Palaeozoic Palaeobotany of Great Britain

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Chapter 6

Upper Carboniferous

The productivity of terrestrial vegetation during the Late Carboniferous was greater than at any other time during the Palaeozoic. This is most clearly seen in the development of thick, coal-forming peats in the tropical lowland habitats – the result of dense forests, dominated by lycopsids, ferns and in some cases cordaites (see Figure 6.3). However, there is also evidence of extensive vegetation in the tropical extra-basinal areas, as well as in parts of the high latitudes, in Angara and Gondwana (Figure 6.1).

Conditions at this time were clearly favourable for plant life in the tropics (e.g. high levels of precipitation). Probably because of this, there were relatively few major evolutionary innovations in these floras; most major events seem to have occurred in other habitats, such as the tropical extra-basinal habitats (e.g. the appearance of conifers) and at higher latitudes (e.g. the appearance of glossopterids). Nevertheless, the plant fossils found in the Upper Carboniferous tropical deposits are of considerable interest, as they represent the acme of palaeophytic vegetation. They also have a major economic importance, through the hydrocarbon fuels (coals, oil and gas) that they generated. Consequently, the palaeobotany of these strata has been more intensely studied over the years than any other part of the geological column.

PALAEOGEOGRAPHICAL SETTING

At the start of the Late Carboniferous, Britain was on the southern margins of the Laurussian continent, positioned near the equator (Figure 6.1). Probably sometime in the late Westphalian or early Stephanian, however, the Gondwanan continent collided with Laurussia to form the Pangaean 'super-continent' that stretched from the south pole to high northern latitudes. During much of the subperiod, a series of major fluvial deltas prograded over large areas of present-day northern Europe and eastern North America. The resulting delta-plains provided the substrate for the growth of extensive forests – the very first major tropical rain-forests.

The forests were at their peak during the Westphalian Epoch, and the peat deposits that they produced have resulted in extensive coals. Economically significant Upper Carboniferous coalfields occur throughout the palaeoequatorial belt, from central North America (Arkansas, Kansas), through much of Europe to the Ukraine, as well as in China. The British coalfields belong to what is often called the Paralic Belt, which was a trough or 'valley' that extended from Poland in the east, through northern Germany, the Netherlands, Belgium, northern France to the British Isles and the Maritime Provinces of Canada.

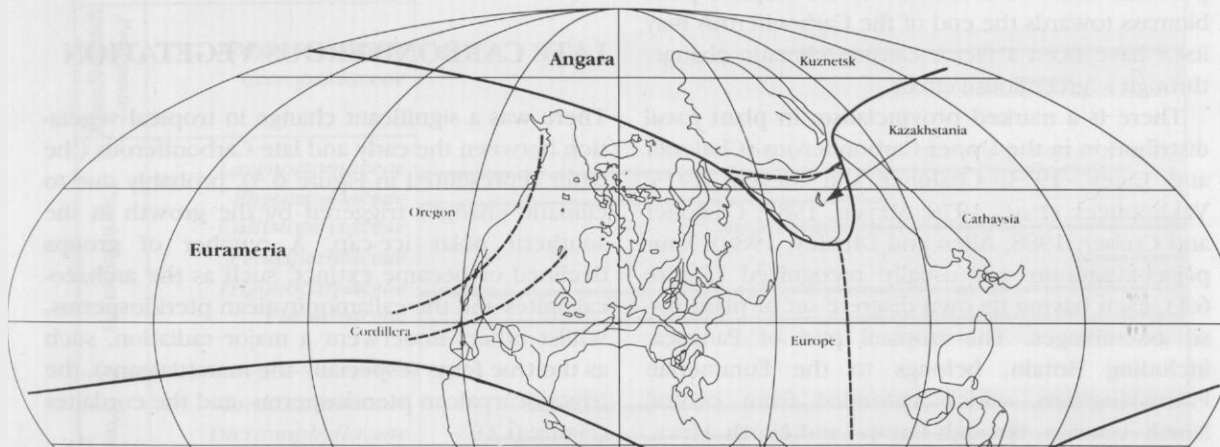

Figure 6.1 The palaeogeography of the Late Carboniferous, showing the distribution of the major floristic zones (phytochoria). Based on Scotese and McKerrow (1990) and Cleal and Thomas *in* Cleal (1991).

Although largely formed under non-marine conditions, the trough was periodically flooded by eustatic rises in sea level. Coal formation in the Paralic Belt eventually ceased towards the end of the Westphalian or very early Stephanian; the youngest British coals are in the basal Cantabrian (Cleal, 1978, 1984b, 1986c).

During the Namurian and most of the Westphalian, Britain was subject to a hot and wet tropical climate. However, the formation of Pangaea disrupted the oceanic and atmospheric currents, and was at least partially responsible for a change to a significantly arid climate in the tropical regions towards the end of the Carboniferous (Rowley *et al.*, 1985). The collision between Laurussia and Gondwana also caused a degree of topographical uplift of the tropical regions. This in turn made the area less suitable for the growth of the lycopsid-dominated forests, which were physiologically constrained to lowland swamps. The lycopsids in the tropical forests of Pangaea were initially replaced by tree-ferns and pteridosperms, which were still capable of generating considerable peat accumulations. Eventually, in the Permian, the latter were in turn largely replaced by tracts of conifers, better adapted to the drier habitats. However, it is unlikely that these were anywhere near as aerially extensive as the lycopsid forests, and certainly never resulted in any significant peat accumulations. It is interesting to postulate that the reduction in the tropical plant biomass towards the end of the Carboniferous may itself have been a factor causing climatic change, through a 'greenhouse effect'.

There is a marked provincialism in plant fossil distribution in the Upper Carboniferous (Chaloner and Lacey, 1973; Chaloner and Meyen, 1973; Vakhrameev *et al.*, 1978; Meyen, 1987; Chaloner and Creber, 1988; Allen and Dineley, 1988). Four palaeokingdoms are usually recognized (Figure 6.1), each having its own discrete set of plant fossil assemblages. The tropical part of Pangaea, including Britain, belongs to the Euramerian Palaeokingdom, which extended from central North America, through Europe and North Africa, to the Caucasus.

STRATIGRAPHICAL BACKGROUND

As pointed out in the introduction to the previous chapter, it is convenient to divide this part of the discussion on British palaeobotanical sites into Upper and Lower Carboniferous chapters. This corresponds both to a natural division of the plant fossil assemblages, and to the sub-systemal division currently accepted by the IUGS Subcommission on Carboniferous Stratigraphy.

The marked provincialism of both fossil faunas and floras in the Upper Carboniferous has made it impossible to establish a chronostratigraphy for use throughout the world. Even within the equatorial belt, problems of detailed correlation have prevented agreement on a unified classification; the outline scheme proposed by Bouroz *et al.* (1978) still requires considerable refinement before it becomes a practical stratigraphical tool.

The British Upper Carboniferous is classified according to a modified form of the 'Heerlen Classification', named after the conferences on Carboniferous stratigraphy held at Heerlen between 1928 and 1958 (Wagner, 1974). The part of this chronostratigraphy relevant to the following discussion is summarized in Figure 6.11, including the revised stage nomenclature outlined by Engel (1989).

Wagner (1984) proposed eleven plant fossil zones for the Upper Carboniferous Eurameria Palaeokingdom, and a twelfth was added by Cleal (1984b). Of these, the top four (Barruelian to Stephanian C in age) are not found in Britain. The remaining eight are shown in Figure 6.11, with the GCR palaeobotanical sites plotted against them.

LATE CARBONIFEROUS VEGETATION

There was a significant change in tropical vegetation between the early and late Carboniferous (the latter represented in Figure 6.3), probably due to climatic changes triggered by the growth in the southern polar ice-cap. A number of groups declined or became extinct, such as the archaeocalamites and the callamopityalean pteridosperms, whilst others underwent a major radiation, such as the true ferns (especially the marattialeans), the trigonocarpalean pteridosperms, and the cordaites (Figure 6.2).

As in the Early Carboniferous, lycopsids were the most important component of this vegetation. If the adpression record is viewed in isolation, this is not immediately apparent, as the dominant fossils preserved there tend to be pteridosperms, ferns and equisetes. However, if the coal-forming peat deposits are examined, either by looking at coal-balls (e.g. Phillips, 1980; Phillips and DiMichele, 1992) or palynology (A.H.V. Smith,

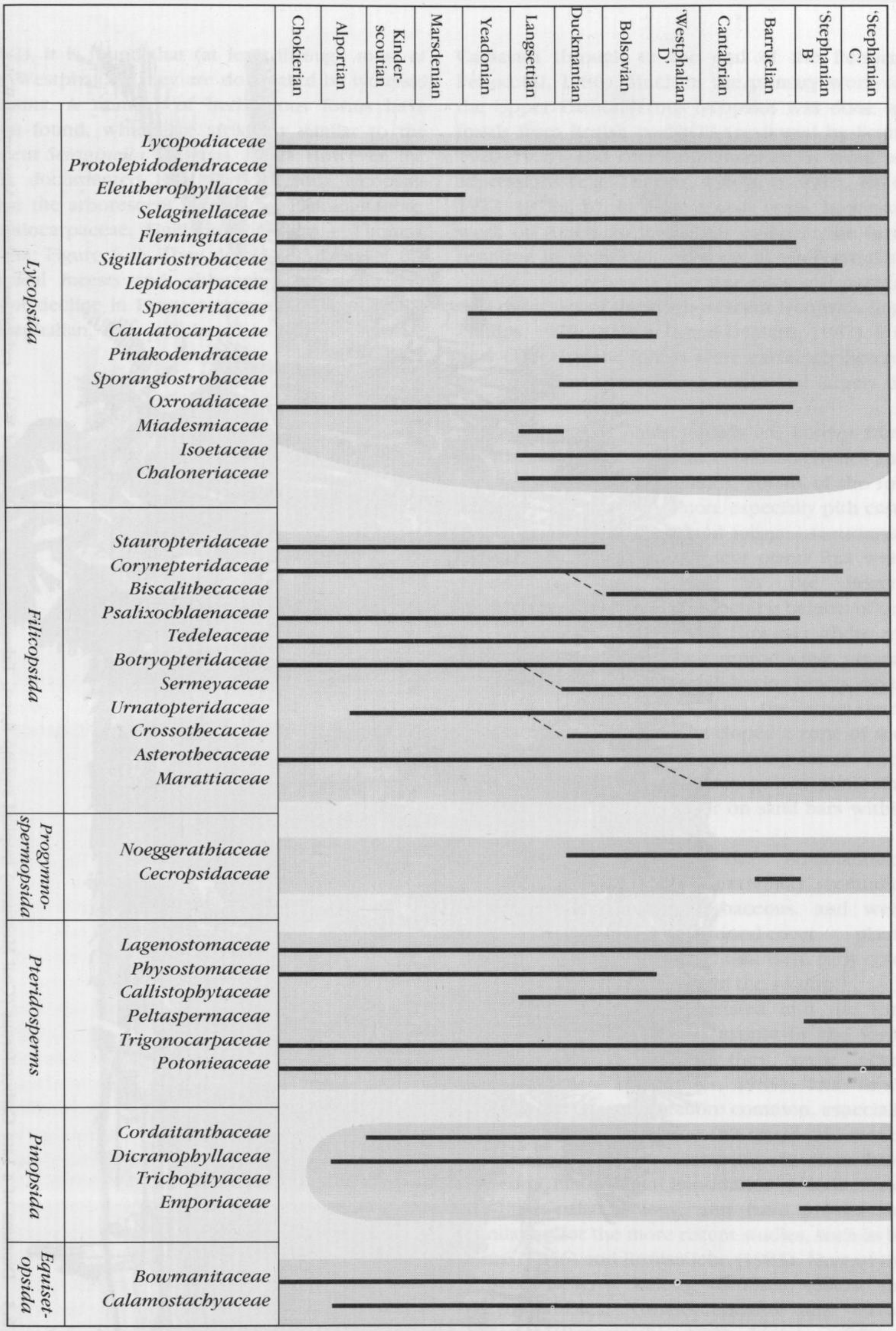

Figure 6.2 The distribution of the principal families of vascular plants in the Late Carboniferous. Based on data from Cleal (1993).

