Vegetation ecology of Early Pennsylvanian alluvial fan and piedmont environments in southern New Brunswick, Canada

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Abstract

The vegetation ecology of Pennsylvanian upland/dryland regions is poorly known, despite its evolutionary significance. Here, fossil plant assemblages are described from well-drained alluvial fan/piedmont deposits in the uppermost Boss Point and Tynemouth Creek formations (late Yeadonian–Langsettian), southern New Brunswick. Beds record the northward building of a large alluvial fan complex over alluvial plain deposits in response to near-continuous sourceland uplift. Proximal alluvial fan environments, characterized by sheetfloods and braided streams, were dominated by large cordaitalean trees, medullosan pteridosperms, ferns, and calamiteans. Distal alluvial fan environments, where braided stream and levee/splay sedimentation predominated, were covered by similar vegetation, together with lycopsids in localized poorly drained depressions. Calamitean thickets were particularly widespread in rapidly aggrading settings on the distal fan. Well-drained alluvial plains beyond the fan toe were characterized by axial braided rivers containing cordaitalean trunks transported from proximal settings. Piedmont vegetation is otherwise poorly resolved. All studied plant assemblages are of low- to medium-diversity, and dominated by the remains of a single group, cordaitalean seed plants. Such dominance-diversity characteristics, together with the presence of charcoal, the product of wildfire, imply that Pennsylvanian upland/dryland vegetation experienced water-stress and that the seed habit was integral to successful colonization.

1. Introduction

Remains of Pennsylvanian tropical vegetation have been studied for two centuries (Scott, 1977; Pfefferkorn et al., 2000), with research focusing on wetland communities (DiMichele and Greb, in press). Best known are the peat-forming rainforests, preserved as coal seams, some of which formed vast, unbroken swaths up to 200,000 km² in size (Greb et al., 2003). Rainforests were dominated by tree-sized lycopsids (Phillips and DiMichele, 1992), interspersed with sphenopsids, ferns, pteridosperms, and cordaitaleans in a heterogeneous mosaic (DiMichele and Phillips, 1994; Gastaldo et al., 2004). Plant communities that occupied poorly drained, mineral soils on floodplains were of similar composition (Gastaldo, 1987; Calder et al., 1996), but with different dominance-diversity characteristics (DiMichele et al., 2001).

In comparison, the vegetation of well-drained environments has received little attention, in part, because plant preservation is poor in dry settings (Falcon-Lang et al., 2004). Limited available data suggest that seasonally dry, lowland alluvial plains...

Here I document plant communities of well-drained alluvial fan/piedmont settings preserved in the uppermost Boss Point and Tynemouth Creek formations (Lower Pennsylvanian) of southern Brunswick, Canada (Fig. 1; Bell, 1944; Plint and van der Poll, 1982; Williams et al., 1985). Pennsylvanian plant assemblages have been rarely described from such environments (Grand’Eury, 1877; Bell, 1940; Galtier and Phillips, 1985; Iwaniw, 1985a,b; Pesek, 2004), and data help clarify the linkage between poorly known upland and dryland communities (Lyons and Darrah, 1989; DiMichele and Aronson, 1992). Furthermore, being approximately coeval with famous fossil assemblages at the nearby Joggins Fossil Cliffs (Lyell and Dawson, 1853) and Fern Ledges (Dawson, 1868; Stopes, 1914), research improves the geological context of these historic sites (Miller and Buhay, 1995; Falcon-Lang and Calder, 2004, 2005; Falcon-Lang et al., in press).

2. Geological setting

The Boss Point and Tynemouth Creek formations are Lower Pennsylvanian units within the palaeotropical Maritimes strike-slip basin complex of Atlantic Canada (Plint and van der Poll, 1982; Gibling, 1995; Calder, 1998). This depocentre developed in Devonian times following the oblique convergence of Gondwana with Laurasia (Scotese and McKerrow, 1990). The Maritimes Basin comprises several sub-basins, partially divided by small, fault-bounded basement massifs (Gibling, 1995; Pascucci et al., 2000). The Boss Point and Tynemouth Creek formations were deposited within the Cumberland sub-basin, bounded to the south by the Fundy–Cobequid Fault (Fig. 2; Van der Poll, 1995). Early Pennsylvanian patterns of sedimentation were spatially complex within the Cumberland sub-basin (Davies and Gibling, 2003), and related to the reorganisation of the Meguma, Avalon, and Cobequid crustal blocks.

In the eastern part of the basin, dextral transpression along the Fundy–Cobequid Fault and anti-clockwise rotation of the Meguma block was accommodated by northward translation of the Cobequid block along the Harvey–Hopewell Fault (Nance, 1986, 1987). Transpression, and associated halokinesis, resulted in rapid subsistence and accumulation of ≥4000 m of Early Pennsylvanian terrestrial sediments in northern Nova Scotia (Waldron and Rygel, 2005). These strata comprise alluvial fan facies of the New Glasgow and Polly Brook formations, shed from the Cobequid Massif along the southern basin margins (Chandler, 1998), and alluvial plain, coastal plain, and brackish bay facies of the Boss Point, Little River, Joggins, and Springhill Mines formations, deposited near the basin centre (Davies and Gibling, 2003; Calder et al., 2005).

