Karst-related outliers of the Cretaceous Chaswood Formation of Maritime Canada[1]

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Abstract: The Lower Cretaceous Chaswood Formation is a terrestrial deposit preserved as scattered outcrops across Maritime Canada. Here we describe newly recognized outliers of the Chaswood Formation near Windsor, Nova Scotia. A Cretaceous age is confirmed only in Bailey Quarry, where sediments are provisionally assigned a Valanginian–Hauterivian (140–130 Ma) age based on palynology, making them among the oldest known deposits of the Chaswood Formation. At three nearby sites, putative Cretaceous sediments are recognized based on similar geological context, facies, and petrography; however, their age cannot be confirmed because sediments either lack palynomorphs or contain equivocal assemblages. Although the Chaswood Formation has been previously documented mainly in small tectonically generated basins, these new-found deposits are fluvial sands and gravels, and lacustrine or floodplain clays associated with a karstified gypsum surface developed on the Carboniferous Windsor Group. Deposits are preserved in karst valleys, sinkholes, and fissures, locally up to 36 m below the paleosurface. Although occupying a karstic setting, sediments were evidently deposited in a through-flowing drainage system because they are quartz-rich and show petrographic similarity to basinal deposits elsewhere. Abundant plant material, including lignite, charcoal, cuticles, and palynomorphs, implies that the surrounding landscape was covered by fire-prone forests of conifers, ginkgos, bennettites, cycads, ferns, and lycopods — typical pre-angiosperm Mesozoic vegetation. Analysis of growth patterns in fossil woods, combined with lithological indicators, suggest a humid, tropical climate, punctuated by aperiodic droughts that may have been accentuated under a karstic hydrological regime.

Résumé : La Formation de Chaswood du Crétacé inférieur est un dépôt terrestre préservé dans des affleurements dispersés dans la région canadienne des Maritimes. Nous décrivons des lambeaux de la Formation de Chaswood récemment découverts près de Windsor (Nouvelle-Écosse). L'âge crétacé de ces sédiments n'est confirmé que dans la carrière Bailey, où un âge valanginien–hauterivien (130–140 Ma) leur est provisoirement attribué à la lumière de données palynologiques, en faisant ainsi un de plus vieux dépôts de la Formation de Chaswood. Dans trois sites à proximité, des sédiments d'âge crétacé putatif sont reconnus à leur contexte géologique, leur faciès et leur pétrographie semblables; toutefois, leur âge ne peut être confirmé étant donné qu'ils sont exempts de palynomorphes ou renferment des assemblages équivoques. Si la Formation de Chaswood a principalement été documentée dans de petits bassins d'origine tectonique, ces nouveaux dépôts sont constitués de sables et graviers fluviatiles et d'argiles lacustres ou de plaine inondable associés à une surface de gypse karstifiée qui s'est développée sur le Groupe de Windsor, d'âge carbonifère. Ces dépôts sont préservés dans des vallées, dolines et fissures karstiques dont la profondeur peut atteindre, localement, jusqu'à 36 m sous la paléosurface. Bien qu'ils se trouvent dans un milieu karstique, les sédiments ont, de toute évidence, été déposés dans un système hydrographique d'écoulement libre puisqu'ils sont riches en quartz et présentent des similitudes pétrographiques avec des dépôts de bassin présents ailleurs. L'abondance des matières végétales, dont de la lignite, du charbon, des cuticules et des palynomorphes, suggère que le paysage environnant était couvert de forêts de conifères, ginkgos, bennettites, cycadophytes, fougères et lycopodes susceptibles au feu, soit une végétation pré-angiospermes mésozoïque typique. L'analyse des modèles de croissance dans les bois fossiles, combinée à des indicateurs lithologiques, témoigne d'un climat tropical humide ponctué de sécheresses apériodiques qui pourraient avoir été accentuées par un régime hydrologique karstique.

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Introduction

Lower Cretaceous terrestrial sediments accumulated widely around the central North Atlantic passive margin (paleolatitude, 30°–40°) following mid- to late-Mesozoic oceanic rifting (Ziegler 1989). On the western Atlantic margin, fluvial, lacustrine, and deltaic deposits of this age are preserved in the eastern USA (Glaser 1969), and more sporadically in eastern Canada, especially in Nova Scotia, where there are several proven outcrops (Stea and Pullan 2001; Pe-Piper et al. 2005*a*), but also as a single known outcrop in southern New Brunswick (Falcon-Lang et al. 2003) and in Ontario's Hudson Bay lowlands (Try et al. 1984; Zippi 1998; Long 2000). In all Canadian onshore occurrences, Lower Cretaceous rocks mantle bedrock surfaces. More extensive successions are present in the offshore Scotian, Newfoundland, and Labrador margins of Canada (Grant and McAlpine 1990; Wade and MacLean 1990; MacLean and Wade 1992). On the eastern Atlantic margin, Lower Cretaceous terrestrial deposits are prominent in southern England (Anderton et al. 1979), Portugal (Salas and Casas 1993), Spain (Clemente and Perezarlucea 1993), and France (Thiry et al. 2006).

