic strata, the macrofloras are very similar. There are 13 species that occur in both floras, just 5 that are only in the Schwalbach Seam flora and 12 only in the Wahlschied Seam flora. Moreover, most of the biostratigraphically indicative taxa are common to both assemblages. For the purposes of this discussion, therefore, the two assemblages can be dealt with together,

Both floras appear to provide a very clear biostratigraphical signal indicating the middle *A. zeilleri* Zone. This is due to the overlap of ranges of two groups of species.

1. *Lobatopteris lamuriana*. In the classic Stephanian successions of the Massif Central of France, *L. lamuriana* does not extend above the *L. lamuriana* Zone, but Knight (1983) has found it in the Unica Beds of the Sabero Coalfield (northern Spain), which belong to the middle *A. zeilleri* Zone.

2. *Odontopteris subcrenulata*, *O. nemejcii*, *Remia pinnatifida*, *Lobatopteris corsinii*, *Sphenopteris weissii*. *O. nemejcii*, *R. pinnatifida* and *S. weissii* are all characteristic elements of the Slaný Formation of Central Bohemia, of which Wagner (1977) stated that '…there is general agreement about a late Stephanian B age…' (i.e. upper *A. zeilleri* Zone). *L. corsinii* is also a characteristic of late *A. zeilleri* Zone floras, this time best known from northern Spain (Wagner, 1958, 1984). *O. subcrenulata* is often regarded as a typically Late Stephanian form, but Vetter (1968) recorded it from the Assise de Campagnac, which clearly corresponds to the middle *A. zeilleri* Zone.

Germer *et al.* (1968) also regard the presence of *Neuropteris gallica* as being of biostratigraphical importance but, as pointed out by Knight (1974), this species was probably an extra-basinal species that was transported into depositional basins and so not a reliable biostratigraphical index.

Reisbach Seam. This assemblage of 31 species is more diverse than those the Wahlschied and Schwalbach seams (25 species and 18 species, respectively), probably mainly due to intensive collecting at the Schäfer Mine near Reisbach during the 1960s and 1970s (Germer *et al.*, 1966; Boersma, 1978, 1979). The Reisbach flora is nevertheless similar to those of the other coals, with only 10 species from the Wahlschied and Schwalbach seams not occurring there.

