Review of Palaeobotany and Palynology 188 (2013) 18–37

Contents lists available at SciVerse ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Research paper

Conifer-dominated palynofloras in the Middle Pennsylvanian strata of the De Lutte-6 borehole, The Netherlands: Implications for evolution, palaeoecology and biostratigraphy

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ARTICLE INFO

Article history:
Received 5 April 2012
Received in revised form 21 September 2012
Accepted 29 September 2012
Available online 1 November 2012

Keywords:
Pennsylvanian
palynology
palaeoecological
biostratigraphy
walchian conifers
climate change

ABSTRACT

The evolutionary history of Pennsylvanian tropical dryland/upland communities remains enigmatic. In this paper, we describe conifer-dominated palynofloras in a facies context from the early to mid-Moscovian (Middle Pennsylvanian) interval of the De Lutte-6 borehole (the Netherlands) that shed light on this issue. Our data suggest that, in the upper Bolsovian–lowermost Asturian part of the borehole succession, *Florinites*-producing cordaitaleans with subordinate tree-ferns, pteridosperms, calamiteans, and lycopsids, covered low-lying braidplains draining the rising Variscan Orogen, while *Cordaitina*/*Latensina*-producing cordaitaleans, walchian conifers and enigmatic pteridosperms mostly grew in hinterland regions (Assemblage I). At one relatively brief interval, a mire dominated by calamiteans and arborescent lycopsids developed within this braidplain complex (Assemblage II). In the mid-Asturian part of the borehole succession, following a switch from humid to seasonally-dry climates (indicated by paleosols), palynofloras associated with a shallow, but extensive, lake deposit imply that communities of walchian conifers, *Cordaitina*/*Latensina*-producing cordaitaleans, and engimatic pteridosperms covered low-lying drylands, but were cyclically replaced by lycopsid 'ephemerals' during short-term pluvial events (Assemblage III). Across tropical Pangaea, the climate-driven migration of diverse conifers from Bolsovian hinterlands to mid-Asturian basins coincides with (1) the more frequent appearance of conifer megafloral remains in the fossil record, (2) a gradual increase in the frequency of tree-ferns in clastic swamps, (3) a decline in the abundance of arborescent lycopsids in mires, and (4) a change from perhumid raised mires to humid planar mires in cratonic areas. We therefore highlight that the mid-Asturian (mid-Moscovian) interval is an under-appreciated event in the evolution of Pennsylvanian tropical vegetation, on a par with the better-known climate-driven floral changeovers that occurred in the earliest Kasimovian and Gzhelian–Asselian. Our palaeoecological findings also clarify a long-running biostratigraphic controversy by showing that conifer dominance in the De Lutte-6 borehole is completely consistent with its Bolsovian–Asturian age, and does not require the invocation of an unconformity separating an inferred Westphalian part of the succession from an inferred upper Stephanian/Permian part of the succession, as suggested by some earlier workers. This, in turn, emphases the importance of selecting isotaphonomic (isoclimatic) samples for biostratigraphic purposes.

1. Introduction

The changeover from Carboniferous Coal Forests, dominated by pteridophytes, to Permian vegetation, dominated by conifers, cordaitaleans and peltasperms (sometimes termed the Palaeophytic–Mesophytic transition) has been recognised for a century (Gothan, 1912; Gothan and Weyland, 1954). However, the temporally and regionally complex nature of this event is only now emerging (Kerp, 1996; DiMichele et al., 2008) as a result of integrated studies of plant fossils, paleosols, and sequence stratigraphy (e.g., Falcon-Lang et al., 2009, 2011a; Dolby et al., 2011). These new findings show that the so-called Palaeophytic–Mesophytic transition is, in large part, a taphonomic artefact, which resulted from the way that climate, and to some extent, tectonics altered the distribution of two co-existing tropical biomes: a humid pteridophyte-dominated Coal Forest biome ('Palaeophytic' vegetation) and a seasonal coniferopsid-dominated biome ('Mesophytic' vegetation) (Mapes and Gastaldo, 1986; Broutin et al., 1990; DiMichele and Aronson, 1992; Kerp, 1996; Falcon-Lang et al., 2006, 2011a,b,c, 2012; DiMichele et al., 2007, 2010; Falcon-Lang and DiMichele, 2010).