Figure 6.3 Diorama of a Late Carboniferous (Coal Measures) tropical swamp forest. Taken from the 'Evolution of Wales' exhibition, National Museum of Wales, Cardiff.

1962), it is found that (at least through most of the Westphalian) they are dominated by lycopsid remains. A number of herbaceous forms have been found, which are strikingly similar to the Recent *Selaginella* (Thomas, 1992). However, the best documented Late Carboniferous lycopsids were the arborescent forms (e.g. Flemingitaceae, Lepidocarpaceae, Sigillariostrobaceae - Thomas, 1978a; Figure 6.4). They dominated many of the tropical forests and, although they suffered a major decline in Pangaea towards the end of the Westphalian, they continued to be important in

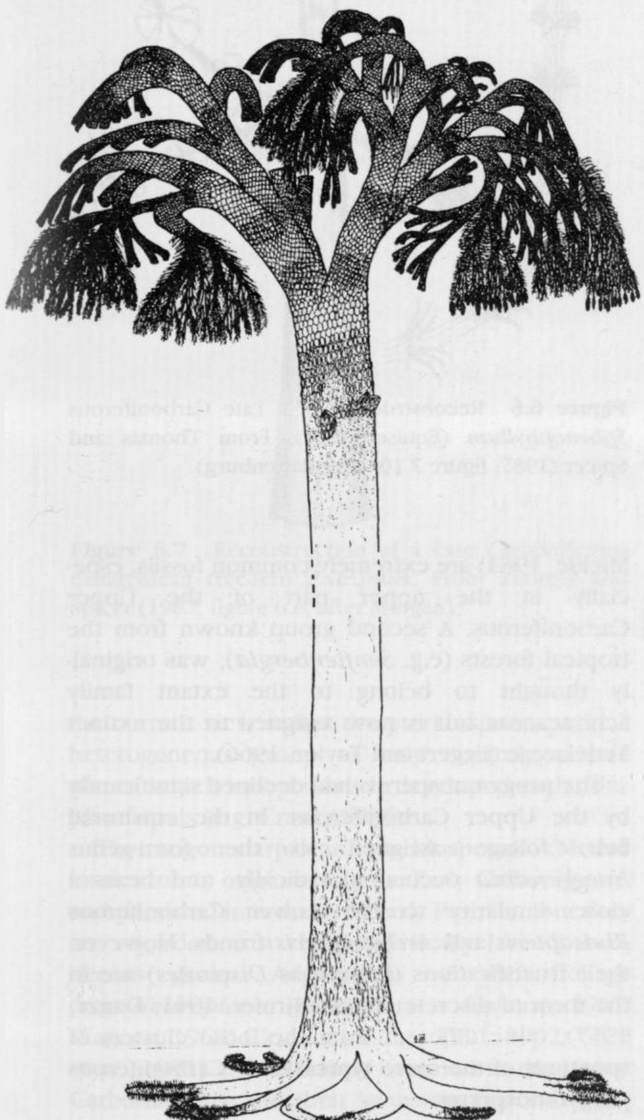

Figure 6.4 Reconstruction of a Late Carboniferous giant lycopsid, *Lepidodendron*. From Thomas and Spicer (1987, figure 7.5).

Cathaysia through to the end of the Permian Period (Li, 1980). Much of the primary work on the Upper Carboniferous lycopsids was done on fossils from British coal-balls (reviewed by Scott, 1920–1923), and later supplemented by work on adpressions (e.g. Thomas, 1967a, b, 1970, 1974, 1977, 1978a, b). In more recent years, however, work on American fossils has come to the fore, resulting in significant progress in understanding the diversity, reproductive strategies and population dynamics of these arborescent lycopsids (e.g. Phillips, 1979; DiMichele and DeMaris, 1987). It is now clear that the forests were extremely heterogeneous, their composition controlled largely by substrate conditions.

Two orders of equisetopsids are known from the forests: the arborescent Calamostachyales and the herbaceous Bowmanitales. Fossils of the former are particularly common, especially pith casts of the stems (*Calamites*) and foliage (*Annularia*, *Asterophyllites*). They represent plants that were superficially very similar to the Recent Equisetales, except in size, reaching heights of ten metres or more (Figure 6.5). However, there are marked differences in their reproductive organs, the calamostachyalean strobili having bracts separating the sporangiophores. Also, the larger stems of the Calamostachyales developed a zone of secondary wood, not seen in the living forms. They are generally thought to have grown along the margins of standing water or on sand bars within streams (Scott, 1977, 1978).

Fossilized foliage of the Bowmanitales (*Sphenophyllum*) is also extremely common. They were exclusively herbaceous, and were probably creeping, ground-cover plants (Batenburg, 1977; Figure 6.6) that were early colonizers of disturbed land within the swamp.

The Coenopteridales persisted into the Late Carboniferous, represented mainly by the form-genus *Corynepteris*, but they were never common (Scott and Galtier, 1985). True ferns, however, became much more common, especially in the tropical forests. Kidston's (1923–25) studies on the British Upper Carboniferous ferns have proved of fundamental importance in understanding their palaeobiology, and have proved the foundation for the more recent studies, such as by Danzé (1956) and Brousmiche (1983). Most of the herbaceous ferns belong to three orders, the Botryopteridales, Urnatopteridales and Crossothecales (Brousmiche, 1983; Meyen, 1987). It was once though that the extant family Gleicheniaceae was present at this time, in the

Figure 6.5 Reconstruction of a Late Carboniferous giant equisetopsid *Calamites*. From Thomas and Spicer (1987, figure 7.11; after Hirmer).

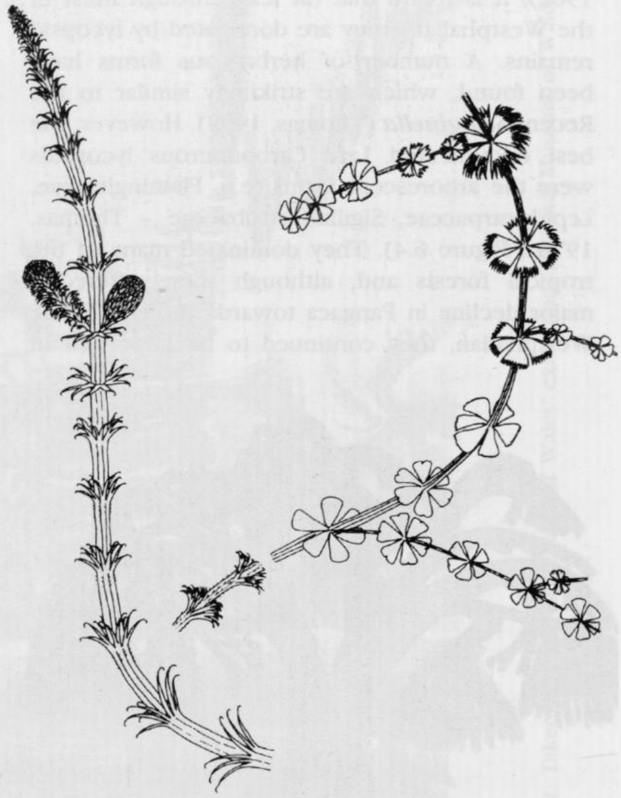

Figure 6.6 Reconstruction of a Late Carboniferous *Sphenophyllum* (Equisetopsida). From Thomas and Spicer (1987, figure 7.10; after Battenburg).

form of *Oligocarpia*, but these fossils are now assigned to the extinct family Sermeyaceae within the Botryopteridales. Evidence as to the habitat of these ferns is still very limited but they probably grew in open areas or in some cases as understorey within the main parts of the forests.

Tree-ferns also became common at this time (Figure 6.7); particularly after the decline of the lycopsids in the Stephanian, they were dominant components of the tropical lowland forests (DiMichele *et al.*, 1985). The most abundant belong to the order Marattiales, which appears to have had a global distribution. Their foliage (*Pecopteris sensu lato* - Kidston, 1923–1925; Dalinval, 1960) and trunks (*Psaronius*, *Caulopteris*, *Megaphyton*, *Artisophyton* – Crookall, 1955; Morgan, 1959; Pfefferkorn, 1976; Mickle, 1984) are extremely common fossils, especially in the upper part of the Upper Carboniferous. A second group known from the tropical forests (e.g. *Senftenbergia*), was originally thought to belong to the extant family Schizaeaceae but is now assigned to the extinct Tedelaceae (Eggert and Taylor, 1966).

The progymnosperms had declined significantly by the Upper Carboniferous. In the equatorial belt, foliage assigned to the form-genus *Noeggerathia* occurs sporadically, and bears a close similarity to the Lower Carboniferous *Rhacopteris* and *Archaeopteris* fronds. However, their fructifications (known as *Discinites*) are in the form of discrete cones (Hirmer, 1941; Danzé, 1957), quite different from the loose clusters of sporangia of the more typical Early Carboniferous progymnosperms.

Of the gymnosperms, the pteridospermous groups were the commonest in the tropical forests. The traditional concept of pteridosperms was of a group of plants with complex, fern-like fronds, but which reproduced by seeds. However,

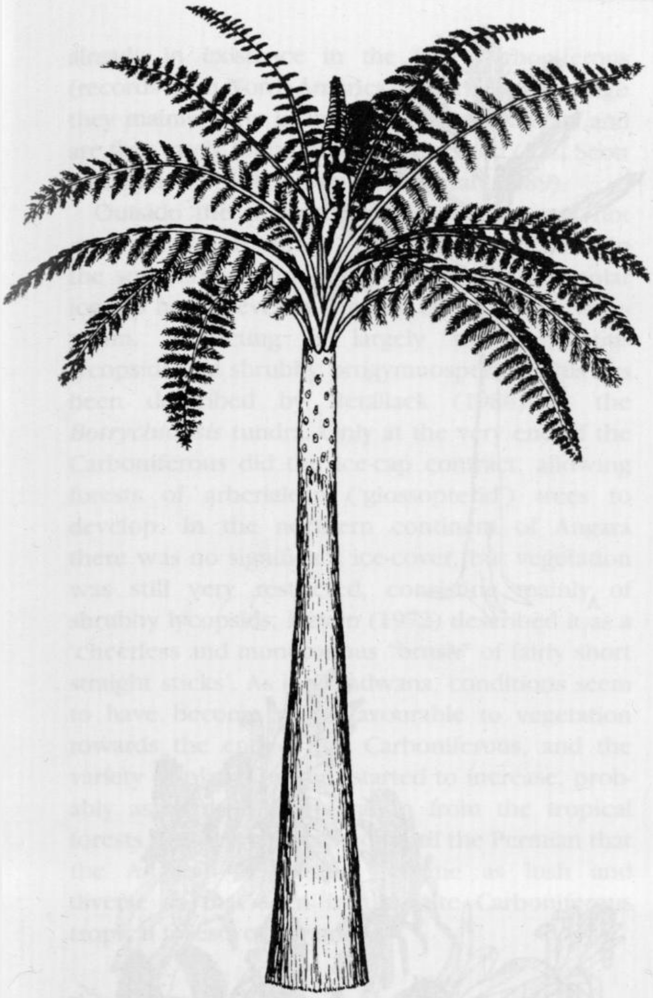

Figure 6.7 Reconstruction of a Late Carboniferous marattialean tree-fern *Psaronius*. From Thomas and Spicer (1987, figure 6.6; after Morgan).

the current view is that the pteridosperms were a heterogeneous group of only distantly related plants, which independently developed such complex fronds (e.g. Crane, 1985).

The trigonocarpalean pteridosperms (Medullosales *auct.*) originated in the Early Carboniferous and persisted into the very early Permian, but they are regarded as a characteristically Late Carboniferous group. Adpressions of their foliage (e.g. *Neuropteris*, *Alethopteris* – Laveine, 1967; Wagner, 1968; Cleal and Shute, 1991, 1992; Cleal *et al.*, 1991) are extremely common in the Upper Carboniferous, and their stems are major components of some of the coals (e.g. Delevoryas, 1955), particularly those representing drier habitats. The trigonocarpaleans developed a variety of growth habits, including lianas, ground-creepers, shrubs and trees, although the latter two were probably the commonest (e.g. Figure 6.8). Some (e.g. *Alethopteris*) had very large fronds (up to seven metres long according to Laveine, 1986), although others (e.g. *Callipteridium*, *Odontopteris*) were much smaller. The seeds, which were attached directly to the fronds, also tended to be large. The Trigonocarpales seem to have been mainly restricted to the equatorial belt; records of *Neuropteris* foliage from the northern high latitudes (e.g. Gorelova *et al.*, 1973) are all extremely doubtful.