The thin, patchy Lower Cretaceous strata of onshore Nova Scotia and New Brunswick represent one of the least investigated deposits in this North Atlantic region (Stea and Pullan 2001). Although first noted by Sir William Dawson (1868, p. 272), a Cretaceous age was confirmed only relatively recently (Stevenson 1959; Stevenson and McGregor 1963; Lin 1971). Strata are formally named the Chaswood Formation (Stea and Pullan 2001), but as yet remain incompletely mapped, as indicated by ongoing discoveries of new outliers (Falcon-Lang et al. 2003).[3] Their significance lies in the fact that they represent the correlative equivalent of thick hydrocarbon-bearing successions in the offshore Scotian Basin and below the Grand Banks of Newfoundland (Wade and MacLean 1990). Onshore sediments of the Chaswood Formation probably accumulated within inland valley systems that fed the deltas that deposited the Mississauga and Logan Canyon formations preserved offshore (Gobeil et al. 2006).

In this paper we describe aspects of the geological context, facies, petrology, biostratigraphy, paleoecology, and paleoclimate of a newly recognized cluster of Chaswood Formation outliers near Windsor, Nova Scotia. One of these outliers, that at Bailey Quarry, is confirmed as Early Cretaceous through age-diagnostic palynofloras. The other outliers, although lacking age confirmation, are so similar in geological setting, facies, and lithology that we consider them to be Early Cretaceous also. The new observations improve knowledge of the age and paleoecological and paleoclimatic settings of Lower Cretaceous deposits in Nova Scotia and provide additional insight into the sourcelands of offshore hydrocarbon-rich fluvio-deltaic successions. Our paper also represents the first detailed indication that parts of the Chaswood Formation are of pre-Barremian age, and we draw attention to the unusual karstic setting of the Cretaceous deposits near Windsor.

The Chaswood Formation

The Lower Cretaceous Chaswood Formation crops out in localized depocentres in Nova Scotia and New Brunswick (Table 1; Fig. 1). Strata are best known from two small, fault-bounded basins (Elmsvale and Shubenacadie basins; Stea and Pullan 2001) that may have resulted from dextral strike-slip motion along the Cobequid – Chedabucto – SW Grand Banks fault system during North Atlantic rifting (Pe-Piper and Piper 2004; Piper et al. 2005). Although deposits represent erosional remnants of a once more extensive succession (Stea and Pullan 2001), lignite moisture content, vitrinite reflectance values of 0.25%–0.48% (Davies et al. 1984; Hacquebard 1984), and fission-track data (Grist and Zentilli 2003) imply that the overburden was never substantial, perhaps less than 1 km thick.

In its type area in the Elmsvale Basin, where the Chaswood Formation is at its thickest (~170 m), most extensive (≤40 km^2), and best-studied, palynological data indicate a Barremian–Albian age (130–110 Ma; R. Fensome in Stea and Pullan 2001). Cores through the adjacent Shubenacadie Basin prove successions of similar age.[4] Three lithostratigraphic members have been defined in this area, but cannot be correlated beyond the two basins (Stea and Pullan 2001). Most distinctive is the middle member, which consists of dark grey clay and lignite beds, interpreted as the deposits of freshwater lakes and fringing peat mires (Calder et al. 1998; Gobeil 2002). These sediments contain plant megafossils, some charred, including conifer woods, leaves, and cones, and abundant ferns (R. Grantham, personal communication 1999; Scott and Stea 2002). Units above and below the middle member consist of quartz-rich sand or gravel associated with successions of varicoloured clay; they are fluvial in origin (Pe-Piper et al. 2005*a*).

Most other outliers of the Chaswood Formation fall into the same age interval as the Elmsvale and Shubenacadie successions (Stea and Pullan 2001; Falcon-Lang et al. 2003), with exceptions at Diogenes Brook (Table 1), the base of which may be as old as Valanginian (140 Ma),[5] and deposits in a sinkhole within the Milford gypsum quarry (Table 1) that may be Valanginian–Hauterivian (R. Fensome, unpublished data). Davies et al. (1984) dated sinkhole deposits at Gays River (Table 1) as Aptian to possibly early Albian. Few studies of sedimentary facies have been undertaken outside the main basins, but successions at West Indian Road and Vinegar Hill (Table 1) contain channelized sand showing large-scale planar cross-stratification, interpreted as deposits of large southeast-flowing braided fluvial systems (Gobeil 2002; Falcon-Lang et al. 2003; Gobeil et al. 2006).

Field description of study sites

We describe one newly recognized confirmed outlier of the Chaswood Formation and three newly recognized probable outliers, each <1–2 km^2 in extent. They occur in a 72 km^2

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[3] Fletcher, K. 2004. Cretaceous deposits of the Windsor area, Nova Scotia: another glimpse of the Chaswood Formation. Unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

[4] K. Eisnor. 2002. Palynology of the Chaswood Formation, Elmsvale Basin and Shubenacadie Outlier, Nova Scotia. Unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

[5] E.H. Davies. 1983. Palynological analysis of the Cretaceous semiunconsolidated sediments, Diogenes Brook, Cape Breton Island, Nova Scotia. Geological Survey of Canada (Atlantic) Internal Report No. EPGS-PAL.3-83EHD. (Unpublished report.)

Table 1. Known outliers of Lower Cretaceous Chaswood Formation proven by palynology or of suspected Cretaceous age.

