The Carboniferous evolution of Nova Scotia

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Abstract: Nova Scotia during the Carboniferous lay at the heart of palaeoequatorial Euramerica in a broadly intermontane palaeoequatorial setting, the Maritimes–West-European province; to the west rose the orographic barrier imposed by the Appalachian Mountains, and to the south and east the Mauritanide–Hercynide belt. The geological affinity of Nova Scotia to Europe, reflected in elements of the Carboniferous flora and fauna, was mirrored in the evolution of geological thought even before the epochal visits of Sir Charles Lyell. The Maritimes Basin of eastern Canada, born of the Acadian–Caledonian orogeny that witnessed the suture of Iapetus in the Devonian, and shaped thereafter by the inexorable closing of Gondwana and Laurasia, comprises a near complete stratal sequence as great as 12 km thick which spans the Middle Devonian to the Lower Permian. Across the southern Maritimes Basin, in northern Nova Scotia, deep depocentres developed en echelon adjacent to a transform platelet boundary between terranes of Avalon and Gondwanan affinity. The subsequent history of the basins can be summarized as distension and rifting attended by bimodal volcanism waning through the Dinantian, with marked transpression in the Namurian and subsequent persistence of transcurrent movement linking Variscan deformation with Mauritainide–Appalachian convergence and Alleghenian thrusting. This Mid-Carboniferous event is pivotal in the Carboniferous evolution of Nova Scotia. Rapid subsidence adjacent to transcurrent faults in the early Westphalian was succeeded by thermal sag in the later Westphalian and ultimately by basin inversion and unroofing after the early Permian as equatorial Pangaea finally assembled and subsequently rifted again in the Triassic.

The component Carboniferous basins have provided Nova Scotia with its most important source of mineral and energy resources for three centuries. Their combined basin-fill sequence preserves an exceptional record of the Carboniferous terrestrial ecosystems of palaeoequatorial Euramerica, interrupted only in the mid–late Viséan by the widespread marine deposits of the hypersaline Windsor gulf; their fossil record is here compiled for the first time. Stratal cycles in the marine Windsor, schizohaline Mabou and coastal plain to piedmont coal measures 'cyclothems' record Nova Scotia's palaeogeographic evolution and progressively waning marine influence. The semiarid palaeoclimate of the late Dinantian grew abruptly more seasonally humid after the Namurian and gradually recurred by the Lower Permian, mimicking a general Euramerican trend. Generally more continental and seasonal conditions prevailed than in contemporary basins to the west of the Appalachians and, until the mid-Westphalian, to the east in Europe. Palaeogeographic, paleoflow and faunal trends point to the existence of a Mid-Euramerican Sea between the Maritimes and Europe which persisted through the Carboniferous. The faunal record suggests that cryptic expressions of its most landward transgressions can be recognized within the predominantly continental strata of Nova Scotia.

> I never travelled in any country where my scientific pursuits seemed to be better understood, or were more zealously forwarded, than in Nova Scotia... (Lyell, 1845, pp. 229–230)

The geological evolution of Nova Scotia during the Carboniferous and the evolution of geological thought about the Carboniferous strata in Nova Scotia both record a strong affinity to western Europe. During the nineteenth century, the splendid coastal exposures of Carboniferous strata (Fig. 1) were proving grounds for the geological principles and philosophy of Sir Charles Lyell, especially as they pertained to the Carboniferous Period. The geological affinity of Nova Scotia to Europe, recorded in elements of the Carboniferous flora and fauna, reflects its palaeogeographic position during the Carboniferous at the heart of palaeoequatorial Euramerica, in proximity to western Europe. If not a Euramerican Rosetta Stone, Nova Scotia and the Maritimes certainly from the keystone in the bridge to understanding the Carboniferous evolution of North America and Europe (Lyell 1843a, 1845; Dawson 1888; Belt 1968*a*, 1969; Carroll *et al.* 1972; Bless *et al.* 1987; Allen & Dineley 1988; Leeder 1988*a*; McKerrow 1988; Calder & Gibling 1994, among many others).

In this paper, the Carboniferous evolution of

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Fig. 1. The Carboniferous section at Joggins, of which Lyell, in a discussion of coal measures in his The Student's Elements of Geology (1871), wrote, 'But the finest example in the world of a natural exposure in a continuous section ten miles long, occurs in the sea-cliffs bordering a branch of the Bay of Fundy in Nova Scotia.' From a nineteenth-century wood block engraving in Dawson's Acadian Geology.

Nova Scotia is considered by linking its tectonic history, basin fill sequence, fossil record and palaeoclimate with those of Carboniferous Euramerica to the west in North America and to the east in Europe. The aim of the paper is not only to review, but also to relate the records of disparate geological disciplines and to consider, from the author's perspective, implications that emerge for long established views of the Carboniferous history of Nova Scotia. A detailed treatment of all stratigraphic units of the Maritimes Basin in Nova Scotia is neither intended nor possible in a paper of this length. The references in this paper, as well as the overview of Gibling (1995, in van de Poll *et al.* 1995) and the *Lexicon* of Williams *et al.* (1985) will provide the reader with access to further details of the Carboniferous stratigraphy and geology of Nova Scotia.

Geological setting: the Maritimes Basin in Euramerica

The Carboniferous strata of Nova Scotia record most of the history of the larger, Late Palaeozoic Maritimes Basin (Williams 1974) of New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland (Fig. 2). The Late Palaeozoic strata of the Maritimes Basin span the Middle Devonian (Dawson 1862; McGregor 1977; Forbes *et al.* 1979) through early Permian (Dawson 1845, 1891; Barss *et al.* 1963) with remarkably few gaps. The Maritimes Basin is a complex of predominantly northeasterly trending intermontane basins, once variously interconnected and now, as then, defined by intervening massifs of the Avalon, Grenville and Meguma terranes. The basin was born of the Devonian (Emsian) Acadian orogeny (Poole 1967), contemporary of the latest stage of the Caledonian orogeny, both of which record final closure of the Iapetus Ocean (McKerrow 1988). The Carboniferous evolution of the Maritimes Basin bears witness to the nativity of Pangaea as Gondwana and numerous platelets of suspect terrane collided with Laurasia and the Old Red Continent, manifested in the Hercynian and Alleghenian orogenies (Schenk 1981; Rast 1988). The evolution of the Maritimes Basin during the late Devonian and Dinantian records extension (McCutcheon & Robinson 1987; Bradley 1982; Hamblin & Rust 1989) most pronounced between the Lubec-Bellisle, Cobequid and Hollow faults, an area that has been termed the Maritimes Rift (Belt 1969; van de Poll *et al.* 1995). This was suceeded in the Silesian by transpression and transtension in a renewed orogenic phase (Plint & van de Poll 1984; Nance 1987; Waldron *et al.* 1989; Yeo & Ruixiang 1987) and broadly across the basin by thermal sag (Bradley 1982) and ultimately in the Permo-Triassic, by inversion (Ryan & Zentilli 1993).

Nova Scotia and the Maritimes Basin in the Carboniferous lay within palaeoequatorial Euramerica, drifting northwards from a palaeolatitude of 12 degrees south to cross the equator by the beginning of the Permian (Scotese & McKerrow 1990). Generally considered a northern

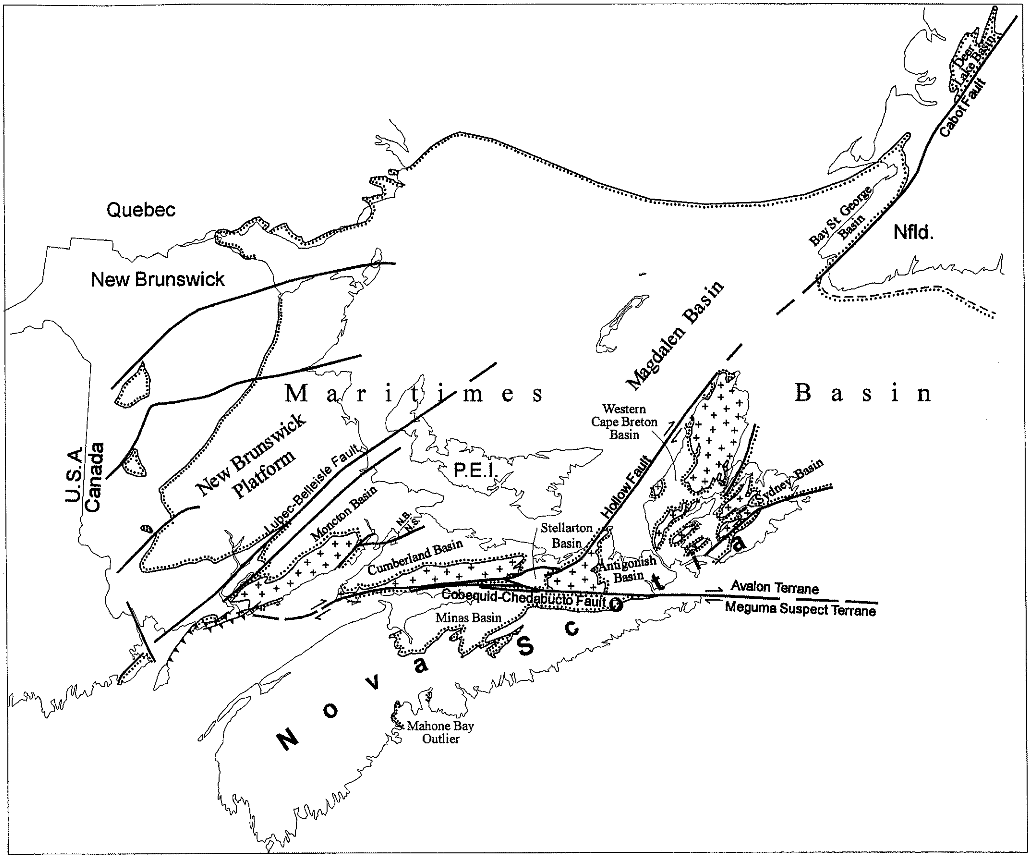


Fig. 2. Areas underlain by Middle Devonian - Permo-Carboniferous strata of the southern Maritimes Basin in Nova Scotia, and neighbouring provinces, with component depositional basins and intrabasinal massifs; modified after Gibling *et al.* (1992) and Gibling (1995).

part of the Appalachian orogenic belt, the Maritimes Basin lay situated at the palaeosoutheastern margin of the Appalachians in a palaeogeographic region distinct from the Appalachian Basin to the west. The mountain range posed an orographic climate barrier, drainage divide and phytogeographic barrier to biotic exchange between these two areas. No such *land* barrier existed to the east, however, and Nova Scotia can be included with Britain and western Europe in a broadly intermontane palaeogeographic region of tropical palaeolatitude lying to the east of the Appalachians, north of the Mauritanides and west of the Urals, and traversed by the Acadian–Hercynide upland belt, here called the Maritimes–West-European Province, modified after Leeder (1987), analagous to the Equatorial-Low-Latitude–Acadia phytogeographic unit of Rowley *et al.* (1985) and long ago known to Dawson (1888).

The evolution of geological thought on the Carboniferous of Nova Scotia

The first comprehensive account of the Carboniferous geology and mineral resources of Nova Scotia is that of Richard Brown (Fig. 3) in 1829, although this contribution in the past, if not overlooked altogether, has been attributed to Thomas Chandler Haliburton, in whose book it appears. Brown was employed by the London-based General Mining Association as manager of coal-mining operations in the Sydney coalfield, Cape Breton, from 1827 to 1864. 'This experienced observer', as he was respectfully described by Lyell (1845, p. 206), described most eloquently that *Stigmariae* are in fact the rootstock of lepidodendrid trees (Brown 1846; 1848), which are so splendidly exposed as fossil forests in the coastal sections of Nova Scotia (Lyell 1843b; Brown 1846, Dawson 1855, Calder *et al.* 1996; Scott & Calder

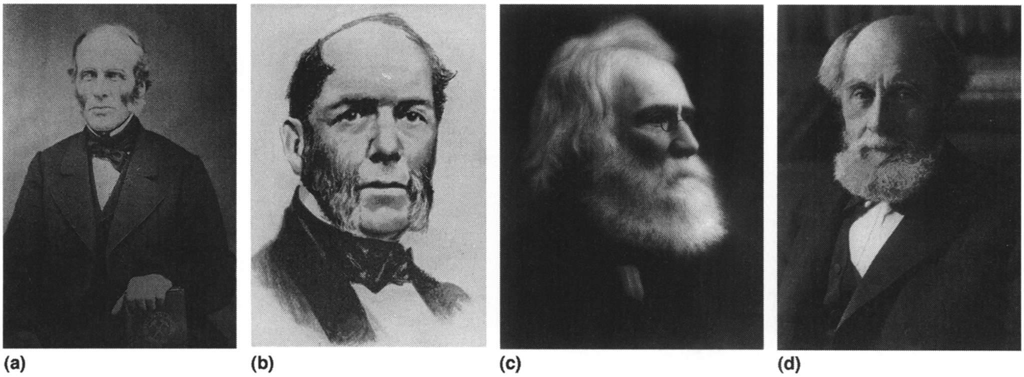


Fig. 3. Nineteenth century contemporaries of Lyell who contributed to the early understanding of the Carboniferous of Nova Scotia. (a) Richard Brown (1805–1882); (b) Abraham Gesner (1797–1864); (c) Sir William E. Logan (1798–1875); (d) Sir J. William Dawson (1820–1899).

1994; Scott this volume). Seemingly inocuous, this discovery had implications for the the origin of coal, the recognition of cyclic sedimentation and for reconsideration of the Deluge.

The stratigraphic nomenclature employed by Brown and his contemporaries of the nineteenth century immediately discloses two important facts: first, that they were both inclined and able to interpret the Carboniferous strata of Nova Scotia in terms of the geology of Europe, and in particular Britain, with which they were familiar; and second, the rock record permitted such a comparison to be drawn. Brown (1829) applied to the Carboniferous strata of Nova Scotia the then recently published stratigraphic nomenclature for Britain of Coneybeare and Phillips (1822). In contrast, the early geological account of Jackson and Alger (1829) was largely anecdotal and geographical in nature. The early stratigraphic interpretation of Brown is striking in its similarity to current subdivisions (Table 1). Current stratigraphic nomenclature has been adopted largely from that employed by Dawson (1878), who drew upon the work in the coalfields of his contemporaries McOuat (1874) and Robb (1874) at the Geological Survey of Canada, and from the subsequently evolved nomenclature of Walter A. Bell (1929, 1944) and Edward Belt (1964).

The words of Sir William Dawson in his opus *Acadian Geology*, which he dedicated to Lyell, are testimony to the influence of Lyell and the esteem in which he was held in Nova Scotia, especially by Dawson:

> The year 1842 forms an epoch in the history of geology in Nova Scotia. In that year Sir Charles Lyell visited the province, and carefully examined some of the more difficult features of its geological structure, which had baffled or misled previous inquirers. Sir Charles also performed the valuable service of placing in communication with each other, and with the geologists of Great Britain, the inquirers already at work on the geology of the province, and of stimulating their activity, and directing it into the most profitable channels. (Dawson 1868, p. 8)

In the following year (1843), Sir William Logan undertook the longstanding bed-by-bed description of the Joggins section, the first field project of the newly formed Geological Survey of Canada (Logan 1845).

Lyell gained much in return through the mutual respect between him and his collaborators Brown and Dawson. Many of his observations on the origin of the Joggins section (Fig. 4) clearly build upon those of Brown (1829). The 1845 geology map that accompanied his *Travels in North America* incorporated the stratigraphy of Dawson (1845) with respect to the age of the widespread Permo-Carboniferous red beds of Prince Edward Island and northern Nova Scotia, and is an admirable precursor to the current map of the Maritimes Basin (Fig. 2). The problematic stratigraphic position of gypsum was resolved by Lyell (1843*a*, *c*) through discussions with Brown and Dawson (Lyell 1845, p. 206; Dawson 1847). Abraham Gesner, avid promoter of Nova Scotian geology and resources (Gesner 1836, 1843) and later inventor of a process to distil kerosene from coal and oil shale, strongly disagreed with this interpretation and sought from the Geological Society Lyell's censure (Lyell 1845). In response to Gesner's criticism, Lyell systematically detailed his case for the stratigraphic position of the Dinantian gypsum and limestone (1845, pp. 208–218), which has been accepted since that time.

Table 1. *The evolution of stratigraphic nomenclature for the Carboniferous basin-fill of Nova Scotia, with special reference to the nineteenth century*

Brown (1829)	Gesner		Lyell (1843)	Dawson		Bell (1944)	Belt, 1964; Ryan et al. (1991)			
	(1836)	(1843)		1855	1878++					
					Permo-Carboniferous Series			Lower Permian		
New Red Sandstone (& Gypsum)	New Red or Saliferous Sandstone Calcareous or Marine Deposit	New Red Sandstone (& Gypsum)	Upper Carboniferous Division+	Upper Coal Formation	Upper or Newer Coal Formation		Pictou Group	Carboniferous	Silesian	S
Coal Measures	Coal Measures	Coal Measures	'Coal Measures'	Middle Coal Formation ('Coal Measures Proper')	Middle Coal Formation	Pictou, Morien, Stellarton, Cumberland Riversdale	Cumberland Group			W
'Millstone Grit'				Millstone Grit Series (Formation)	Millstone Grit Series	? *hiatus* Canso	? *hiatus* Mabou Group			N
Carboniferous Limestone	Old Mountain or Carboniferous Limestone	Old Red Sandstone or Devonian	Lower Carboniferous or Gypsiferous Series	Carboniferous Limestone (Lr. Carb. Limestone & Marine Fm.)	Windsor Series or Lr. Carb. Limestone & Gypsum Beds	Windsor ?	Windsor ?		Dinantian	V
Old Red Sandstone	Old Red Sandstone			Lower Coal Measures	Horton Series or Lower Carboniferous Coal Measures	Horton	Horton Group			T
'Greywacke'	'Slate'					?	? D / C Fountain Lake Group & Equivalents	Upper Devonian		

\+ after Dawson
\++ also McOuat (1874) and Robb (1874)

Fig. 18.

Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

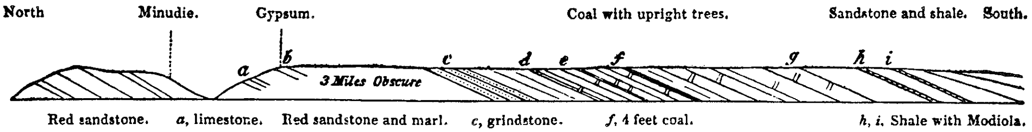


Fig. 19.

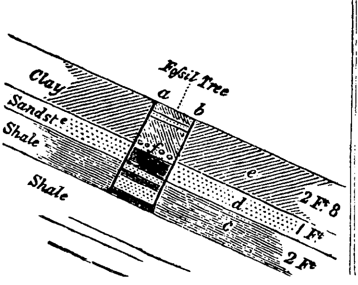


Fig. 20.

Stigmaria in micaceous sandstone.

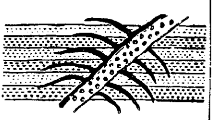


Fig. 21.