In the western part of the basin, crustal rotation was restrained by a bend in the Fundy–Cobequid Fault, resulting in oblique-slip thrusting of the Meguma block against the Avalon block (Fig. 2; Plint and van der Poll, 1984; Nance, 1986, 1987). In southern New Brunswick, small, elongate, ENE–WSW-oriented, en echelon depocentres accumulated relatively thin (≤1000 m) successions of syntectonic terrestrial sediments (Plint, 1985). Alluvial fan deposits of the Tynemouth Creek Formation, were shed off the Meguma thrust-front (Plint and van der Poll, 1982; Rast et al., 1984), and built northwards into areas dominated by alluvial plains, coastal plains and brackish bays, repre-
represented by the Boss Point and Lancaster formations (Nance, 1986, 1987).

3. Stratigraphy

The stratigraphy and age determination of the uppermost Boss Point Formation and Tynemouth Creek Formation in southern New Brunswick, and indeed the entire Early Pennsylvanian succession in Atlantic Canada, has proved controversial (Calder, 1998). This is due, in large part, to the absence of marine index fossils in this predominantly non-marine basin complex (Falcon-Lang, 2005c), and the resultant difficulty in precisely determining the position of the Namurian–Westphalian boundary using palynological proxies (Calder et al., 2005).

The Boss Point Formation is a distinctive c. 800 m thick lithostratigraphic unit recognizable across most the Cumberland sub-basin in New Brunswick and Nova Scotia (Plint and van der Poll, 1984; Plint and Browne, 1994; Johnson, 1995). Based on palynological assemblages it has been variously assigned to the Yeadonian (Calder et al., 2005), the late Yeadonian/early Langsettian (Utting et al., 2005), or the Langsettian (Johnson, pers. comm., 2005). Megafloral data suggest a Langsettian age for the Boss Point Formation (Utting and Wagner, 2005). Palynological data for the Tynemouth Creek Formation, which is much more localized in its distribution, indicate a latest Yeadonian/Langsettian age for the middle part of this unit (Dolby, 1997), while megafloral data suggest that the highest strata may extend into the Duckmantian (Utting and Wagner, 2005).

In southern New Brunswick, the Tynemouth Creek Formation demonstrably overlies of the Boss Point Formation without a stratigraphic break (Plint and van der Poll, 1984). Whilst the precise age of this succession is unclear, this relationship permits lithostrati-
graphic correlation (Fig. 3). Near Saint John, New Brunswick, the fine-grained strata of the Lancaster Formation (Alcock, 1938), which contain the famous Fern Ledges fossil biota (Dawson, 1868; Stopes, 1914), overlie rocks strongly reminiscent of the Boss Point Formation, and are assigned to the Langsettian on megafossil evidence (Utting and Wagner, 2005). Near Joggins, Nova Scotia, strata of the Little River and Joggins Formations, which also contain a famous fossil biota (Falcon-Lang and Calder, 2004), overlie the Boss Point Formation, and are assigned a late Yeadonian/Langsettian age (Calder et al., 2005). Consequently, there can be little doubt that the Tynemouth Creek Formation is time-equivalent, at least in a large part, with the two famous fossil biotas at Joggins and Fern Ledges. Problematic age determination based on megafloral and palynofloral assemblages may, in part, reflect the unusual plant ecologies evident in these formations, as discussed in this paper.

4. Structure and sedimentology of the section

This study focuses on a 16 km long coastal cliffsection of the Bay of Fundy, located between Emerson Creek (Latitude 45°16′ N; Longitude 65°47′ W) and Roger’s Head (Latitude 45°18′ N; Longitude 65°35′ W), southeast of St. Martins, southern New Brunswick (Fig. 4). At this site the uppermost beds of the Boss Point Formation are conformably overlain by the Tynemouth Creek Formation (Plint and van der Poll, 1984). The precise stratigraphic relationship of different parts of this coastal section has been complicated by the development of a northward-verging fold and thrust belt, and subsequent large-scale normal faulting. Plint and van der Poll (1982) recognized and logged four relatively undeformed successions at Giffin Pond, Tynemouth Creek East, Tynemouth Creek West, and Gardner Creek (Fig. 4).

At Giffin Pond (Section 1) the uppermost Boss Point Formation (lower 122 m in fig. 19 of Plint and van der Poll, 1982) represents a well-drained alluvial plain association, and is overlain by the basal beds of the Tynemouth Creek Formation, which comprise a distal alluvial fan association. The facies transition between the two units is gradational (Plint and van der Poll, 1982, 1984). At the remaining sites (Sections 2–4) only fault-bounded successions of Tynemouth Creek Formation occur. These strata show hectometre-scale upward coarsening, and comprise distal alluvial fan deposits overlain by proximal alluvial fan deposits (Plint and van der Poll, 1982). The boundary between distal and proximal associations is taken as coinciding with the first appearance of sheetflood deposits. Upward coarsening indicates continuous alluvial plain progradation, and shows that sedimentation took place whilst the Fundy–Cobequid Fault was active. This interpretation is additionally supported by syntectonic sedimentary features within the Tynemouth Creek Formation (Plint, 1985).