Locality (Nova Scotia except where noted)	Geological setting	Thickness and area	Age	Reference
1. Avondale	**Karstic surface**	**1.5 m**	**Unconfirmed Cretaceous**	**This paper**
2. Belmont, Colchester County	Fault-bounded basin	20 m	Early Cretaceous	Dickie (1986); Pe-Piper et al. (2005*c*)
3. Bailey Quarry, Windsor, Hants County	**Karstic surface**	**36 m; <1 km^2**	**Valanginian–Hauterivian**	**This paper**
4. Brierly Brook, Antigonish County	Unknown	40 m	Early Cretaceous	Stea and Fowler (1981); Stea et al. (1995); Pe-Piper et al. (2005*c*)
5. Vinegar Hill, Kings County, New Brunswick	Downthrown side of fault block	<5 m; <2 km^2	Early Cretaceous	Falcon-Lang et al. (2003)
6. Diogenes Brook, Inverness County, Cape Breton Island	Fault-bounded basin	>125 m	Valanginian to Early Aptian	Dickie (1986); E.H. Davies in both Dickie (1986) and Wade and MacLean (1990); Pe-Piper et al. (2005*c*)[a]
7. East Milford Gypsum Quarry, Halifax Regional Municipality	Karstic surface	Unknown	Possibly Valanginian–Hauterivian	R.A. Fensome, unpublished data
8. Elmsvale Basin, Halifax Regional Municipality	Fault-bounded basin	<170 m; <40 km^2	Barremian–Aptian (–Albian)	Stea and Pullan (2001); Pe-Piper et al. (2005*a*)[b]
9. Gays River, Colchester County	Karstic surface	90 m	Aptian – Early Albian	Davies et al. (1984)
10. Halfway Lake, Halifax Regional Municipality	Unknown (from a water well)	Unknown	Aptian	E.H. Davies, personal communication to R.A. Fensome (1997)
11. Little Narrows, Victoria County, Cape Breton Island	Unknown	Unknown	Early Cretaceous	R.A. Fensome, unpublished data
12. McKay Settlement	**Karstic surface**	**Unknown**	**Unconfirmed Cretaceous**	**Dickie (1986)**[b,c]
13. Shubenacadie Outlier, Colchester County	Fault-bounded basin	Unknown	Barremian–Aptian	
14. Upper Stewiacke Crossroads, Colchester County	Fault-bounded basin	Unknown	Unconfirmed Cretaceous	Dickie (1986); R.A. Fensome, unpublished data
15. West Indian Road, Hants County	Fault-bounded basin	>60 m	Unconfirmed Cretaceous	Dickie (1986); Gobeil (2002); Gobeil et al. (2006)
16. Wentworth 4A Quarry	**Karstic surface**	**1 m**	**Unconfirmed Cretaceous**	**This paper**

Note: Locations shown in Fig. 1.

[a] See footnote 5.

[b] See footnote 4.

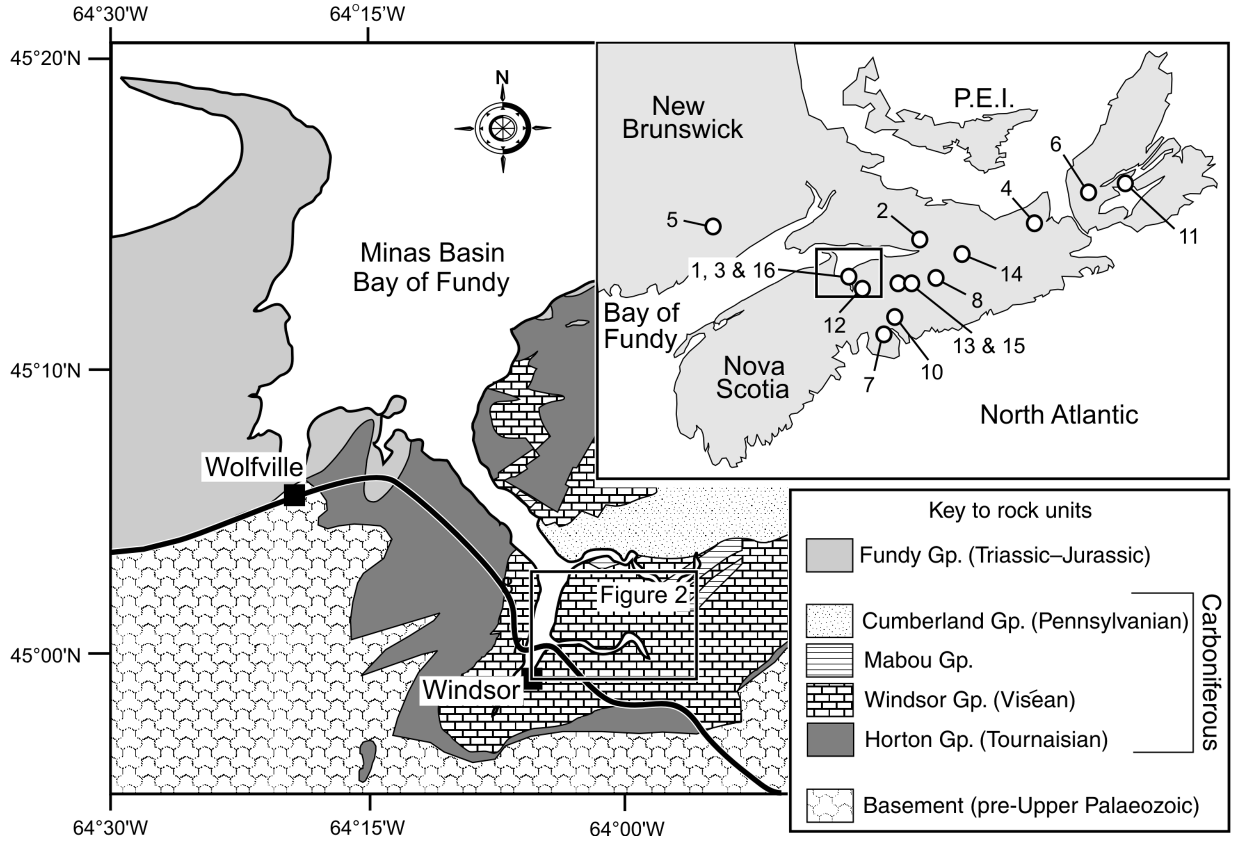
[c] R.A. Fensome. 1995. Palynological analysis of the interval 82′6″ to 120′, onshore Shubenacadie 94-3 borehole. Geological Survey of Canada (Atlantic) Internal Report MAR.RES.GEOL.-PAL.6-95RAF. (Unpublished report.)