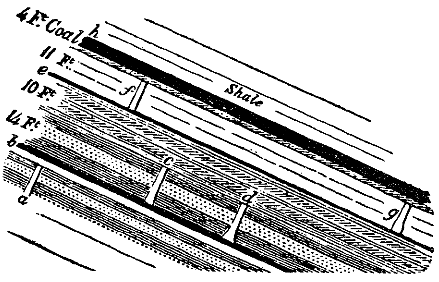


Fig. 4. Lyell's illlustrations of the Joggins section, from his *Travels in North America* (1845), reprinted in part in *The Student's Elements of Geology* (1871). Illustrated are the stratigraphic relationship of gypsum and coal measures (1871, fig. 18) and the nature and occurrence of fossil lepidodendrid trees, including: the nature of their casting (1871, fig. 19); *Stigmaria*, yet to be shown conclusively to be a lepidodendrid rootstock (1871, fig. 20); and the disposition of erect trees within the inclined strata, which was taken as evidence that the strata had been tilted subsequent to their deposition.

In 1852 Dawson and Lyell discovered, either through serendipity (Dawson 1868) or a careful search strategy (Lyell & Dawson 1853), the remarkable occurrence of tetrapods and land snails within the casts of erect lepidodendrid trees at Joggins. Dawson continued the search alone thereafter; in all, over 100 specimens comprising at least 11 tetrapod and five terrestrial invertebrate taxa (Appendix A) have been discovered in the trees (Carroll *et al.* 1972), the great majority by Dawson (1878, 1894). Perhaps the most famous of these, *Hylonomus lyelli* (Dawson 1860), for well over a century was the earliest known reptile. The strange circumstance of the tree stump fauna long has been favoured to have come about as the result of pitfall (Dawson 1878; Carroll *et al.* 1972); however, the weight of evidence including current research by the author and A. C. Scott (see Scott this volume) suggests otherwise; denning is seen by the author as a more probable scenario.

In the late nineteenth and early twentieth centuries, field relationships in the Carboniferous basins were mapped in precise detail across the Province of Nova Scotia by the Geological Survey of Canada. The resulting maps, at the scale of one inch to the mile, and accompanying reports are the valued legacy of Hugh Fletcher (1875–1909).

Bell (1929, 1940, 1944) erected series for the Carboniferous strata of Nova Scotia largely on the basis of the macroflora (Appendix B) and bivalve fauna (see Appendix A), which he correlated with equivalent European stages. The series of Bell, which established the age relationship of coal-bearing strata within the disjunct Carboniferous basins, subsequently were adopted as lithostratigraphic groups (Table 1). The diachronous nature of the lithostratigraphic units of the Maritimes Basin was illustrated by the application of miospore biostratigraphy (Belt 1964; Hacquebard *et al.* 1960; Barss *et al.* 1963). The problems inherent in the adoption of a lithostratigraphy born of biostratigraphy have been acknowledged by virtually all subsequent stratigraphers. This inherent stratigraphic problem has been accommodated in part by the growing practice of assigning diachronous coal measures within the disjunct coal basins to the Cumberland Group and succeeding red beds to the Pictou Group, as proposed by Ryan and colleagues (1991).

Because the biostratigraphy of the Carboniferous of the Maritimes Basin is rooted in the terrestrial fossil record except during the mid to late Viséan (Fig. 5), the effects of provincialism and palaeogeography can be particularly problematic in achieving precise correlations with stage boundaries based on marine fauna elsewhere in Euramerica. Depauperate miospore floras attend the red beds of Nova Scotia; in the lower Mabou Group, for example, the impoverished flora has been ascribed to playa conditions (Neves & Belt 1970). The exceptional thickness of the component basin-fills diffuses the record of first and last appearances of miospores and the introduction of hinterland floras is problematic (Dolby, pers. comm. 1997). The scarcity of recognized tonsteins (Lyons *et al.* 1994) further stymies the use of absolute radiometric dates which otherwise could be employed to assist in the resolution of chronostratigraphy.

Evolution of the Carboniferous basin-fill sequence in Nova Scotia

The major basinal depocentres of the southern Maritimes Basin in Nova Scotia (Fig. 2), modified from Gibling (1995), from west to east, are: (1) Cumberland Basin; (2) Minas Basin (including Windsor–Shubenacadie, Musquodoboit–Mahone-Bay and depocentres along the southern Cobequids); (3) Stellarton Gap and Basin; (4) Antigonish Basin; (5) Western Cape Breton, at the margin of the submarine Gulf of St. Lawrence; (6) Central Cape Breton, including Glengarry, Loch Lomond and the Salmon River; and (7) Sydney Basin. Each of these component basins in turn comprises smaller depocentres, in part reflecting the anastomosing fault configuration generated by the transcurrent fault systems of the Maritimes Basin. The accrued Carboniferous fill of these component basins may reach 12 km in thickness (Belt 1968*b*). The reader is referred to Bell (1929, 1940, 1944, 1960), Belt (1965), Ryan *et al.* (1991), Williams *et al.* (1985) and Gibling (1995) for comprehensive details of their stratigraphy. The component formations of the six main lithostratigraphic groups are given in Table 2.

Beginnings: Middle – Upper Devonian

The formation of depocentres within the Maritimes Basin (Williams 1974) during the Late Palaeozoic was initiated at the close of the Acadian orogeny (Poole 1967), following the Caledonian orogeny in western Europe, which together record the final closure of the Iapetus Ocean (McKerrow 1988). The earliest basin-fill, recorded in the McAdam Lake Formation on Cape Breton Island, has been assigned a Lower or Middle Devonian age on the basis of its *Arthrostigma–Psilophyton* macroflora (Bell & Goranson 1938) but is better constrained to the latest Emsian to early Eifelian age on the strength of palynomorphs (McGregor 1977). The strata of the McAdam Lake Formation provide the earliest record of coal formation and sapropelic lacustrine deposits ('oil shales' according to Gilpin

1899, but unreplicated by Smith & Naylor 1990) in the evolution of the Maritimes Basin in Nova Scotia. The lacustrine deposits and basin margin conglomerates co-occur with felsic volcanics (Bell & Goranson 1938). Within the Murphy Brook Formation in the Cobequid Highlands, a flora has been reported and provisionally identified as the primitive tracheophytes *Taeniocrada* and *Drepanophycus* co-occuring with axes and sporangia 'probably referable to the genus *Psilophyton*' (Forbes *et al.* 1979), which has been taken to represent a similar age (Donohoe & Wallace 1982).

The subsequent Devonian basin-fill, which is assigned to the Fountain Lake Group and its equivalent, reaches nearly 3 km in thickness (Williams *et al.* 1985) and is consistent with continental rift facies: bimodal basalt–rhyolite volcanic suites, extensive basin margin conglomerates and basinal lacustrine deposits. Volcanics of this loosely defined group occur adjacent to major transform faults: the Cobequid and Hollow Faults of northern Nova Scotia and correlative faults in southwest Newfoundland, and along the Lubec–Belleisle Fault in southern New Brunswick (Blanchard *et al.* 1984) (Fig. 2). This facies assemblage historically has been interpreted as Devono-Carboniferous on the basis of rather limited and equivocal biostratigraphic data. The lacustrine strata have yielded late Devonian to early Carboniferous (Donohoe & Wallace 1982) and Tournaisian miospores (Blanchard *et al.* 1984) and, on Cape Breton Island, compressions of the Devonian progymnosperm *Archaeopteris* (Kasper *et al.* 1988). Recent U/Pb and biostratigraphic dating increasingly constrain these rocks to the pre-Carboniferous, from Middle to Late Devonian age (Barr *et al.* 1995; Martel *et al.* 1993; Dunning *et al.* 1997). The suggestion of Martel and colleagues (1993) to assign this early basin-fill to an expanded Horton Group (see below) as yet has not been widely adopted.

Volcanics of the Fountain Lake Group are inferred to be extrusive equivalents of high-level plutons emplaced along the Cobequid Fault (Pe-Piper *et al.* 1989, 1991, 1996). They co-occur with dyke swarms and are consistent with reflect within-plate crustal extension (Pe-Piper *et al.* 1989). Uranium/lead dating of rhyolites best constrains Devono-Carboniferous volcanism in Nova Scotia to the Middle Devonian to late Tournaisian / early Viséan, wherein four main episodes are recognized (Dunning *et al.* 1997). Along the trend of the Cobequid Fault system, volcanics were extruded during the Middle Devonian (385–389 Ma). In western Cape Breton, bimodal basalt–rhyolite suites of the Fisset Brook Formation in Cape Breton terminated in the Late Devonian (373±4 Ma; Barr *et al.* 1995). Extensive volcanism and related plutonism at the Devono-Carboniferous boundary (362–356 Ma) is recorded along the Kirkhill–Rockland-Brook Fault system of the Cobequid Highlands and associated faults in western Cape Breton, in association with transpression (Dunning *et al.* 1997). A subsequent phase of Mid-Dinantian volcanism is discussed below.

Dinantian

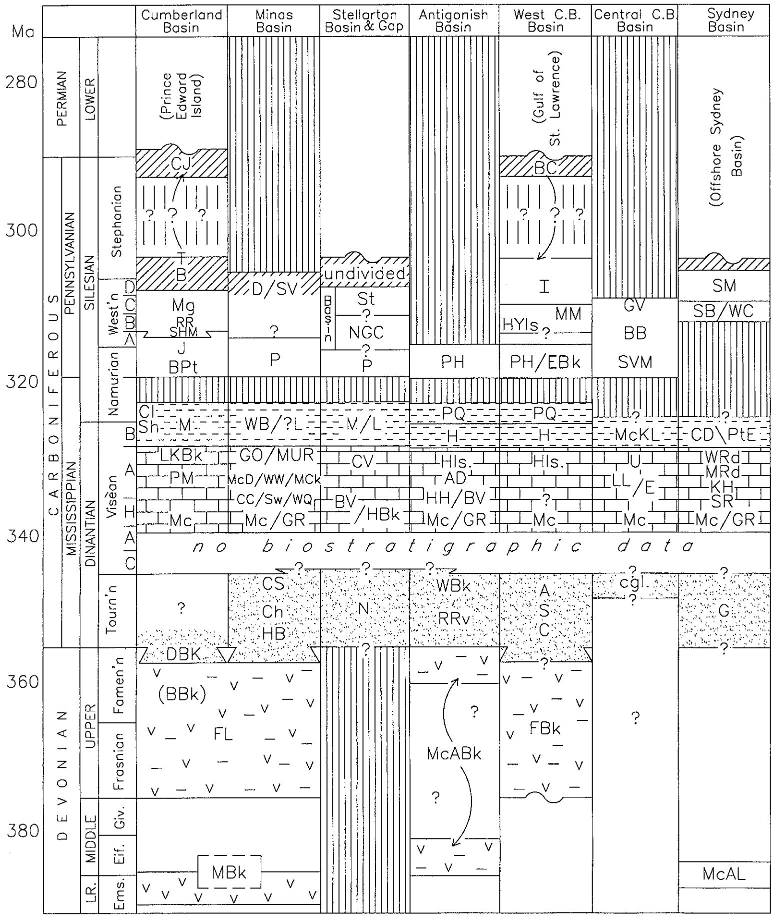
Latest Devonian to Tournaisian

In the latest Devonian and throughout the Tournaisian (Martel *et al.* 1993), predominantly continental alluvium was deposited across all tectono-stratigraphic terranes of both Avalonian and Meguma affinity, confirming the earlier assembly of the Northern Appalachian orogen (Hamblin & Rust 1989). Half-grabens developed adjacent to the Cobequid Fault system in northern Nova Scotia (Martel & Gibling 1991, 1996), the Hollow Fault in western Cape Breton (Hamblin & Rust 1989) and its extension in southwest Newfoundland (Miller *et al.* 1990) and probably within the Moncton Basin of southern New Brunswick as well. These half-graben segments record an early distensional phase of Maritimes Basin development consistent with the rifting proposed by Belt (1968a). Similar half-graben basins developed contemporaneously in the Dinantian of Britain (Leeder 1987, 1988a). This suggests a prevalence of regional distension across central and eastern Euramerica as plates reorganized between the Caledonian–Acadian and Alleghenian–Hercynian orogenies (Hamblin & Rust 1989); in Nova Scotia, basins adjacent to the Cobequid Fault system may have developed as collapse structures in response to thrusting that attended forceful intrusion of Devono-Carboniferous granites (Piper 1994). Mafic intrusions and basaltic flows of late Tournaisian to early Viséan age are scattered widely along the Cobequid Fault zone and from southern New Brunswick through Prince Edward Island to western Cape Breton (Dunning *et al.* 1997) (Fig. 2).

The basin-fill of the half grabens, assigned to the Horton Group (Dawson 1873; Bell 1929) of latest Devonian (Famennian) to latest Tournaisian (T_3) age (Utting *et al.* 1989; Martel *et al.* 1993), ranges from 600 m (Martel & Gibling 1996) or more (1100–1500 m; Bell 1960) in the type area of the Minas Basin to as much as 3000 m in western Cape Breton (Hamblin & Rust 1989). Characteristically, it comprises marginal thick extrabasinal conglomerates (Murphy *et al.* 1994) and a tripartite basinal stratigraphy of alluvial strata above and below intervening lacustrine beds (Hamblin & Rust 1989; Martel & Gibling 1996) (Fig. 5). The lacustrine component has been inferred by these authors to represent a period of accelerated subsidence during which the basins were underfilled. Sediment-starved organic-rich lakes accumulated oil shales (Smith & Naylor 1990). Coarsening upward sedimentary cycles have been ascribed to tectonism (Martel & Gibling 1991), but the lacustrine rocks, which record the effects of storm conditions (Martel & Gibling 1991) doubtless bear witness to climatic cyclicity, yet to be described.

The *Lepidodendropsis corrugatum* compression flora of the Horton Group (Bell 1960) was a cosmopolitan flora of the Tournaisian Old Red Continent (Jongmans 1952; Chaloner & Lacey 1973). The Tournaisian fauna of the Horton Group (see Appendix A) are represented in the aquatic realm by a restricted invertebrate record of ostracods, conchostracans and xiphosurans, and by a more diverse vertebrate fauna of palaeoniscid fish, crossopterygians, dipnoi, gyracanthids and symmoriid and probable other sharks. Recent re-evaluation of microfauna of the Horton Bluff Formation, long held to be solely lacustrine, has revealed the presence of a marginal marine ostracod fauna within profundal to lagoonal beds of the basal Blue Beach Member, including species of the western European genera *Copelandella* and *Carbonita* and the more cosmopolitan *Shemonaella* (Tibert 1996). The elasmobranch shark *Stethacanthus* (Bell 1929, p. 35) is known from the famous Carboniferous marine localities of Bear Gulch, Montana and Bearsden, Scotland.

Table 2. *Formations of the Carboniferous basin-fill of Nova Scotia*[a]



[a] Modified after Gibling (1995). Absolute age dates after Cowie & Bassett (1989).

The Tournaisian strata of Nova Scotia nonetheless are prevailingly continental (Belt 1968b) in contrast to the widespread marine beds of western Europe (Leeder 1988*a*) and afford an important locality for establishing the early evolution of terrestrial vertebrates, recorded in both trackways and osteological remains. Skeletal remains from Horton Bluffs include an anthracosauran reptiliomorph, comprising the earliest tetrapod record in both western Euramerica and the western hemisphere exclusive of Greenland (Carroll *et al.* 1972) and the only known Tournaisian tetrapod locality (Milner *et al.* 1986; Carroll 1992; Ahlberg & Milner 1994).

Viséan

Whereas the uppermost Horton strata dated are latest Tournaisian and the oldest dated succeeding strata of the Windsor Group (Lyell 1843*a*, *c*; Bell 1929) are of mid-Viséan (V_2 to early V_3) age, the possibility exists of a hiatus during part of the early (V_1) to middle (V_2) Viséan (Utting *et al.* 1989) (Fig. 5). Although the gap could be apparent given the paucity of age data from red beds of this interval (Utting *et al.* 1989), the regional stratigraphic relationship of the two groups suggests otherwise: the isochronous base of the Windsor overlies Horton rocks of variable Tournaisian age, and nowhere has an unequivocally continuous record been documented between the two groups (P. S. Giles, pers. comm. 1997).

During the mid-Viséan, marine waters breached the Maritimes rift valley from the east, rapidly transgressing as far as the New Brunswick Platform (Fig. 2) (Bell 1929; Mamet 1970; Howie 1984). The body of water known as the Windsor Sea was a restricted, hypersaline tropical gulf near the scale of the Caspian Sea (Schenk *et al.* 1994). The sea opened to the northeast (Schenk 1969; pers. comm. 1997) of present-day Nova Scotia and east to southeast across the Meguma terrane (Mamet 1970; Giles 1981a; Howie 1984). There, in the east, an equatorial Phoibic seaway (McKerrow & Ziegler 1972), inferred to have been westward circulating (Allen & Dinely 1988), existed between the continental margins of the Old Red Continent (Laurussia) and Gondwana. At this time, marine conditions prevailed across much of tropical Euramerica (Bell 1929; Bless *et al.* 1987; Rast 1988), and the rapid incursion of the sea into the Maritimes rift valley may have occurred as the seaway became compressed by the convergence of Gondwana and the Old Red Continent; alternatively, regional distension across the Maritimes–Western-European province may have ushered in the sea. The marine carbonate–sulphate strata intertongue towards basin margins locally with red conglomerates of the Grantmire Formation (Schenk 1969) and in New Brunswick with conglomerates

Table 2. *Key.*

FORMATIONS

Pictou Group: ▨
B – Balfron
BC – Broad Cove
CJ – Cape John
T – Tatamagouche

Cumberland Group: □
BB – Big Barren
BPt – Boss Point
D – Delaney
EBk – Emery Brook
GV – Glengarry Valley
HYls – Henry Island
I – Inverness
J – Joggins
Mg – Malagash
MM – Mabou Mines
NGC – New Glasgow Conglomerate
P – Parrsboro*
PH – Port Hood
RR – Ragged Reef
SHM – Springhill Mines
St – Stellarton
SV – Scotch Village
SVM – Silver Mine

Mabou Group: ▤
CD – Cape Dauphin
Cl – Claremont*
H – Hastings
L – Londonderry
M – Middleborough
McKL – McKeigan Lake
PQ – Pomquet
PtE – Point Edward
Sh – Shepody
WB – West Bay

Windsor Group: ▦
AD – Addington
BV – Bridgeville
CC – Carroll's Corner
CV – Churchville
E – Enon
GO – Green Oaks
GR – Gays River
HBk – Holmes Brook
HH – Hartshorn
HIs – Hood Island
KH – Kempt Head
LKBk – Lime Kiln Brook
LL – Loch Lomond
Mc – Macumber
MCk – Miller Creek
McD – MacDonald Road
MUR – Murphy Road
MRd – Meadows Road
PM – Pugwash Mine
Sw –Stewiacke
SR – Sydney River
U – Uist
WQ – White Quarry
WRd – Woodbine Road
WW – Wentworth

Horton Group: ░
A – Ainslie
C – Creignish
Ch – Cheverie
CS – Coldstream
DBk – Diamond Brook
F – Falls
G – Grantmire
HB – Horton Bluff
S – Strathlorne
WBk – Wilkie Brook

Fountain Lake et al. V
BBk – Byers Brook
FBk – Fisset Brook
FL – Fountain Lake
MBk – Murphy Brook
McABk – McArras Brook
McAL – McAdam Lake

of the Hopewell Cape Formation during the Mid Viséan (McCutcheon 1981). In southwestern Cape Breton, small gabbroic plutons and possible sills are coeval with the Windsor Group (U/Pb: 339 ± 2 Ma) and are inferred to reflect continued extension (Barr *et al.* 1994).