Structural and lithofacies relationships suggest that Sections 2–4 overlie Section 1, however, it is unknown whether there is any stratigraphic overlap (Fig. 5). The precise correlation between Sections 2 and 4 is unclear. As already noted, these three sections show hectometre-scale upward coarsening from distal to proximal alluvial fan associations. Given that the sections occur over

![Figure 4. Geological map of coastal section studied (after Plint and van der Poll, 1982; Barr and White, 2004a,b) showing the location of the four logged sections mentioned in the text.](image-url)
a 5 km transect orientated approximately normal (NE–SW) to the inferred NW direction of alluvial fan progradation (Plint and van der Poll, 1982), the lithofacies transition provides a possible, though uncertain, tie-point between adjacent outcrops. Accepting this reasoning, the total inferred thickness of the Tynemouth Creek Formation is about 700 m (Fig. 5).

5. Sedimentary facies and associations

Five main plant-bearing sedimentary facies occur and are organized into three facies associations (Fig. 6). Facies descriptions are based, with minor revision, on details given in Plint and van der Poll (1982, 1984).

5.1. Facies description

Facies 1 consists of 16–31 m thick, erosive-based (≤4 m relief), multi-storey, medium- to coarse-grained, channelized sandstone bodies containing quartz pebble lenses. Trough cross-bedding and large-scale tabular cross-stratification are common and indicate an ENE palaeoflow. Upper channel-fills locally comprise ≤1 m thick grey mudstone successions containing rare carbonaceous lenses.

Facies 2 consists of 1–8 m thick, erosive-based (≤3 m relief), multi-storey, fine- to coarse-grained sandstone bodies. Units are tabular or lenticular, laterally continuous over tens to hundreds of metres, and fine upwards. They contain large-scale, tabular cross-stratification, and where channelized, exhibit trough cross-
bedding with a NW palaeoflow. Upper channel-fills may contain grey mudstone with sandstone lenses.

Facies 3 consists of 2–6 m thick units of clast-supported, polymictic, pebble to cobble conglomerate. Beds are sharp-based, laterally traceable for tens to hundreds of metres, typically massive, or may show large-scale tabular cross-stratification. Interdigitating with, and locally overlying, many conglomerate beds are ≤1.4 m thick, ≤15 m wide pods of locally matrix-supported sediment comprising grey mudstone, medium- to coarse-grained sand, pebbles, and coarse woody debris.

Facies 4 consists of massive or laminated red mudstone containing fine-grained sandstone laminae. Palaeosols, developed at some intervals, consist of blocky, green/grey-mottled zones, ≤10–60 cm thick, locally showing slickensides, ≤2 cm carbonate nodules, and an irregular, upper surface. Palaeosols are overlain by laminated red or grey mudstone.

Facies 5 consists of ≤1 m thick (typically ≤10 cm thick), erosive-based sheets of fine-grained sandstone containing ripple cross-lamination and planar lamina- tion, and locally showing basal tool marks. Sheets may be isolated, or grouped into packages up to 15–20 m thick, interbedded with red mudstone.

5.2. Facies associations and interpretation

The first facies association comprises Facies 1, 4 and 5, and is represented by the uppermost Boss Point Formation at Section 1 (0–122 m). Multistorey sandstone bodies with tabular cross-stratification (Facies 1) are interpreted as large braided river channel deposits (Browne and Plint, 1994; cf. Plint and van der Poll, 1982), whilst red/green mudstone (Facies 4) and sheet sandstone units (Facies 5) represent floodbasin suspension and splay/levee deposits, respectively. Collective- ly, beds represent deposits of an axially draining alluvial plain within a piedmont setting (Plint and van der Poll, 1982).

The second facies association comprises Facies 2, 4 and 5. It is represented by the lower part of the Tyne-mouth Creek Formation at Section 1 (122–150 m), Section 2 (0–85 m), Section 3 (0–163 m) and Section 4 (0–379 m), and has a thickness of ≥379 m. Pebbly, coarse-grained sandstone bodies with tabular cross-stratification (Facies 2) represent deposits of incised, braided streams, while Facies 4 and 5 represent interchannel suspension and splay/levee deposits, respectively. Collectively, beds represent deposits of distal alluvial fan environments (Plint and van der Poll, 1982).

The third facies association comprises Facies 2, 3, 4 and 5. It is represented by the upper part of the Tyne-mouth Creek Formation at Section 2 (85–114 m), Section 3 (163–215 m) and Section 4 (379–615 m), and has a thickness of ≥236 m. These strata are distinguished from the second facies association by the addition of conglomerate lenses (Facies 3), which represent sheet-flood deposits, with associated mud-rich pods representing run-out slurry deposits. Collectively, beds represent deposits of proximal alluvial fan environments (Plint and van der Poll, 1982).

Proximal and distal alluvial fan deposits are further distinguished in two respects. First, braided stream deposits (Facies 2) are more deeply incised and channelized in the proximal fan association. Second, splay/ levee-deposited sandstone sheets (Facies 4) are much more abundant in the distal fan association (50% stratal thickness versus 15%) according to Plint and van der Poll (1982). Both differences are linked to the higher inferred gradient in the former setting, where drainage channels would be excepted to be more confined, and more deeply down-cutting.