The Lagenostomales were the second major group of pteridosperms of the tropical forests (Taylor and Millay, 1981). Unlike most of the Early Carboniferous members of the order, they appear to have been relatively small plants. The *Lyginopteris*-bearing plants were probably shrubs, that favoured the wetter habitats in Namurian and early Westphalian swamps. Most of the others,

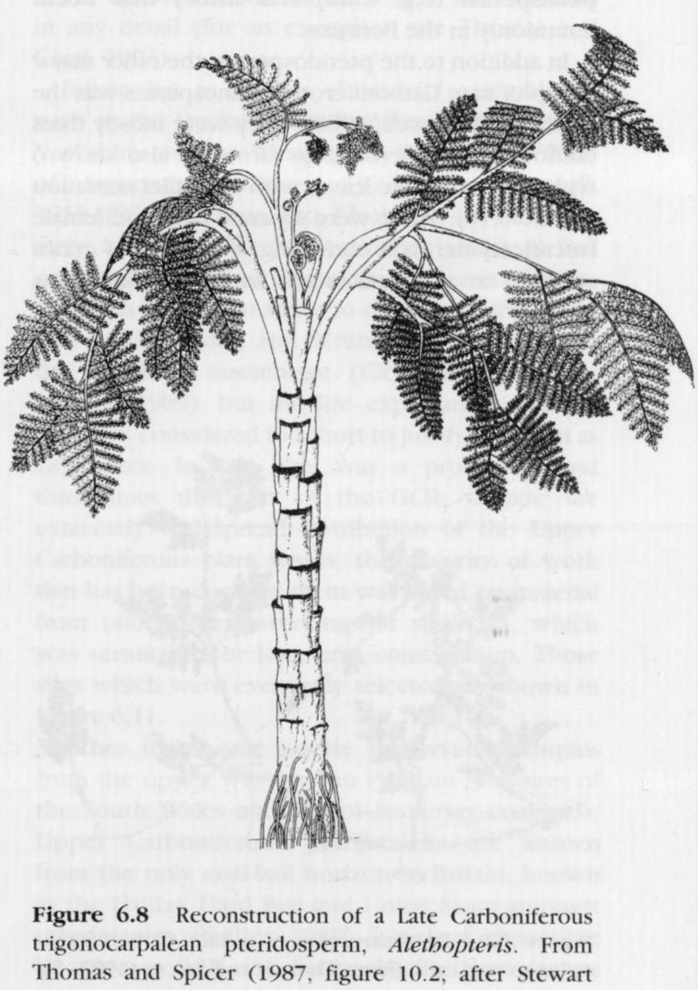

Figure 6.8 Reconstruction of a Late Carboniferous trigonocarpalean pteridosperm, *Alethopteris*. From Thomas and Spicer (1987, figure 10.2; after Stewart and Delevoryas).

however, such as the *Eusphenopteris/Heterangium* and the *Mariopteris/Schopfiastrum* plants, had a creeping or vinose habit. Most lagenostomalean fronds were consequently rather smaller than those of the Trigonocarpales. The only unequivocal records of this order are from the equatorial belt.

A third pteridosperm order known from the tropical forests was the Callistophytales (Rothwell, 1975, 1981). It first appears both as adpressions and coal-ball petrifactions in the middle Westphalian D, and occurs consistently through the rest of the Carboniferous. The few known species assigned to the order probably represent creeping plants (Figure 6.9), with fronds bearing lobed pinnules (*Dicksonites*), and there is therefore some superficial comparison with the Lagenostomales. However, in just about every other character (e.g. stem and rachial anatomy, seed structure, pollen) they are quite different, and suggest possible affinities with the peltasperms (e.g. *Callipteris auct.*) that occur commonly in the Permian.

In addition to the pteridosperms, the other major group of Late Carboniferous gymnosperms was the cordaites (Rothwell, 1988). They were mostly trees (although some herbaceous forms are also known) with long, strap-like leaves with a parallel nervation (Figure 6.10). There were separate male and female fructifications, each consisting of clusters of cones attached to a central rachis. In the tropical areas

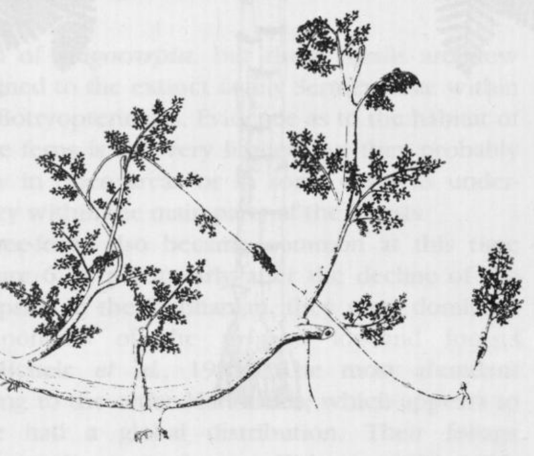

Figure 6.9 Reconstruction of a Late Carboniferous callistophyte liana. From Thomas and Spicer (1987, figure 10.6; after Rothwell).

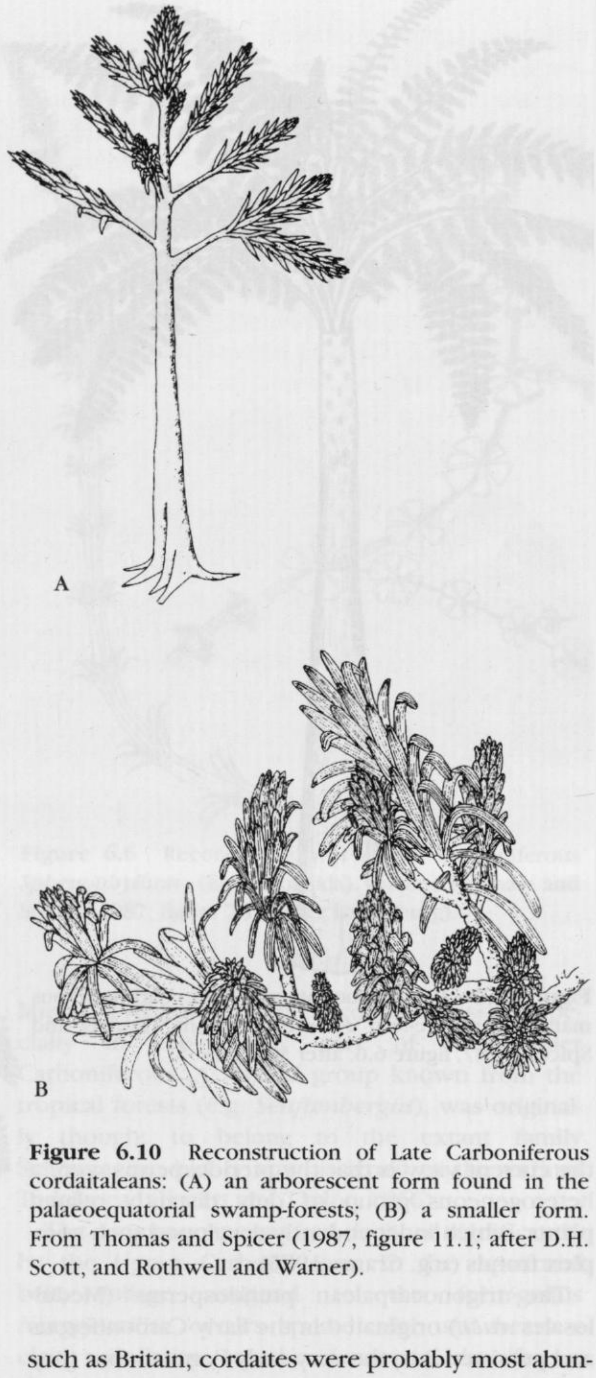

Figure 6.10 Reconstruction of Late Carboniferous cordaitaleans: (A) an arborescent form found in the palaeoequatorial swamp-forests; (B) a smaller form. From Thomas and Spicer (1987, figure 11.1; after D.H. Scott, and Rothwell and Warner).

such as Britain, cordaites were probably most abundant in the drier, extra-basinal habitats, although some also seem to have grown within the swamp-forests, perhaps on the raised levée banks. During the somewhat drier interval in the mid-Westphalian, they even formed major components of the forest, particularly in coastal areas where they were similar to Recent mangroves (DiMichele *et al.*, 1985).

From the detailed structure of the fructifications, the cordaites seem to have been closely related to the early conifers. The conifers themselves were already in existence in the Late Carboniferous (records from North America and Britain), although they mainly grew in the extra-basinal habitats and are thus rarely found in the fossil record (A.C. Scott and Chaloner, 1983; Lyons and Darrah, 1989).

Outside the tropical belt, vegetation was not particularly lush during the Late Carboniferous. In the southern continents of Gondwana, the polar ice-cap had a severely limiting effect on the vegetation, restricting it largely to herbaceous lycopsids and shrubby progymnosperms. This has been described by Retallack (1980) as the *Botrychiopsis* tundra. Only at the very end of the Carboniferous did the ice-cap contract, allowing forests of arberialean ('glossopterid') trees to develop. In the northern continent of Angara there was no significant ice-cover, but vegetation was still very restricted, consisting mainly of shrubby lycopsids; Meyen (1972) described it as a 'cheerless and monotonous "brush" of fairly short straight sticks'. As in Gondwana, conditions seem to have become more favourable to vegetation towards the end of the Carboniferous, and the variety of plants present started to increase, probably as a result of migration from the tropical forests. However, it was not until the Permian that the Angaran vegetation became as lush and diverse as that seen in the Late Carboniferous tropical forests of Eurameria.

UPPER CARBONIFEROUS PLANT FOSSILS IN BRITAIN

During the Namurian, extensive fluvial deltas in Britain produced sandstone bodies, belonging to the Millstone Grit. There is some evidence of the vegetation growing on these deltas (e.g. Lacey, 1952c), but the preservation of the fossils is often poor and they have not been studied to the same extent as elsewhere in Europe (e.g. Stockmans and Willière, 1952–1953; Josten, 1983). British Namurian vegetation is thus somewhat of an unknown quantity and no GCR sites have been selected for the palaeobotany of this series.

In the Westphalian, the sedimentary regime in Britain changed to mainly middle and then upper delta-plain deposits. The resulting strata, known as the Coal Measures (Figure 6.3), are particularly suited to the preservation of plant fossils. In the South Wales and Bristol–Somerset coalfields, plant fossils can be found throughout the sequence, from the basal Langsettian to the basal Cantabrian (Dix, 1933, 1934; Moore and Trueman, 1942; Cleal, 1978; Cleal and Thomas, 1991). In the Forest of Dean, they are restricted to the upper Westphalian D and Cantabrian (Wagner and Spinner, 1972). In the English Midlands and Pennines coalfields, plant fossils are mainly restricted to the Langsettian and Duckmantian parts of the sequence (e.g. Arber, 1914, 1916; Kidston 1923–1925), as much of the Bolsovian and Westphalian D is represented by red-beds (the Etruria Formation – Besly and Turner, 1983) in which the plant fragments have been mostly removed by oxidation. There is a short interval in the upper Westphalian D of these coalfields where plants are found (the Halesowen Formation and its lateral equivalents – e.g. Arber, 1914). This in turn is succeeded by more red-beds (the Keele Formation – probably upper Westphalian D and Cantabrian) in which they are extremely uncommon and consist mainly of conifer fragments. In northernmost England and Scotland, plant fossils are known mainly from the upper Langsettian to lower Bolsovian, but few sites have been studied in any detail (for an exception see Thomas and Cleal, 1993).

Britain has a number of 'classic' assemblages, such as the Duckmantian Barnsley Seam 'flora' of Yorkshire and the Westphalian D Radstock 'flora' of Somerset (Kidston, 1923–1925; Crookall, 1955–1975; Thomas and Cleal, 1994). Unfortunately, in neither case has it proved possible to find conservable sites to represent these assemblages. Attempts have been made to conserve parts of the tips at Kilmersdon and Writhlington to represent the Radstock assemblage (Cleal, 1985; Jarzembowski, 1989), but the life expectancy of these sites was considered too short to justify selection as GCR sites. In fact, this was a problem found throughout this part of the GCR; despite the extremely widespread distribution of the Upper Carboniferous plant fossils, the majority of work that has been done on them was based on material from underground workings or spoil-tips, which was unsuitable for long-term conservation. Those sites which were eventually selected are shown in Figure 6.11.