The Windsor Sea in its early history subsequent to its breach of the Maritimes Rift has been called Loch Macumber (Schenk *et al.* 1994); the widespread, basal Macumber Formation records relatively deep water with profundal laminated carbonate and mudrock associated with turbidite and debris flow deposits. The deeper basinal waters shoaled laterally, where formed lime mud reefs or hydrothermal tufa mounds of the Gays River Formation. Subsequent to the accumulation of evaporite deposits hundreds of metres in thickness, the Windsor seafloor became exposed subaerially (Schenk *et al.* 1994) with playa flats and subsequent karstification (Boehner 1986). This transgressive–regressive cycle (Subzone B of Bell 1929; Cycle 1 of Giles 1981a) defines a stratigraphic sequence (Schenk *et al.* 1994). Four subsequent sequences in the upper Windsor Group record repeated rapid transgression and protracted withdrawal from the Maritimes rift valley during the mid and late Viséan (Bell 1929; Schenk 1969) (Fig. 5). They comprise cyclic stratal successions of carbonate, thin red claystone, sulphate and thick red claystone that have been interpreted as algal carbonate strandlines shoaling to supratidal, dolomitizing salt flats with saline lakes and lagoons (Schenk 1969). Upon these sequences are superimposed numerous parasequence cycles recording lesser regressions (Giles 1981a; Schenk *et al.* 1994). The total thickness of Windsor strata is difficult to determine in areas of diapirism, but in the Minas Basin area is in the order of 800–900 m (Boehner 1986).

The transgressive–regressive sequences of the Windsor correlate approximately with the mid-Arundian to Brigantian of Britain and Belgium (Giles 1981b), represented by mid-mesothem 3–6 of Ramsbottom (1977). The driving mehanism of these sequences has been inferred to have been glacioeustacy (Giles 1981b), possibly caused by the waxing and waning of the developing Gondwanan ice cap (Crowell 1978; Veevers & Powell 1987; Gonzalez-Bonorino & Eyles 1995). The Windsor transgressive–regressive cycles mimic the strong asymmetry of glacial ice-cap meltout and growth evidenced by the oxygen isotope record from Pleistocene ice (Chappell & Shackleton 1986). The accumulation of thick evaporite deposits must also have contributed to progressive shoaling (Schenk *et al.* 1994).

The Viséan marine macrofauna record in Nova Scotia (Appendix A) is most prolific in the deeper-water Macumber limestone of the B subzone (Bell 1929, pp. 66–68), which also contains an undescribed fish fauna (R. G. Moore pers. comm. 1997). The subsequent faunal record derives primarily from carbonate units (Moore 1967), where the low diversity of bottom dwellers reflects adverse biotic conditions imposed by the shallow muddy carbonate sea bottom. The resulting meagre crinoid and echinoderm fauna contrasts with that of interior North America (Bell 1929). Suspension feeders such as the articulate brachiopod productids and *Composita* dominated, which together with pelecypods and gastropods, comprised a mollusc–brachiopod fauna (Bell 1929). The abundant pelecypod fauna is akin to that of northern Britain, where similar substrate conditions to those in Nova Scotia are inferred. The coral fauna, primarily Rugosa and Tabulata, is strikingly less abundant, albeit with notable exceptions such as in the Musquoboboit sub-basin (Boehner 1977), than in coeval sandy shelf areas of southern Britain. Taken together, these faunal elements suggest unstable substrate and salinity and restricted circulation within the Windsor gulf (Bell 1929; McKerrow 1978).

Restricted circulation is recorded as well in the increasing fractionation of evaporitic brines from carbonates through calcium sulphate to salts northwestward across the Maritimes Basin (Howie 1984). This fractionation suggests a palaeogeographic restriction of the Windsor Sea, either by shoaling or by straits, from deeper waters in western Europe, where carbonates prevail. The existence of straits above a basement low on the Grand Banks east of Newfoundland has been suggested (Geldsetzer 1978). The faunal record has been interpreted to indicate that normal marine conditions were approached only by the upper Viséan (Bell 1929). Corals overlain by thick sulphate and halite deposits in the upper Windsor Group, however, indicate that unstable salinities prevailed throughout the history of Windsor Group regressions (P. S. Giles, pers. comm. 1997).

The mollusc–brachiopod fauna of Nova Scotia show strong affinity with that of northwestern Europe, and therefore were interpreted by Bell (1929) before the theory of continental drift as common residents of a 'proto-North Atlantic', whereas in contrast, the Mississippian marine fauna of interior North America show but scant evidence of 'distant migratory connexions'. Benthonic foraminifers of the upper Viséan of the Maritimes Basin and eastern Newfoundland shelf, however, have affinity to North American fauna rather than the Tethyan fauna of western Europe, which suggests that a deep ocean barrier between Tethys and the Windsor Sea existed at this time (Jansa *et al.* 1978; Jansa & Mamet 1984). Evidence in support of the persistence of such a Mid-Euramerican Sea in the Silesian is discussed subsequently in this paper.

The ultimate withdrawal of the Windsor Sea from the Maritimes Basin by the late Viséan may have been a consequence of a major phase of Gondwanan glaciation and a consequent fall in global sea level. (Gibling 1995; Veevers & Powell 1987). The withdrawal pre-dates, however, the Namurian maxima inferred for the Gondwanan ice cap (Gonzalez-Bonorino & Eyles 1995) and is inconsistent with documented major global regressions (Veevers & Powell 1987), including the Mississippian–Pennsylvanian boundary event (Saunders & Ramsbottom 1986). At the same time across Euramerica, the converging circumequatorial continents heralded a Mid-Carboniferous episode of thrusting, transpression and inversion, discussed below, which had potential to effect a similar result.

Following withdrawal of the Windsor Sea, a semiarid climate persisted through the late Viséan as lake margins of the Hastings Formation, basal Mabou Group, contracted and desiccated, depositing cyclic 'cementstone' carbonate and red beds (Belt 1968*b*) in a schizohaline, inland mimic of the marine cycles of the earlier Viséan (Crawford 1995; cf. Leeder 1992). The predominance of grey beds and growth lines of the pelecypod *Carbonicola*, which span up to 10 years (E. S. Belt, pers. comm. 1997) has been cited as evidence in support of the persistence of deeper parts of the Mabou lakes; the ecology of *Carbonicola*, oft stated as 'brackish', is key to this argument.

Halokinesis, with flow into kilometre-scale diapirs and salt anticlines adjacent to basement fault blocks, deformed much of the Windsor Group and locally, the subsequent Permo-Carboniferous basin-fill (Bell 1944, 1958; Howie 1988; Boehner 1992; Brown *et al.* 1996). Extensional detachment faulting of possible basin-wide extent within the Windsor Group (Lynch & Giles 1995) and major salt movements (Bell 1944; Boehner 1992) were initiated early in the subsequent depositional history of the basins, possibly as early as the late Namurian, subsequent to deposition of the Mabou Group (Lynch & Giles 1995) and the Mid Carboniferous event discussed below. The halokinetic history of the Maritimes Basin fill as a whole stands in marked contrast to the Carboniferous of North America and western Europe.

Silesian

Namurian

The Namurian set the stage for the most profound changes in basin evolution during the Carboniferous in Nova Scotia, events that can be linked to the evolution of Euramerica. The Mabou Group (Belt 1964, superseding the Canso Group of Bell 1944, with revisions below) succeeds the Windsor Group in the late Viséan and persists through the Namurian A/B (Neves & Belt 1970). The age of the uppermost Mabou strata has proved to be especially problematic (see below); similar uncertainties in age attend red-bed-dominated strata within the Carboniferous basin-fill (Fig. 6; see also Neves & Belt 1970). The group attains a thickness of at least 3000 m in Nova Scotia (Belt 1965; Lynch & Giles 1995), where typically it is fine grained (Belt 1965; 1968b). Widespread grey beds of the Hastings and equivalent formations first were deposited throughout most basinal depocentres in Nova Scotia, and persisted adjacent to the Cobequid Fault in the Minas Basin, succeeded regionally by red mudrock-dominated strata of the Pomquet Formation (Belt, 1965, fig. 5). The younger grey strata of the Parrsboro Formation are assigned herein to the Cumberland Group as redefined by Ryan *et al.* (1991), as similarly advocated for the Emery Brook Formation (Giles 1995), formerly of the Mabou Group (Belt 1965).

The early to mid-Namurian aquatic fauna is typified by eocarid and conchostracan crustaceans and by sarcopterygian fishes, ctenacanth sharks and acanthodians represented by *Gyracanthus* (Fig. 6a) which has a sparse record elsewhere in North American Euramerica (Baird 1978). The absence of open marine fauna, however, underscores the relatively landward or inland position of the Mabou beds. The eocarid *Pseudotealliocaris* (Fig. 6c) and *Anthracophausia* fauna of the lower Mabou Group (Copeland 1957) have been interpreted elsewhere to be representatives of a nearshore marine community (Schram 1981). Within the lower Mabou occur also the ostracods *Shemonaella (Paraparchites) scotoburdigalensis* and *Beyrichiopsis* sp., which are indicative of a nearshore environment and which are found also in the Dinantian of Scotland (Copeland 1957; Tibert 1996). It is possible, therefore, that maximum transgressions from the retreating Windsor Sea continued for some time to influence the basinal waters of the Maritimes during deposition of the succeeding strata, the Mabou Group. The basal Hastings Formation may be the best candidate for recording a change from marine to lacustrine deposition (Crawford 1995). Continental deposition to which the Mabou Group historically has been ascribed (Belt 1968*b*), probably predominated, especially in the upper strata (Copeland 1957), but the ecology of the aqautic fauna should be studied further in order to ascertain whether transgressions still were still experienced from the withdrawing sea. The terrestrial vertebrate fauna of the late Viséan–Namurian is best recorded in the exceptional trackway record of the West Bay Formation of the Minas Basin (Carroll *et al.* 1972; Sarjeant & Mossman 1978).

The Mid-Carboniferous break/event in Nova Scotia: Mabou–Cumberland contact

The most profound changes in basin evolution and palaeoclimate during the Carboniferous evolution of Nova Scotia occurred during the mid-Namurian between the deposition of the Mabou Group and the disconformable to unconformable Cumberland Group (Fig. 5). Namurian (K/Ar: 329 ± 11 Ma) deformation and overthrusting of plutons emplaced adjacent to the terrane-bounding Cobequid Fault in the early Dinantian have been interpreted to be a consequence of transpression or convergence of the Meguma and Avalon terranes along the Cobequid Fault (Waldron *et al.* 1989; Pe-Piper *et al.* 1991). Dextral transpression is inferred to have inverted the Cobequid and Caledonia massifs adjacent to the Cumberland Basin (Fig. 2), and strata of Namurian B age were later cannibalized by early Westphalian deposystems of the basin, as witnessed by reworked spores in the Westphalian strata (Dolby *in*

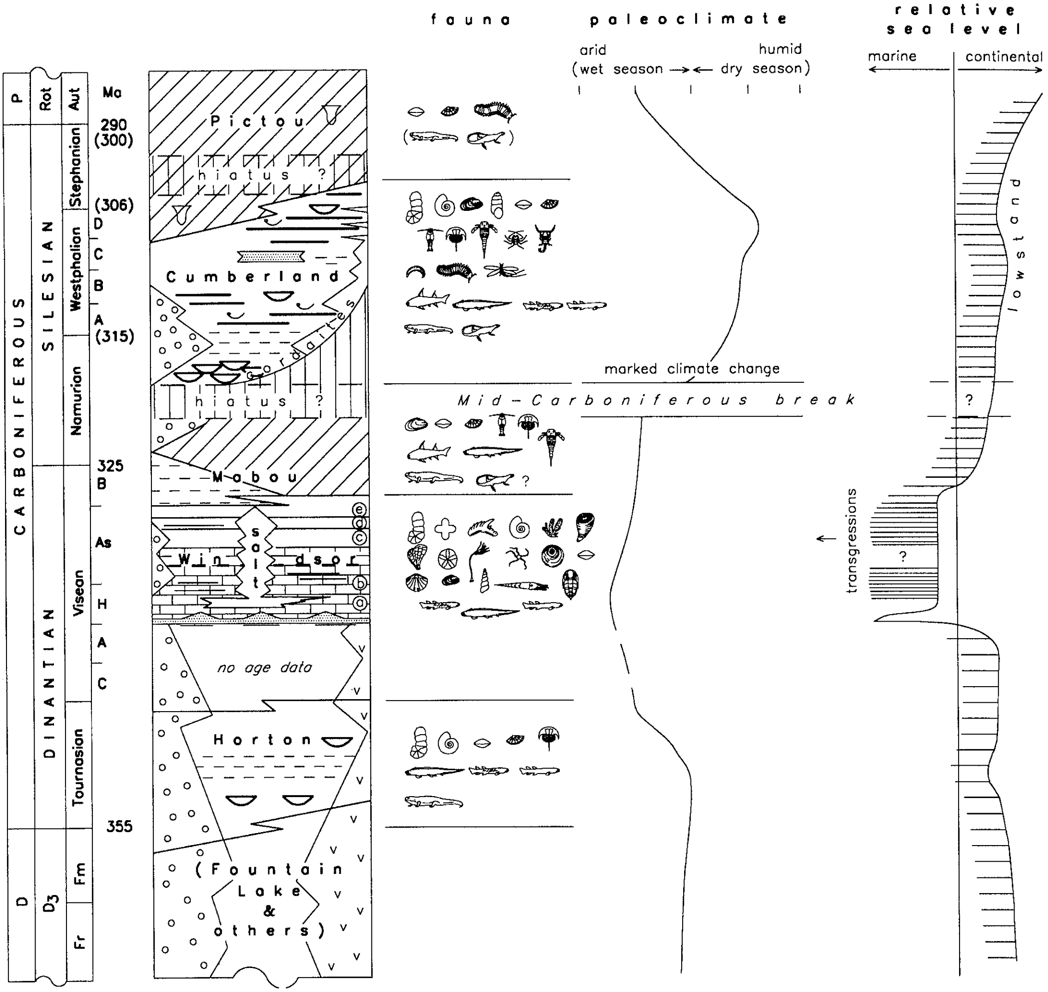


Fig. 5. The stratigraphic column for the Carboniferous basin-fill of the southern Maritimes Basin in Nova Scotia, with representative faunal groups and inferred palaeoclimate and sea-level curves. Sea-level curve for the mid to late Viséan modified after Giles (1981*b*); absolute age dates after Cowie and Bassett (1989), and Hess and Lippolt (1986) (in parentheses).

press). An intra-Namurian disconformity may be recorded in the miospore palynostratigraphy (Utting, pers. comm. 1997), but its placement remains equivocal at present.

This regional Namurian event in Nova Scotia deformed to varying degree the entire Dinantian basin-fill of the Maritimes (Hamblin & Rust 1989) and defines a change in basin evolution from extensional to transtensional and transpressive (Gibling 1995). Supporting evidence of both the

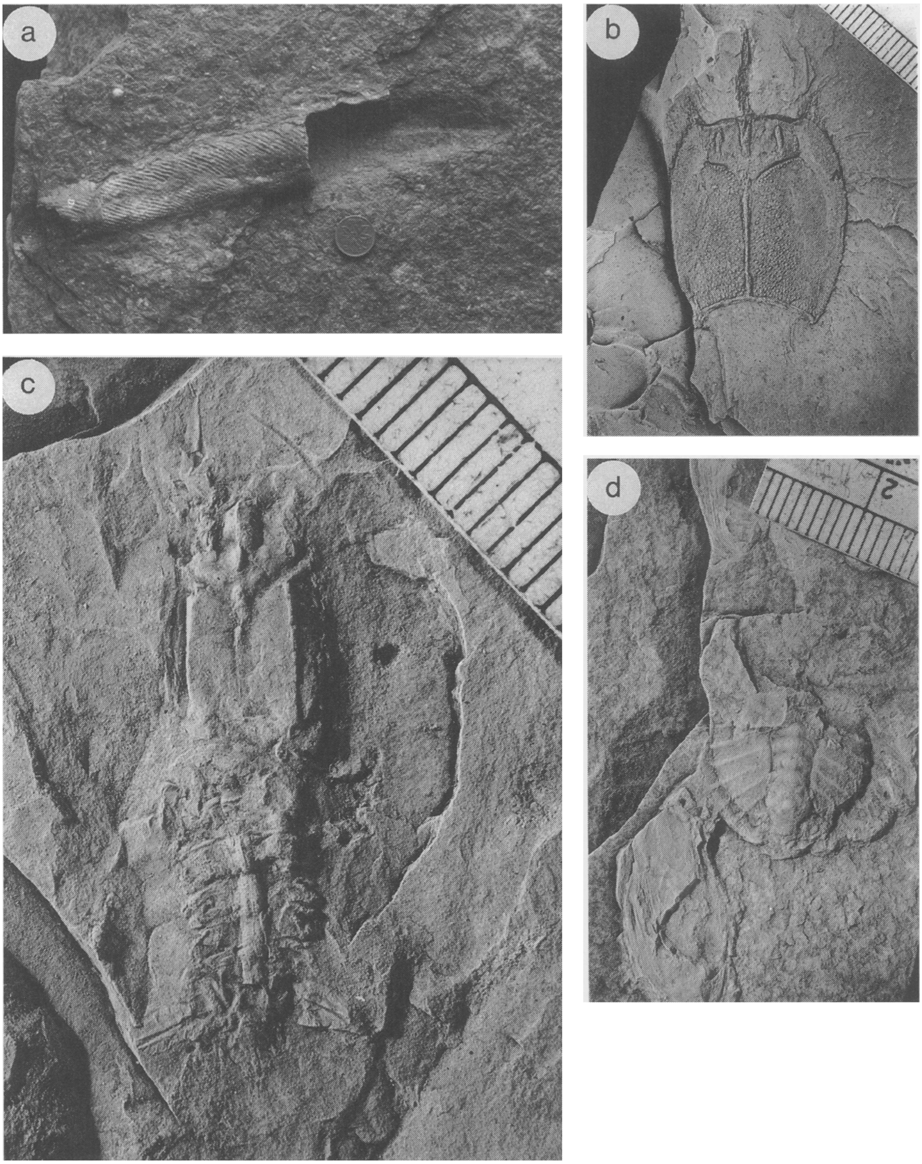


Fig. 6. Selected fossils from the aquatic realm of the Carboniferous basin-fill of Nova Scotia. (a) *Gyracanthus cf. duplicatus*, NSMNH No. FGM.998.GF.1, Joggins Formation, Cumberland Group (Westphalian A); (b) *Pygocephalus (Anthrapalaemon) dubius*, dorsal view of carapace, Hypotype, GSC No. 12821, Joggins Formation, Cumberland Group (Westphalian A); (c) *Pseudotealliocaris (Tealliocaris) belli*, dorsal view of type specimen, Holotype, GSC No. 10381, West Bay Formation, Mabou Group (late Viséan – Namurian); (d) *Euproöps amiae*, ventral view of abdominal segments, Hypotype, GSC No. 12808a, Sydney Mines Formation, Cumberland Group *sensu latu* (Westphalian D).