Red/green mottled palaeosols with slickensides and carbonate nodules, present in all three associations, are interpreted as vertisols, and indicate that seasonally dry climatic conditions prevailed throughout the deposition of the succession (Mariott and Wright, 1993). The primary red coloration of most mudstone successions imply dominantly well-drained interchannel soils. Similar palaeosols are seen in coeval deposits in the Cumberland sub-basin (Browne and Plint, 1994; Calder et al., 2005).

6. Fossil plant assemblages

Plant assemblages were recorded in their sedimentary facies context using published sedimentary logs (Plint and van der Poll, 1982), although several key sections were re-logged in detail (e.g. Fig. 6). Fossil plant identification was facilitated using Bell’s (1944) monograph, and later revised. It proved impractical to quantify fossil remains using quadrat analysis (Falcon-Lang, 2003b; Gastaldo et al., 2004) because plant assemblages were relatively scarce, and it was difficult to collect large quantities of material from vertical seacliff sections. When describing plant preservational types, the terminology of Cleal and Thomas (1994) was used. Fossil plants are preserved as impressions, commonly covered by a haematitic film, or rarely as compressions. Locally plants may be anatomically preserved as calcite-permineralizations, and rarely as silica-permineralizations and charcoal. The identity of
these latter fossils was determined using transmitted light microscopy and scanning electron microscopy.

6.1. Uppermost Boss Point Formation

In this piedmont setting, plant fossils (Fig. 7) are only common in braided river channel deposits (Facies 1). Here, calcite-permineralized and coalified trunks, \( \leq 56 \) cm diameter and \( \leq 8.5 \) m long, are highly abundant, especially in lower channel storeys, and in one unit alone, 67 trunks were counted. Trunks are oriented sub-horizontal to bedding. All trunks are monopodial, and where permineralized have Dadoxylon-type wood, and Artisia pith casts features, indicating cordaitalean affinity (Fig. 7A, B). Additionally, a few examples may show attached rooting systems (Fig. 7C) or numerous side branches. Other plant fragments, \( \leq 10 \) cm diameter, are common but mostly indeterminate, except for a few sandstone-cast Calamites. Upper channel-fills comprising grey, rooted mudstone, contain Stigmaria impressions at one level (Plint and van der Poll, 1982).

Well-drained floodbasin muds (Facies 4) contain common plant fossils. At Giffin Pond, a single sandstone-cast lycopsid stump with vertical ribbing suggestive of Sigillaria is rooted in a palaeosol, and buried by splay deposits (Fig. 8A), whilst two other palaeosols elsewhere contain Stigmaria (Fig. 8C). Several palaeosols also contain impressions of (putatively gymnospermous) rooting systems showing \( \geq 4 \) orders of branching. Laminated grey/green mudstone overlying palaeosols may contain several of the following elements: Calamites, Annularia, Asterophyllites, Pecopteris, Sphenopteris, Zeilleria, Alethopteris, Maripteris, Neuralethopteris, Neuropteris, Karinopteris, Cordaites, and Samaropsis. Where mudstone beds are associated with Stigmaria-bearing palaeosols, indeterminate juvenile lycopsid foliage may occur (Fig. 8B). Red mudstones lacking evident palaeosols (Facies 4) contain unfragmented, randomly orientated Cordaites impressions at many

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Fig. 7. Fossil plant assemblages in piedmont alluvial plain deposits, Boss Point Formation, Giffin Pond, (A) Artisia pith cast, scale: 1 cm, (B) calcite-permineralized Dadoxylon trunk, scale: 10 cm, (C) Allochthonous stump with attached roots, scale: 20 cm.
horizons (Fig. 8G), with a few examples attached to branches and showing helical arrangement. A faint *Artisia* impression is present on one surface, and *Alethopteris* and *Pecopteris* pinnae occur on others.

Splay/levee-deposited sandstone sheets (Facies 5), contain abundant upright sandstone-cast calamitean stems at hundreds of horizons. *Calamites* are 4–12 cm in diameter with preserved heights of ≤1 m. Several stems show adventitious sprouting of secondary axes.

Fig. 8. Fossil plant assemblages in lower alluvial fan deposits, Tynemouth Creek Formation, (A) Lycopsid stump, scale: 25 cm, (B) Lycopsid foliage, scale: 1 cm, (C) Stigmaria, scale: 5 cm, (D) Upright *Calamites* stems showing adventitious sprouting, scale: 5 cm, (E) *Calamites* grove in growth position, scale: 20 cm, (F) *Artisia* pith cast, scale: 1 cm, (G) unfragmented *Cordaites* leaves, scale: 5 cm, (H) *Pecopteris* pinnae, scale: 2 cm.
(Fig. 8D), and occur with localized densities up to 3–5 stems m$^{-2}$ (Fig. 8E). More rarely Stigmaria also occur in growth position, but are limited to significantly pedogenized surfaces. Other associated plant fossils include Calamites, Annularia, Cordaites, and fern pinnae (Fig. 8H).