Other than some poorly preserved examples from the upper Westphalian Pennant Measures of the South Wales and Bristol–Somerset coalfields, Upper Carboniferous petrifactions are known from the only coal-ball horizon in Britain, known as the Halifax Hard Bed and Union Seam amongst other names (Phillips, 1980). It proved impossible to select a GCR site for coal-balls, however, as they nearly all originated from defunct and now

Chronostratigraphy: Series	Chronostratigraphy: Stage	Biostratigraphy	GCR palaeobotany Sites
Stephanian	Cantabrian	*Odontopteris cantabrica*	
Westphalian	'Westphalian D'	*Lobatopteris vestita*	
		Lobatopteris micromiltoni	Jockie's Syke
		Linopteris bunburii	Llanbradach Quarry
	Bolsovian ('Westphalian C')	*Paripteris linguaefolia*	Nostell Priory
	Duckmantian ('Westphalian B')	*Lonchopteris rugosa/ Alethopteris urophylla*	
	Langsettian ('Westphalian A')	*Lyginopteris hoeninghausii/ Neuralethopteris schlehanii*	Cattybrook Claypit Wadsley Fossil Forest Nant Llech
Namurian	Yeadonian	*Neuralethopteris larischii/Pecopteris aspera*	
	Chokierian		

Figure 6.11 Chronostratigraphical and biostratigraphical classification of the Upper Carboniferous, and the positions of the GCR palaeobotany sites.

sealed mine workings. One spoil tip was, until recently, still available for collecting coal-balls (Rowley Tip, Burnley) although the quality of the petrifactions was rather poor; this has now been landscaped for recreational use.

Stephanian plant fossils are very poorly represented in Britain. There are records of the basal *Odontopteris cantabrica* Zone from the Forest of Dean (Wagner and Spinner, 1972; Cleal, 1986c) and South Wales (Cleal, 1978), although no conservable outcrops yielding the fossils are known. The zone may also occur in the Keele Formation of the English Midlands. The species list given by Dix (1935) from these strata refers to *Odontopteris* cf. *schlotheimii* Brongniart, a name which has often been given in error for specimens of *O. cantabrica* Wagner (see Wagner *in* Wagner *et al.*, 1969). She also mentions *Pecopteris miltoni* (Artis) Brongniart, which could in fact refer to *Lobatopteris vestita* (Lesquereux) Wagner. Dix's material is in clear need of taxonomic revision.

The best available review of the literature pertaining to British Upper Carboniferous plant fossils was that provided by Jongmans (1940).

NANT LLECH

Highlights

Nant Llech has yielded the best known example of a lower *Lyginopteris hoeninghausii* Zone plant adpression assemblage from Britain. It is of particular interest as being coeval with the coal-ball horizons from northern England, which have played such a significant role in developing a better understanding of Late Carboniferous palaeoequatorial floras.

Nant Llech

Introduction

This locality exposes Westphalian Coal Measures in the bed of Nant Llech, near Abercrave, Powys (SN 836123). Plant fossils were first discovered here by a local geologist, W.D. Ware, probably in the 1920s. They were briefly mentioned by Robertson (1932), but a more complete account was provided by Dix (1933) including some illustrations. Her identifications were partly modified in a later published list (Dix, 1934). Specimens from here were also figured by Crookall (1959).

In passing, it is worth mentioning the *in situ* lycopsid stumps, discovered here in the 1830s by W.E. Logan. They were the first examples of such stumps in Europe to be properly excavated, and are of some historical interest (see account in North, 1931). However, as the trunks were removed from the site shortly after their discovery, to be placed in the grounds of the Royal Institution at Swansea, they can no longer be regarded as an integral part of the interest of the site.

Description

Stratigraphy

The geology of the basal Coal Measures on the north crop of the South Wales Coalfield has been described by Leitch *et al.* (1958), who included a stratigraphical log for this locality (summarized in Figure 6.12). Three shale beds yielding plant fossils are known and were named by Dix (1933): Bed B, immediately above the Farewell Rock; Bed C, 15 metres higher; and Bed D, 9 metres above that. The palaeontology indicates that they are early Langsettian in age. They are almost certainly interdistributary bay deposits in a lower delta-plain setting.

Palaeobotany

The plant fossils are preserved here as impressions. The following species are known, with their occurrence in the three plant beds (B, C and D) given in parentheses:

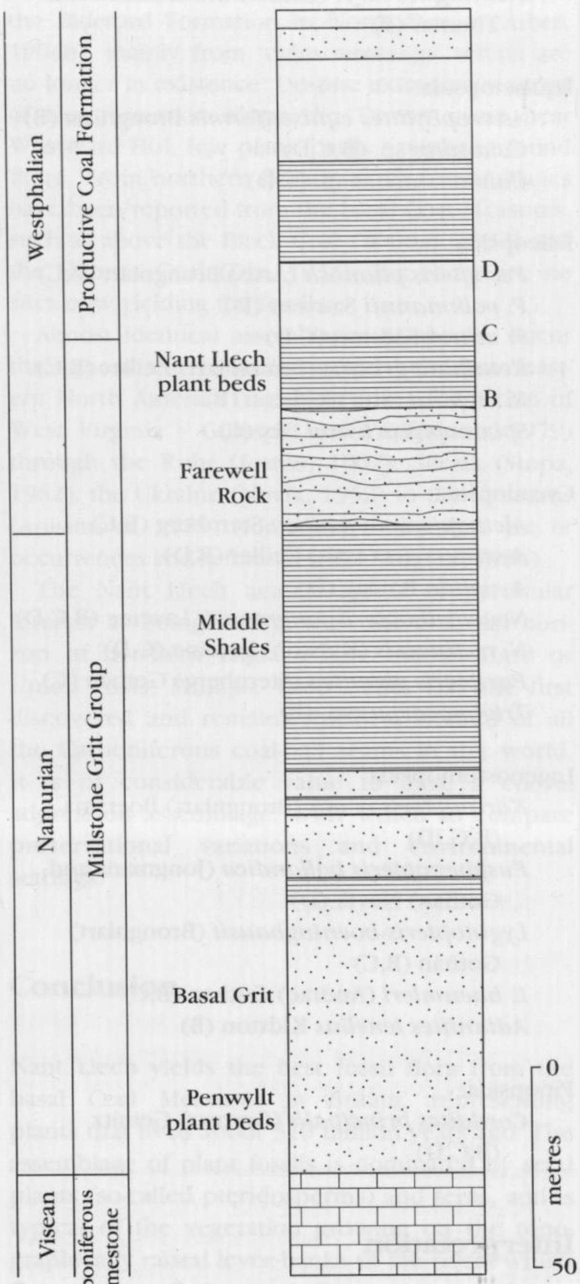

Figure 6.12 Stratigraphical section at Nant Llech, showing position of plant beds. Based on Dix (1933).

Lycopsida:

- *Lepidodendron aculeatum* Sternberg (B,C)
- *Sigillaria elegans* (Sternberg) Brongniart (C,?D)
- *Lepidophloios acerosus* Lindley and Hutton (B,D)
- *Bothrodendron minutifolium* Boulay (B)
- *B. punctatum* Lindley and Hutton (B,C)
- *Lepidostrobophyllum lanceolatum* (L. and H.) Bell (B,D)
- *Lepidostrobus ornatus* Brongniart (B)

Flemingites olryi (Zeiller) Brack-Hanes and Thomas (B)

Equisetopsida:

Asterophyllites equisetiformis Brongniart (B)
Calamites sp. (B,C,D)
Calamostachys sp. (C,D)

Filicopsida:

Pecopteris plumosa (Artis) Brongniart (B,C)
P. volkmannii Sauveur (D)
P. minor Kidston (C,D)
Renaultia gracilis (Brongniart) Zeiller (B,C)
R. crepinii (Stur) Kidston (B)
Sphenopteris warei Dix (C)

Cycadopsida:

Alethopteris lonchitica Sternberg (B,C)
A. decurrens (Artis) Zeiller (B,D)
A. valida Boulay (D)
Neuralethopteris jongmansii Laveine (B,C,D)
N. rectinervis (Kidston) Laveine (C,D)
Paripteris gigantea (Sternberg) Gothan (C)
Trigonocarpus sp. (B)

Lagenostomopsida:

Karinopteris acuta (Brongniart) Boersma (B,C,?D)
Eusphenopteris hollandica (Jongmans and Gothan) Novik (D)
Lyginopteris hoeninghausii (Brongniart) Gothan (B,C)
L. baeumleri (Andrae) Gothan (B,C)
Adiantites tenellus Kidston (B)

Pinopsida:

Cordaites principalis (Germar) Geinitz (B,C,D)

Interpretation

The lycopsids, as listed in Dix's papers, are represented by a variety of stems and fructifications. Some of the identifications mentioned by Dix have been generally accepted in the literature (e.g. *Sigillaria elegans* by Crookall, 1966). There are problems with others, however, which are in clear need of critical revision. For instance, she lists both *Lepidodendron obovatum* and *L.* cf. *aculeatum*, two species which have frequently been confused, and which Thomas (1970) places in synonymy. The list given above only mentions *L. aculeatum*, the earliest published of these two names; but it is possible that the specimens might instead belong to *Lepidodendron mannebachensis* Presl (compare comments by Thomas, 1970, pp. 149–51). As pointed out by Crookall (1966), similar problems arise with the species of strobili *Lepidostrobus ornatus* and *L. variabilis*, both of which were again mentioned from Nant Llech. Crookall's interpretation of *L. ornatus* is very flexible, and means little more than compressed 'cigar-shaped' strobili; but Brack-Hanes and Thomas (1983) give a much narrower circumscription, including details of the spores that it contained. The Nant Llech strobili need to be re-examined in the light of the observations by Brack-Hanes and Thomas.

Among the equisetopsid remains, Dix mentioned from Nant Llech stem pith casts as *Calamites* cf. *cistiiformis* Stur. However, *C. cistiiformis* Stur does not normally occur as high as the Westphalian (Leggewie and Schonenfeld *in* Gothan *et al.*, 1959), and so the Nant Llech specimens are listed here merely as *Calamites* sp.

The ferns are represented by a number of species, which can be essentially divided into two groups: the *Pecopteris* species with *Senftenbergia*-type sporangia and belonging to the family Tedeleaceae (Botryopteridales), and the *Renaultia* species, which belong to the Urnatopteridaceae (Urnatopteridales). Dix recorded *Sphenopteris lanarkiana* Kidston from here, but Brousmiche (1983) has transferred this species to *Renaultia crepinii,* although she made no reference to the Nant Llech material (Figure 6.13). Dix's *Sphenopteris warei* has been retained in the list, although it is based on very inadequate material and has been virtually ignored in the literature.

Dix (1933) documented the pteridosperm foliage fragments in rather more detail than the other elements in the assemblage. A number of her identifications have been reviewed and in some cases revised (e.g. *Lyginopteris* by Patteisky, 1957; *Neuralethopteris* by Laveine, 1967; *Eusphenopteris* by van Amerom, 1975) and the species list quoted above has taken these amendments into account.

In addition to the listed pteridosperm taxa, Dix recorded *Neuropteris* cf. *heterophylla* (Brongniart) Sternberg and *Mariopteris* cf. *sphenopteroides* (Lesquereux) Zeiller. *N. heterophylla* has been substantially revised since Dix's work (Laveine, 1967; Cleal and Shute, 1991) and is now normally thought to occur at higher stratigraphical levels. It is possible that Dix's record refers to distal fragments of *Neuralethopteris*.