area of Hants County adjacent to the Avon and St. Croix rivers, near Windsor, central Nova Scotia (Fig. 2; Table 1; Appendix A). The putative Cretaceous sediments are generally poorly exposed and are mostly confined to two-dimensional cuts in outcrops and quarry faces; one is a core. Hence, only limited geological investigation was possible; specifically, sedimentary structure could not be determined and no paleocurrent measurements were obtained. Although in a few occurrences the sediments are cemented with gypsum, most are poorly consolidated, and they are described here using soft-sediment terms (gravel, sand, clay). The putative Cretaceous sediments overlie the Miller Creek and White Quarry formations, part of the A and B subzones of the Carboniferous (Visean) Windsor Group. These basement units are thick gypsum successions with thin dolostone, limestone, and mudstone beds, which are deformed into tight, locally recumbent folds. The axes of the larger-scale folds trend ENE–WSW, and bedding is near vertical in many areas (Moore and Ferguson 1986). Outcrop belts are cut by numerous faults.

Avondale

At our first locality, putative Cretaceous sediments occur in a faulted section along the eastern bank of the Avon

Fig. 1. Location of Chaswood Formation outliers onshore in Atlantic Canada. **1.1.** Schematic geological map of Atlantic Canada showing the distribution of proven or suspected Lower Cretaceous outliers on Carboniferous basement. Key: 1, Avondale; 2, Belmont; 3, Bailey Quarry; 4, Brierly Brook; 5, Cassidy Lake; 6, Diogenes Brook; 7, East Milford Quarry; 8; Elmsvale; 9, Gays River; 10, Halfway Lake; 11, Little Narrows; 12, McKay Settlement; 13, Shubenacadie; 14, Stewiacke; 15, West Indian Road; 16, Wentworth 4A Quarry (see Table 1 for details). **1.2.** Geological map of Windsor area, the focus of this study. Figure 1.1 is modified from Stea and Pullan (2001) and Falcon-Lang et al. (2003).



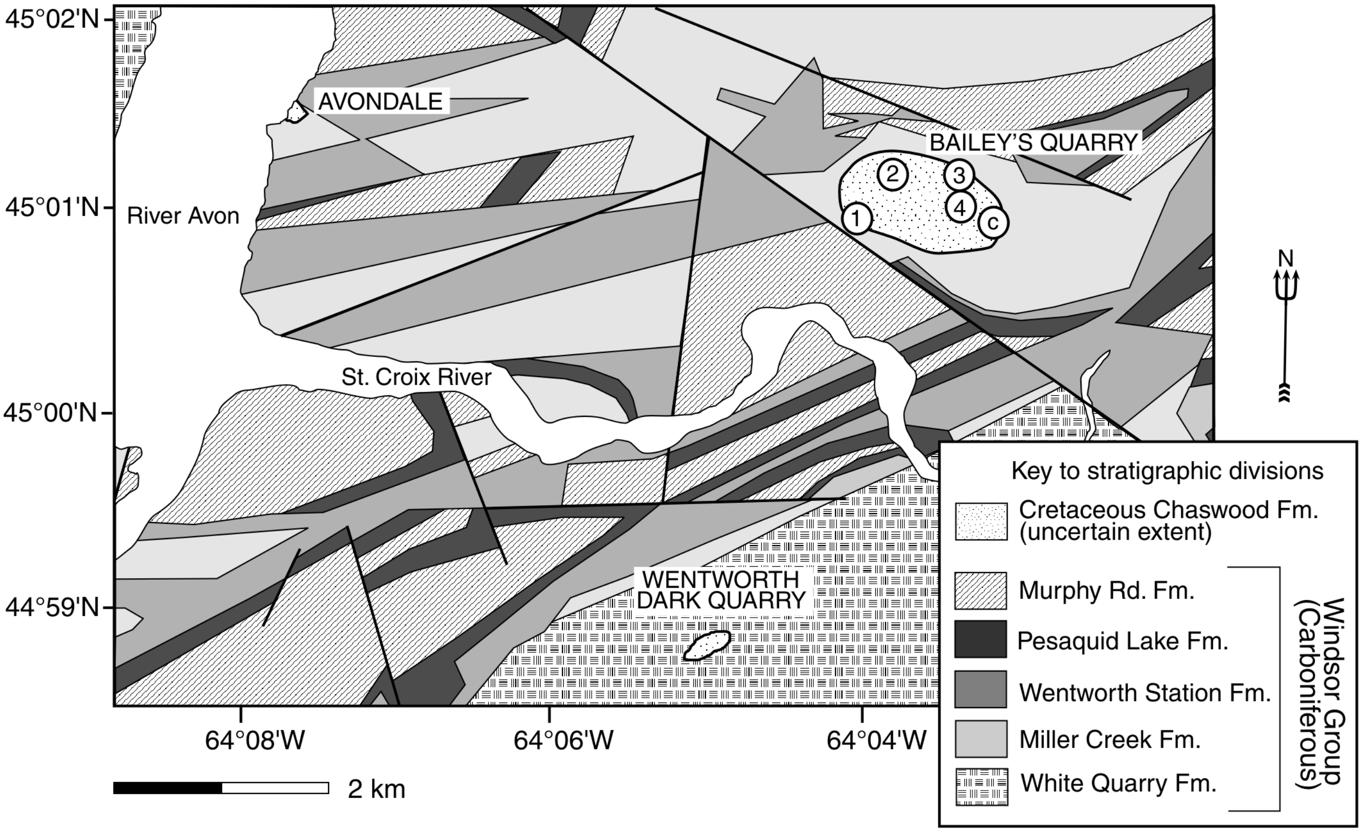
River, 2 km north of its confluence with the St. Croix River near Avondale. Here, sediments fill a narrow hollow in Windsor Group gypsum (Fig. 3.1). The occurrence is 1.5 m thick and only 3 m in lateral extent in the cliff and consists of cemented pebbly sands that are also present in large, fallen blocks on the foreshore. The in situ occurrence contains a single set of low-angle cross-strata, although the block may have tilted from horizontal. Clasts consist predominantly of quartz, up to 10 mm in diameter. Pebbly sands overlie a zone of rubbly fragments of gypsum and grey siltstone, close to a contact with an antiformal gypsum mass with steeply dipping limbs (Fig. 3.1). The gypsum is locally cut by subvertical fissures, 5–15 cm wide, which contain pebbly sands resembling those in the main stratified body. Although the fissure fill closest to the in situ block can be traced for only 1 m below the base of the block, field relationships show that other fissure fills penetrate more than 8 m below an inferred paleosurface developed on top of the gypsum, and their position north of the block (Fig. 3.1) implies that clastic sediments formerly covered a wider area than at present.