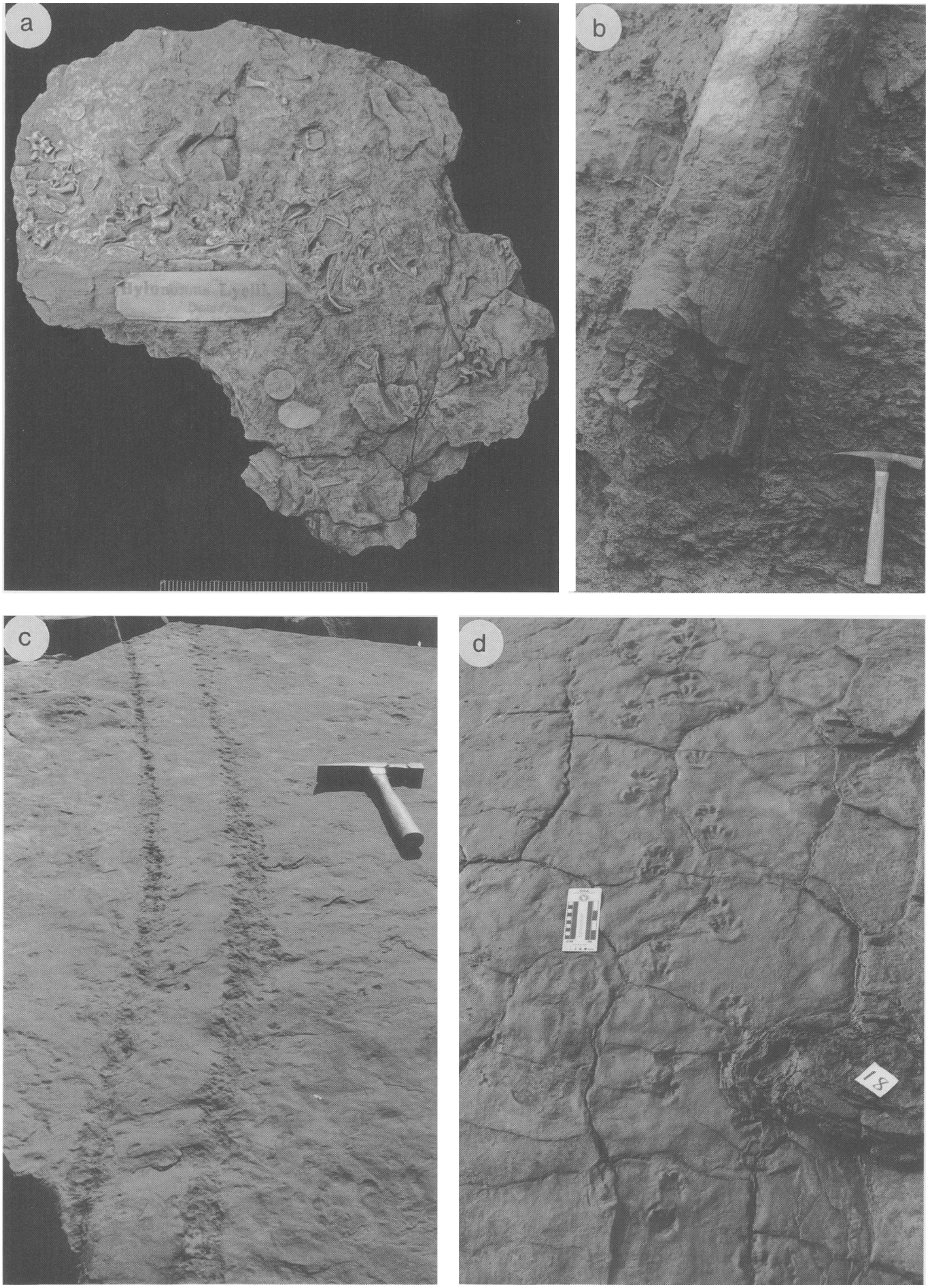


Fig. 7. Selected fossils from the terrestrial realm of the Permo-Carboniferous basin-fill of Nova Scotia. (a) *Hylonomus lyelli*, Holotype, NHM R4168, Joggins Formation (Westphalian A); (b) erect cast of a lycopsid tree, Joggins Formation, Cumberland Group (Westphalian A); (c) *Diplichnites sp.*, ichnogenus ascribed to *Arthropleura*, Joggins Formation, Cumberland Group (Wetphalian A); (d) *Amphisauropus latus* trackway, ascribed to a seymouriamorph cotylosaur, impressed in dessication-cracked redbeds adjacent walchian conifer stump casts, Cape John Formation, Cumberland Group (Carboniferous–Permian boundary beds).

timing and locus of deformation is found in the structural deformation (Hamblin & Rust 1989) and elevated thermal maturity of the Horton (Utting & Hamblin 1991) and Mabou Groups adjacent to the Cobequid Fault zone in the northern Minas Basin and in the Stellarton Gap, relative to Westphalian strata above, which generally are unaffected by the thermal event. A Mid-Carboniferous event, the 'Maritimes Disturbance' (Poole 1967), has long been recognized although poorly constrained and loosely defined. Its timing and significance as described herein are now becoming more fully understood.

This late Namurian event in Nova Scotia links the Variscan and Alleghanian orogenies (Nance 1987; Gibling 1995), with dextral transpression accomodating Alleghanian thrusting in the central and southern Appalachians (Quinlan & Beaumont 1984). The event coincides approximately with the Mississippian–Pennsylvanian boundary of continental North America (see Rehill 1996, fig. 4.3), which is marked by a widespread and pronounced unconformity across the Appalachian Basin (White 1891; Ettensohn & Chesnut 1989), and in shelf areas globally (Saunders & Ramsbottom 1986). This unconformity has been ascribed to a global eustatic event (Donaldson *et al.* 1985), which resulted in extinctions in the marine realm and marked evolutionary changes (Saunders & Ramsbottom 1986). In the Appalachian Basin, the unconformity coincides with early stages of the Alleghanian orogeny and has been ascribed to continental flexure (peripheral bulge according to Quinlan & Beaumont 1984) caused by continental convergence; foreland areas of greater subsidence cratonward of continental promontories do not record the unconformity (Ettensohn & Chesnut 1989). Evidence for a Mid to Late Namurian hiatus is found as far west as the Porcupine Basin of the western Irish shelf, which represents the westernmost edge of Carboniferous Europe (Tate & Dobson 1989).

The late Namurian and early Westphalian response to the events of the Namurian is recorded in a change in dominant depositional system from lacustrine to fluvial, the 'Coarse Fluvial Facies' of Belt (1964, 1965), now referred to the Cumberland Group (Ryan *et al.* 1991; redefined after Bell 1944). Across the Maritimes Basin an unparalleled cosmopolitan alluvial facies north of the Cobequid Fault dominantly comprising multistorey sandstones up to 90 m thick, the Boss Point Formation and equivalents, records response to seasonal rainfall and erosion of inverted and uplifted source areas southwest of the Maritimes Basin (Browne & Plint 1994). The distinctive composition of these mature Boss Point sandstones favoured both their use as grindstones and building stones during the nineteenth century and their assignment to the Millstone Grit (Brown 1829).

The establishment of these widespread river systems was preceded by deposition in northwestern Nova Scotia and southern New Brunswick of red extrabasinal conglomerate and grit with reduction haloes, assigned to the Claremont and equivalent Enragé formations, which bespeak locally sourced deposition before the palaeoclimate changeover. Although currently included in the Cumberland Group (Ryan *et al.* 1991), their lithology, fossil record and the possibility of an intervening mid-Namurian hiatus point to their affinity with the Mabou Group. The sandy Boss Point river systems incorporated pedogenic calcrete, inferred to have been eroded from vertisols and aridosols (Browne & Plint 1994), although in some cases these may represent truncated soils (F. W. Chandler, pers. comm. 1997). Great cordaite trees, characteristically found in a permineralized state (*Dadoxylon acadianum*; Dawson 1868), were consumed from the inverted hinterland or from riparian sites and are found from the type section north of Joggins in the Cumberland Basin to the Port Hood section of the Western Cape Breton Basin. A simultaneous, marked introduction of the saccate cordaite pollen *Florinites* accompanies these macroflora (Dolby 1991; in press). A permineralized cordaite flora occurs above the Cumberland–Mabou unconformity in the Sydney Basin in strata as young as the mid-Westphalian South Bar Formation (R. Chisholm, pers. comm. 1997).

Bell (1944, p. 24) concluded that in the continental record of Nova Scotia, 'The top of the Canso [Mabou] group marks the most pronounced palaeontological break in the sequence of Canadian maritime Carboniferous floras.' This break is mirrored in the miospore record (Dolby pers. comm. 1997), but Copeland (1957) observed no such abrupt change in the arthropod record.

Westphalian

A period of rapid basinal subsidence unsurpassed in Euramerica, wherein 1000 m of strata may represent as little as one million years (Calder 1994), was generated in the southern and central Maritimes Basin by transcurrent wrench faulting, from the Late Namurian through Duckmantian/Westphalian B persisting locally through the Bolsovian/Westphalian C to early D. The dextral transpression of the Meguma against the Avalon terrane to the north (Fig. 2) resulted in inversion of the Caledonia massif in New Brunswick and the Cobequid massif north of the Cobequid Fault (Waldron *et al.* 1989). In southeastern New

Brunswick (Fig. 2), this dextral movement generated west-directed thrusting during the early to mid-Westphalian (Plint & van de Poll 1984), and consequent reworking of Devono-Carboniferous sediment in alluvial fans of the Cumberland Group. Concurrent with both these changes in palaeoclimate and basin tectonics, coal measures of Late Namurian to Cantabrian age were deposited diachronously in virtually all depocentres. The Cumberland Group coal measures range in thickness from less than 2 km in the Sydney Basin (Bell 1938) to 2.7 km in the Stellarton Basin (Hacquebard 1972) and 4 km in the Cumberland Basin, where they are associated with extensive alluvial fan deposits (Calder 1994).

Subsequent to the widespread deposition of the Boss Point and equivalent sandstones, rapidly subsiding depocentres bordered by alluvial fans developed in the latest Namurian and early Westphalian in basins adjacent the Cobequid and Hollow Faults. The early fine-grained fill of these basins, exposed at Joggins in the Cumberland Basin, the Parrsboro shore of the Minas Basin and along the Port Hood section of western Cape Breton Island, shows a remarkably similar lithology and fauna, dominated by mudrock alternating with metre-scale sheet sandsone bodies, with thin humic to sapropelic coals, some of which are overlain by basin-wide persistent black, organic-rich and bivalve-bearing shale or limestone. These fossiliferous beds yield a pelecypod–ostracod bivalve, eocarid pygocephalomorph and syncarid crustacean and varied, disarticulated fish fauna (Appendix A). The Emery Brook Formation bears biostratigraphic and lithostratigraphic affinity to these strata as well, which supports its reassignment from the Mabou to the Cumberland Group (Giles 1995).

During the early Westphalian, regional basin inversion (Waldron *et al.* 1989) led to a widespread diastem in the Duckmantian/Westphalian B of the Maritimes Basin (Bell 1944), but in the Cumberland Basin transpression along the Cobequid Fault created positive uplift of the neighbouring massifs and transtension of the Athol Syncline, which consequently became the main depocentre of this time in the Maritimes Basin. Before continuing their preferred northeastward course (Gibling *et al.* 1992), through-flowing rivers were diverted southward into the Cumberland Basin (Browne & Plint 1994; S. J. Davies & M. R. Gibling pers. comm. 1997). Rheotrophic mires developed in distributary settings and in areas of groundwater recharge along the northern Cobequid alluvial fan piedmont, under a humid climate prohibitively seasonal for the widespread development of raised mires (Calder 1994).

At this time, dextral strike-slip of the parallel Hollow and Cobequid Faults in the Stellarton Gap between the Cobequid and Antigonish massifs initiated an equally rapidly subsiding pull-apart basin (Yeo & Ruixiang 1987). Lacustrine sedimention predominated in the pull-apart through the Westphalian C/Bolsovian and early D (Bell 1940; Naylor *et al.* 1989; Yeo & Ruixiang 1987), with thick, rheotrophic peat accumulation resulting in bituminous coal beds up to 13.4 m thick (Hacquebard & Donaldson 1969; Calder 1979) and organic-rich cannel shales in deeper water during periods of underfilling (Smith & Naylor 1990; Smith *et al.* 1991). Elsewhere, red beds with calcrete-bearing vertisols (Chandler 1997) developed widely.

By the Westphalian D, diminished subsidence rates attended the thermal sag experienced earlier in the Pennine and neighbouring basins of the British Isles, although sporadic thermal events continued along the Avalon–Meguma terrane boundary at least until the late Westphalian (K/Ar: 303 ± 11 Ma; Waldron *et al.* 1989). Widespread peat accumulated across the Sydney Basin (Hacquebard & Donaldson 1969; Marchioni *et al.* 1994) and beneath the Gulf of St Lawrence (Hacquebard 1986; Grant 1994; Rehill 1996) on near coastal plains where the effects of glacioeustacy were felt in the cyclothemic alternation of peat formation and palaeovalley incision of red beds (Gibling & Bird 1994). Fauna of the coal roof strata include the xiphosuran *Euproöps amiae* (Fig. 6d), which is exclusive to the strata of the eastern Sydney Basin (Copeland 1957) and agglutinated foraminifera, which show an easterly gradient from upper to lower estuarine environments (Wightman *et al.* 1993). The oppportune 'coal window' for peat accumulation (Calder 1994; Calder & Gibling 1994) and succeeding changeover to red beds was broadly diachronous from west to east across the Maritimes Basin in Nova Scotia, with the exception of widespread early fluviolacustrine deposits coeval with the basal Joggins coals. By the Stephanian, the last vestiges of mires and hydromorphic gleysols had all but given way to the deposition of red beds across the Maritimes Basin.

Stephanian to Lower Permian

In the Westphalian D to Lower Permian (Barss & Hacquebard 1967), continental red beds of the Pictou Group (Bell 1944; redefined by Ryan *et al.* 1991) were deposited widely across the Maritimes Basin during a period of regional thermal sag and growing aridity. The Pictou red beds reach 1650 m in thickness in the Cumberland Basin (Ryan *et al.* 1991) and 3000 m northward in the Gulf of St Lawrence (van de Poll *et al.* 1995). By the end of the Cantabrian (Zodrow & Cleal 1985), lepidodendrid-based wetland ecosystems, last witnessed in Nova Scotia by the fossil forest at Cranberrry Head, Sydney Basin, collapsed and were replaced by a mesic to xeric flora, recorded in the compression flora by taxa such as *Pecopteris arborescens*, *Cordaites* sp. and *Walchia* sp.

The paucity of fossil fauna and flora from the latest Carboniferous basin-fill of the Maritimes can be ascribed to loss of habitat, particularly for wetland and aquatic biota, and also for environments conducive to the preservation of fossils. This has proved troublesome in defining the chronostratigraphy of the Stephanian to Permian red beds; indeed Bell (1944), who defined the age relationships of the Carboniferous of Nova Scotia primarily on the basis of macroflora, considered the basin-fill in Nova Scotia to be no younger than Westphalian D. The miospore record (Barss & Hacquebard 1967) indicates that the youngest red beds of the Maritimes Basin reach into the Permian. Abundant *Vittitina* from the Cape John Formation lend support to an Early Permian age for the uppermost red beds in Nova Scotia (Dolby 1991). The possibility of a mid-Stephanian hiatus within the red beds of Euramerica, although suggested in Nova Scotia (Wagner & Lyons 1997), has yet to be recognized definitively here and will be challenging to ascertain because of the dearth of biostratigraphic data for the red beds of this time interval. Paraconformities between late Silesian formations in the Tatamagouche Syncline of the eastern Cumberland Basin (Ryan *et al.* 1991) warrant closer inspection in search of an intra-Stephanian hiatus.

Eloquent testimony to the age and environment of the uppermost red beds of the Maritimes Basin fill in Nova Scotia has recently been discovered in red beds of the Cape John Formation of the Pictou Group, Cumberland Basin (Calder *et al.* in press). At Brule, on the Northumberland Strait, the only known walchian conifer forest is preserved within thinly bedded, mud-draped silty sandstones with pervasive desiccation cracks, infilling a monsoon-fed dryland river bed. Impressed within the red beds (Fig. 7d) is a prolific record of vertebrate trackways that bear close affinity to the lower Rotliegend ichnofauna of western Europe, including *Amphisauropus latus, A. imminutus, Batrachichnus delicatulus* aff. *B. (Anthichnium) salamandroides, Varanopus microdactylus* and *Dimetropus nicolasi* (Calder *et al.* in press). Included are ichnotaxa that are rare or excluded west of the Appalachian Mountains, suggesting that the Appalachians continued to pose a barrier to terrestrial species exchange between North America and the Maritime–West-European province until the end of the Carboniferous.

The final assembly of Pangaea brought about basin inversion regionally both in the Maritimes Basin (Ryan & Zentilli 1993) and in basins of western Europe (Leeder 1988a). Fission track data suggest unroofing of 1500–4000 m of strata from the Maritimes Basin during the time interval 280–200 Ma (Ryan & Zentilli 1993), and a pronounced unconformity exists between Carboniferous and Triassic strata of the Mesozoic Fundy Rift along the Minas Basin.

The Carboniferous fossil record of Nova Scotia

One of the most notable aspects of the Carboniferous palaeontology of Nova Scotia is its affinity to western Europe (Bell 1929, 1944; Baird 1978; Zodrow & Vasey 1986), at least since the Acadian orogeny and closing of the Iapetus Ocean (Nowlan & Neuman 1991). The faunal record of the Carboniferous basin-fill in Nova Scotia (Appendix A) is compiled herein, in part from unpublished data, for the first time since the pioneering work of Lyell's contemporary of the nineteenth century, Sir William Dawson. The faunal list will provide the reader with details of the taxonomic groups discussed in the paper and hopefully will induce subsequent researchers to make further comparisons with the palaeontological record of Euramerica in North America and Europe. The chronostratigraphy of the Carboniferous of Nova Scotia was developed foremost on the basis of floral biostratigraphy, but with notable exceptions (Zodrow & Cleal 1985; Zodrow & Vasey 1986) has been underutilized in recent decades. The macroflora taxonomy, although in need of revision, similarly is compiled here for the first time in recognition of its fundamental importance to the chronostratigraphy of the Nova Scotian Carboniferous (Appendix B). Systematic study of the revised macrofloral taxonomy, such as that undertaken for the later Westphalian and Stephanian by Zodrow & Cleal (1985) is required to realize their potential contribution to Maritimes Basin and Euramerican correlation (Wagner & Lyons 1997).

The terrestrial environments that attended the lower sea levels of the Maritimes Basin favoured the evolution and migration of early tetrapods. The Nova Scotia record is particularly significant during the Tournaisian, when tetrapods are virtually unknown elsewhere in the world (Carroll 1992; Ahlberg & Milner 1994). Seasonality and fluctuating water levels may have contributed to the evolution of terrestrial vertebrates, and early amniotes in particular. The record in Nova Scotia of terrestrial vertebrate evolution during the Carboniferous, both osteological (Carroll *et al.* 1972) and ichnological (Sarjeant & Mossman 1978; Calder *et al.* submitted), may be the most complete of equatorial Euramerica. The fossil record in Nova Scotia of tetrapods spans the earliest Carboniferous to earliest Permian, interrupted only by the marine conditions of the mid to late Viséan, and here too the regressive shorelines may yet prove to be productive. Conspicuously absent from this predominantly terrestrial record, however, are the aquatic lepospondyls (Carroll *et al.* 1972).

To the vertebrate record can be added a fuller account of invertebrate and plant life during this formative period in the evolution of terrestrial ecosystems. Fossil forests exposed on the sea coast range from earliest Carboniferous *Lepidodendropsis* stands of the Horton Group to a late North American example of a lepidodendrid forest of the Cumberland Group coal measures in the Cantabrian and the only known example in the world of the succeeding xeric conifer *Walchia*, at the Permo-Carboniferous boundary.

Aquatic fauna: how 'nonmarine' ?