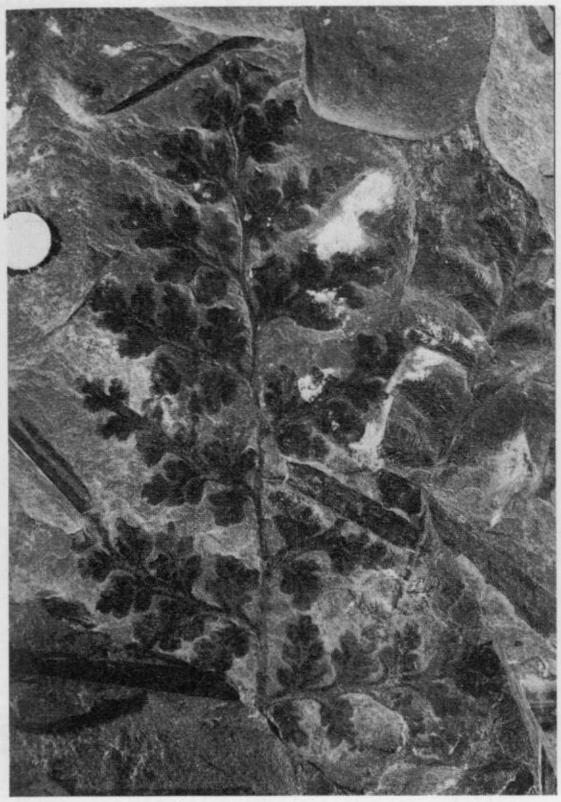

Figure 6.13 *Renaultia crepinii* (Stur) Kidston. Part of frond from a small herbaceous fern; Natural History Museum, London, specimen V.23353. Lower Productive Coal Formation (Langsettian), Nant Llech. × 2. (Photo: Photographic Studio, Natural History Museum, London.)

As pointed out by Boersma (1972), *M. sphenopteroides* is a taxon of doubtful validity. He does not refer directly to the Nant Llech material, but argued that the only record of the species from Europe prior to Dix was by Zeiller (1886–1888, pl. 19, figs 3 and 4), and that this belongs to *Fortopteris latifolia* (Brongniart) Boersma. Dix's identification needs to be reviewed in the light of Boersma's comments.

This assemblage belongs to the lower part of the *Lyginopteris hoeninghausii* Zone of Wagner (1984), now referred to as the *Neuralethopteris jongmansii* Subzone of Cleal (1991), and is the best example of its type in Britain (Figure 6.14). Similar assemblages are known from the Tenby–Saundersfoot coast in Pembrokeshire (Goode, 1913; Jenkins, 1962) but the fossils from there are not as well preserved, due largely to tectonic deformation. They are also known from the Bideford Formation in North Devon (Arber, 1904b), mainly from 'culm workings' which are no longer in existence. Despite extensive outcrop of the formation along the Devon coast near Westward Ho!, few plant fossils have been found there. From northern Britain, similar assemblages have been reported from the basal Coal Measures, such as above the Black Coal (Walton, 1932) and the Kilburn Coal (Dix, 1934), but there are no sites now yielding the fossils.

Almost identical assemblages of species occur throughout the palaeoequatorial belt, from eastern North America (e.g. New River Formation of West Virginia – Gillespie and Pfefferkorn, 1979) through the Ruhr (Josten, 1962), Silesia (Stopa, 1962), the Ukraine (Novik, 1952) to the Caucasus (Anisimova, 1979) (for a more complete list of occurrences and references, see Wagner, 1984).

The Nant Llech assemblage is of particular interest as being coeval with the coal-ball horizon of northern England (the Halifax Hard or Union coals; Phillips, 1980). This was the first discovered and remains the best studied of all the Carboniferous coal-ball seams in the world. It is of considerable value to have a coeval adpression assemblage, with which to compare preservational variations and environmental settings.

Conclusion

Nant Llech yields the best fossil flora from the basal Coal Measures in Britain, representing plants that lived about 310 million years ago. The assemblage of plant fossils is dominated by seed plants (so-called pteridosperms) and ferns, and is typical of the vegetation growing on the topographically raised levée-banks of the rivers which flowed through the tropical swamps at this time. Similar fossil floras of this age occur in many of the coalfields of North America and Europe, including West Virginia, the Ruhr, Silesia, Ukraine and the Caucasus. They represent the start of the growth of the large-scale swamp-forests that spread throughout the tropical belt at this time and lasted for some 10–15 million years. The peats generated by these forests were converted by geological processes into the economically important coal deposits of Europe, North America and China.

Figure 6.14 *Neuralethopteris jongmansii* Laveine. Part of trigonocarpalean frond; Natural History Museum, London, specimen V.23359. Lower Productive Coal Formation (Langsettian), Nant Llech. × 1. (Photo: Photographic Studio, Natural History Museum, London.)

WADSLEY FOSSIL FOREST

Highlights

Wadsley Fossil Forest is the only conserved example of *in situ* fossilized tree stumps in the Coal Measures of Britain (Figure 6.15).

Introduction

This group of *in situ* Westphalian fossil tree stumps was discovered in 1873, during excavations for new buildings, in the grounds of what was then the Wadsley Lunatic Asylum, now the Middlewood Hospital, Sheffield (SK 318913; Thorpe, 1972). Formerly, out-buildings were constructed to protect the fossils but over the years they have become seriously degraded and covered by debris. However, recent work by Gaynor Boon and other staff of the Sheffield City Museum has uncovered them again, and has allowed the stumps to be re-examined. This account includes information supplied by Ms Boon, which is very gratefully acknowledged. The only published scientific account of the stumps was by Sorby (1875).

Description

Stratigraphy

The stumps occur in sandstones of the Middle Rock Formation, between the Coking and Clay coal seams, and are thus early Langsettian in age. The sandstone is likely to be a crevasse-channel deposit.

Palaeobotany

Sorby (1875) stated that ten stumps were originally present, spread over a distance of 35–45 metres, but the recent re-excavations have only revealed four of these. They are up to 1.5 metres in diameter and show the remains of the stigmarian rooting structures penetrating the underlying sea earth. Although surface details are poorly preserved, Sorby maintained that *Sigillaria*-like markings could just be made out.

Figure 6.15 Wadsley Fossil Forest. *In situ* fossilized tree stumps preserved in the lower Langsettian Middle Rock Formation. (Photo: G. Boon, Sheffield City Museum.)

Interpretation

A point emphasized by Sorby was that the stumps appear to show a regular distortion. He argued that this reflected a prevailing westerly wind at the time and was apparently impressed by the fact that this was very similar to present-day wind directions in Sheffield! However, Gastaldo (1986) has suggested that similar distortion in the Lower Carboniferous stumps at Victoria Park (see Chapter 6) was a 'streamlining' effect, caused by movement of the entombing sediment.

This is the only place where such stumps are conserved *in situ* in the British Coal Measures. Their significance lies in establishing a palaeoecological model for these strata. There have been a number of attempts to establish such a model using the transported fragments that form the majority of the plant macrofossils found in the Coal Measures (e.g. Scott, 1977, 1978, 1979). Establishing a robust model using such transported fragments is extremely difficult, however, even when there is evidence of the hydrological regime operating at the time; and Gastaldo (1985, 1987) has argued that *in situ* stumps such as those found at Wadsley are the only reliable means of determining plant distribution (see also Cleal, 1987a). The Wadsley stumps appear to confirm that at least parts of the Late Carboniferous palaeoequatorial floodplains were covered by lycopsid forests, rather than pteridosperm-dominated assemblages as suggested in the Scott model.

Conclusion

Wadsley Fossil Forest is the only conserved example in Britain of stumps from the Coal Measures swamp-forests, about 310 million years old. They are the remains of giant club-mosses, probably originally up to 40 metres high, embedded in the fossilized soil in which they grew. Although historically well-known, for many years they had become inaccessible, and were only recently re-excavated to allow their study to be resumed. The site is a rarity, and provides a graphic impression of these ancient forests.

CATTYBROOK CLAYPIT

Highlights

Cattybrook Claypit has yielded the best plant fossil assemblage from the upper *Lyginopteris hoeninghausii* Zone in Britain. It is of particular interest as having yielded exceptionally large examples of *Karinopteris acuta* and *Sphenophyllum cuneifolium*.

Introduction

This Westphalian site is in part of the brickworks at Almondsbury near Bristol (ST 592833). Brickmaking clays have been worked here since the 1860s and the geology of the site was discussed by Smith and Reynolds (1929). Plant fossils from the Upper Carboniferous were first recorded by Moore and Trueman (1942), whose list of identifications were repeated by Welch and Trotter (1961). The only systematic account of the assemblage, however, is by Cleal and Thomas (1988).

There are two discrete pits at Cattybrook (Figure 6.16): the Golden Quarry, from which much of the earlier information was derived, and the Red Quarry, which was the basis of the Cleal and Thomas (1988) study (the names derive from the colour of the bricks after firing). The Golden Quarry described by Smith and Reynolds (1929) is now seriously overgrown.

Description

Stratigraphy

The Coal Measures exposed near Almondsbury are part of the Ridgeway Thrust Zone, a Variscan structural feature which has caused considerable distortion to the strata. They are often referred to as part of the Severn or Avonmouth Coalfield (e.g. Welch and Trotter, 1961), but they are in fact more properly regarded as part of the Bristol–Somerset Coalfield (Cleal and Thomas, 1988).

The most recent account of the geology of the Red Quarry, including a lithological log, is by Cleal and Thomas (1988). The 85 metre thick sequence consists of coals, seat earths and mudstones (Figure 6.17), which probably represent 'flood-plain' deposits formed in the middle or upper

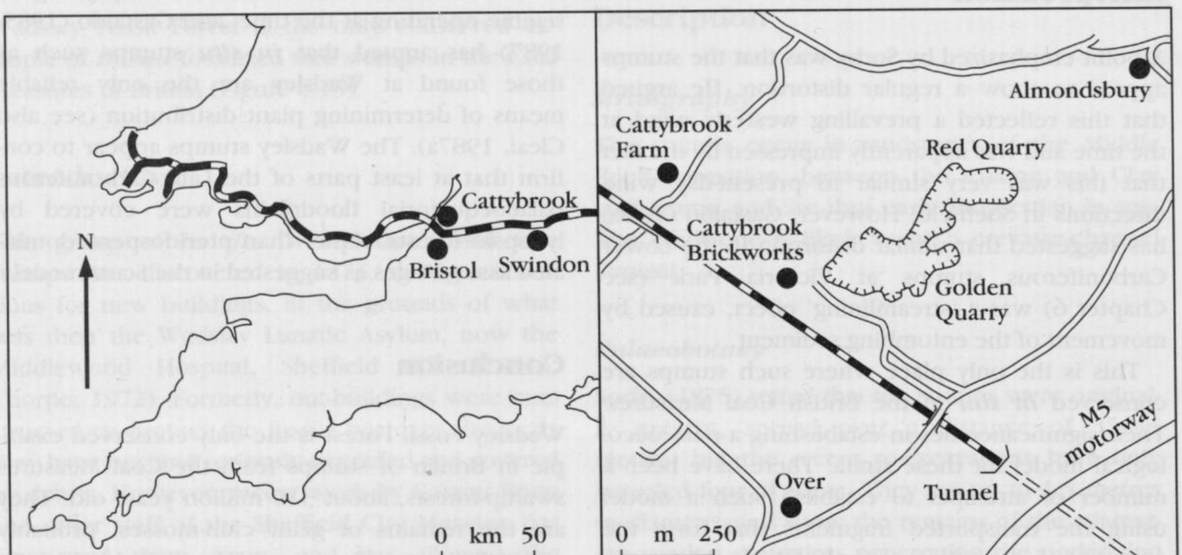

Figure 6.16 Locality maps for Cattybrook Claypit. Based on Cleal and Thomas (1988, figure 1).