6.3. Upper part of Tynemouth Creek Formation

In proximal alluvial fan settings, plant fossils are locally abundant (Fig. 9). Braided stream deposits (Facies 2) contain common coalified, or rarely calcite-permineralized, Dadoxylon trunks, ≤50 cm diameter and ≤3 m long, with a ropy external structure, and in a few examples, attached rooting systems. Trunks have a sub-horizontal orientation relative to bedding. Other fossils include Dadoxylon charcoal, Artisia pit casts, impressions of Cordaites (Fig. 9B), Calamites, and in one unit, large pteridosperm trunks with recurved branches.

Sheetflood deposits (Facies 3) contain rare Calamites, <10 cm in diameter (Fig. 9F), and indeterminate fragments in conglomerate units. Mud-rich pods, representing run-out slurry deposits, contain abundant coalified, locally calcite-permineralized, or rarely silicified, Dadoxylon trunks, 5–30 cm in diameter and ≤4.5 m long, with a ropy external structure (Fig. 9A), together with Dadoxylon charcoal fragments, 1–2 cm in diameter. Trunks are sub-horizontally to sub-vertically oriented, occurring as dense accumulations, with tens of trunks observable within each unit over only a few square metres of outcrop. Intermixed plant fragments include Artisia pith casts (Fig. 9E), Cordaites impressions, and sandstone-cast Calamites.

Well-drained interchannel mudstone deposits (Facies 4) contain locally abundant plants. Several palaeosols contain impressions of (putatively gymnospermous) rooting systems showing ≤4 orders of branching (Fig. 9D). Two palaeosols contain calcite-permineralized Dadoxylon stumps, ≤46 cm diameter, in growth position, one example showing Artisia pith features in a primary root (Fig. 9H–K). Roots are ≤19 cm diameter, and may be traced laterally through the palaeosol for 2.3 m. One of the stump horizons is overlain by laminated red mudstone and very fine-grained sandstone containing only abundant, unfragmented Cordaites leaves, whilst overlying the other palaeosol, Cordaites and Alethopteris pinnae occur. A variety of vegetation-induced sedimentary structures (VISS of Rygel et al., 2004) occur in these beds including sediment mounds and stratral downturns.

Laminated red mudstones, overlying other palaeosols without Dadoxylon stumps, are dominated by Cordaites (Fig. 9C), subordinate Alethopteris, and locally common Cardiocarpus, Samaropsis, Megalopteris, Neuropteris, Sphenopteris, Zeilleria, and Asterophyllites, and Annularia (Fig. 9G). Fossil plants also occur at tens of horizons in red mudstone successions that lack palaeosols, and include abundant, unfragmented Cordaites impressions, locally associated with Cardiocarpus and Alethopteris pinnae.

Splay/leveé-deposited sandstone sheets (Facies 4), locally contain closely spaced Calamites stems in growth position, but these are very uncommon relative to their occurrence in distal alluvial fan units. At one interval, this facies overlies one of the palaeosols with Dadoxylon stumps. The tree stump is mostly uprooted, tipped on its side, and almost entirely enclosed by the sandstone sheet, although some of the roots remain anchored in the underlying palaeosol (Fig. 9I, K). The thickness and depth of erosive scour of the sandstone sheet greatly increases in the vicinity of the stump, an example of the scour and mound VISS (Rygel et al., 2004).

6.4. Museum collections

A small plant fossil collection from the Tynemouth Creek Formation is housed at the New Brunswick Museum, Saint John (Fig. 10). The provenance of only one specimen is known, a sandstone-cast lycopsid stump collected from distal alluvial fan units, east of Gardner Creek. Although decorticated, it displays external ribbing suggestive of Sigillaria, and contains charred lycopsid periderm (cf. Falcon-Lang, 1999, figs. 7 and 9). The facies context of other New Brunswick Museum fossils is unknown. These include many haematite-coated impressions and sandstone-casts of Calamites suckowi, with diameters of ≤18 cm (Fig. 10A), Cordaites leaves, Cardiocarpus seeds (Fig. 10B), and Alethopteris (Fig. 10C) and Neuropteris pinnae. One final specimen is a silicified Dadoxylon trunk with a 26 mm diameter Artisia pith (Fig. 10D), showing a haematoletic coating (Fig. 10E). The outer pith comprises a layer of large, rectangular parenchyma that extends out into septa (Fig. 10F). Stem maturation is endarch, primary xylem tracheids showing a progression from spiral to scalariform to reticulate thickening (Fig. 10G). Leaf traces are not preserved. Secondary xylem is of Dadoxylon-type, and comprises 40–50 μm diameter tracheids showing 1–3-seriate, alternate, circular bordered pits (Fig. 10H, I). Rays are uni-
Fig. 9. Fossil plant assemblages in upper alluvial fan deposits, Tynemouth Creek Formation, (A) Dadoxylon trunk in slurry associated with sheetflood, scale: 25 cm, (B) Cordaites leaf, scale: 5 cm, (C) Cordaites leaf, scale: 2 cm, (D) Putative gymnospermous roots, scale: 10 cm, (E) Artisia pith cast, scale: 1 cm, (F) Calamites, scale: 2 cm, (G) Annularia, scale: 2 cm, (H, J) Photograph and drawing of two autochthonous Dadoxylon stumps rooted in vertisol, scale: 50 cm, and (I, K) Photograph and drawing of autochthonous Dadoxylon stump on its side in a splay deposit, scale: 50 cm.
seriate, 1–12 cells high, spaced 2–8 tracheids apart, and exhibit 1–6 araucarioid pits per cross-field. Growth rings are absent (Fig. 10J).