Apart fom the marine fauna of the Viséan, virtually all other aquatic fauna of the Carboniferous in Nova Scotia historically have been described as nonmarine, which, as asserted in this paper, is a too restrictive generalization. The term 'nonmarine' fails to describe the spectrum from marine to inland aquatic communities. Aquatic invertebrate taxa of equivocal affinity are found among the agglutinated foraminifera, spirorbids, limulids, ostracods, eocarid crustaceans and pelecypods. The crustacean fauna, including the eocarid *Pseudotealliocaris–Anthracophausia* and ostracod *Shemonaella–Beyrichiopsis* communities of the lower Mabou Group, belie the consistency of 'nonmarine' conditions. The pygocephalomorph–syncarid fauna of the Cumberland Group coal measures, typified by the widely occurring *Pygocephalus dubius*, (Fig. 6b) which occurs also in the coal measures of Britain (Copeland 1957), may represent specialization of a more inland crustacean community relative to the nearshore *Pseudotealliocaris–Anthracophausia* (Fig. 6c) community of the Mabou Group (Schram 1981). It has beeen suggested (Brooks 1962) that *Pygocephalus* was anadramous, migrating from marine to estuarine and inland environments to spawn.

Similar comments apply to the 'nonmarine' bivalve taxa, wherein an ecological gradient from near marine to inland freshwater is likely. Apart from *Carbonicola* of the Windsor and Mabou Groups, however, the taxa found in Nova Scotia historically have been designated restrictively as 'nonmarine'. The apparent contradiction that certain of these are associated with near-marine environments in western Europe has been accomodated by invoking ecological adaptation to the lower-salinity waters inferred for Nova Scotia (Bell 1944; Vasey 1984). An exception is the study of the Joggins section by Duff & Walton (1973), who concluded that 'in the light of European studies, *Curvirimula* and *Naiadites* could suggest a salinity nearer the "marine" rather than the "fresh" end of the spectrum'. A similar expression of marine influence in associated beds has been suggested for a *Kouphichnium–Cochlichnus–Treptichnus* invertebrate trace fossil assemblage (Archer *et al.* 1995). The pseudoplanktonic, hence widespread, pelecypod *Curvirimula* of the early Silesian (Vasey, 1984) is associated with near-marine faunas in transgressive sequences of the Appalachian Basin and British Isles (Rogers 1985), and *Anthraconaia* similarily may record marine inluence in the Westphalian D (Vasey 1984). The geochemistry of aragonitic *Naiadites* shells from the Joggins Formation, which shows both high Sr/Ca and Mg and a $^{87}Sr/^{86}Sr$ signature of >0.7093, led Brand (1994) to conclude a freshwater habitat although aspects of the geochemistry are equivocal. Within the Maritimes–Western-European province, the nearshore to nonmarine pelecypod taxa exhibit striking similarities (Eagar 1961), with *Carbonicola* and *Naiadites* being endemic genera (Vasey 1984).

The fish fauna of Nova Scotia (see Appendix A) – comprising acanthodians, chondrichthyes, palaeonisciformes and sarcopterygians – is inferred to represent a restricted freshwater habitat and is similarly represented in western Europe (Allen & Dineley 1988). The fauna includes the palaeoniscids *Rhadinichthys* and *Elonichthys* from the Tournaisian, the acanthodian *Gyracanthus* (Fig. 6a) and the dipnoid *Sagenodus*, common in Europe but rare in North America (Baird 1978; Allen & Dinely ibid.); in Nova Scotia. *Sagenodus* lungfish scales are more common than the literature would suggest, however, preserved most often within bivalve-bearing organic-rich limestones.

Similar comments about nearshore marine to inland palaeoenvironments apply to the fish fauna. *Rhabdoderma*, for example, has been shown to have spawned in estuaries (Schultze 1985). Preliminary isotope data from fish fossils derived from bivalve-bearing organic-rich limestones of the Cumberland Group (H. Falcon-Lang pers. comm. 1997) show $^{87}Sr/^{86}Sr$ signatures consistent with estuarine salinities. These range from 0.7097772 ± 300 (palaeoniscid fish scale) to 0.710338 ± 83 (xenacanth shark tooth, *Diplodus*).

It can be generally stated that the palaeoecology of the faunal groups has been underutilized in modern times in interpretations of the basin-fill. The search for the inland expression of transgressive events in stratal groups historically deemed perennially 'nonmarine', in particular, will benefit from closer scrutiny of the faunal record. Ultimately, the faunal and floral records bear witness to the palaeogeographic and phytogeographic evolution of Euramerica and the relationship between Europe and North America during the Carboniferous.

The Carboniferous palaeoclimate of Nova Scotia

The arid–humid–arid cycle of Late Palaeozoic Euramerican palaeoclimate (Bless *et al.* 1987, fig. 4.2) is recorded in the basin-fill of the Maritimes Basin (Fig. 5). The semiaridity of the Dinantian and early Namurian was approached once again by the early Permian. Maximum humidity is recorded during the Westphalian, followed by a sharp decline in the Stephanian, a trend that mimics broadly that deduced for Euramerica on the basis of the floral record (Phillips & Peppers 1984). The most significant departure from the palaeoclimate inferred for Euramerica west of the Appalachians and east of the Mid-Euramerican Sea is the greater seasonal distribution of rainfall inferred for the Maritimes Basin during the early Silesian. The preliminary Carboniferous palaeoclimate curve for the Maritimes Basin, here published for the first time (Fig. 5), is intended to serve as a model to be tested and refined in the course of future research.

During the Tournaisian, grey lacustrine beds are widespread. The lakes are inferred to have ranged in water depth from relatively deep in the type Horton Bluffs Formation, where hummocky cross-stratification indicates water depths below wave base (Martel & Gibling 1991), to shallow where on, Cape Breton Island for example, playa lake beds exhibit calcrete and desiccation cracks (Hamblin & Rust 1989); algal stromatolites are developed locally. Oil shales of the Horton Bluff and neighbouring Albert Mines formations occur within the *Vallatisporites vallutus* spore zone (Utting 1987), a flora representative of the subtropical arid belt of southern Euramerica (Van der Zwan 1981). The conchostracan fauna that occurs in strata of Tournaisian, early Namurian and Stephanian to early Permian age is similar to extant 'clam shrimp' fauna that can withstand prolonged periods of desiccation, opportunistically inhabiting water-stressed environments where ephemeral ponds develop in prevailing dryland settings (Tasch 1969). The Viséan has long been held to represent a semiarid palaeoclimate (Bell 1929; Schenk 1967a, b) in which strandline algal stromatolite carbonates, playa salt flats, halite, anhydrite and potash formed. Laminated carbonate of the Macumber Formation, basal Windsor Group, has been ascribed to semiarid seasonality (Schenk *et al.* 1994). Considerable evidence exists for the persistence of semiaridity during the late Viséan following retreat of the Windsor Sea: playa lakes, deep desiccation cracks, gypsum casts, calcareous 'cementstone' beds (Belt et al. 1967; Neves & Belt 1970; McCabe & Schenk 1982; Crawford 1995) and a conchostracan fauna (Copeland 1957). The palaeoclimate may have moderated by the early Namurian (Crawford 1995), during which time the developing monsoon is said to have been recorded in vertisols of the Hastings Formation (Chandler 1995).

The dramatic floral changeover across the Mid-Namurian divide reflects a marked climate change from semiarid to subhumid or seasonal humid (Fig. 5), similarly recorded in the palaeoclimate of the Central Appalachian Basin (Cecil *et al.* 1985). This changeover in macroflora (Bell 1944) similarly is recorded in the miospore record by the entry of saccate *Florinites* prepollen and *Lycospora* (G. Dolby, pers. comm. 1997; J. Utting pers. comm. 1997). Care must be excercised in the interpretation of the basin-fill record across this time interval, given its coincidence with the marked change in tectonic regime from distensional to transpressional at the Mid-Carboniferous event, which may correlate with the Mississippian–Pennnsylvanian unconformity. The attendant inversion of massifs and neighbouring basinal areas has potential to introduce to the basin elements of hinterland flora (*cf.* Chaloner 1958), such as the saccate *Florinites,* which accompanied the abundant permineralized cordaite logs of the Boss Point Formation. Indeed, the hinterland flora includes bisaccate pollens of Gondwanan affinity (Dolby *in press*), and sand grain microtextures have even been cited as evidence of local mountain glaciation (D'Orsay & van de Poll 1985). The increase in *Lycospora,* however, reflects the widespread development of lepidodendrid peat-forming wetland ecosystems in the lowlands. Densopores *sensu latu* are relatively rare in the Carboniferous of the Maritimes Basin in Nova Scotia (Neves & Belt 1970; Dolby in press, pers. comm. 1997), in marked contrast to their abundance in coal-bearing strata in the Appalachian Basin (Eble 1996) and in Europe (Butterworth 1966). Smith (1962) and Butterworth (1966) attributed the paucity of densospores to a precipitation deficit, which is consistent with their relative scarcity in the Maritimes Basin.

Seasonality prevailed even during the most humid periods when mires persisted, represented by rheotrophic to mesotrophic coal beds (Calder

1994; Calder *et al.* 1996), and climate shifts were experienced in the range of the Crowell–Milankovitch band at which time seasonality was more pronounced (Calder 1994), to the point that calcrete was developed (Tandon & Gibling 1994). The trophic status of coal can be used to infer the relative degree of dry seasonality within a humid climate: solely rain-fed, ombrotrophic, raised mires require year-round distribution of precipitation, whereas rheotrophic peats can be sustained through a short dry season by groundwater. The development of calcrete during the Westphalian D, when the climate and glacioeustatic cycles also favoured the development of mesotrophic coals (Tandon & Gibling 1994), inferred to tolerate only moderate dry seasons, serves to illustrate the point that palaeoclimate history should always be considered in terms of climate maxima and minima (see Cecil 1990; Perlmutter & Matthews 1989). Calcrete occurs in red beds coeval with coals from the Langsettian/Westphalian A (Chandler 1995) to D (Tandon & Gibling 1994; Chandler 1995, 1997).

Evidence of Westphalian seasonality (Calder 1979; 1994; Calder *et al.* 1996; Chandler 1995, 1997) perhaps is recorded most eloquently in the rhythmic alternation of siliciclastic and organic-rich laminae in lacustrine mudrocks (Kalkreuth *et al.* 1990) and in the ubiquitous fusain clasts throughout the 13.4 m thick Foord seam and other coal beds, all of the Stellarton Basin. The fossil charcoal bears witness to a humid palaeoclimate with a pronounced dry season with recurring wildfires ignited by lightning strikes, as in modern continental regions of the tropics (Lottes & Ziegler 1994). Vertisols with calcrete in coeval red beds of the Malagash Formation (Chandler 1997) bear similar palaeoclimatic testimony in areas of better drainage (Naylor *et al.* 1989). This record of seasonality contrasts with inferences of a non-seasonal humid climate drawn from the palaeobotanical record elsewhere in Euramerica (Chaloner & Creber 1975; Phillips *et al.* 1985). Seasonality notwithstanding, across the Mid-Namurian divide, the Westphalian clearly records an abrupt shift to a more humid palaeoclimate (Fig. 4), suggesting a marked change in oceanic or orographically influenced circulation patterns. The humid seasonal palaeoclimate of the Westphalian Maritimes Basin was a harbinger of the developing Pangaean monsoon (Rowley *et al.* 1985; Broadhurst 1988; Parrish 1992). The timing of monsoonal circulation in the Maritimes in comparison with other regions of Euramerica has implications for modelling the effects of the equatorial Appalachian–Caledonian, Mauritanide and Hercynide mountain belts on climate circulation models for Euramerica (Parrish 1992; Rowley *et al.* 1985).

The Stephanian to early Permian trend of increasing aridity is mirrored across Euramerica, with notable wetland refugia persisting in the Hercynides and Cantabrians of western Europe and in China (DiMichele & Phillips 1994). The Late Carboniferous palaeoclimate change in Euramerica to more arid conditions has been ascribed to northward continental drift from an equatorial rainy belt into a tropical climate belt (Rowley *et al.* 1985; Bless *et al.* 1987, Cecil 1990, Calder & Gibling 1994), and locally to development of orographic rainshadows (Besly 1988). The assembly of Pangaea into a cross-equatorial landmass and closure of latitudinal seaways may have had even greater palaeoclimatic impact (Rowley *et al.* 1985; Parrish 1992). Orographic effects of the rising assembly of the Pangaean plates and consequent basin inversion and subsequent unroofing in the Maritimes–West-European province and global fall in world ocean levels during the Permian also contributed to the trend. The latest vestiges of peat accumulation and hydromorphic gleysols are found in the Cantabrian (Zodrow & Cleal 1985) fossil lepidodendrid forest atop the Point Aconi seam of the Sydney Basin. Succeeding calcrete-bearing vertisols (Chandler pers. comm. 1997), monsoonally fed dryland river systems and xeric walchian flora of the Cape John Formation, Pictou Group at the Permo-Carboniferous boundary (Fig. 7d; Calder *et al.* in press) serve to frame the end Carboniferous palaeoclimate of Nova Scotia and the Maritimes Basin.

Carboniferous mineral and energy deposits

For more than two centuries, and since the first recorded export of minerals from Canada, from the coal mines of Cape Breton to the Boston colonies in 1720 (Brown 1871), the Carboniferous strata have proved to be the most important source of metallic, industrial and energy minerals in Nova Scotia. The mineral resources of the Carboniferous strata can be linked directly or indirectly to the genesis of the Carboniferous basin-fill. They can be categorized by their mode of occurrence within the basin-fill: (1) primary sedimentary (stratal) deposits (Dinantian salt, limestone and rehydrated gypsum; Silesian rheotrophic to mesotrophic coal and oil shale; Carboniferous marine to terrestrial hydrocarbon source rocks), which have proved to be the most productive of the province's resources; (2) strata-bound deposits (lead, zinc, copper, silver; liquid and gaseous hydrocarbons, including coal bed methane); (3) infracontact and intracontact deposits, commonly at redox boundaries (copper, silver, uranium); (4) fracture-fill deposits (barium, lead, zinc, silver, iron); and (5) physically derived (palaeoplacer) deposits (gold). The disposition and types of mineral deposits in the basin-fill are shown in Fig. 8.

The thermal evolution and burial history of the Maritimes Basin have determined the generation of petroleum and base metal deposits. The source of heat flow has variously been ascribed to underlying plutons, depth of burial or elevated heat flow inherent within the Maritimes Basin (see Sangster *et al.* 1998). Lead–zinc–barium deposits, which occur as strata-bound, replacement and fracture fillings, are inferred to have been sourced from basinal brine expulsion during the Carboniferous; apatite fission track analysis places the expulsion as earlier than 280 Ma (Ryan & Zentilli 1993). Transpression and inversion associated with the Mid-Carboniferous event in Nova Scotia may have initiated the movement of basinal brine. The source of these brines remains contentious. Geochemical analysis of mine waters in the collieries of the Sydney Basin provides evidence that marine evaporative brines of probable Windsor Group affinity are present at depth in Carboniferous strata (Martel *et al.* 1997). Metallogenic models for the continental formations of the Maritimes Basin which were developed on the strength of consistently terrestrial conditions (van de Poll 1978; Sangster & Vaillancourt 1990) may warrant reconsideration in light of the possible cryptic inland signatures of marine transgressions suggested here. Continental red bed copper–silver–uranium deposits in late Westphalian–Stephanian strata of the Cumberland Basin have been ascribed to epigenetic reddening associated with unroofing and aridity in the Permo-Triassic (Ryan & Boehner 1994). As asserted earlier, however, the red beds of the Pictou Group are inferred to record increasing aridity in the latest Carboniferous and early Permian, which alternatively raises the possibility of earlier diagenetic processes, for example in rheotrophic 'copper bogs' (Chandler 1997).

Bituminous coal deposits of the Cumberland Group of Westphalian A–C age developed as areally restricted rheotrophic mires nourished through the dry season by supplemental groundwater flow (Calder 1994) generated at piedmont margins (Springhill coalfield: Calder 1994), in distributary (Joggins coalfield: Calder 1994) and lacustrine (Stellarton Basin: Calder 1979; Naylor *et al.* 1989; Waldron 1996) settings during regional transpression and transtension. Subsequent mire development in the Westphalian D to Cantabrian may have attained a mesotrophic status if only through the increased, hence insular, area of the peatlands on coastal plains during thermal sag (Hacquebard & Donaldson 1969; Gibling & Bird 1994; Marchioni *et al.* 1994; Calder *et al.* 1996).

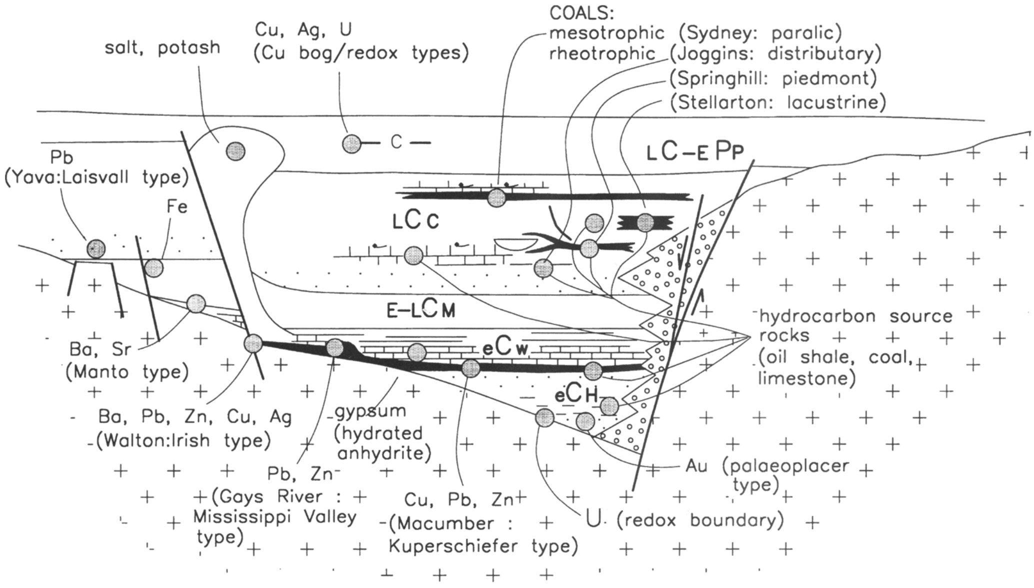


Fig. 8. Schematic representation of the occurrence of mineral and energy deposits in the Carboniferous basin-fill of Nova Scotia. Base metals disposition modified from Ryan and Boehner (1994).

The latter coal deposits constitute the main economic seams of Nova Scotia, mined in collieries of the Sydney Basin.

With few exceptions (Utting & Hamblin 1991), the strata of the Maritimes Basin at surface lie everywhere within the oil or gas windows, with R_0 (vitrinite reflectance) at surface ranging from 0.4 where suppressed by liquid hydrocarbons (Mukhophadyay *et al.* 1991) to >2 (Hacquebard & Donaldson 1970; Ryan & Boehner 1994). Oil seeps occur at present (Bell 1958; Short 1986), even though the apatite fission track record indicates that the oil window was attained early in the basin's history, before 250 Ma (Grist *et al.* 1995). Kinematic research into coal bed methane generation indicates that gas desorption in coal beds of R_0 <0.9 may be impeded by micropore blockage by earlier generated oil, but enhanced above that maturity by cracking of the oil (Mukhopadhyay *et al.* 1993). In all basins, rank increases with depth of burial (Hacquebard & Donaldson 1970). Hydrocarbon source rocks include sapropelic shales of the MacAdam Lake Formation and Horton Group, widespread organic-rich carbonate laminites of the Windsor Group, and sapropelic shales, sapropelic and humic coals, and basin-wide, organic-rich bivalve-bearing limestones and shales, all of the Cumberland Group. New models of hydrocarbon generation in Nova Scotia should incorporate the different thermal and structural histories of Horton, Windsor and Mabou strata before the Mid-Carboniferous event, and Cumberland and Pictou strata thereafter, and should consider possible cryptic marine transgressions within groups traditionally described as 'nonmarine'.