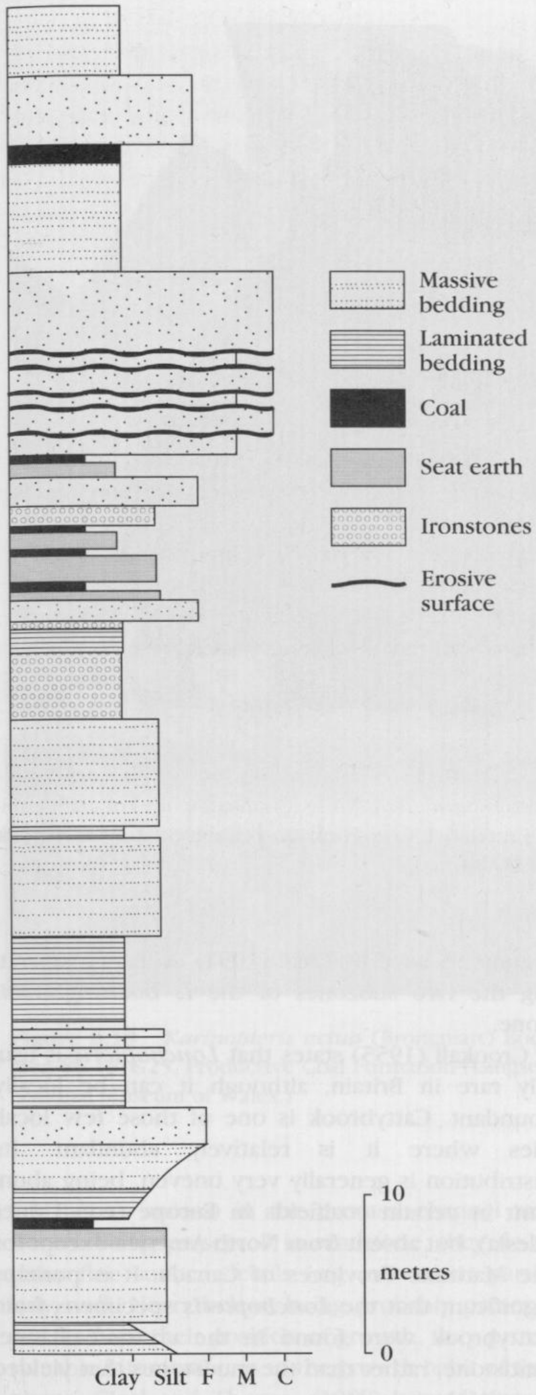

Figure 6.17 Stratigraphical section through part of the lower Productive Coal Formation (upper Langsettian) at Cattybrook Claypit. Based on Cleal and Thomas (1988, figure 2).

regions of a fluvial delta. There are also sandstone bodies, at least one of which contains large pieces of plant fossil, and which may be crevasse-channel deposits. The biostratigraphical evidence (mainly from the plant fossils) discussed by Cleal and Thomas suggests that the sequence belongs to the topmost Langsettian.

Palaeobotany

The plant fossils here are preserved as adpressions. Those from the mudstones are fragmentary, but often retain carbonized tissue (i.e. compressions). The fossils from the sandstone bodies are impressions. The following taxa have been described:

Lycopsida:
- *Lepidodendron aculeatum* Sternberg
- *L. lycopodioides* Sternberg
- *Lepidostrobophyllum* sp.
- *Sigillaria scutellata* Brongniart

Equisetopsida:
- *Calamites carinatus* Sternberg (Figure 6.18)
- *Asterophyllites equisetiformis* Brongniart
- *Annularia* cf. *radiata* (Brongniart) Sternberg
- *Calamostachys paniculata* Weiss (Figure 6.18)
- *Sphenophyllum cuneifolium* (Sternberg) Zeiller

Filicopsida:
- *Pecopteris plumosa* (Artis) Brongniart
- *Corynepteris angustissima* (Sternberg) Němejc
- *Renaultia* cf. *schatzlarensis* (Stur) *sensu* Brousmiche
- *R.* cf. *crepinii* (Stur) Kidston

Cycadopsida:
- *Laveineopteris loshii* (Brongniart) Cleal, Shute and Zodrow
- *L. tenuifolia* (Sternberg) Cleal, Shute and Zodrow
- *Cyclopteris orbicularis* Brongniart
- *Paripteris pseudogigantea* (Potonié) Gothan
- *Alethopteris decurrens* (Artis) Zeiller
- *A.* cf. *lancifolia* Wagner
- *Lonchopteris rugosa* Brongniart

Lagenostomopsida:
- *Karinopteris acuta* (Brongniart) Boersma (Figure 6.19)

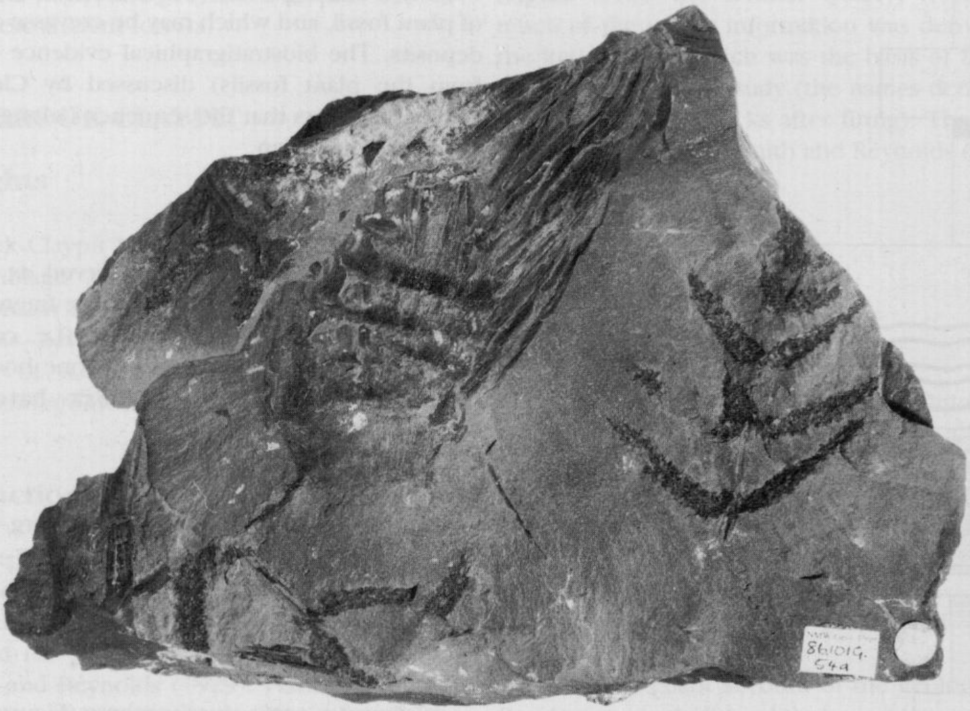

Figure 6.18 *Calamites carinatus* Sternberg and *Calamostachys paniculata* Weiss. Stem and cones of giant equisetopsids; National Museum of Wales, specimen 86.101G54. Productive Coal Formation (Langsettian), Cattybrook Claypit. x 1. (Photo: Photographic Studio, National Museum of Wales.)

Eusphenopteris cf. *neuropteroides* (Boulay) Novik
Palmatopteris geniculata (Germar and Kaulfuss) Potonié

Pinopsida:
Cordaites principalis (Germar) Geinitz
Cordaitanthus sp.
Cordaicarpon cf. *cordai* Geinitz

Interpretation

The Cattybrook assemblage is typical for the *L. loshii* Subzone, being dominated by *Laveineopteris loshii*, *Karinopteris acuta* and *Sphenophyllum cuneifolium*. It differs from assemblages from the underlying *Neuralethopteris jongmansii* Subzone (e.g. from Nant Llech – see p. 204) in the absence of *Lyginopteris* and *Neuralethopteris*. Both these form-genera tend to be rare in the *L. loshii* Subzone, a point which was recognized by Dix (1934) and was one of the arguments used by Cleal (1991) to justify separating the two subzones of the *L. hoeninghausii* Zone.

Crookall (1955) states that *Lonchopteris* is usually rare in Britain, although it can be locally abundant. Cattybrook is one of those few localities where it is relatively abundant. Its distribution is generally very uneven, being abundant in certain coalfields in Europe (e.g. Upper Silesia), but absent from North America except for the Maritime Provinces of Canada. It is perhaps significant that the *Lonchopteris* specimens from Cattybrook were found in the crevasse-channel sandstone, rather than the mudstones that yielded most of the other taxa.

Another Cattybrook taxon that is otherwise rare to Britain is *Alethopteris lancifolia*. Only one other specimen is known from Britain, from the Duckmantian of Yorkshire (Crookall, 1955, pl. 5, fig. 1 – see Wagner, 1961).

Perhaps of most interest at Cattybrook, however, is the presence of large specimens of *Karinopteris acuta* and *Sphenophyllum cuneifolium* (up to

Figure 6.19 *Karinopteris actua* (Brongniart) Boersma. Pteridosperm frond; National Museum of Wales, specimen 86.101G25. Productive Coal Formation (Langsettian), Cattybrook Claypit. x 0.5. (Photo: Photographic Studio, National Museum of Wales.)

0.5 metres across) in the crevasse-channel sandstones. Being preserved in sandstone, they do not show fine surface details (e.g. nervation) particularly well. Nevertheless, being probably preserved not far from their position of growth, they provide valuable information as to the growth habit of these plants. Cleal and Thomas (1988) argued that the specimens from here suggest that *K. acuta* was a liana-like plant, and that *S. cuneifolium* was a ground-creeper, adding support to similar suggestions based on material from elsewhere by Batenburg (1977) and Scott (1978).

This is the best available site in Britain for plant fossils of the upper *Lyginopteris hoeninghausii* Zone of Wagner (1984), and referred to as the *Laveineopteris loshii* Subzone of Cleal (1991). Similar upper Langsettian assemblages are known throughout the palaeoequatorial belt, from eastern North America to the Caucasus (evidence reviewed by Wagner, 1984), but mainly from underground or temporary workings. In Britain, the best documented assemblage of similar age is the so-called Ravenhead 'flora' collected from Thatto Heath railway cutting in the Lancashire Coalfield (Kidston 1889d; Cleal, 1979). This has many taxa in common with the Cattybrook assemblage, although it has a rather higher preponderance of ferns. However, the Thatto Heath exposure no longer yields plant fossils. Dix (1934) lists species from a number of similar assemblages from South Wales, and which she assigns to her 'Flora' D, but they are nearly all from underground mines. No published systematic account exists for these Welsh assemblages. According to the evidence reviewed by Jongmans (1940) comparable assemblages have been reported from the North Wales, South Staffordshire, Yorkshire and Central Scottish coalfields, but these are again nearly all from underground mines, and taxonomic analyses have never been published.

Conclusion

Cattybrook Claypit has yielded the best plant fossils in Britain representing the vegetation from a time known as the late Langsettian, about 310 million years ago (part of the Carboniferous Period). It was the time when the tropical swamp-forests, of which these plants were a part, were starting to reach their maximum development. It marks a clear change from the plant fossils found lower in the Langsettian (such as at Nant Llech – see p. 204), which probably represented a less densely forested setting, more like that evinced by the plant beds in the underlying Millstone Grit. Of particular interest at Cattybrook is the existence of a sandstone, thought to have formed as a river deposit near a levée-bank on which many of these plants lived, and into which large pieces of the plants fell and were buried. This has provided a useful insight into the growth form of some of them, such as the horsetail *Sphenophyllum*, which seems to have been a ground-creeper, and the seed plant *Karinopteris*, which was a liana. Also, Cattybrook has yielded some of the largest known examples of the seed plant frond *Lonchopteris*, which is one of the very earliest examples of a leaf with mesh-veining, as now developed in most dicotyledonous flowering plants.

NOSTELL PRIORY BRICKPIT

Highlights

Nostell Priory Brickpit has yielded one of the best documented plant fossil assemblages in Britain belonging to the *Paripteris linguaefolia* Zone (indicating the Bolsovian). It is particularly significant for cordaites and is the type locality for two species of cordaite cone (Figure 6.20).

Introduction

This brickpit (SE 430170), between Ackworth Moor Top and Crofton, about 8 km south-east of Wakefield, is cut in Westphalian shales. Plant fossils were first discovered in these rocks by James Wright in the early 1930s and were described in detail by Barker (*in* Barker and Whittle, 1944). Cordaite cones were subsequently re-described by Crookall (1970).

Description

Stratigraphy

Barker and Whittle (1944) describe the bed containing the plant fossils as 5.5 metres of 'laminated mudstones', overlying the Shafton Marine Band. They are thus of early Bolsovian age. Barker and Whittle interpret these beds as 'estuarine'.

Palaeobotany

The fossils are preserved as adpressions. The following species have been described:

Lycopsida:
- *Lepidodendron* cf. *simile* Kidston
- *Lepidodendron* sp.
- *Bothrodendron punctatum* Lindley and Hutton
- *Stigmaria ficoides* (Sternberg) Brongniart
- *Flemingites* sp.