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http://dx.doi.org/10.1016/j.revpalbo.2012.09.003

A critical reading of the Carboniferous fossil record indicates that the humid Coal Forest biome first assembled, in a recognisable form, in late Visean times (DiMichele et al., 2001) and rose to dominance beginning in mid- to late Serpukhovian times (Cleal and Thomas, 2005; Gastaldo et al., 2009). The origins of the seasonal coniferopsid-dominated biome occurred more or less simultaneously, with the earliest of records of conifer and cordaitalean pollen grains (e.g., *Potonieisporites* and *Florinites*, respectively; Gomankov, 2009), dating from the late Visean (Owens et al., 1978) before becoming abundant in some facies in the late Serpukhovian (Chaloner, 1958; Davies and McLean, 1996; Stephenson et al., 2008; Utting and Giles, 2008). However, whereas the Coal Forest biome was centred in wetland depocentres and left an excellent Bashkirian–Moscovian fossil record (DiMichele et al., 2001, 2007; Falcon-Lang et al., 2006), the coeval fossil record of the coniferopsid-dominated biome centred in extrabasinal drylands is, at best, cryptic (Chaloner, 1958; Rothwell, 1982; Falcon-Lang et al., 2009, 2011b, 2012; Dolby et al., 2011). Only following a series of step-changes towards drier climates in tropical Pangaea did the latter biome progressively increase its proportional representation in the fossil record; these three step-changes were broadly in the mid-Moscovian (Pfefferkorn and Thomson, 1982; Phillips and Peppers, 1984; Lyons and Darrah, 1989; Falcon-Lang et al., 2009), earliest Kasimovian (Phillips et al., 1974, 1985; Kosanke and Cecil, 1996; DiMichele et al., 2010; Falcon-Lang and DiMichele, 2010; Falcon-Lang et al., 2011a), and Gzhelian-Asselian (Kerp, 1988; Kerp et al., 1990; Hernandez-Castillo et al., 2003).

Much remains to be learned about the diversity, distribution, and extent of coniferopsid-dominated drylands, especially in Bashkirian–Moscovian times, and its earlier origin in the Serpukhovian. In this paper, we describe and analyse the facies context of conifer-dominated palynofloras from the Pennsylvanian (upper Bolsovian–Asturian; Moscovian) interval of the De Lutte-6 borehole, the Netherlands (Pagnier and Van Tongeren, 1996). This succession was deposited directly northwest of the Variscan Orogen, the uplift of which commenced in the mid-Bolsovian (Leveridge and Hartley, 2006; Fig. 1). De Lutte-6 palynofloras straddle the Bolsovian–Asturian (mid-Moscovian) boundary, which marks a step-change from perhumid to (sub)humid climates in this region in particular (Bertier et al., 2008) and more widely across much of tropical Pangaea (Cecil et al., 1985; DiMichele et al., 2010). Our data improve knowledge of the development of the seasonal coniferopsid biome in tropical Pangaea and help resolve a biostratigraphic controversy.

2. The controversial age of the De Lutte-6 succession

The 3194 m deep De Lutte-6 borehole was drilled, in 1989, 7 km NNE of Enschede in the Twente region of the eastern part of the Netherlands, close to the German border (52°17′42″N; 6°56′20″). The Carboniferous (Pennsylvanian) part of the borehole was divided into two units: the lower part, from 3194 to 2972 m, was assigned to the coal-bearing Tubbergen Formation while the upper part, from 2972 to 2232 m, was designated as the type section of the De Lutte Formation, a succession of 'barren red measures' (Fig. 2; Van Adrichem Boogaert and Kouwe, 1995). The boundary between the two formations was placed at the Itterbeck Horizon at 2972 m (Selter, 1989), the correlative equivalent of the uppermost regionally mapable Itterbeck Coal (Pagnier and Van Tongeren, 1996). Following drilling, detailed studies of sedimentary facies, paleosols (Van der Zwan et al., 1993; Rößler, 1995; Pagnier and Van Tongeren, 1996), sandstone petrology (Van der Meer and Pagnier, 1996), megafloras (Van Amerom, 1996a,b), palynofloras (Van der Zwan et al., 1993; Van de Laar and Van der Zwan, 1996), invertebrate faunas, and biostratigraphy (Van Amerom, 1996a) were undertaken, and the entire borehole core was accessioned at the TNO (Toegepast Natuurwetenschappelijk Onderzoek) storage facility at Zeist, near Utrecht, the Netherlands.