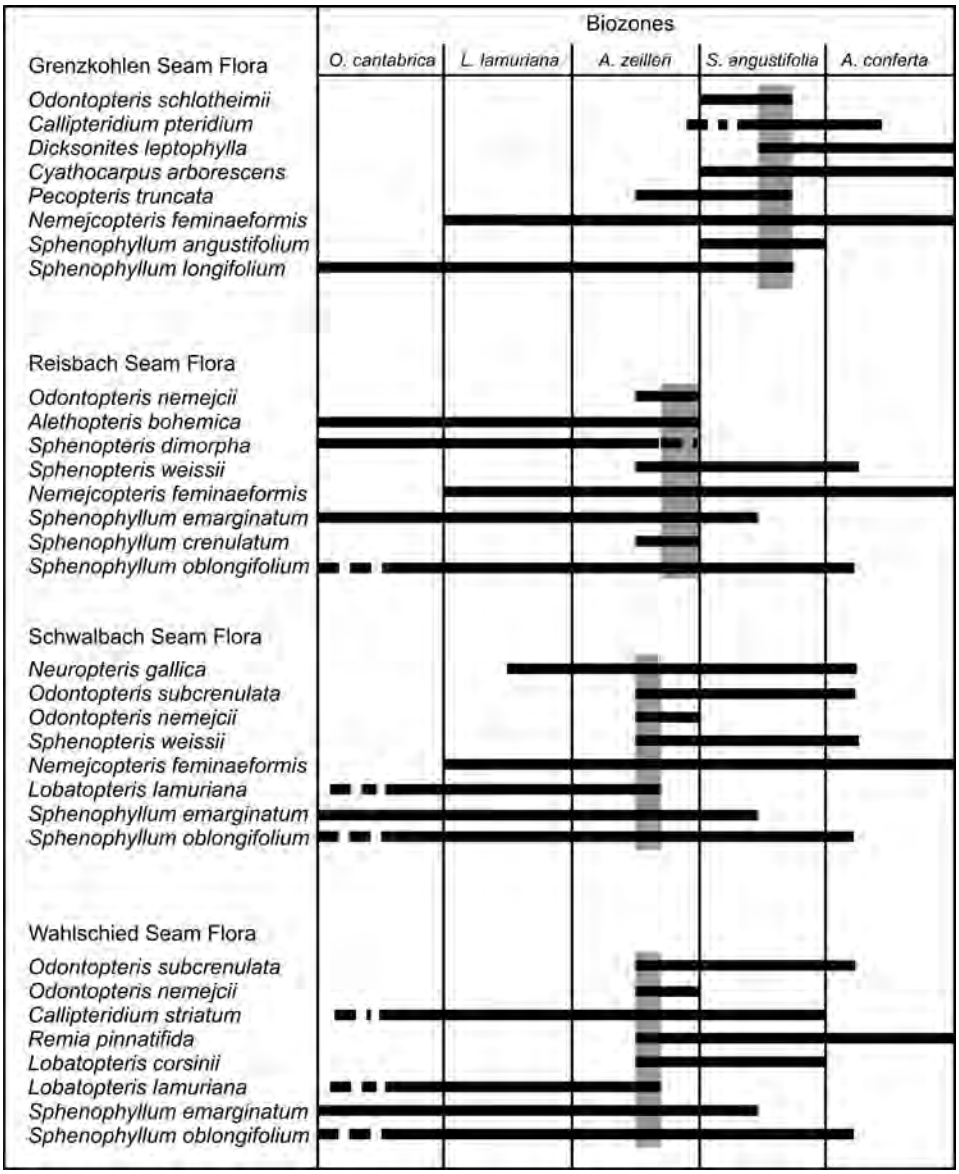

Fig. 3. Stratigraphical ranges of key macrofloral taxa from the four main coals within the Ottweiler Group of Saar-Lorraine, plotted against the macrofloral biozones of Wagner (1984)

The continued presence of *Odontopteris nemejcii* and *Sphenopteris weissii* suggest that the assemblage is from the upper half of the *A. zeilleri* Zone. The reported presence here of *Odontopteris subcrenulata* (e.g., Germer, 1971) would also support such an age, although in his review of this macroflora Boersma (1978) was unable to verify its presence here. The presence of *Alethopteris bohemica* also indicates that the Reisbach flora is no younger than the *A. zeilleri* Zone. However, *Lobatopteris lamuriana* is now absent, which removes the one species found in the stratigraphically older floras that indicated the middle rather than upper *A. zeilleri* Zone. In view of the extensive collecting that has taken place here, this absence is unlikely to be due to poor sampling, and suggests that the Reisbach flora is from the upper part of the *A. zeilleri* Zone.

Mention should be made of another macroflora, reported by Boersma (1973) from Hinzweiler in the Pfalz, which came from a stratigraphical level in the middle of the upper part of the Heusweiler Formation. Although the assemblage was not illustrated and the present author has not had the opportunity to examine material from here, the species list provided by Boersma (1973) suggests a position in the lower *Sphenophyllum angustifolium* Zone. If correct, then this suggests that the boundary between these two zones occurs within the upper Heusweiler Formation.

Grenzkohlen Seam. Although many of the species found in the Reisbach Seam flora also range up to the Grenzkohlen Seam, there are a few additional and biostratigraphically-important species here, notably *Odontopteris schlotheimii*, *Callipteridium pteridium*, *Dicksonites leptophylla*, *Sphenophyllum angustifolium* and *S. longifolium*. Doubinger (1956) regarded the flora as 'Stephanian D' in age, a concept that she had introduced for what was traditionally taken for the upper Stephanian C Substage, where rare callipterids (often taken as an index for the Autunian Stage) appear. Later, however, Bouroz & Doubinger (1977, p. 163) implied that the flora was Stephanian C in age (i.e. early Stephanian C in age in the currently-accepted meaning) based primarily on the palynology. The 'Stephanian D Substage' has not been formally recognised as it is regarded as having too short a time-span, but the division of the Stephanian C into two parts based on the macrofloras is valid.

Based on the ranges given in Wagner (1984), the Grenzkohlen Seam flora clearly belongs to the *S. angustifolium* Zone (Fig. 3). Doubinger (1956) argued that the co-existence here of *Dicksonites leptophylla* and *Sphenophyllum longifolium* is particularly informative, as she believed that their ranges only overlap in the middle *S. angustifolia* Zone (what she terms lower 'Stephanian D'). Neither of these species is especially abundant, and so there must be some reservation about the stratigraphical ranges that have been quoted for them. However, the evidence as it stands seems to confirm Doubinger's (1956) original assessment that the Grenzkohlen Seam belongs to what we now call the middle *S. angustifolia* Zone, rather than the lower part of that zone as suggested by Bouroz & Doubinger (1977).