Equisetopsida:
- *Calamites suckowii* Brongniart
- *Annularia radiata* Brongniart
- *A. sphenophylloides* (Zenker) Gutbier
- *Asterophyllites equisetiformis* Brongniart
- *A. grandis* (Sternberg) Geinitz
- *Palaeostachya ettingshausenii* Kidston
- *Calamostachys* sp.
- *Myriophyllites gracilis* Artis
- *Pinnularia columnaris* (Artis) Zeiller
- *Sphenophyllum emarginatum* Brongniart
- *S. majus* Bronn

Filicopsida:
- *Lobatopteris miltoni* (Artis) Wagner
- *Crossotheca* cf. *crepinii* Zeiller
- cf. *Renaultia* sp.

Figure 6.20 Nostell Priory Brickpit. Working quarry, as seen in 1985. The beds are associated with the lower Bolsovian Shafton Marine Band. (Photo: C.J. Cleal.)

Cycadopsida:
- *Alethopteris lonchitica* Sternberg
- *Laveineopteris loshii* (Brongniart) Cleal, Shute and Zodrow
- *Cyclopteris* sp.

Lagenostomopsida:
- *Mariopteris sauveurii* (Brongniart) Zeiller
- cf. *Karinopteris robusta* (Danzé-Corsin) Boersma
- *Rhodea wrightii* Barker
- *Carpolithus reticulatus* Sternberg
- *C. minimus* Sternberg

Cordaites:
- *Cordaites borassifolius* (Sternberg) Unger
- *Cordaitanthus flagellibracteatus* Barker
- *C. nostellensis* Barker
- *Cordaicarpus ventricosus* Grand'Eury
- *Samaropsis orbicularis* Ettingshausen
- *S. pyriformis* Barker

Interpretation

The presence together of *Asterophyllites grandis*, *Annularia sphenophylloides* and *Sphenophyllum emarginatum* clearly points to this assemblage belonging to the middle *Paripteris linguaefolia* Zone of Wagner (1984), or the *Laveineopteris rarinervis* Subzone of Cleal (1991). This is compatible with its position above the Shafton Marine Band, which is in about the middle Bolsovian.

Lycopsida

Those uncovered here to date are generally unexceptional, comprising mainly leafy shoots and stigmarian rooting structures. However, Barker reported an incomplete strobilus and some associated megaspores, which might reward further study. Barker identified it as *Lepidostrobus variabilis* Lindley and Hutton, and Crookall (1966) transferred it to *Lepidostrobus ornatus* Brongniart. In view of the reported association of megaspores, however, the strobilus is more likely to be a species of *Flemingites* (Brack-Hanes and Thomas, 1983).

Equisetopsida

There is rather more variety in the calamitid equisetopsids. At least one species of *Annularia* and two of *Asterophyllites* have been reported. Barker has also described specimens of *Annularia radiata* Brongniart. However, the illustrated specimen shows leaves which are too slender and parallel-sided and may instead belong to *Asterophyllites equisetiformis*.

Also, a number of calamitid strobili have been reported from here. The most abundant was described by Barker as *Palaeostachya ettingshausenii*, and the figured specimen seems to confirm the identification (compare with similar specimens figured by Crookall, 1969). A single specimen of a much more slender strobilus was described by Barker as *Calamostachys* ?sp. nov. Since he did not illustrate this specimen, it is difficult to judge, but the dimensions given in his description suggest a comparison with *Calamostachys ramosa* Weiss.

A number of species of sphenophyll foliage were listed by Barker, but were only poorly described and illustrated. In view of the more recent work on the variation of leaf form in different parts of the sphenophyll plant (e.g. Storch, 1966; Batenburg, 1977), the identity of the Nostell Priory specimens must be regarded as tentative.

Filicopsida

At Nostell Priory, ferns are relatively uncommon, which is typical of middle Westphalian palaeoequatorial assemblages. The most abundant is the marattialean *Lobatopteris miltoni*, a species recently reviewed by Shute and Cleal (1989). In addition, Barker reported a single example of *Crossotheca*. He compared it with *C. boulayi* Zeiller, but Brousmiche (1982) has demonstrated that this is merely part of the range of morphological variability within *C. crepinii*. Although many palaeobotanists (e.g. Taylor and Millay, 1981) still regard *Crossotheca* as a lagenostomalean pteridosperm fructification (following Kidston, 1923d), Danzé (1955, 1956) and Brousmiche (1982) have shown that it was a fern.

Cycadopsida

The dominant pteridosperm is an alethopterid. Its identification as *A. lonchitica* is based on the authority of Barker, but he did not illustrate any specimens. As pointed out by Wagner (1968, 1984), however, this species is widely misidentified, and records from the middle Westphalian often refer to *Alethopteris urophylla* (Brongniart) von Roehl.

Neuropteroid foliage is represented here by *Laveineopteris loshii*. Barker identified it as *Neuropteris heterophylla* (Brongniart) Sternberg, a species which has frequently been confused with *L. loshii* (see Laveine, 1967; Cleal and Shute, 1991, 1992). It is perhaps significant that it is associated here with cyclopterid pinnules, which occur in the lower part of the *L. loshii* frond but not of the *N. heterophylla* frond. There is no direct evidence of *N. heterophylla* in the Nostell Priory assemblage. A single fragment was also identified by Barker as *Neuropteris* cf. *obliqua* (Brongniart) Zeiller, although there seems little reason for separating it from the *L. loshii*.

Lagenostomopsida

Two types of mariopteroid frond were reported (Barker *in* Barker and Whittle, 1944). One was identified as *Mariopteris sauveurii*, which, from the illustrations, appears to be correctly identified. The second was stated to be specifically identical with *Mariopteris* sp. D of Kidston (1925), which Danzé-Corsin (1953) formally named *Mariopteris robusta*, and which Boersma (1972) assigned to the form-genus *Karinopteris*. There is indeed an apparent comparison with Kidston's figured specimens, especially with the one selected by Boersma as the lectotype of *K. robusta*, but additional material from Nostell Priory will be needed before this rare species (otherwise only known from a few specimens from South Wales, Nord-Pas-de-Calais, the Ruhr and the Donets) can be unequivocally recorded from here.

The specimen figured by Barker under the new name *Rhodea wrightii* appears to be a small type of *Palmatopteris*. In the absence of more complete material, however, it is difficult to assess this species.

Pinopsida

Barker reports a number of excellently preserved cordaite fossils, including some large leaf fragments and isolated seeds. Of most interest, however, was the discovery of a male and a number of female cones, which were made the types of *Cordaitanthus nostellensis* and *C. flagellibracteatus*, respectively. The latter is particularly distinctive, having very slender, elongate bracts, quite unlike those of any other described species. Both species are known only from this locality.

General remarks

Adpression floras dominated by pteridosperms, cordaites and equisetopsids are relatively uncommon in the upper Duckmantian and lower Bolsovian of Britain. In South Wales, for instance, conditions seem to have become rather wetter and less favourable for the development of this type of vegetation (Davies, 1929; Dix, 1934); lycopsid-dominated vegetation instead seems to have been the norm. In much of the English Midlands, most strata of this age are in the Etruria red-bed facies, which seem to have been unfavourable for the preservation of plant fossils (Besly and Turner, 1983). There is some evidence of a similar assemblage from the Bradford Four Feet Seam in the Lancashire Coalfield (Kidston, 1892, 1894b), but illustrations of the fossils have never been published and the identifications have not been revised in nearly a hundred years. There is very little evidence of plant fossils from coeval strata in northernmost England or Scotland (Jongmans, 1940).

This seems to follow the same pattern seen in most of the paralic coalfields of the palaeoequatorial belt, where assemblages of plant fossils, similar to those at Nostell, are only sporadically found (see Wagner, 1984 for a review of the available evidence). This may reflect the greater marine influence on the delta at this time (Guion and Fielding, 1988), which would allow relatively few river levées to develop. In those relatively few situations where the levées did develop, however, they supported a pteridosperm/cordaite/equisete-dominated type of vegetation, such as found at Nostell.

In addition to their relative scarcity value, sites in the English Pennines, such as Nostell, have the advantage over most of these other areas because the fossils often still retain their cuticles, which can provide important information about the affinities of the plants (e.g. Cleal and Shute, 1991, 1992). The best comparison from this point of view is with the intra-montane basins of central Europe, such as with the Sulzbach Formation in Saar-Lorraine (Laveine, 1989) and the Radnice Member of Central Bohemia (Wagner, 1977), where cuticles are often preserved. As pointed out by Gothan (1954), however, the composition of species found in these intra-montane basins is different from that of the paralic belt. Nostell Priory Brickpit is thus of considerable importance for studying the vegetation of the paralic belt of coalfields.

Conclusion

Nostell Priory Brickpit has yielded some of the best documented plant fossils from middle Westphalian rocks in Britain, about 305 million years old. The assemblage consists mainly of primitive and now extinct seed plants with fern-like fronds (pteridosperms) and horsetails, that were typical of the river, levée-bank vegetation growing within the swamp-forests of the time. The site is also important for another group of primitive and now extinct seed plants, the cordaites, which were related to the conifers, but had large, palm-like leaves. The flora here is a typical example of the so-called Coal Measures flora, representing the height of development of the tropical swamp-forests in Late Palaeozoic times, and which generated the thick, economically important coals of the northern and central European coalfields.

LLANBRADACH QUARRY

Highlights

Llanbradach Quarry yields the best examples of plant petrifactions from the South Wales Pennant Measures. The only other Upper Carboniferous petrifactions known from Britain are the rather older (early Langsettian) coal-balls of northern England.

Introduction

This site is a disused quarry in upper Westphalian sandstones (Figure 6.21), south of the village of Llanbradach, 3 km north of Caerphilly (SO 146894). The only detailed account of the plant fossils from here is that given by Crookall (1931b). They appear to have been first discovered by J. Storrie, at some time in the second half of the nineteenth century, and Storrie's collection

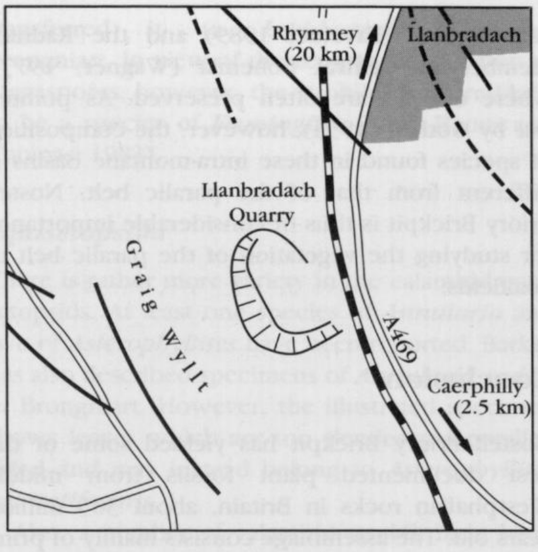

Figure 6.21 Locality map for Llanbradach Quarry.

formed the basis of Crookall's work. Additional material was, however, also collected during the 1920s by W.D. Ware.

Description

Stratigraphy

The plant fossils here occur in the Brithdir Beds, the topmost member of the Lower Pennant Measures. They are therefore early Westphalian D in age (Cleal, 1978). Some ten metres of mainly massive Pennant sandstones are exposed here. The best preserved specimens were found in conglomeratic bands within the coarse sandstones. They clearly underwent considerable transportation before being entombed in the sediment, and so any palaeoecological interpretation is difficult. They are, however, unlikely to represent plants from the swampy, peat-forming parts of the forests, but rather levée-bank or extra-basinal assemblages.

Palaeobotany

The fossils are calcareous petrifactions, with only the more robust, woody tissue being preserved. Crookall mentioned the following taxa:

Calamites sp.
Psaronius sp.
cf. *Mesoxylon* spp.
Dadoxylon sp.

Interpretation

The Llanbradach specimen of *Calamites* only shows secondary wood. It was assigned to this form-genus because the wood has mainly scalariform pitting on the radial xylem walls, the rays consist of vertically elongate cells, and the presence of 'infra-nodal canals'.

Llanbradach has yielded only the second known species of the marattialean tree-fern *Psaronius* from Britain, the other being the coal-ball species *P. renaultii* Williamson. The specimens described by Crookall show the characteristic peripheral 'root-zone', that forms the outer part of the *Psaronius* stems. Although some evidence of the vascular and cortical structure was found by Crookall, better preserved material will be needed before a specific identification can be made.