Bailey Quarry

Our second locality, Bailey Quarry, near Mantua, north of the St. Croix River, lies within an area underlain by Miller Creek Formation, exposed in a local anticline and cut by faults (Moore and Ferguson 1986). Probable Cretaceous material was noted at four localities in the 1 km diameter quarry, identified as BQ 1 to BQ 4, and in a borehole core (685) northeast of the quarry (Fig. 2).

BQ 1 comprises 4 m of sand with lenses of clay, exposed over a distance of 25 m (Fig. 3.2). Mean grain size is 2.53ϕ (medium-grained sand) with a standard deviation of 0.64 (moderately well sorted, Folk 1974). Sands are poorly consolidated and planar-laminated to low-angle cross-laminated. The basal contact is not exposed, and beds are overlain by Quaternary till. BQ 2 consists of a cemented block of pebbly sand, with clasts predominantly of quartz up to 6 mm in diameter and abundant charcoal up to 1 cm in size (~5% of the sediment). The block is 1 m high and 1.5 m wide and lies within B-zone gypsum of the Miller Creek Formation. BQ 3 is a collection of fossiliferous material brought from unknown locations in the quarry. The host sediment is quartz-rich gravel with clasts up to 6 mm in diameter, with abundant pyrite, charcoal fragments up to 3 cm in diameter, and one woody fragment 15 cm in diameter and 30 cm long. BQ 4 comprises a more extensive area of Cretaceous sediment, 7 m thick and 18 m wide, with abrupt, near-vertical contacts with gypsum on either side (Fig. 3.3). The sediment is poorly consolidated and overlain by recent rubble and sheet

Fig. 2. Detailed geological map of the Windsor area showing the distribution of the newly discovered cluster of Lower Cretaceous outliers. In the Bailey Quarry, nos. 1–4 indicate individual localities, and "c" indicates the location of Core 685. Modified from Moore and Ferguson (1986).



wash, so that a complete stratigraphic section could not be obtained, and no basal contact was observed. However, the exposure consists of brown clay with dark grey patches and bands, passing up into quartz-rich gravel with 7 mm clasts. The clays contain abundant charcoal fragments up to 6 cm in diameter, large amounts of which have been weathered out of the clay, as well as lignitic material, pyrite nodules, and gypsum. Limestone beds in the gypsum on the western side are near-vertical, suggesting that the Cretaceous material occupies a narrow "trench" within Carboniferous strata. Near the eastern margin, gypsum boulders up to 1 m in diameter are incorporated into the Cretaceous clastic sediment.

In BQ 685, a 90 m long core, Windsor Group gypsum is subvertically bedded, and putative Cretaceous sediments occupy a zone about 20 m wide located in the axis of a tight fold with near-vertical limbs. The lowermost succession encountered in the borehole consists of 41.7 m of steeply dipping Windsor Group strata, comprising dolomitic siltstone and minor sandstone, with abundant gypsum veins and inclusions. This is overlain by a further 11.8 m of gypsum with grey silty inclusions and stringers. Probable Cretaceous clastic sediment and associated material overlie these strata, first appearing at a depth of 36.5 m in the borehole core. Cretaceous sediments consist of 6.8 m of silt and fine-grained sand with gypsum veins and clay-rich cavity fills, overlain by 5.7 m of olive-green clay with charcoal, gypsum, and limestone fragments. The uppermost strata in the core comprise Quaternary clays.