Gypsum, as rehydrated anhydrite (Bell 1929; D. Shearman pers. comm. 1997), forms thick, areally extensive deposits across much of the Maritimes Basin. The open-pit operations are the largest in the world (Adams 1991). Halite, which together with potash is unrepresented in outcrop due to solubility in the present humid climate, was discovered in Nova Scotia only in 1917, at Malagash, Cumberland Basin (Bell 1929). This deposit in the Cumberland Basin subsequently became the location of Canada's first underground salt mine (Bell 1929 1944); mining continues in the basin from salt-cored halokinetic anticlines that parallel basement faults (Boehner 1986).

The Carboniferous history of Nova Scotia: implications for Euramerican studies

The Carboniferous history of Nova Scotia can be understood fully only by considering it in the context of the regional history of Euramerica (Fig. 9); the same observation can be made for Europe and for North America, and in these cases, the story as recorded in Nova Scotia is significant. Salient points of the palaeogeography and evolution of Euramerica arising from this study of the Carboniferous evolution of Nova Scotia are discussed below.

Implications for the tectonic history of circum-Atlantic Euramerica

The Carboniferous evolution of Nova Scotia serves to corroborate or weigh against tectonic interpretations for the Appalachians of the United States and for western Europe. The Namurian transpressive event and subsequent changeover to a transcurrent regime in the Maritimes records the Variscan orogeny in the west of the Maritimes–West-European province and is consistent with Alleghenian thrusting in the Appalachians (Nance 1987; Gibling 1995; Rehill 1996). This Mid-Carboniferous event in Nova Scotia is coeval with the Mississippian–Pennsylvanian unconformity west of the Appalachian Mountains. The transpression in Nova Scotia at this time lends support to the role of tectonic inversion in the development of the unconformity (Ettensohn & Chesnut 1989) rather than to eustasy alone (Saunders & Ramsbottom 1986). These events in Euramerica and coincident inversion and volcanism in Gondwana (Gonzalez-Bonorino & Eyles 1995) mark the global convergence of plates and assembly of Pangaea.

In Nova Scotia, the distensional period of rifting had ended by the Westphalian and so does not accord with widespread extension and rifting across the Maritimes–West-European province subsequently in the Silesian (Hazeldine 1984). Rather, it lends credence to continued linkage of transcurrent tectonism in western Europe with that in the Maritimes (Matte 1986; Leeder 1988a) as plates continued to reorganize in eastern Euramerica to accommodate Gondwana.

Silesian Appalachian drainage divide

Palaeoflow compilations from the Appalachian Basin (Archer & Greb 1995) and from the Maritimes Basin (Gibling *et al.* 1992) have determined that prevailing drainage was to the east across the Maritimes Basin during the Silesian and to the west through the Appalachian Basin. The Appalachian Basin study, however, infers that drainage was sourced in part in the Maritimes basinal area, which clearly could not have been the case, with the possible exception of during the

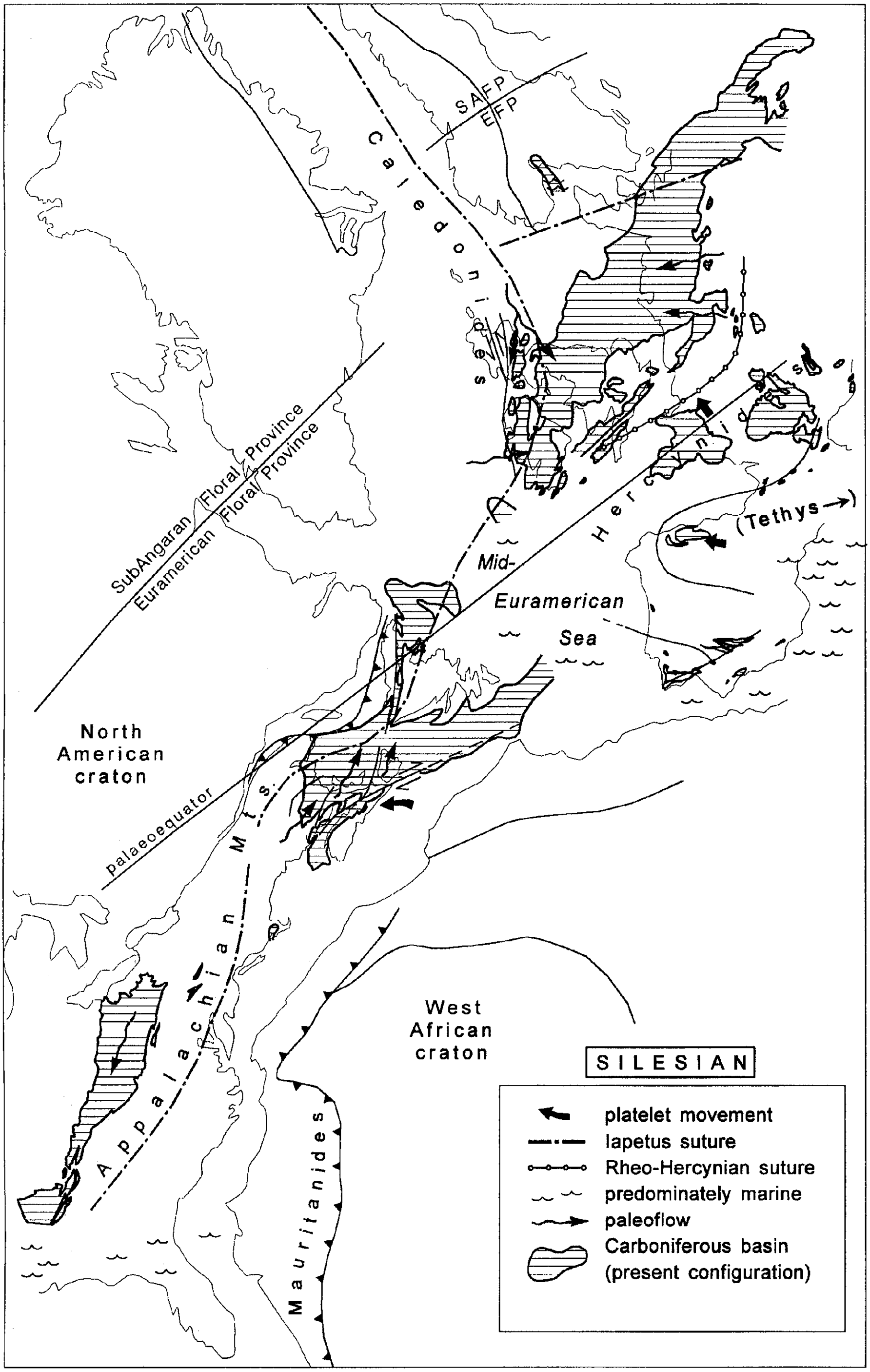


Fig. 9. Nova Scotia in the context of equatorial Euramerica during the Carboniferous (Silesian). Base map is that used by Hazeldine (1984) and Williams (1984). Palaeoflow after Archer and Greb (1995) for the Appalcahian Basin, Gibling *et al.* (1992) for the Maritimes Basin, and Leeder (1988*b*, 1992) for western Europe. Western European Carboniferous Basin outline after Maynard *et al.* (1997).

period of inversion attending the Mid-Carboniferous event. The Maritimes Basin lay to the palaeosoutheast of the orogen, whereas the Appalachian Basin lay to the palaeonorthwest (Fig. 9). Opposing palaeoflow directions suggest the existence of an Appalchian Divide during the Silesian (*Gibling et al.* 1992; Rehill 1996) with reversed polarity of basins about the position of the New York Promontory / Pennsylvania Embayment.

The Mid-Euramerican Sea

Circumstantial evidence points to the existence of a Mid-Euramerican Sea between the Maritimes Basin and western Europe during the Carboniferous (Fig. 9). The presence of an intervening deep oceanic realm which acted as a barrier to benthonic species exchange in the Viséan was hypothesized by Jansa *et al.* (1978) and Jansa & Mamet (1984). The invertebrate macrofauna (Bell 1929) and ostracode fauna (Dewey 1989), however, show affinity to western European fauna of similar environments, and conodonts such as *Taphrognathus transatlanticus* permit cross Maritimes–West-European correlation (Von Bitter & Austin 1984). The Silesian pelecypod fauna of Nova Scotia demonstrates a close affinity to western Europe, suggesting a palaeooceanic link between the two areas and an Appalachian barrier to the west (Vasey 1984). It has been proposed that the Mid-Euramerican Sea persisted through the Dinantian and Silesian and may have been one of the last remaining seas between the closing continents of Gondwana and the Old Red Continent, representing either a part of the Phoibic Ocean (McKerrow & Ziegler 1972) or Proto-Tethys (Leeder 1988*b*) or their vestige (W. S. McKerrow, pers. comm. 1997). Marine connections with the Boreal Sea may have been possible via rifted basins in the area of Svalbard and Greenland (Stemmerik *et al.* 1991; Rehill 1996), although faunal and palaeogeographic trends favour a cross-Maritimes-West European connection. Less certain is whether the ocean was connected with the southern Appalachian Basin by a seaway between the converging African and North American cratons, which would have become increasingly restricted if not closed during Alleghenian–Mauritainide orogenesis.

River drainage through the Maritimes Basin during the Silesian period of transcurrent movement followed the northeast structural grain of intervening basins and massifs to a common destination with the system draining southwestward across the Pennine Basin (Leeder 1988*b*) – inferred to have been the Mid-Euramerican Sea. Palaeoflow from the Maritimes Basin earlier had been inferred to have fed into the Rheo-Hercynian Ocean (Gibling *et al.* 1992); however, the Rheic purportedly had closed by that time (Leeder 1988*a*; Maynard *et al.* 1997). A thick succession of Dinantian and Silesian strata in the Porcupine Basin west of Ireland at the westernmost remnant of the European plate contains marine strata of Westphalian A age and a record of marine transgressions through the Stephanian (Tate & Dobson 1989). This evidence of a Mid-Euramerican Sea is supported by recurring marine transgressions from the southwest across the British Isles until the Westphalian C (Ramsbottom 1977), and by westerly derived marine influence across the Western European Carboniferous Basin, from Poland and Germany to the British Isles (Maynard *et al.* 1997).

Phytogeographic implications for Euramerican correlations

Although the stage boundaries of the Carboniferous, with the notable exception of the Westphalian D, have been established largely on the strength of goniatite faunal zones, these seldom coincide with major floral breaks (Wagner 1984). In the Maritimes Basin where goniatites are absent, this situation is exacerbated by phytogeogeographic differences from other Euramerican regions. The recognition of the Namurian–Westphalian boundary in Nova Scotia is a case in point. Few floral extinctions or appearances occur across this boundary, which is defined by the basal Westphalian *Gastrioceras subcrenatum* goniatite band in Europe (Ramsbottom *et al.* 1978). Index miospores used to recognize the base of the Westphalian elsewhere in Euramerica (Clayton *et al.* 1977; Maynard *et al.* 1997) include densospores *sensu latu* (including the related crassicingulate genera *Densosporites*, *Cristatisporites* and *Radiizonites*; DiMichele & Phillips 1994) produced by the subarboreous lycopsid *Bodeodendron* (*Sporangiostrobus*) (Wagner 1989), and *Endosporites* produced by the diminutive lycopsid *Chaloneria* (*Polysporia*). The subarboreous lycopsids, and densospores and their parent plant in particular, are rare in the fossil record of Nova Scotia and may have been environmentally excluded, as discussed earlier. The biostratigraphy of the prevailingly continental Maritimes Basin in Nova Scotia, perhaps more so than elsewhere in Euramerica, must be interpreted in the light of its regional palaeoenvironment and provincialism. The faunal record, even with its affinity to western Europe, nonetheless requires similar interpretation, specifically with respect to the aquatic spectrum from open marine to nearshore and inland communities.

Conclusions

Doubtless, we are biased in our perceptions of Carboniferous Euramerica by the configuration of the modern world and by geopolitical boundaries. The Carboniferous of Nova Scotia, though adjacent to the northern Appalachian orogen, nonetheless represents part of the Maritime–West-European palaeogeographic province of tropical Euramerica, albeit with an intervening Carboniferous sea. It shares many attributes with Europe, including elements of its tectonic history and fossil fauna and flora, as described more than a century ago by Lyell (1845 and others) and by Dawson (1888 and earlier works). The Carboniferous history in Nova Scotia of distension, transpression, thermal sag and inversion links the tectonic history of the Alleghanian orogeny in North America and the Variscan–Hercynian orogeny in western Europe. The Mid-Carboniferous Break marks the most profound period of change in the evolution of the Carboniferous of Nova Scotia; the tectonic and palaeoclimatic changes experienced across this equivocally dated interval are linked to global plate tectonics, and in particular, to Appalachian orogenesis.

The palaeoclimate record of the Silesian stands Nova Scotia apart from the nonseasonal humid palaeoclimate inferred for Euramerica and suggests that Nova Scotia may have experienced seasonal rainshadow effects, presumably as a consequence of its intermontane palaeogeography. The record of cycles of duration, largely within the Crowell–Milankovitch band, is superimposed on the longer-term evolution from marine to continental strata (Fig. 6). Carbonate–sulfate cycles of the Viséan probably represent semiarid marine equivalents of seasonally humid continental coal-bearing cyclothemic stratal successions of Westphalian coastal plains (Gibling & Bird 1994) and alluvial valley piedmonts (Calder 1994), as hypothesized by Schenk (1969 p. 1060). Intermediate between these end members are the predominantly continental, schizohaline late Viséan to mid-Namurian cycles of the Mabou Group (Belt 1968b; Crawford 1995), in which the marine record may yet be discerned. All are primarily allocyclic, driven most probably by orbitally induced climate change as it affected global glacioeustacy (Veevers & Powell 1987) and local climate change (Calder 1994), although tectonic causes have long been proposed for the 'nonmarine' strata.

Of the great river systems that drained the Maritimes–West-European province during the Silesian, two drained eastwards through the interconnected Maritimes basins and southwestward across the Pennine Basin towards a common destination, the Mid-Euramerican Sea. The existence of such a sea during the Carboniferous has attendant implications for cross-Maritimes–West-European correlations of sea-level change.

Although open marine conditions occurred only during the mid to late Viséan, the signature of transgression and regression should be variably discernible throughout much of the Carboniferous basin-fill. Traditional interpretation of the basin-fill simply in terms of marine or 'nonmarine' is too restrictive. It is better to consider the palaeogeographic gradient from open marine to nearshore and inland, which may be identified through careful reconsideration of the faunal record, even within the prevailingly continental, inland strata of Nova Scotia. A particular challenge, however, will be to discern brackish water caused by evaporation and contraction of lakes from the most inland expressions of a transgressing sea. This approach will have implications for modelling not only the basin-fill of the Maritimes but also its mineral and energy deposits. Strata-bound base metal and hydrocarbon models that have had to assume consistently continental conditions for groups other than the Windsor in particular stand to profit from such a re-examination of basin modelling. The Mid-Carboniferous Break, which links the tectonic evolution of Euramerica to the west and east in the Namurian, must also be considered in the development of hydrocarbon and base metal models for Nova Scotia.

To achieve these ends, the collaboration of European and North American geologists with those of Nova Scotia, so profitable during the time of Sir Charles Lyell, is required. In so doing, we will continue to loosen Lyell's 'Gordian knot' as it pertains to Euramerican Carboniferous geology.

The concepts of this paper draw on the distillation of published research by many Carboniferous workers, and discussions during the past 20 years with my colleagues in Nova Scotia and abroad. The research for this paper has been supported by the Nova Scotia Department of Natural Resources. Graham Dolby and John Utting were most open in sharing their wealth of experience in the palynostratigraphy of Nova Scotia. The faunal compilation would not have been possible without the generous and open collaboration of Andrew Milner and Reg Moore. Jean Dougherty and David Lewis are thanked for graciously supplying photographs of specimens in the collections of the GSC and NHM, respectively. The *Gyracanthus* spine (Fig. 6a) was discovered in 1997 by Brian Hebert. The incisive reviews by E. S. Belt and M. R. Gibling and generous insightful discussions with Bob Boehner, Fred Chandler, Sarah Davies, Howard Falcon-Lang, Peter Giles, David Piper, Paul Schenk, John Waldron and Erwin Zodrow provided welcome improvement to the breadth of the paper. Many thanks to Patricia Fraser and Janet Webster for drafting the figures, and to Tracey Lenfesty for her literature searches. I am grateful for the invitation and financial support of the convenors of the Lyell Bicentennial Meeting, Professors Derek Blundell and Andrew Scott, to undertake this comprehensive assessment of the Carboniferous evolution of Nova Scotia and I thank the many participants at the Lyell meeting from whom I received welcome input; to the likes of Sir Charles Lyell and Sir J. William Dawson, we owe much. Finally, to my uncle, John Lynton Martin, my thanks for your wonderful gift those years ago of *Acadian Geology*.

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Appendix A. The Carboniferous fauna of Nova Scotia

Systematic taxonomy for many of these groups in the fossil record is problematic and many variations exist on the structure of the compilation presented here. Stratigraphic occurrence: Horton Group [H]; Windsor group [W]; Mabou Group [M], with formations: Point Edward [Mpe], Grand Etang [Mge], West Bay [Mwb]; Cumberland Group, *sensu* Ryan *et al.* (1991) [C], with formations: Joggins [Cj], Parrsboro [Cp], Port Hood [Cph], Springhill Mines [Csp], Stellarton [Cs], Mabou Mines [Cmm], Sydney Mines [Csm]; Pictou Group red beds [P], with formation: Cape John [Pcj]. Primary sources: Baird (1978); Bell (1929, 1944, 1960); Carroll *et al.* (1972); Copeland (1957); Dawson (1855 and others); Gardiner (1966); J. Kukulova-Peck (pers. comm. 1994); Mamet (1970); Masson & Rust (1984); A. Milner (pers. comm. 1994, 1995); R.G. Moore (unpublished data, pers. comm. 1997); Moore & Ryan (1976); A. C. Scott (pers. comm. 1996); Tibert (1996); Von Bitter (1976); Wightman *et al.* (1993); Zodrow & Hitchcock (unpublished, 1995); and Calder (this study).