Table 1

Distribution of macrofloral species in the Ottweiler Group of Saar-Loraine

	Wahlschied Seam	Schwalbach Seam	Reisbach Seam	Grenzkohlen Seam
Sigillaria brardii Brongn.	+	+	+	+
S. ichthyolepis Sternb.	+	+	+	
S. tessellata (Steinhauer) Brongn.			+	
Lepidodendron scutatum Lesq.			+	
Lepidophloios laricinus Sternb.			+	
Asolanus camptotaenia Wood			+	
Asterophyllites equisetiformis Brongn.	+	+	+	+
Annularia spinulosa Sternb.	+		+	+
A. sphenophylloides (Zenker) Gutbier	+	+	+	+
Sphenophyllum emarginatum Brongn.	+	+	+	
S. oblongifolium (Germar & Kaufuss) Unger	+	+	+	+
S. crenulatum Knight			+	
S. marsiliaefolia (Sternb.) Batenburg				+
S. angustifolium (Germar) Goepp.				+
S. longifolium Germar				+
Pecopteris monyii Zeiller			?	
P. paleacea Zeiller	+			
P. rarinervosa Corsin	+		+	
P. truncata Rost				+
P. victoriae Corsin	+			
Cyathocarpus arborescens (Brongn.) C.E. Weiss	?	?	?	+
C. hemitelioides (Brongn.) Mosbrugger	+	+	+	+
Senftenbergia plumosa (Artis) Stur	+		+	+
Ptychocarpus unitus (Brongn.) Zeiller	+	+	+	+
Nemejcopteris feminaeformis (Sterzel) Barthel		+	+	+
Remia pinnatifida (Gutbier) Knight	+			
Lobatopteris corsinii Wagner	+			
L. lamuriana (Heer) Wagner	+	+		
Acitheca polymorpha (Brongn.) Schimper	+	+	+	+
Alloiopteris erosa (Gutbier) D. White	+		+	
Corynepteris angustissima (Sternb.) F. Nemejc	+		+	
Discopteris saarensis Doubinger & Germer			+	
Hymenophyllites quadridactylites (Gutbier) Kidst.	+			
Oligocarpia gutbieri Goepp.	+			

Following Cleal (2005), only the bark morphospecies are give for the lycophytes, and only the foliage morphospecies for the other groups. The name of species authors have been abbreviated following Stafleu & Cowan (1976–1988)

Table 1 continued

	Wahlschied Seam	Schwalbach Seam	Reisbach Seam	Grenzkohlen Seam
Sphenopteris beyschlagii (Potonié) Wagner				?
S. dimorpha (Lesq.) Wagner			+	
S. rutaefolia Gutbier		+		
S. weissii (Potonié) F. Němejc		+	+	
S. goniopteroides Lesq.		+		
Pseudomariopteris ribeyronii (Zeiller) Danzé-Corsin				+
Dicksonites plueckenetii (Sternb.) Sterzel	+			
D. leptophylla (Bunbury) Doubinger				+
Neuropteris gallica Zeiller		+		
N. schaeferi Doubinger & Germer			+	
'Reticulopteris' odontopteroides Remy				+
Odontopteris subcrenulata (Rost) Zeiller	+	+	?	
O. schlotheimii Brongn.				+
O. nemejcii Šimůnek & Cleal	+	+	+	+
Alethopteris bohemica Franke			+	?
Callipteridium striatum Wagner	+		+	
C. pteridium (Goepp.) Zeiller				+

DISCUSSION

The macrofloras of the Ottweiler Group all appear to belong to the middle to upper *A. zeilleri* or middle *S. angustifolium* Zones. Assuming that the correlation suggested by Wagner (1984) between his macrofloral zones and the 'stages' (now substages) in the Heerlen chronostratigraphy is correct, then the entire Group is late Stephanian B to middle-late Stephanian C in age, representing as little as 1.5 Ma (Fig. 4). The stratigraphical gap at the base of the Holz Conglomerate is thus larger than previously suggested, such as by Germer *et al.* (1968): not only is the Cantabrian and lower Barruelian Substages missing, but all of the Barruelian and the lower Stephanian B as well. This tends to undermine the case for Saar-Lorraine having 'a continuous depositional sequence of its Carboniferous–Permian basin-fill' (Schäfer, 2005, p. 369) as there is evidently at least one major hiatus representing some 3–4 Ma.