Wentworth 4A Quarry

Our third locality, Wentworth 4A Quarry, is a gypsum pit, located east of Windsor. Putative Cretaceous sediments are poorly exposed at one locality in this quarry, where they lie in a hollow within gypsum of the White Quarry Formation. The exposure is 1 m thick and 6 m long, and comprises fine- to coarse-grained sand with sparse quartz gravel with clasts up to 6 mm in diameter. Associated with the sands are centimetre- to metre-sized lignite patches. Although the nature of the outcrop precludes a full investigation, the lignite is probably present as clasts within the sand.

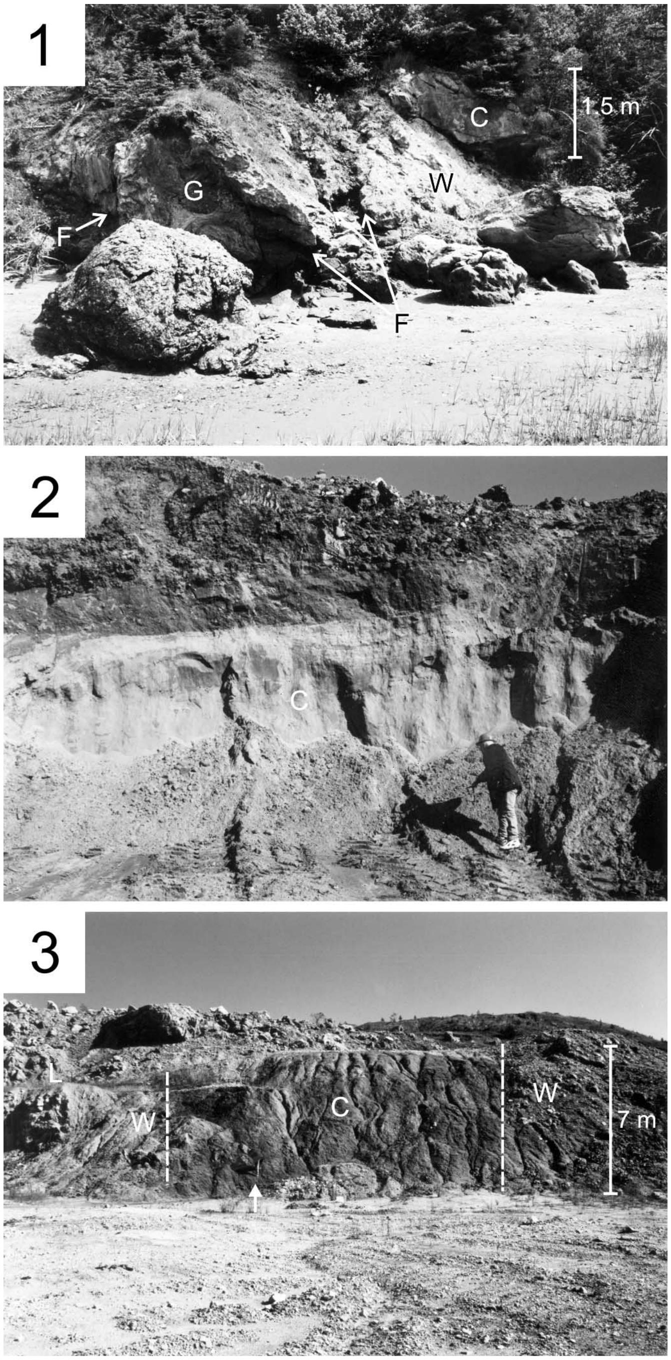
McKay Settlement Quarry

Our fourth locality, McKay Settlement Quarry, is another gypsum pit, 4 km east of Brooklyn. Dickie (1986) noted that an occurrence of white sand was exposed in an abandoned part of an active gypsum quarry, close to a major fault that separates the Windsor Group from the adjacent Lower Paleozoic Meguma Group. The sand was thought to be filling a sinkhole or to lie along an unconformity above Windsor Group gypsum, limestone, and shale. We visited the site, but although tip heaps of unconsolidated sand were located, no in situ outcrop was found.

Sediment petrology

Standard petrographic thin sections ($n = 7$) were prepared from sands and granule gravels at Avondale, Bailey Quarry,

Fig. 3. Field photos of outcrops. **3.1.** Avondale locality. Cemented sand and gravel (C) of probable Cretaceous age occupy a hollow within rubbly Windsor Group gypsum and mudstone (W) near the contact with an antiformal mass of steeply dipping gypsum (G). Fissure fills of sand and fine gravel (F) penetrate down into the gypsum from the Windsor Group paleosurface. North to left. **3.2.** Locality BQ 1. Unconsolidated sands up to 4 m thick with thin mud laminae are overlain by till. The sands yielded one Cretaceous palynomorph. **3.3.** Locality BQ 4. Muds and sands (C) yielded rich Cretaceous palynomorph assemblages and abundant charcoal. They are up to 7 m thick and occupy a narrow zone about 18 m wide, with steep contacts against Windsor Group gypsum (W), with limestone (L) to the left (west). Person (arrow) for scale.



and McKay Settlement (tip heap material); Wentworth 4A Quarry was not sampled. Compositional analysis was undertaken based on counts of 500 points per slide. Because of the variable proportion of matrix, cement, and pore space in the samples, these three groups were excluded in calculating the grain proportions shown in Table 2. Matrix and cement are shown as percentages of solid material. X-ray diffraction of one 5 g Avondale sample was also utilized to aid identification of some minerals. The sample was ground and placed in a dry mount, and analyzed using Cu K-α radiation. Semiquantitative mineral proportions were estimated using the method of Cook et al. (1975), in which diagnostic peak heights are multiplied by intensity factors for each mineral and proportioned to 100%.