Phylum Protista (single-celled organisms)

- Class Sarcodina
  - Order Foraminifera
  - Suborder Textularidae (agglutinated)
    - *Trochammina* sp. [H, Cc, Csm]
    - *Ammobaculites* sp. [H, Cc, Csm]
    - *Ammodiscus* sp. [H,W]
    - *Ammotium* sp. [H, Cc, Csm]
  - Suborder Miliolina
    - *Cornuspira* sp. [W]
  - Suborder Textulariina
    - *Ammovertella* sp. [W]
    - *Pseudoammodiscus volgensis* [W]
    - *Trepeilopsis* sp. [W]
  - Suborder Fusulinina
    - *Archaediscus* sp. [W]
    - *A. krestovnikovi* [W]
    - *A. koktjubensis* [W]
    - *A. infantis* [W]
    - *A.* aff. *A. moelleri* [W]
    - *A.* aff. *A. chernoussovensis* [W]
    - *Archaesphaera (Vicinesphaera)* sp. [W]
    - *Asteroarchaediscus baschkiricus* [W]
    - *Biseriammina? windsorensis* [W]
    - *Brunsia* sp. [W]
    - *Climacammina* aff. *C. patula* [W]
    - *C.* aff. *C. prisca* [W]
    - *Cribostomum* sp. [W]
    - *Earlandia* aff. *E. clavatula* [W]
    - *E.* aff. *E. elegans* [W]
    - *E.* aff. *E. vulgaris* [W]
    - *Endothyra bowmani* [W]
    - *E. obsoleta* [W]
    - *E. excentralis* [W]
    - *E.* aff. *E. prisca* [W]
    - *E.* af. *E. similis* [W]
    - *Endothyranella* sp. [W]
    - *Endothyranopsis compressa* [W]
    - *E. crassa* [W]
    - *E. sphaerica* [W]
    - *Eoendothyranopsis* aff. *E. pressa – E. rara* [W]
    - *E.* aff. *E. ermakiensis* [W]
    - *Eostaffela? discoidea* [W]
    - *E. radiata* [W]
    - *Globoendothyra globulus* [W]
    - *?Haplophragmella* sp. [W]
    - *?Haplophragmina* sp. [W]
    - *Irregularina* sp. [W]
    - *Mikhailovella* sp. [W]
    - *Neoarchaediscus grandis* [W]
    - *Neoarchaediscus* sp. [W]
    - *N. incertus* [W]
    - *N. parvus regularis* [W]
    - *Palaeotextularia consobrina* [W]
    - *P.* aff. *P. longiseptata* [W]
    - *P. asper* [W]
    - *P. dagmarae* [W]
    - *Parathurammina* sp. [W]
    - *Pseudoendothyra* aff. *P. ornata* [W]
    - *Pseudoglomospira* spp. [W]
    - *P. infinitesima* [W]
    - *?Saccaminopsis* sp. [W]
    - *Tetrataxis* aff. *T. angusta* [W]
    - *T.* aff. *T. conica* [W]
    - *T.* aff. *T. eominima* [W]
    - *T.* aff. *T. maxima* [W]
    - *Tuberitina* sp. [W]
  - *Incertae sedis*
    - *Calcisphaera* sp. [W]
    - *C. laevis* [W]
    - *C. pachysphaerica* [W]
    - *Diplosphaerina* sp. [W]
    - *Koskinobigerina* spp. [W]
    - *Koskinotextularia* sp. [W]
    - *Planospirodiscus gregorii* [W]
    - *P. minimus* [W]
    - *Radiosphaera* sp. [W]
    - *Zellerina* spp. [W]
    - *Zellerina discoidea* [W]
- Class Arcellinida (thecamoebians)
  - Order Arcellinida
    - *cf.Centropxsis* sp. [H, Csm]
    - *?Difflugia* sp. [H]
    - *cf. Nebela* sp. [Csm]

Phylum Conodonta

- *Apatognathus?* spp. [W]
- *Bispathodus* spp. [W]
- *Cavusgnathus windsorensis* [W]
- *C.* aff. *C. regularis – C. unicornis* [W]
- *Ellisonia* spp. [W]
- *Gnathodus bilineatus* [W]
- *G. girtyi intermedius* [W]
- *G. scotiaensis* [W]
- *Hindeodus cristulus* [W]
- *H. parva* [W]
- *Kladognathus tenuis* [W]
- *Mestognathus* spp. [W]
- *Spathognathus campbelli* [W]
- *S. cristatus* [W]
- *S. scitulus* [W]
- *S.* sp. [W]
- *Taphrognathus* sp. [W]
- *T. transatlanticus* [W]

Vogelgnathus campbelli [W]
V. pesaquidi [W]
V. dhindsai [W]
V. postcampbelli [W]

Phylum Annelida (segmented worms)
Class Polychaeta
Serpula annulata [W]
S. caperatus [W]
S. hartii [W]
Spirorbis avonensis [H]
S. carbonarius [C]
?S. arietina [C]
Scolecodonts
Anisocerasites spp. [W]
Arabellites spp. [W]
Diopatraites spp. [W]
Eunicites spp. [W]
Lumbriconcereites spp. [W]
Staurocephalites spp. [W]
Stauronereisites spp. [W]
Ungulites spp. [W]

Phylum Porifera
Belemnospongia sp. [W]

Phylum Cnidaria
Class Anthozoa (corals)
Chaetetes spp. [W]
Order Rugosa
Bothrophyllum sp. [W]
Caninia juddi [W]
Corwenia sp. [W]
Clisiophyllum (Dibunophyllum) billingsi [W]
Dibunophyllum lambii [W]
Diphyphyllum sp. [W]
Enniskillenia enniskilleni (=Zaphrenitis minas) [W]
Lonsdaleia floriformis [W]
L. pictoense [W]
Koninckophyllum (Lophophylum) avonensis [W]
K. (Lophophyllum) interruptum [W]
K. cf. *O*⊖[W]
Lithostrotion pauciradiale [W]
L. proliferum [W]
L. aff. *scoticum* [W]
Thysanophyllum cf. *orientale* [W]
Order Tabulata
Cladochonus sp. [W]
Pseudoromingeria sp. [W]
Syringopora sp. [W]

?Phylum Conulariida
Paraconularia (Conularia) planicostata [W]
P. sorrocula [W]

Phylum Bryozoa
Class Gymnolaemata
Incertae sedis
Paleocrisidia (Nodosinella) priscilla [W]
Order Cryptostomata
Rhombopora sp. [W]
Streblotrypa biformata [W]
Order Fenestrata
Fenestrellina (Fenestella) yelli [W]
Polypora schucherti [W]
Septopora primitiva [W]
Order Trepostomata
Anisotrypa sp. [W]
Tabulipora acadica [W]
Stenopora sp. [W]
Order Halloprina
Batostomaella abrupta [W]
B. exilis [W]
Order Ctenostomata
Eliasopora spp. [W]

Phylum Echinodermata
Class Echinoidea (sea urchins)
Cravenechinus spp. [W]
Proterocidaris spp. [W]
?Archaeocidaris spp. [W]
Class Crinoidea (crinoids)
indet. columnals, plates [W]
Class Ophiuroidea (brittle stars)
2 genera, 3 species [W]

Phylum Brachiopoda
Class Inarticulata
Order Acrotretida
Orbiculoidea limata [W]
Crania cincta [W]
C. brookfieldensis [W]
Class Articulata
Order Terebratulida
Beecheria davidsoni [W]
B. v. *latum* [W]
B. v. *mesaplanum* [W]
B. v. *milviformis* [W]
B. (Dielasma) sp. [W]
Cranaena tumida [W]
Hartella dielasmoidea [W]
H. parva [W]
Romingerina anna [W]
Tornquistia polita (=Chonetes politus) [W]
Order Strophomenida
Avonia spinocardinata [W]
Buxtonia cogmagunensis [W]
Diaphragmus (Productus) avonensis [W]
D. tenuicostiformis [W]
Dictyoclostus (Productus) subfasciculatus [W]
Echinoconchus exigunus (=Pustula exigua) [W]
Ovatia (Productus) dawsoni [W]
O. (Productus) lyelli [W]
O. (Productus) semicubicula [W]
Protoniella baddeckensis [W]
P. beedii [W]
Rugosochonetes aff. *hindi* [W]
Schellwienella kennetcookensis [W]
Schuchertella pictoense [W]
Semiplanus aff. *latissimus* [W]
Spinulicosta (Productella) baddeckensis [W]
Order Rhynchonellida
Allorhyncus hartti [W]
A. macra [W]
A. ramosum [W]
Camarotoechia acadiansis [W]

- *C. atlantica* [W]
- *Pugnax dawsonianus* [W]
- *P. dawsonianus v. magdalena* [W]
- *Pugnoides* sp. [W]
- *Streptorhyncus* cf. *minutum* [W]

Order Spiriferida

- *Ambocoelia acadica* [W]
- *Composita dawsoni* [W]
- *C. obligata* [W]
- *C. strigata* [W]
- *C. windsorensis* [W]
- *Gigantoproductus giganteus* [W]
- *Martinia galatea* [W]
- *M. thetis* [W]
- *Punctospirifer (Spiriferina) octoplicata* [W]
- *P. (Spiriferina) verneuli* [W]
- *Spirifer adonis* [W]
- *S. nox* [W]

Phylum Mollusca

- Class Pelecypoda (bivalves: clams)
    - ?*Carbonicola angulata* [Mpe, wb]
    - ??*Carbonicola bradorica* [W, Mh, pq]
    - *Carbonita* sp. [Csm]
  - Order Paleoconcha
    - *Edmondia hartti* [W]
    - *E. rudis* [W]
    - *Sanguinolites niobe* [W]
    - *S. parvus* [W]
    - *S. striatogranulatus* [W]
  - Order Taxodonta
    - *Grammatodon (Parallelidon) dawsoni* [W]
    - *G. (Parallelidon) hartingi* [W]
  - Order Schizodonta
    - *Schizodus chevierensis* [W]
    - *S. depressus* [W]
  - Order Dysodonta (Mytilacea)
    - *Anthraconauta phillipsii [Csm]*
    - *Aviculopecten lyelli* [W]
    - *A. lyelliformis* [W]
    - *A. subquadratus* [W]
    - *Bakewellia shubenacadiensis* [W]
    - *Curvirimula ?ovalis* [Cp]
    - C. sp [C]
    - *Leptodesma acadica* [W]
    - *L. borealis* [W]
    - *L. dawsoni* [W]
    - *Lithophaga (Lithophagus) poolii* [W]
    - *Modiolus dawsoni* [W]
    - *M. hartti* [W]
    - *Naiadites carbonarius* [Cp]
    - *N. longus* [C]
    - *Pteronites gayensis* [W]
    - *Spathella insecta* [W]
    - *Streblopteria (Pseudamusium) debertianum* [W]
    - *S. (Pseudamusium) simplex* [W]
  - Order Heterodonta
    - *Cypricardella acadica* [W]
    - *Scaldia fletcheri* [W]
    - *S. fundiensis* [W]
- Class Gastropoda (snails)
- Subclass Amphigastropoda
  - Order Bellerophontida
    - *Bellerophon* sp. [W]
    - *Bucanopsis beedii* [W]
- Subclass Prosobranchia
  - Order Archaeogastropoda
    - *Aclisi(n?)a acutula* [W]
    - *Anematina (Holopea)* cf. *proutana* [W]
    - *Cyclonema ?subangulatu* [W]
    - *Euphemites* cf. *urei* [W]
    - *Euomaphalus exortivus* [W]
    - *Mourlonia* sp. [W]
    - *Murchisonia gypsea* [W]
    - *Naticopsis hartii* [W]
    - *N. howi* [W]
    - *Platyschisma ?dubium* [W]
    - *Pseudophorus (Flemingia) dispersa* [W]
    - *P. minuta* [W]
    - *Stegocoelia abrupta* [W]
    - *S. compactoidea* [W]
    - *Straparollus minutus* [W]
    - *Worthenia longi* [W]
  - Order 'Caenogastropoda'
    - *Bulimorpha maxneri* [W]
    - *Pseudozygopleura (Zygopleura) ?cara* [W]
- Subclass Pulmonata (Stylommatophora) (land snails)
  - Order Orthurethra
    - *Dendropupa vetusta* [Cj]
    - *Pupa bigsbii* [Cj]
  - *Incertae sedis*
    - *Zonites priscus* [Cj]
- Class Cephalopoda
- Subclass Nautiloidea
  - Order Nautilida
    - *Diodoceras avonensis* [W]
    - *Stroboceras hartti* [W]
  - Order Michelinoceroidea/Orthocerida
    - *Campyloceras* cf. *C. unguis* [W]
    - *Hemidolorthoceras belli* [W]
    - *H. windsorensis* [W]
    - *Kionoceras* spp. [W]
    - *Michelinoceras (Orthoceras) vindobonense* [W]
    - *Mitorthoceras* sp. [W]
    - *Mooreoceras* aff. *M. hindei* [W]
    - *Pseudorthoceras knoxense* [W]
  - Order Oncocerida
    - *Poterioceras* sp. [W]

Phylum Arthropoda (jointed-leg invertebrates)

- SuperClass Trilobitomorpha
- Class Trilobita
  - Order Opisthoparia/Polymerida
    - *Paladin (Phillipsia) eichwaldi* [W]
- Superclass Crustacea
- Class Ostracoda
  - Order Palaeocopida
    - *Amphisites* sp. aff. *A. centronotus* [W]
    - *Beryichiopsis cornuta* [W]
    - *B. ophota* [W, M]
    - *Copelandella (Hollinella) novascotica* [H,W]
    - *Glyptopleura parvacostata* [W]
    - *G. elephanta* [W]
    - *'Gortanella'* sp. [W]
    - *Kirkbya novascotica* [W]
    - *Paraparchites gibbus* [W]
    - *P. inornatus* [W]
    - *P. okeni* [W]

- *P. scotoburdigalensis* [W]
- *Pseudoparaparchites ensigner* [W]
- *Sansabella carbonaria* [C]
- *S. reversa* [C]
- *Youngiella* sp. [H]
- Order Podocopida
  - *Acrat(a)ia acuta* [W]
  - *Bairdia brevis* [W]
  - *B. pruniseminata* [H]
  - *Bairdiacypris quartziana* [W]
  - *B. striatiformis* [H]
  - *Bythocypris aequalis* [W]
  - *Carbonita agnes* [C]
  - *C. altilis* [C]
  - *C. elongata* [C]
  - *C. fabulina* [M, C, c, s, m, sm, P?]
  - *C. inflata* [Cm, sm, Ppei]
  - *C. pungens* [C]
  - *Carbonita rankiniana* (=*Candona salteriana*) [H,C]
  - *C. scalpellus* (=*C.* cf. *subula*) [H, Csm, P]
  - *C. secans [C]*
  - *Chamisella suborbiculata* [W]
  - *Chamishaella* sp. [H]
  - *Gutschickia ninevehensis [C]*
  - *G. bretonensis [C]*
  - *Healdianella* sp. [W]
  - *Hilboldtina evelinae* [C]
  - *H rugulosa* [C]
  - *Monoceratina youngiana [W]*
  - *?Paraparchites okeni* [M]
  - *P.* sp. aff. *P. kelletae* [W]
  - *Paraparchites* sp. [H]
  - *Shemonaella (Paraparchites) scotoburdigalensis (=Limnoprimitia hortenensis)* [H,W]
  - *S. tatei* [H]
  - *Sishaella moreyi* [W]
  - *Sulcella levisulcata* [W]
- Order Platycopida
  - *Cavellina ?lovatica* [H]
  - *Geisina* sp. [H]
- Order Myodocopida
  - *?Cypridina acadica* [W]
  - *Polycope spinula* [W]
- Class Branchiopoda
  - Order Conchostraca (clam shrimps)
    - *Paraleaia leidyi (=Leaia leidyi)* [M]
    - *Leaia baentschiana* [M, ?C]
    - *L. tricarinata* [M,C]
    - *L. silurica* [M,Cl,p]
    - *L. (Eoleaia) laevicostata* [H]
    - *L. (Eoloeaia) leaiaformis* [H]
    - *L. laevis* [C-P]
    - *L. acutangularis* [M]
    - *L. acutilirata* [M]
    - *L. magnacostata* [Cp]
    - *L. elongata* [C]
    - *L.* sp. [H]
    - *L.* sp. [P]
    - *Monoliolophus (conemaughensis) unicostatus* [C]
    - *Asmussia alta* [H, Cl, s]
    - *A. tenalla* [C, P]
    - *Cyzicus (Euestheria) belli [H]*
    - *C. (Euestheria) dawsoni* [M]
    - *C. (Euestheria) lirella* [H]
    - *C. (Euestheria) raymondi* [?M]
    - *?C. (Lioestheria) simoni* [?M]
    - *C. (Lioestheria) striata* [M,Cs]
    - *Cyclетherioides blackstonensis* [M]
    - *Palaeolimnadiopsis pruvoti* [?C]
  - ?Order Notostraca
    - *Lynceites cansoensis* [M]
- Class Malacostraca (soft-shelled: crayfish etc.)
- Superorder Eocarida
  - Order Pygocephalomorpha
    - *Pygocephalus (Anthrapalaemon) dubius (hillianus) (=Diplostylus dawsoni)* [Cj, p, spm, ph, mm]
    - *P. cooperi* [?Mwb, Cp]
    - *Pseudotealliocaris caudafimbriata* [Mm]
    - *P. belli (=Tealliocaris barathrota)* [Mm, wb]
  - Order Eocaridacea
    - *Anthracophausia* sp. cf. *dunsiana* [M]
- ?Superorder Syncarida
  - *Paleocaris* cf. *typus* [Cs]
  - *Incertae sedis*
    - *Dithyrocaris glabradoides* [M]
- Superclass Chelicerata (pincer-bearing)
- Class Merostomata
  - Order Xiphosurida (sword-tailed: horseshoe crabs etc.)
    - *Belinurus reginae* [Mwb, Cp, rv]
    - *B. grandaevus* [Mwb, C]
    - *Euproops* cf. *danae* [Mmar, ?C]
    - *E. amiae* [C?s,sm]
    - *E.* sp. [H]
  - Subclass Eurypterida (wing-like legs)
    - *Eurypterus brsadorensis* [Csm]
    - indet. cuticle, *cf. Hibbertopterus /Mycterops* [Cj]
    - *Dunsopterus* sp. [Mge]
- Class Arachnida (spiders, scorpions)
  - Order Anthracomartida
    - *Coryphomartus triangularis* [?Cj]
  - Order Phrynichida (whip spiders)
    - *Graeophonus carbonarius (=Libellula carbonaria)* [Cj, c, sm]
  - Order Scorpionida
    - *Eoscorpius* sp. [?Cs]
    - indet. cuticle [Cj]
- Superclass Myriapoda
- Class Diplopoda (millipedes)
  - Order Eurysterna/Spirobolida
    - *Xyloiulus (Xylobius) sigillariae [Cj]*
  - *Incertae sedis*
    - *Archiulus xylobioides* [Cj]
  - Order Amynilyspedida
    - *Amynilyspes springhillensis* [Cj, sp]
- *Incertae sedis*
  - Arthropleurida[1]
    - *Arthropleura* sp. [Cj, Pcj]
- Superclass Hexapoda
- Class Insecta
- Subclass Pterygota (winged insects)
- Infraclass Palaeoptera
  - Order Megasecoptera
    - *Megasecoptera incertae familiae* [C]
    - *Brodioptera cumberlandensis* [C]
    - *B. amiae* [?M]
  - Order Protodonata

- *Meganeura* sp. [?Csm]
- Order Palaeodictyoptera
  - *Palaeodictyoptera incertae sedis* [?Csm]
- Infraclass Neoptera
  - Order Blattaria
    - *Archimylacris ?acadica* [Cs]
    - *Archimylacris moriensis* [Csm]
    - *A.* sp. [Cs]
    - *Hemimylacris* sp. [Cs]
    - *'Blattoidea' carri* [Csm]
    - *'Blattoidea' schchertiana* [Csm]
    - *?Phylloblatta* sp. [Cs]
  - ?Order Mixotermitoidea
    - *Geroneura wilsoni* [Cl]