The new evidence also suggests that there may be minor non-sequences above and below the Breitenbach Formation. It will be difficult to obtain independent verification of this within the main part of the coalfield due to limited exposure. However, there are relatively good outcrops in the eastern part of the Saar-Lorraine basin, near Königsberg in the Palatinate, which hold the potential for the further investigation of these important deposits (D. Uhl, pers. comm., 2007). It is notewor-

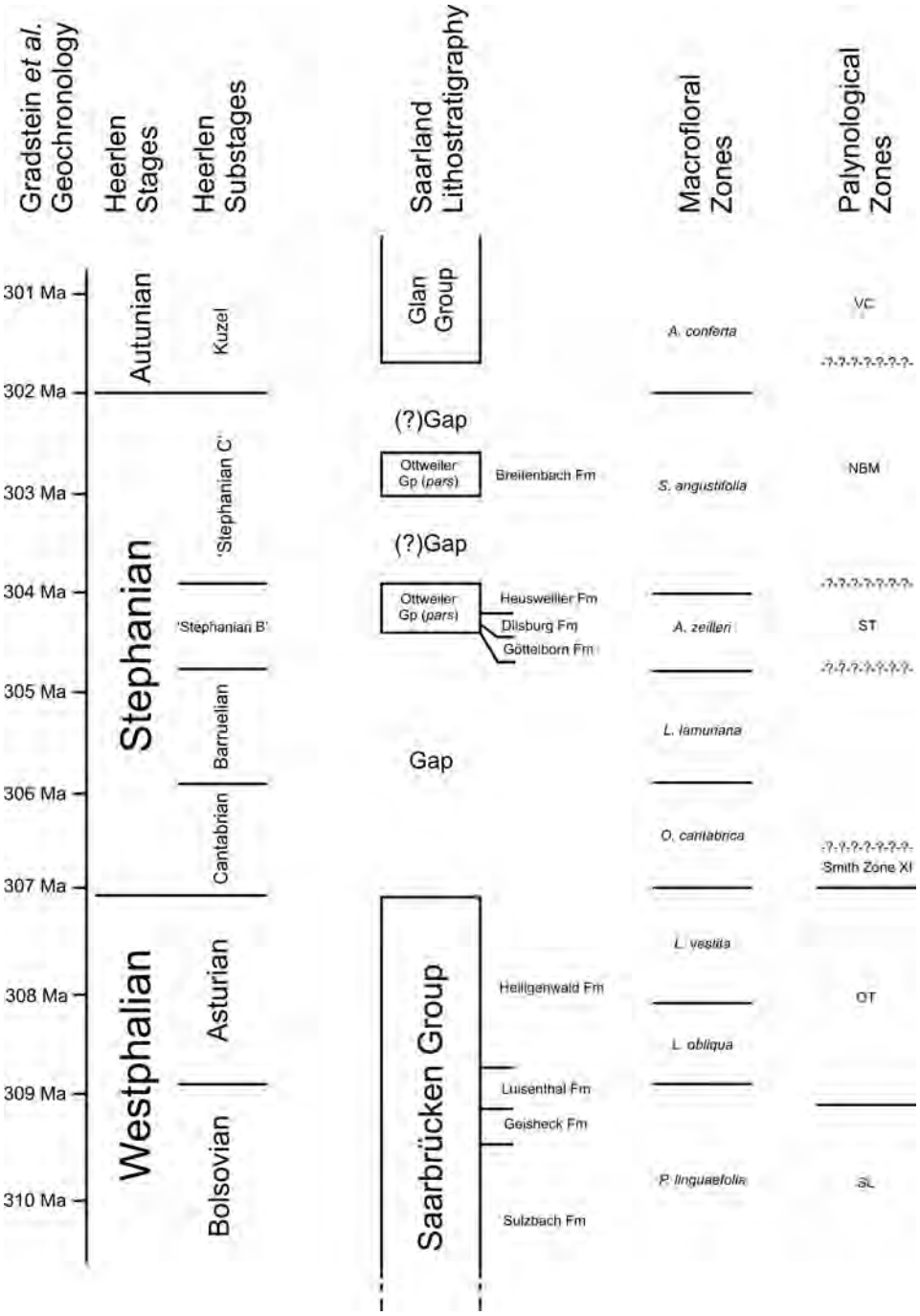

Fig. 4. Correlation of Ottweiler Group with the substages of the Heerlen chronostratigraphy, geochronology (Gradstein *et al.*, 2004), the macrofloral biozones (Wagner, 1984) and palynological biozones (Clayton *et al.*, 1977; Smith, 1987, Cleal *et al.*, 2003)

thy that the difference in age between the Breitenbach Formation and the middle Heusweiler Formation is almost identical to that between the Líně and Slaný Formations in Central Bohemia, and the latter is regarded as being due to non-sequence (Pešek, 1994)