The seven samples are compositionally similar (Table 2). Quartz (mainly monocrystalline) predominates in all samples, with total quartz up to 93% and constituting more than 75% of total grains in all but one sample. Some grains show partial crystal faces, but these appear to be remnants of the original crystal form rather than diagenetic overgrowths. K-feldspar (mostly microcline, rarely orthoclase) greatly predominates over plagioclase, and total feldspar is up to 17.6% and greater than 9% in most samples. K-feldspar grains are weathered with a cloudy appearance, and pores are prominent within most grains. Lithic grains, including a few chert fragments, mainly comprise less than 2%. Applying the classification of Folk (1974), the samples are sublitharenites, subfeldsarenites, and quartzarenites. Heavy minerals are muscovite, staurolite (with many inclusions of quartz, feldspar, zircon, and biotite), tourmaline, and opaques (principally Fe–Ti oxides), with rare hornblende, rutile, and zircon. Ferromagnesian grains are commonly ferruginized in finer-grained samples.

The proportion of matrix material (iron oxides; green and brown clays) is variable, with local matrix-rich patches in which the clays are oriented in domains and around embedded quartz grains. The majority of quartz grains were coated with an iron oxide rim. Gypsum is the cementing agent in indurated samples, and shows a poikilotopic texture, with grains appearing to "float" in the cement locally; the large grains are visible in some hand specimens as lustre mottling. Where gypsum cement is present, quartz and feldspar grains are fractured and penetrated by the gypsum, quartz grains are embayed, and muscovite grains are commonly bent and split along their cleavages.

Quartz, K-feldspar, and gypsum were identified from XRD analysis of the Avondale sample, with semiquantitative proportions of 64%, 3%, and 33%, respectively. Although these proportions should be considered very general estimates, the gypsum proportion is in accord with that estimated under the microscope for cemented samples.

Palynomorphs

Palynological samples were collected from Bailey Quarry at BQ 1 (Geological Survey of Canada (GSC) Atlantic sample No. P39159) and BQ 4 (P39160 and P39161). Although no suitable samples were obtained from putative Cretaceous sediment at Wentworth 4A Quarry, samples P39157 and P39158 were taken from a nearby outcrop, 20 m long, of unconsolidated fine-grained sediments, which contained a 15 cm layer of organic-rich clay. It was not clear that the exposure was

Table 2. Quantitative mineralogy of sands and granule gravels, based on 500 points counted in thin sections.

Mineral	Slide number						
	KF-3.2	KF-3.3	KF-3.4	BQ-1.1	BQ-1.4	BQ-4.2	MS-2.1
Monocrystalline quartz (Qm)	67.3	64.5	61.6	67.4	48.6	59.9	79.1
Polycrystalline quartz (Qp)	19.9	16.7	18.2	8.0	14.4	30.1	13.8
K-feldspar (K)	9.4	14.9	17.6	1.4	2.5	9.3	3.0
Plagioclase feldspar (P)	0.3	0.6	0	1.7	1.2	0	0
Lithic grains (Lt)	1.1	2.1	2.0	13.1	11.2	0.6	0
Muscovite	1.1	0.6	0	0	1.0	0	0
Staurolite	0	0	0.3	1.7	1	0	0
Tourmaline	0	0	0.3	0	0	0	0
Opaques	0.9	0.6	0	4.9	20.1	0	4.1
Clay minerals	0	0	0	1.7	0	0	0
Number of counts	352	335	302	350	403	332	268
Iron oxides, clays (matrix)	5.5	5.8	0.5	0	19.4	5.1	7.6
Gypsum (cement)	17.1	22.8	30.8	0	0	27.3	0

Note: The mineral grain proportions are percentages of the number of grains counted (excluding matrix, cement, and pore space). Matrix and gypsum cement are noted in percentage of solid materials (excluding pore space). KF samples are from Avondale, BQ samples are from Bailey Quarry localities, and the MS sample is from McKay Settlement.

related to the putative Cretaceous sediments. No samples suitable for palynological analysis were obtained from the Avondale and McKay Settlement localities. Samples were prepared using standard processing techniques (Barss and Williams 1973). The resulting residues were stained using Bismarck Brown and examined with a Zeiss Axioplan 2 microscope. Residues are stored in the National Collection of Type Invertebrate and Plant Fossils, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8.

The sample from BQ 1 (P39159) was dominated by Carboniferous palynomorphs, but contained one doubtful Mesozoic fern spore, possibly assignable to *Cicatricosisporites*. The two samples from BQ 4 (P39160 and P39161) contained unequivocal Cretaceous palynofloras, comprising abundant and diverse miospores. Included in these samples are fern spores of the Gleicheniaceae, Lygodiaceae, Osmundaceae, and Schizaeaceae; conifer pollen belonging to the Araucariaceae, “Taxodiaceae”, and Cheirolepidiaceae; and representatives of ginkgos, cycads, bennettites, lycopsids, liverworts, and freshwater algae (Figs. 4, 5; Table 3). Sediment samples adjacent to our site at Wentworth 4A Quarry (P39157 and P39158) contained only Quaternary taxa.