Phylum Chordata

- Subphylum Vertebrata
- Superclass Pisces
- Class Acanthodii
  - *Incertae sedis*
  - Gyracanthidae
    - *Gyracanthus duplicatus* [H, M, Cj, p, ph]
    - *G. magnificus* [M]
- Class Chondrichtyes (cartilaginous fishes) (sharks)
  - Order Symmoriida
    - *Stethacanthus* sp. [H]
  - Order Xenacanthida
    - *Xenacanthus acinaces* [Cs]
    - *X. penetrans* [Cs]
    - *X.* sp. [Cj, s, sm]
    - *Oracanthus* sp. [W]
    - *Orthacanthus* sp. [Csm]
  - Order Ctenacanthiformes
    - *Ctenacanthus* sp. [?H, M, C]
  - Order Petalodontiformes (?ray-like fishes)
    - *Ctenoptychius cristatus* [Cj]
  - *Incertae sedis*
    - *Ageleodus (Callopristodus) pectinatus* [Cj]
- Class Osteichthyes (bony fishes)
- Subclass Actinopterygii (ray-finned fishes)
  - Order Palaeonisciformes
    - *'Acrolepis hortonensis'* [H]
    - *Amblypterus* sp. [Csm]
    - *Canobius modulus* [H]
    - *Elonichthys* sp. [H]
    - *?Gyrolepsis* sp.[Csm]
    - *Haplolepis* cf. *corrugata* [C]
    - *H. (Parahaplolepis) canadensis* [Cp]
    - *Palaeoniscus* sp. [Csm]
    - indet. palaeoniscid [W, Csm]
- Subclass Sarcopterygii (lobe fins)
  - [Order Actinistia]
  - Order Crossopterygii
    - *Megalichthys hibberti* (*=Psammodus bretonensis*) [?Cph]
    - *Megalichthys* sp. [Mpe, Cj, p, sm]
    - *Rhadinichthys* sp. [H, Cj]
    - *Rhizodopsis/ Strepsodus* sp. [H, Mpe, ge, Cj, sm]
    - *Rhizodopsis (Strepsodus) dawsoni* [Cj]
    - *Rhizodus hardingi* [H, Cs]
    - *R. lancifer* [H, Cs]
  - Suborder Coelacanthini
    - *Coelacanthus* sp. [?Cm]
    - *?Rhabdoderma* sp. [Csm]
    - (indet. scales) [Cj]
  - Superfamily Dipnoi (lungfish)
    - *Ctenodus* sp. [?H]
    - *Ctenodus cristatus* [Mge]
    - *C. murchisoni* [Csm]
    - *Monongahela stenodonta* [Csm]
    - *Sagenodus cristatus* [Cj]
    - *S. sp* [Mpe, ge, Csm]
    - *S. plicatus* nomen vanum [Cj]
- Superclass Tetrapoda
  - *Incertae sedis, nomen vanum*
    - *Novascoticus (Hylonomus) multidens* [Cj]
    - *Hylonomus ociedentatus* (*= Smilerpeton aciedentatum*) [Cj]
    - *Hylonomus wymani* [Cj]
- Class Amphibia
- Subclass Batrachomorpha (true amphibians)
  - Order Temnospondyli
    - Temnospondyli *incertae sedis* [Cp]
    - *Dendrerpeton acadianum* (*=D. oweni, Platystegos loricatum, Dendryazousa dikella*) [Cj]
    - *Dendrepeton helogenes* (*=Dendrysekos helogenes*) [Cj]
    - *Denderpeton* sp. nov. [Cj]
    - *Spathicephalus pereger* [Mpe]
    - Cochleosauridae *incertae sedis* [Cj, Csm]
  - Order Microsauria (Lysorophа)
    - *Archerpeton anthracos* [Cj]
    - *Asaphestera (Hylerpeton) intermedium* [Cj]
    - *Hylerpeton dawsoni* (*= Amblydon problematicum*) [Cj]
    - *Leiocephalikon problematicum* (*?=Trachystegos megalodon*) [Cj]
    - *?Ricnodon* sp. [Cj]
- Subclass Reptiliomorpha
  - Order Anthracosauria (Embolomeri)
    - *Baphetes planiceps* [Cs]
    - *'B'. minor* [Cj]
    - *Calligenethlon watsoni* [Cj]
    - *Carbonoherpeton* sp. [Csm]
    - *'Pholiderpeton' bretonense* [Mpe]
    - Seymouriamorpha *incertae sedis* [H]
    - (*'Eosaurus acadiensis'*= exotic ichthyosaur?)
- Class Reptilia
- Subclass Anapsida
  - Order Captorhinomorpha (protorothyrids and captorhinids)
    - *Romeriscus periallus* [Cph]
    - *Hylonomus lyelli* (*=Fritschia curtidentata*) [Cj]
    - *Paleothyris acadiana* [Csm]
- Subclass Synapsida
  - Order Pelycosauria
    - *Protoclepsydrops haplous* [Cj]

Appendix B. Carboniferous fossil flora of Nova Scotia

Principal sources: Bell (1929, 1940, 1944), Calder *et al.* (1996), W. G. Chaloner (pers. comm. 1995), Lyons *et al.* (1997), A. C. Scott (pers. comm. 1994–1996), Zodrow & Gao (1991), Zodrow & Cleal (1985), Zodrow & McCandlish (1980); and Calder (this study). Stratigraphic occurrence: H = Horton Group; W = Windsor Group; M = Mabou Group; C = Cumberland Group *sensu stricto*; CR = Riversdale Series of Cumberland Group; CS = Stellarton Series of Cumberland Group; CM = Morien Series of Pictou Group. 'r' denotes rare occurrence.

Kingdom Plantae

Division Bryophyta
Class Hepaticaea (liverworts)
Marchenites sp. [CM]

Division Tracheophyta
Class Lycopsida (club mosses and relatives)
Order Protolepidodendrales
Lepidodendropsis corrugatum [H]
Order Lepidodendrales (trees with stigmarian rootstock)
Stem genera
Asolanus camptolaenia [CM]
**Bothrodendron* cf. *minutifolium* [CM]
**B.* cf. *punctatum* [C]
Diaphorodendron (Lepidodendron) scleroticum [CM]
Lepidocarpon lomaxii [CS]
Lepidodendron aculeatum [C, CM]
L. bretonense [CM]
L. dawsoni [CM]
L. dichotomum var. *bretonensis* [C, CS, CM]
L. jaraczewskii [C]
L. lanceolatum [CR, C, CM]
L. lycopodioides [CM]
L. obovatum [C]
L. ophiurus [CS, CM]
L. praelanceolatum [M]
L. pictoense [CR, CM]
L. rimosum [C]
L. wortheni [C, CM]
Lepidophloios laricinus [CR, CM]
Paralycopodites brevifolius [CS] (=*Ulodendron majus* [C, CM])
Sigillaria boblayi [CM]
S. cf. *brardi* [CM]
S. elegans [C]
S. cf. *elegans* [CM]
S. fundiensis [C]
S. laevigata [C, CM]
S. lorwayana [CM]
S. mammillaris [C]
S. ovata [CS]
S. reticulata? [C]
S. scutellata [C]
S. tessellata [CM]
S. tessellata var. *eminens* [CM]
Root genera
Stigmaria ficoides [CR, C, CS, CM]
Foliar genera
Cyperites sp. (=*Lepidophylloides* sp.) [C, CM]
Reproductive organ genera
Lepidophyllum (Lepidostrobophyllum) fimbriatum [H]
Lepidostrobophyllum acuminatum [CS]
L. fletcheri [C]
L. cf. *jenneyi* [CM]
L. lanceolatum [CR, C, CS, CM]
L. majus [C]
L. cf. *mintoensis* [CM]
L. moyseyi [CM]
L. triangulare [CM]
Lepidostrobus variabilis [CR, CM]
L. hydei [M]
L. olryi [CR, C]
Sellaginites gutbieri [CM]
Sigillariostrobus? crépini [CM]
Class Sphenopsida
Order Sphenophyllales
Foliar genera
Leeites oblongifolis [CM]
Sphenophyllum cuneifolium [CR, C, CM]
S. emarginatum [CM]
S. majus [CM]
S. myriophyllum [rCM]
**S. oblongifolium* forma *trizygia* [CM]
S. trichomatosum [CM]
Order Equisetales
Stem genera
Asterocalamites scrobiculatus [H, M]
Calamites carinatus [CM]
C. cisti [C]
C. (Mesocalamites) cistiiformis [M]
C. discifer [CM]
C. extensus [CR]
C. multiramis [CM]
C. paniculata [C]
C. ramosus [CR, C, CM]
C. suckowi [CR, C, CM]
C. undulatus [CR, CM]
C. of *varians* group [C]
C. waldenburgensis [CM]
Calamostachys germanica [C, CM]
C. of *varians* group [C]
C. paniculata [C]
Nematophyllum sp. [H]
Root genera
**Pinnularia* sp. [CR, C, CM]
Foliar genera
Annularia acicularis [CR, C]
A. aculeata [CR, C]
A. asteris [C]
A. latifolia [C]
A. mucronata [CM]
A. radiata [C, CM]
A. sphenophylloides [CM]
A. stellata [rC, CM]
A. stellata forma *longifolia* [C]
Asterophyllites charaeformis [CR, C, CS, ?CM]
A. equisetiformis [?M, CR, C, CM]
A. grandis [CR, C]
A. longifolius forma *striata* [C]
Reproductive organ genera
Calamostachys of. *A. aculeta* [CR, C]

Calamostachys of *A. charaeformis* [CR, C]
Calamostachys of *A. grandis* [CR, C]
C. germanica [C]
C. superba [CM]
C. paniculata [C]
C. tuberculata [CM]
Macrostachya hauchecorni [CM]
M. ifundibuliformis [CM]
Palaeostachya elongata [C, CM]
P. striata? [C]
Class Filicopsida (ferns and relatives)
Order Filicales
Foliar genera
Adiantites adiantoides [C]
A. bondi [CM]
A. oblongifolius [CR]
A. obtusus [C]
A. pooli [CS]
A. tenuifolius [H]
Botryopteris tridentata [CS]
Corynepteris sternbergi [CM]
C. winslovii [CM]
C. sp. [CR]
Oligocarpia brongniarti [C, CM]
O. missouriensis [CM]
O. sp. *cf. gutbieri* [CM]
Renaultia gracilis [C]
R. hydei [CR]
Sphenopteris (Oligocarpia?) crenatodentata [CM]
S. (Renaultia) rotundifolia [C]
S. (Zeilleria) hymenophylloides [C]
S. (Zeilleria) sp. [C]
Zeilleria avoldensis [CM]
Z. delicatula [CM]
Z. frenzli [C, rCM]
Z. schaumburg-lippeana [C]
Senftenbergia sp. [CM]
Order Marattiales (tree ferns)
Stem genus
Caulopteris sp. [C, CM]
Foliar genera
Eupecopteris (Asterotheca) cyathea [CM]
E. (Senftenbergia) obtusa [CM]
Lobatopteris (Asterotheca) miltoni [CM]
L. (Pecopteris) vestita [jc: CM]
Pecopteris (Asterotheca) acadica [CM]
P. clarkii [CM]
P. cf. *densifolia* [CM]
P. (Asterotheca) hemitelioides [CM]
P. herdii [CMb]
P. (Asterotheca) miltoni [CM]
P. (Senftenbergia) pennaeformis [CM]
P. pilosa [C]
P. plumosa forma *crenata* [C]
P. plumosa forma *dentata* [CM]
P. sterzeliformis [CM]
P. sp [C]
P. (Ptychocarpus) unitus [CM]
Pecopteridium sullivantii [CM]
Reproductive organ genera
Asterotheca cf. *abbreviata* [CM]
A. daubreei [CM]
A. herdi [CM]
A. oreopteridia [CM]
A. robbi [CM]
Scolecopteris sp. [CS]
Order Zygopteridales
Alloiopteris (Corynepteris) almaensis [CR]
A. (Corynepteris) coralloides [CR]
A. (Corynepteris) major [CM]
A. (Corynepteris) sternbergi [M?, C, CM]
Class Progymnospermopsida
Order *incertae*
Rhacopteris robusta [W]
Class Gymnospermopsida (plants with naked seeds)
Order Pteridospermales (seed ferns)
Stem genus
**Medullosa* sp. [C]
Foliar genera
Alethopteris davreuxi [CM]
A. decurrens [CR, C]
A. friedeli [CM]
A. grandini [CS, CM]
A. hartti [CR]
A. lonchitica [CR, C, CM]
A. scalariformis [CM]
A. serli [CM]
A. (Megalethopteris) hartii [CR]
A. valida [CM]
Aneimites acadica [H]
Callipteridium sullivanti [CM]
Dicksonites pluckeneti [CM]
Eusphenopteris neuropteroides
(= *Sphenopteris squamosa*) [CM]
E. (Sphenopteris) nummularia forma *dilatata* [C]
E.(Sphenopteris) obtusiloba [CR, C]
E. (Sphenopteris) striata [CM]
E. (Sphenopteris) trifoliolata [CR]
Eremopteris artemisiaefolia [CS, CM]
Fortopteris (Mariopteris) latifolia [CM]
Karinopteris (Mariopteris) acuta [CR]
K.? (Mariopteris) grandepinnata [C]
K. (M.) soubeirani [CM]
Linopteris bunburii [CM]
L. muensteri [CM]
L. neuropteroides var. *major* [CM]
L. obliqua [CM]
L. obliqua var. *bunburii* [CM]
Lonchopteris eschweileriana [eCM]
Mariopteris comata [C]
M. disjuncta [C]
M. hirsuta [CM]
M. nervosa [rC, CM]
M. sphenopteroides [CM]
M. tenuifolia [C, CM]
M. tenuis [CM]
M. sp. [C]
Megalopteris kellyi [Cng]
Neuralethopteris kosmanni? [CR]
N. schlehani forma *rectinervis* [CR, C]
N. smithsii [CR]
N. sp. [C]
Neurocardiopteris barlowi [CR]
Neuropteris aculeata [CM]
N. crenulata [CM]
N. (Mixoneura) flexuosa [CM]
N. gigantea [C]
N. heterophylla [CM]
N. macrophylla [CM]
N. (Mixoneura) obliqua [C]

    - *N. (Mixoneura) ovata* [CM]
    - *N. pseudogigantea* [C, CM]
    - *N. rarinervis* [CM]
    - *N. scheuchzeri* [CM]
    - *N. tenuifolia* [C, CM]
    - *Odontopteris cantabrica* [CM]
    - *O. minor* [CM]
    - *O. schlotheimii* [CM]
    - *O. subcuneata* [CM]
    - *Paripteris* spp. [CM]
    - *Pseudomariopteris* (M.) *ribeyroni* [CM]
    - *Rhodea laqueata* [CR]
    - *R.* cf. *sparsa* [CR]
    - *R. wilsoni* [C]
    - *Sphenopteridium crassum*? [M]
    - *S. dawsoni* [M]
    - *S. macconochei*? [H]
    - *S.* sp. [H]
    - *Sphenopteris (Diplotmema) furcatum* [CR, C, CM]
    - *S. (D.) geniculatum* var. *erectum* [CM]
    - *S. (D.) patentissimum* [H]
    - *S. (D.) zobeli*? [CM]
    - *Telangium* cf. *affine* [M]
    - *T. bretonensis* [W]
    - *T.? potieri* [CM]
    - *Triphyllopteris minor* [H]
    - *Triphyllopteris virginiana* [H]
  - *Incertae sedis*
    - *Reticulopteris muensteri* [CM]
  - Reproductive organ genera
    - *Heterangium* sp. [CS]
    - **Holcospermum* sp. [C]
    - *Polypterocarpus* sp. [C]
    - **Trigonocarpus parkinsoni* [C]
    - *T. praetextus* [CR]
    - *Whittleseya brevifolia* [CR, C]
    - *W. desiderata* [CR]
- Filicales or Pteridospermales *incertae sedis*
  - Foliar genera
    - *Sphenopteris aculeata* [CM]
    - *S. amoenaeformis*? [CR]
    - *S. brittsii* [CM]
    - *S. cantiana* [CM]
    - *S. cuneoliformis* [CR]
    - *S. deltiformis* [CR, C]
    - *S. dixoni* [C]
    - *S. fletcheri* [C]
    - *S. goniopteroides* [CM]
    - *S. (Renaultia) gracilis* [C]
    - *S. haliburtoni* [CS]
    - *S.* cf. *hoeninghausi*? [CM]
    - *S. licens* [CR]
    - *S. lineata* [CR]
    - *S. missouriensis*? [CM]
    - *S. moriensis* [CM]
    - *S. mixta* [C]
    - *S. moyseyi* [C]
    - *S. oxfordensis* [CR]
    - *S. philipensis* [CR]
    - *S. polyphylla* [CR]
    - *S. pseudo-furcata* [CR]
    - *S. rhomboidea* [CR, C]
    - *S. (Renaultia?) schatzlarensis* [CR, C]
    - *S. spiniformis* [CM]
    - *S. spinulosa* [CM]
    - *S.* spp. [C]
    - *S. stipulataeformis* [C]
    - *S. sulcata* [CR]
    - *S.* cf. *suspecta* [CM]
    - *S. strigosa* [H]
    - *S. valida* [C]
    - *S. (Diplotmema) whitii* [rCM]
    - *S. (Rhodea) wilsoni* [C]
- Reproductive organ genera
  - *Crossotheca boulayi* [CS]
  - *C. communis* [CM]
  - *C. compacta* [CM]
  - *C. denticulata* [CM]
- *Incertae sedis*
  - *Hymenophyllites quadridactylites* [CM]
  - *Hymenotheca broadheadi* [CM]
  - *H. bronni* [CM]
  - *H. dathei* [CM]
  - *Sphenopteris (Hymenophyllites) bronni* [CM]
  - (?= *Boweria schatzlerensis* [C, CM])
- Order Cordaitales
- Stem genus (pith cast)
  - *Artisia transversa* [CR, C, CM]
- Stem genus (permineralized)
  - *Cordaixylon* sp. [CR, C, CM]
- Foliar genera
- *Cordaites principalis* [CR, C, CM]
- Reproductive organ genera
  - *Cardiocarpon carinatum* [CM]
  - *Cordaianthus devonicus* [C]
  - *C. pitcairniae* [CS]
  - *C. spinosus* [CM]
  - *Cordaicarpus dawsoni* [C, CM]
  - *Samaropsis ampullacea* [CM]
  - *S. baileyi* [C, (Cng)]
  - *S. cornuta* [CR, C, CM]
  - *S. crampii* [C]
  - *S. ingens* [C]
  - *S. wilsoni* [C]
- Order Voltziales
- Form genus
  - *Walchia* sp.[P]
- Gymnopermopsida *incertae sedis*
  - *Gymnocladus salisburyi* [C]
- Seeds *incertae sedis*
  - *Carpolithus tenellus* [H]
  - *Rhabdocarpus* sp. [C]
  - *Radiospermum* sp.[CM]
- Order Dicranophyllales
  - *Dicranophyllum glabrum* [C*]
  - ?*Dicranophyllum* sp. [P]
- *Incertae sedis*
  - *Nematophyllum* sp. [H]
- *Incertae sedis*
  - *Acitheca polymorpha* [CM]
  - *Dactylotheca plumosa* [CM]
  - *Desmopteris elongata* (*cf. D. longifolia*) [CM]
  - *Sporangites acuminata* [C]
  - *Tetrameridium caducum* [CM]
  - *Volkmannia?* sp. [CR]

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* First report of taxon.