This has some consequences for the palynostratigraphy of the Stephanian. In the palynological biostratigraphy of Clayton *et al.* (1977), Zone ST (*Angulisporites splendidus – Latensina trileta*) is shown as ranging through most of the Barruelian and Stephanian B substages. However, most of the evidence for a Barruelian age for this zone is based on its presence in the Wahlschied and Schwalbach seams (base of the Dilsburg and of the Heusweiler formations, respectively). Most of the other palynofloras mentioned by Clayton *et al.* for this zone (from the Carmaux, Figeac-St. Perdoux, Decize, Decazeville and Autun Basins) are Stephanian B or Stephanian C in age (e.g. Vetter, 1986). The only other possible Barruelian-aged ST Zone palynoflora is from the Grande Masse coal of the Assise de Rive de Gier in St Étienne (described by Liabeuf & Alpern, 1969). However, the published species list for the Assise de Rive de Gier palynoflora provides little evidence of it belonging to the ST Zone as defined by Clayton *et al.* (1977). Re-assigning the Dilsburg and Heusweiler formations to the upper Stephanian B Substage thus removes the only reliable evidence that the ST Zone extends down into the Barruelian Substage. As a consequence, there is clearly a major gap in our knowledge of Stephanian palynostratigraphy, with no biozone representing the interval between the Stephanian B ST Zone and Smith's (1987) Zones XI/XII from the lower Cantabrian Substage of Britain (Cleal *et al.*, 2003).

There are also consequences for the insect biostratigraphy proposed by Schneider & Werenburg (2006; see also Schneider *et al.*, 2005). The two lowest Stephanian zones in this scheme (the *Sysciophlebia* n. sp. A – *Sysciophlebia intermedia* Zone and *Sysciophlebia variegate* Zone) are assigned Barruelian and Barruelian – Stephanian B boundary ages based on their presence in the lower Ottweiler group of Saarland. If the new correlations suggested in the present paper are correct, both of these insect zones are in fact late Stephanian B in age.

Finally, there are consequences for the geochronology of the Stephanian Stage. There are only two reliable $^{40}Ar/^{39}Ar$ dates for the Stephanian Stage, obtained from Tonstein 0 in the Wahlschied Seam in Saarland, and another tonstein found in the nearby Schwarzwald that has been correlated with the Breitenbach Formation of Saarland. The 302.5 ± 0.6 Ma age that Gradstein *et al.* (2004) give for the Breitenbach Formation (recalibrated from a 300.3 ± 0.6 Ma data given by Burger *et al.*, 1997 and Menning *et al.*, 2000, 2004), is compatible with the macrofloral evidence of a Middle Stephanian C age, albeit at the upper end of the error-range for the radiometric date (i.e. 303 Ma). However, there appeared to be a major problem with the 304.2 ± 0.6 Ma date quoted by Gradstein *et al.* (2004) (recalibrated from a 302.2 ± 0.6 Ma dated given by Burger *et al.*, 1997 and Menning *et al.*, 2000, 2004). Based on both the Gradstein *et al.* and Menning *et al.* time scales, this would make the Wahlschied Seam late Stephanian B in age, in apparent variance with the generally-accepted middle Barruelian age for that coal. However, the revised macro-

floral biostratigraphy is now compatible with the Stephanian B age suggested by the radiometric data

The revised chronostratigraphical position of the lower Ottweiler Group also resolves the apparent problem of the large (3.6 Ma) time gap that the Holz Conglomerate non-sequence represented based on the available radiometric dates (Burger *et al.*, 1997). Menning *et al.* (2000) argued that this was too long if it was only including the Cantabrian and lower Barruelian substages and that there may have been methodological problems with the Burger *et al.* (1997) analysis. However, with the Holz Conglomerate being re-assessed as middle Stephanian B in age, the gap below it includes all of the Cantabrian and Barruelian and the lower half of the Stephanian B substages. On both the Menning *et al.* (2000, 2006) and Gradstein *et al.* (2004) time scales these substages represent 3–4 Ma, which is thus perfectly compatible with the Burger *et al.* (1997) analysis.

CONCLUSIONS

The macrofloras of the Ottweiler Group in the Saar-Lorraine Coalfield indicate that this succession ranges from middle Stephanian B to middle Stephanian C in age (middle *Alethopteris zeilleri* to middle *Sphenophyllum angustifolium* Zones), which is a much narrower time interval than has been hitherto suggested. The revised interpretation also lengthens significantly the time-gap represented by the non-sequence below the Holz Conglomerate. The revision has removed the apparent conflict between the Stephanian chronostratigraphy and the recently proposed time scales for the Carboniferous. However, it has highlighted a problem with the standard palynological biozonation for the Stephanian Stage, as there now seems to be a substantial gap between the ST Zone (lower Stephanian B Substage) and Smith's (1987) Zones XII/XIII (lower Cantabrian Substage).

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