A much larger collection of fossil plants from the Tynemouth Creek Formation is stored at the Geological Survey of Canada, Ottawa, and illustrated in Bell (1944). These collections were not examined firsthand. Bell (1944) noted eight genera not encountered during the course of this field study. These include rare lycopsids (*Lepidodendron*, *Lepidostrobus*, *Lepidostrobophyllum*), ferns (*Corynepteris/Alloiopteris*, *Oligocarpia*, *Rhodea*), and pteridosperms (*Laveineopteris* and *Paripteris*). Based on his locality data, these could be placed in their facies context, albeit with some reservation (see taxa marked with an asterisk in Table 1).

### 6.5. Palynology

In addition to field observations and the museum collections, a third source of fossil plant data is palynological assemblages (CS96-405 to -409) analyzed from distal alluvial fan deposits at Sections 2–3 by Dolby (1997). These assemblages are sparse, but all dominated by saccate pollen of cordaitaleans (*Florinates*, 4 species) and putative conifers (*Potonieisporites*, *Petonieisporites*, *Glospeumisporites*, *Kornerupites*).
Table 1
Facies distribution of fossil plant taxa in the uppermost Boss Point and Tynemouth Creek Formation of southern New Brunswick

<table>
<thead>
<tr>
<th>Plant taxa (n=27 genera)</th>
<th>Upper fan</th>
<th>Lower fan</th>
<th>Piedmont</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lycopsida</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lepidodendron lanceolatum</em></td>
<td>–</td>
<td>Present</td>
<td>–</td>
</tr>
<tr>
<td><em>Lepidostrobus sp.</em></td>
<td>Present</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><em>Lepidostrobophyllum majus</em></td>
<td>Present</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>CF. Sigillaria sp.</td>
<td>–</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Stigmaria ficoides</td>
<td>–</td>
<td>Rare</td>
<td>Rare</td>
</tr>
<tr>
<td>Sphenopsida</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annularia 3 sp.</td>
<td>Common</td>
<td>Common</td>
<td>–</td>
</tr>
<tr>
<td>Asterophyllites sp.</td>
<td>Common</td>
<td>Common</td>
<td>–</td>
</tr>
<tr>
<td>Calamites 2 sp.</td>
<td>Common</td>
<td>Abundant</td>
<td>Common</td>
</tr>
<tr>
<td>Filicopsida</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corynepteris/Alloiopteris*</td>
<td>Present</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Oligocarpia brongniartii*</td>
<td>Present</td>
<td>Present</td>
<td>–</td>
</tr>
<tr>
<td>Pecopteris pilosa</td>
<td>–</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Rhodea wilsoni*</td>
<td>Present</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sphenopteris 4 sp.</td>
<td>Rare</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Zeilleria 2 sp.</td>
<td>Rare</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cycadopsida</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alethopteris lonchitica</td>
<td>Common</td>
<td>Common</td>
<td>–</td>
</tr>
<tr>
<td>Karinopteris sp.+</td>
<td>–</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Laveineopteris tenuifolia*</td>
<td>Present</td>
<td>Present</td>
<td>–</td>
</tr>
<tr>
<td>Mariopteris 2 sp.</td>
<td>–</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Megalopteris dawsonii+</td>
<td>Rare</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Neurolethopteris schlehanii</td>
<td>Common</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Neuropteris 3 sp.</td>
<td>Common</td>
<td>Common</td>
<td>–</td>
</tr>
<tr>
<td>Paripteris pseudogigantea*</td>
<td>Present</td>
<td>Present</td>
<td>–</td>
</tr>
<tr>
<td>Coniferopsida</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Artisia transversa</em></td>
<td>Common</td>
<td>Rare</td>
<td>Rare</td>
</tr>
<tr>
<td>Cordaites Dawsoni</td>
<td>Common</td>
<td>Rare</td>
<td>–</td>
</tr>
<tr>
<td>Cordaites principalis</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
</tr>
<tr>
<td>Dadoxylon 2 sp.</td>
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<td>Common</td>
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</tr>
<tr>
<td>Samaropsis 3 sp.</td>
<td>Common</td>
<td>Common</td>
<td>–</td>
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</table>

Symbols: * denotes taxon recorded by Bell (1944) but not observed in this field study, and + denotes taxon observed in this study but not by Bell (1944).