The remaining specimens from Llanbradach are probably cordaite wood. Two of them described by Crookall show a siphonostele and were identified as cf. *Mesoxylon* sp. They are unusual for cordaite stems in that they have very poorly developed rays in the secondary wood. However, neither specimen was well enough preserved to demonstrate the maturation of the cauline stele or the structure of the leaf traces, which is essential for a reliable identification of such stems. The situation is further complicated by the proposals by Rothwell and Warner (1984) and Trivett and Rothwell (1985) to change the concept of the two main form-genera of petrified cordaite stems, *Cordaixylon* Grand'Eury (synonyms *Cordaioxylon* Felix and *Pennsylvanioxylon* Vogellehner) and *Mesoxylon* Scott and Maslen, to include fertile structures and leaves, thus making them in effect whole-plant genera.

The specimens assigned by Crookall to *Dadoxylon* sp. are mainly just fragments of secondary wood. One might have a siphonostele, but the primary region in the centre of the stem is not preserved. The identification of such secondary wood in isolation is difficult but, in the Upper Carboniferous, it usually belongs to the cordaites. The tracheid pitting and form of the rays would seem to support this.

This is the best site for plant petrifactions in the Pennant Measures. Lillie (1910) and Crookall (1927) describe similar specimens from Staplehill near Bristol, although this site no longer exists. Elsewhere in Britain, Upper Carboniferous plant petrifactions are known only from the coal-balls of the basal Coal Measures (lower Langsettian) of northern England (Phillips, 1980). These are not only significantly older than the Pennant fossils, but represent quite a different, swampy habitat, dominated by lycopsids. Abroad, the nearest comparisons are with coal-ball assemblages from the Upper Moscovian of the Ukraine (Snigirevskaya, 1972) and the middle of the Carbondale Formation of Indiana (Canwright, 1959), but again these contain predominantly the lycopsids of the swamp habitats, rather than the equisetes, ferns and pteridosperms of the levée vegetation. Llanbradach thus yields the only known anatomically-preserved plant fossils representing the levée-bank vegetation of the early Westphalian D.

Conclusion

Llanbradach Quarry is the only site in Britain to yield plant fossils from the upper Coal Measures with anatomical features preserved. The fossils include the remains of giant horsetails, tree-ferns and seed plants, which were growing on raised levée-banks of rivers flowing through the tropical swamp-forests of the time. The fossils nearest in age showing details of anatomy are some five million years older, found in the Coal Measures of northern England, and these are dominated by quite different types of plant, mainly giant club-moss trees that grew within the wetter parts of the swamp-forests. Although the Llanbradach fossils were subject to a considerable degree of transport and erosion, having drifted some distance down rivers, they give a good impression of the type of vegetation growing in South Wales in the late Westphalian times, about 305 million years before the present.

JOCKIE'S SYKE

Highlights

Jockie's Syke is the best available locality for *Lobatopteris micromiltoni* Zone plant fossils in Britain.

Introduction

Late Westphalian plant fossils can be found in this small stream (Figure 6.22), a tributary of Liddel Water, near Longtown, Cumbria (NY 424756). They were first collected from here in 1879 by A. Macconochie of the Geological Survey and were briefly mentioned by Kidston (1894b). Further collecting was done by Macconochie and Kidston in 1902, and their results were published by Kidston (1903a, b). There has been no subsequent work on the palaeobotany here, apart from an illustration of one of Kidston's alethopterids by Crookall (1955), and some passing comments made by Crookall (1969) and Wagner (1968).

Description

Stratigraphy

The plant fossils occur in red mudstones within the Red Sandstone Group of the Canonbie Coalfield (*sensu* Peach and Horne, 1903) (Figure 6.23). According to Ramsbottom *et al.* (1978), this part of the sequence contains an *Anthraconauta tenuis* Zone fauna, which indicates an age no older than latest Bolsovian (Cleal, 1984a). The plant fossils appear to belong to the *Lobatopteris micromiltoni* Zone, indicating a middle Westphalian D age (Cleal, 1978, 1984b). The beds probably represent floodplain deposits within a fluvial plain environment.

Palaeobotany

The plants are preserved as fossil impressions in a red mudstone. They were reported by Kidston

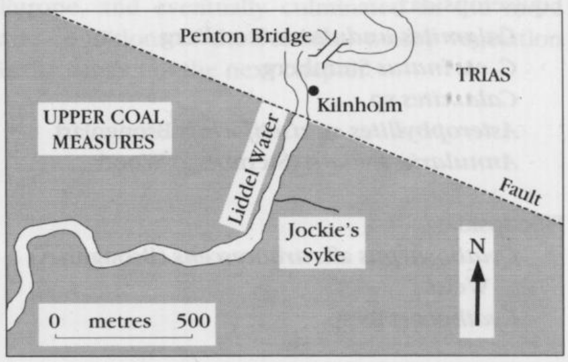

Figure 6.22 Geological map showing the area near Jockie's Syke. Based on Peach and Horne (1903, plate 1).

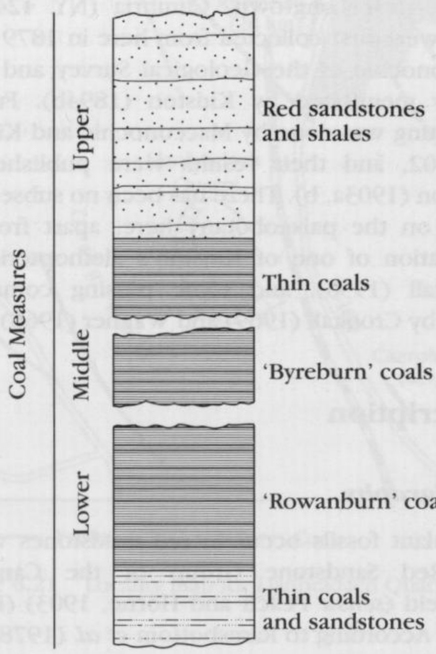

Figure 6.23 Stratigraphical succession in the Canonbie Coalfield. Based on Peach and Horne (1903, plate 4).

(1903a, b) from four distinct locations within the site. In the absence of details as to their relative stratigraphical distributions, however, the following is a combined list of species from all four:

Lycopsida:
- *Lepidodendron fusiforme* (Corda) Corda
- *Lepidostrobophyllum* sp.
- *Stigmaria ficoides* (Sternberg) Brongniart

Equisetopsida:
- *Calamites undulatus* Sternberg
- *C. carinatus* Sternberg
- *Calamites* sp.
- *Asterophyllites equisetiformis* Brongniart
- *Annularia stellata* (Sternberg) Wood

Filicopsida:
- *Cyathocarpus* aff. *arborescens* (Brongniart) Weiss
- *Cyathocarpus* sp.

Cycadopsida:
- *Neuropteris ovata* Hoffmann
- *N. flexuosa* Sternberg
- *Macroneuropteris scheuchzeri* (Hoffmann) Cleal *et al.*
- *Alethopteris ambigua* Lesquereux
- ?*A. grandinioides* Kessler
- *Alethopteris* sp.

Interpretation

The above species list points strongly to the assemblage belonging to the *Lobatopteris micromiltoni* Subzone of Cleal (1991) (previously regarded as a separate zone by Cleal, 1984b); *Cyathocarpus* aff. *arborescens* does not extend below the base of this zone, and there is no evidence of the species that characterize the base of the overlying *Lobatopteris vestita* Zone: *Lobatopteris vestita* (Lesquereux) Wagner, *Polymorphopteris polymorpha* (Brongniart) Wagner and *Dicksonites plueckenetii* (Sternberg) Sterzel. This indicates that the strata exposed at Jockie's Syke are mid-Westphalian D in age.

Kidston (1903b) recorded specimens from here as *Calamites ramosus* Artis, but Kidston and Jongmans (1917) showed that this was a later synonym of *C. carinatus*. Crookall (1969) specifically lists the Jockie's Syke specimens within the synonymy of the latter species and notes that, in Britain, *C. carinatus* is particularly common in the upper Bolsovian and Westphalian D. Kidston (1903b) also lists *Calamites undulatus,* now generally recognized as a preservational form of a number of different calamite species.

Kidston (1903b) also recorded *Annularia radiata* (Brongniart) Sternberg, which he regarded as the foliage borne by *Calamites ramosus* (syn. *C. carinatus*). However, *A. radiata*-type foliage rarely occurs this high stratigraphically, and in any case is a fairly artificial concept (Walton, 1936). In view of its association here with *Annularia stellata,* whose smaller leaves can often resemble *A. radiata*, the record has been deleted from the list.

The brief comments by Kidston (1903b) on the pecopteroid species appear to confirm that they belong to one of the *Cyathocarpus* species with small pinnules, such as *C. arborescens*. Unfortunately, however, he did not figure any specimens, either at that time or in his later monographic treatment of the British pecopteroid species (Kidston, 1924, 1925). In view of the complications surrounding this difficult group of species (Barthel, 1980), the identification of the Jockie's Syke material has been left open.

Kidston's (1903b) records of neuropteroid taxa, although unillustrated, are of easily recognized species which occur commonly in the Westphalian D of Britain.

Kidston's (1903b) record of *Alethopteris aquilina* (Brongniart) Goppert was transferred to *Alethopteris davreuxii* var. *friedelii* Bertrand by Crookall (1955). However, *A. friedelii* Bertrand is a later synonym of *Alethopteris grandinii* (Brongniart) Goppert (Wagner, 1968; Cleal, 1984b) and has nothing to do with *A. davreuxii* (Brongniart) Zeiller. Wagner (1968) instead transferred Kidston's specimen (which had been figured by Crookall, 1955, pl. 10 fig. 2) to *Alethopteris ambigua*. This is a rare species in Britain, which according to Wagner is otherwise only known from the late Westphalian D of the Bristol and Somerset Coalfield.

Crookall (1955) questioned Kidston's (1903b) record of *Alethopteris serlii* (Brongniart) Goppert, and placed the specimens in *Alethopteris grandinii*. Crookall's own interpretation of *A. grandinii* is clearly flawed, however, since the two species that he illustrated under that name (neither from Jockie's Syke) belong to *Alethopteris grandinioides* and *Alethopteris quadrata* Wagner (Wagner, 1968). From Crookall's comments on the Jockie's Syke specimens, it is likely that they in fact belong to *A. grandinioides*, a relatively common species in the Westphalian D of Britain.

Plant fossils of this age are rare in Britain. In southern Britain, there are few strata of this age, due to the effects of the Leonian folding phase. Only in South Wales are there reliable records of *L. micromiltoni* Zone plant fossils, from the Swansea Beds in the western part of the main coalfield, and these were all collected from underground workings (Cleal, 1978). In North Wales and the English Midlands, strata of this age are either missing or occur as the Etruria facies, in which plants are not normally preserved. In most of northern England and Scotland, there is little evidence of coeval strata.

In the rest of Europe, this zone is also very rare. Sedimentation appears to have ceased in the early Westphalian D throughout most of the paralic basin that stretches from northern France through Germany to Poland. In the Iberian Peninsula, the effects of the Leonian folding, mentioned above, again seem to have disrupted the non-marine stratigraphical record at this level. The only undoubted record of the zone comes from the intra-montane basin of Saar-Lorraine, and this is based on material collected from underground mine workings (Cleal, 1984b; Laveine, 1989). It is evident, therefore, that Jockie's Syke is one of the very few sites in Europe yielding plant fossils of this age.

Conclusion

Jockie's Syke is one of the few sites in Europe, and the only one in Britain, to yield this particular assemblage of plant fossils from the Upper Coal Measures, rocks deposited as sediments about 300 million years before the present. Two species are found here (*Alethopteris ambigua* and *Cyathocarpus* aff. *arborescens*) which do not occur in older floras; their appearance represents the start of the gradual change from the typical Coal Measures vegetation represented by the British fossil floras, to the later (Stephanian) vegetation, more typically found in central and southern Europe. This vegetational change was probably triggered by topographic and possible climatic changes, which in turn were the result of the collision between two major continental plates (Gondwana and Laurussia). These large-scale environmental changes brought an end to the swamp-forest vegetation that had typified Coal Measures (Westphalian) times across northern Europe, and eventually culminated in the more arid conditions of the Permian, whose vegetation is the subject of the next chapter.