2.1. Mismatch of megafloral and palynofloral data

Despite these detailed biostratigraphic investigations, controversy about the age of the Pennsylvanian succession in the De Lutte-6 borehole quickly broke out as a result of an apparent mismatch between megafloral and palynofloral biozonation (Van der Zwan et al., 1993). While megafloras found in the De Lutte-6 borehole and at tens of localities across parts of northwest Europe (Germany, Belgium, and the Netherlands) have been considered characteristic of Bolsovian–

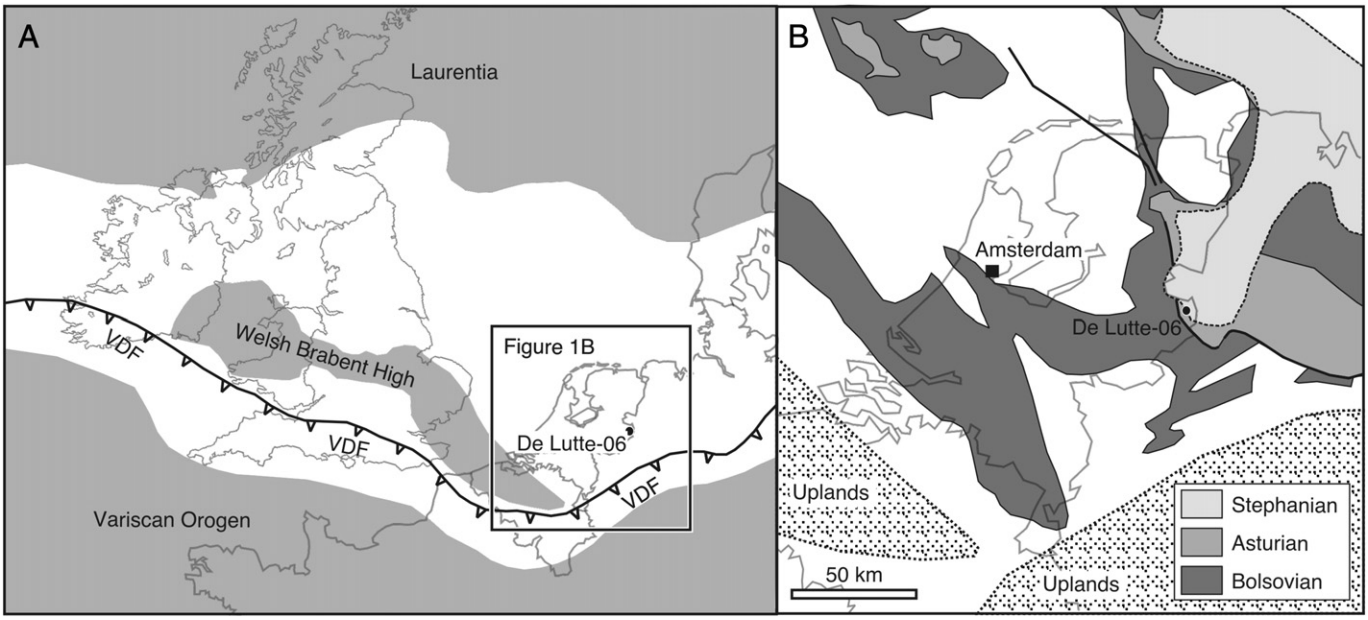

Fig. 1. Location details. (A) Map of northwest Europe showing the distribution of Moscovian basins and coal-bearing strata in relation to the Variscan Orogen (after Ziegler, 1989; Kombrink, 2008). VDF = Variscan Deformation Front, grey in uplifted massif and white is basin. (B) The location of the De Lutte-6 borehole in relation to Bolsovian, Asturian and Stephanian strata (after Kombrink et al., 2007; Van Waveren et al., 2008).