Table 1

<table>
<thead>
<tr>
<th>Plant taxa (n=27 genera)</th>
<th>Upper fan</th>
<th>Lower fan</th>
<th>Piedmont</th>
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<td>Lycopsida</td>
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<tr>
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<td>–</td>
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<tr>
<td>CF. Sigillaria sp.</td>
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<td>–</td>
</tr>
<tr>
<td>Stigmaria ficoides</td>
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<td>Rare</td>
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<tr>
<td>Sphenopsida</td>
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<td>Karinopteris sp.+</td>
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<td>Laveineopteris tenuifolia*</td>
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<td>Samaropsis 3 sp.</td>
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</tr>
</tbody>
</table>

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7. Interpretation of vegetation ecology

Analysis of locally abundant plant assemblages within the uppermost Boss Point and Tynemouth Creek formations of southern New Brunswick allows reconstruction of Early Pennsylvanian vegetation in this alluvial fan/piedmont setting (Fig. 11). Plant megafossil assemblages are of low- to medium-diversity (27 genera containing 40 species) compared with typical Pennsylvanian coal-bearing strata (Table 1; Bell, 1944). Furthermore, assemblages are numerically dominated by a single plant group, the cordaitaleans (Dadoxylon trunks, Artisia pith casts, Cordaites leaves, Cordaicarpus and Samaropsis seeds, and Florinites pollen). Based on the presence of four seed taxa, and four pollen taxa, and despite their conservative leaf morphology (cf. Šimůnek, 2000), the cordaitaleans were clearly a relatively diverse group in the Tynemouth Creek Formation. Other plants such as pteridosperms, ferns, and calamiteans were locally common, but lycopsids were very rare, and mostly restricted to distal alluvial fan/piedmont environments, although Bell (1944) does record one Lepidostrobus specimen from proximal alluvial fan deposits. The very similar composition of field collections, museum collections, and palynological assemblages, suggest that observations truly reflect the main floral elements of this environment in rough proportions, although it is likely that some groups (e.g. vines, small groundcover) are generally underrepresented (Wing and DiMichele, 1995). One such group is the conifers whose megafoossils are absent despite the abundant occurrence of putative coniferous pollen (Potonieisporites) in the section.

Proximal alluvial fan environments were covered by large cordaitalean trees as indicated by Dadoxylon stumps in growth position, and parautochthonous assemblages in associated vertisols, dominated by Cordaites, Samaropsis and Cordaicarpus. Cordaitalean trees were occasionally uprooted by overbank flows on the fan surface. Allochthonous Dadoxylon trunks, abundant in slurry run-out deposits associated with sheetfloods, may have been transported from forests beyond the fan apex (Falcon-Lang and Bashforth, 2004, 2005), although at least some trunks originated on the fan surface (Fig. 9H–K). Pteridosperms (Alethopteris, Laveineopteris, Megalopteris, Neuropteris, Paripteris), ferns, and calamiteans probably formed understorey vegetation on proximal alluvial fan surfaces. The occurrence of Megalopteris is important, given that all previous records of this taxon have been associated with upland/dryland settings (Leary and Pfefferkorn, 1977), whilst Laveineopteris has also been associated with upland terrains (Shute and Cleal, 2002; Cleal and Shute, 2003).

Distal alluvial fan environments were covered by very similar cordaitalean- and pteridosperm-dominated vegetation, with two key differences. First, calamitean thickets were much more common in distal alluvial fan settings (Briggs et al., 1984), preferring
rapidly aggrading levee/splay settings (Gastaldo, 1992). Second, a very few lycopsids (Stigmaria, sandstone-cast stumps) occupied localized patches of poorly drained soils, especially within channel abandonments, and riparian settings. The predominantly sigillarian affinity of the stumps is suggested by vertical ribbing and the occurrence of Crassipora, the only lycopsid taxon in palynoassemblages. Sigillaria was the most drought tolerant of the Pennsylvanian lycopsids (Philips and DiMichele, 1992), and grew within dryland deposits at other sites (Falcon-Lang et al., 2004). Based on Bell’s (1944) collections, less drought-tolerant lycopsids such as Lepidodendron were extremely rare.

The vegetation of piedmont alluvial plains is very poorly resolved, but likely similar to that of distal alluvial fan environments. Although cordaitaleans dominated this setting, rare lycopsids colonized poorly drained soils within channel abandonments as indicated by Stigmaria rooting systems. Allochthonous cordaitalean trunks in the braided channel deposits may have been derived from adjacent alluvial plains (Scheiwing and Pfefferkorn, 1984), alluvial fans, or even uplands beyond the fan apex (Falcon-Lang and Bashforth, 2004, 2005).

8. Regional palaeogeography and vegetation

Plant assemblages in the uppermost Boss Point and Tynemouth Creek formations in southern New Brunswick have dominance-diversity characteristics, indicative of ecological stressed communities (Falcon-Lang, 2003b,c). Drought, together with the occurrence of wildfire, indicated by fossil charcoal, were the most likely sources of disturbance. Similar plant assemblages occur throughout the Cumberland sub-basin, especially in other coeval deposits of alluvial fans and dryland alluvial plains (Fig. 12).

Plant fossil records are sparse for the alluvial fan deposits of the Langsettian Polly Brook Formation, which occurs further northeast along the line of the Fundy–Cobequid Fault in Nova Scotia (Bell, 1944). Assemblages comprise cordaitaleans (Cordaites principalis), pteridosperms (Neuropteris obliqua, Alethopteris lonchitica), ferns (Pecopteris plumosa), and sphenopsids (Annularia, Calamostachya). In the Langsettian alluvial fan deposits of the New Glasgow Formation at the eastern extremity of the basin, Bell (1940, 1944) and Chandler (1998, pers. comm. 1999) recorded an assemblage dominated by cordaitaleans (C. principalis, Dadoxylon, Samaropsis 2 sp.) with
minor pteridosperms (*Paripiteris pseudogigantea*, *Megalopteris dawsonii, N. obliqua*) and ferns (*Sphenopteris valida*), taxa all present within the Tynemouth Creek Formation.

Similar plant assemblages occur within the late Yeadonian/Langsettian Little River and Joggins Formations, exposures along Chignecto Bay, in the eastern part of the Cumberland sub-basin. All of the Little River Formation, and some 31% of the Joggins Formation, comprises red bed deposits of well-drained alluvial plains (Davies and Gibling, 2003; Calder et al., 2005). Red bed successions are dominated by cordaitalean remains, with calcite-permineralized trunks (*Dadoxylon*, *Mesoxylon*, *Artisia*) being abundant in channel deposits (Falcon-Lang and Scott, 2000; Falcon-Lang, 2003c), and cordaitalean adpressions (*Cordaites*, *Cordaiocarpus*), together with pteridosperms (*Alethopteris, Eusphenopteris, Rhacopteris, Trigonocarpus*), ferns (*Aristophyton*), calamiteans, and rare lycopsids common in floodbasin deposits, a relatively low- to moderate-diversity assemblage containing 16 genera (Falcon-Lang, 2003a,b,c, 2005a; Calder et al., 2005). The deposits of poorly drained coastal plain, and associated brackish bays, at other intervals in the Joggins Formation contain a wetland plant assemblage, more typical of Pennsylvanian palaeotropical settings (Hower et al., 2000; Calder et al., in press; Falcon-Lang et al., in press).

Similar assemblages to the Tynemouth Creek Formation are also found within the Lancaster Formation of Saint John, New Brunswick (Dawson, 1868; Stopes, 1914), at the western end of the Cumberland sub-basin. Here plant assemblages are of low- to moderate-diversity (c. 28 genera), and dominated by cordaitalean remains, including highly abundant leaves (*Cordaites*), common trunks (*Dadoxylon*), rare pith casts (*Artisia*), and rare reproductive organs (*Cordaiocarpus, Samaropsis*). Less common pteridosperms (*Alethopteris, Neuropteris, Megalopteris, Paripiteris*), putative ginkgoaleans (*Dicranophyllum*), ferns, calamiteans, and rare lycopsids also occur (Stopes, 1914; Wagner, 2005a,b). The rare occurrence of *Megalopteris* and *Dicranophyllum* is particularly interesting as both are considered upland elements (Leary and Pfefferkorn, 1977; Wagner, 2005b).

The Lancaster Formation comprises the deposits of wetland coastal plains and brackish bays, adjacent to areas of alluvial fans and uplands. As almost all the fossil plants are allochthonous, the assemblages probably represent remains washed down from uplands, as well as those that originated in coastal wetlands. For example, taphonomic considerations imply that *Dadoxylon* trunks in braided channel bodies probably represent remains from large upland cordaitaleans (cf. Falcon-Lang and Bashforth, 2004, 2005) whilst adpressed *Cordaites* leaves bearing *Spirorbis* polychaete worm tubes and overlying brackish-influenced coastal palaeosols probably represent debris from cordaitalean coastal wetlands (cf. Falcon-Lang, 2005c). In her classic memoir, Stopes (1914) recognized that at least part of the Lancaster Formation plant assemblage was derived from extrabasinal settings. She noted that

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**Fig. 12.** Palaeogeography and tectonics of the Cumberland sub-basin showing the relationship between the fossil assemblages of the Fern Ledges, Joggins, and this paper, adapted from Nance (1986, Fig. 11).
“we are not dealing with the typical, mixed swamp flora of the Coal Measures [within the Lancaster Formation] but with one principally growing on dry land” (p. 124).

It will be clear from this summary that large parts of the sedimentary fill of the Cumberland sub-basin of Atlantic Canada contain very atypical fossil plant assemblages. In marked contrast to the Appalachian, Illinois, and North Variscan basin complexes (Oplusˇtil, 2004), where peat-forming lycopsid vegetation dominated environments, both temporally and geographically (DiMichele and Phillips, 1994; DiMichele et al., 2001), vegetation communities in the Cumberland sub-basin were dominated by cordaitaleans and pteridosperms (Falcon-Lang, 2003b,c). In this small, tectonically active depocentre, where all successions accumulated within a few tens of kilometres of the active depocentre, where all successions accumulated within a few tens of kilometres of the basin margin (Gibling, 1995), such an amplified upland/dryland signal would be expected. In such well-drained settings, a gymnospermous reproductive strategy would have afforded plants a distinct ecological advantage (Fig. 12).

9. Conclusions

(1) Early Pennsylvanian plant assemblages are documented from alluvial fan and piedmont deposits in the uppermost Boss Point and Tynemouth Creek formations of southern New Brunswick, Canada.

(2) Assemblages have low- to medium-diversity, show a high degree of dominance by large cordaitalean trees, and are locally preserved as charcoal, indicating that fire was an important disturbance process in upland/dryland communities.

(3) Regional analysis show that the Cumberland sub-basin was dominated by upland/dryland plants, with peat-forming wetland communities restricted to the eastern end of the basin, which was open to marine incursions.

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Nance, R.D., 1987. Dextral transpression and Late Carboniferous sedimentation in the Fundy coastal zone of southern New Bruns-