In addition to palynomorphs, abundant cuticle mesofossils were noted in the two samples from Bailey Quarry, BQ 4 (P39160 and P39161). The two dominant types probably belong to the extinct gymnosperm order, Bennettitales (Fig. 6). Type A cuticles have elongate cells, about 100 μm in diameter, arranged in poorly defined rows, and showing strongly sinuous, though indistinct, anticlinal walls, superficially similar to those of *Zamites* (Watson and Sincock 1992). Type B cuticles have cells showing various tetragonal shapes with anticlinal walls tightly and evenly sinuous, typically about 50 μm in diameter; cuticles are comparable to those of *Ptilophyllum*, *Pseudocycas*, and *Nilssoniopteris* among other Bennettites (Watson and Sincock 1992). Without the preservation of stomata neither cuticle type can be identified with precision.

Fossil woods

A collection of fossil wood, preserved as charcoal, was also studied from Bailey Quarry, at BQ 2 – BQ 4. The charred nature of the wood was confirmed by its black streak, cubic gross morphology, high reflectance, cell-wall homogenization, exquisite preservation of plant anatomy (Scott 1989; Jones and Chaloner 1991), and the occurrence of firecracks (Jones 1993). Specimens were cleaned in 40% HCl (1 day) and 35% HF (7 days), mounted on aluminum stubs, gold-coated, and examined with a Hitachi S-3500N scanning electron microscope at the University of Bristol, UK (Malcolm 2004). Thirty-five specimens were studied, and these are stored in the Nova Scotia Museum of Natural History, 1747 Summer Street, Halifax, NS B3H 3A6, Canada. Fossil woods were described from radial longitudinal view (RLV), tangential longitudinal view (TLV), and transverse view (TV; the term “view” is preferred to “section” as the woods were analyzed under SEM rather than in thin section). Anatomical dimensions given in this paper are reported as measured, uncorrected for the ~33% contraction that occurs during charring (Jones and Chaloner 1991).

Group I woods

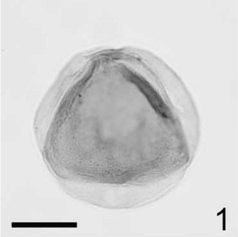
Group I is the dominant wood type (Fig. 7), comprising 27 specimens numbered NSM004GF047.001–010, 014, 016–020, 022–029, 031, 032, and 035. In RLV, earlywood tracheids are characterized by uni- to bi- (rarely tri-) seriate, circular bordered pits (15–19 μm) with circular apertures (4–5 μm). Tracheid pits are contiguous or spaced less than half a pit diameter apart and show opposite to locally subopposite arrangement (Fig. 7.1). Latewood tracheid pits are uniseri-

Fig. 4. Representative palynomorphs from Bailey Quarry, sublocality 4 (P39160). Microscope coordinates quoted are from the Vernier scale of Zeiss Axioplan 2 microscope, serial no. 310243 at GSC Atlantic, Dartmouth, Nova Scotia; and England Finder locations are also given. Specimens are curated in the National Collection of Type Invertebrate and Plant Fossils, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8 (at the time of writing on long-term loan to GSC Atlantic, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada B2Y 4A2); in the captions, these specimens are designated GSC collection numbers. All specimens have been stained using Bismarck Brown, and all photomicrographs are from digital originals and have been made under bright-field illumination. The scale bar in all figures represents 20 µm. **4.1.** *Callialasporites trilobatus*: proximo-distal view; GSC type collection No. 128933, sample P39160, slide 02, coordinates 20.0 × 90.1, England Finder T33/3. **4.2.** *Cerebropollenites macroverrucatus*: proximal view of proximal surface; GSC type collection No. 128934, sample P39160, slide 02, coordinates 17.8 × 94.9, England Finder R38/3. **4.3.** *Cerebropollenites mesozoicus*: proximal view of distal surface; GSC type collection No. 128935, sample P39160, slide 02, coordinates 19.0 × 73.1, England Finder S15/4. **4.4–4.5.** *Ruffordiaspora australiensis*: proximo-distal views of proximal (4) and distal (5) surfaces; GSC type collection No. 128936 sample P39160, slide 01, coordinates 13.3 × 95.6, England Finder N38/2. **4.6.** *Cibotiumspora sinuata*: proximo-distal view; GSC type collection No. 128937, sample P39160, slide 02, coordinates 20.0 × 100.5, England Finder T43/4. **4.7.** *Cicatricosisporites* sp.: view uncertain; GSC type collection No. 128938, sample P39160, slide 02, coordinates 17.3 × 93.5, England Finder R36/0. **4.8–4.9.** *Cicatricosisporites* sp.: distal views of distal (8) and proximal (9) surfaces; GSC type collection No. 128939, sample P39160, slide 02, coordinates 18.5 × 99.5, England Finder S42/2. 4.**10.** *Cicatricosisporites* sp: distal view of distal surface; GSC type collection No. 128940, sample P39160, slide 02, coordinates 18.7 × 102.3, England Finder S45/0. **4.11.** *Concavisporites toralis*: distal view of proximal surface; GSC type collection No. 128941, sample P39160, slide 01, coordinates 17.8 × 91.3, England Finder R34/0. **4.12.** *Concavissimisporites crassatus*: proximal view of distal surface; GSC type collection No. 128942, sample P39160, slide 01, coordinates 12.1 × 90.4, England Finder L33/0. **4.13.** *Concavissimisporites crassatus*: distal view; GSC type collection No. 128943, sample P39160, slide 02, coordinates 18.2 × 94.8, England Finder S38/1. **4.14.** *Crassitudisporites problematicus*: proximal view of distal surface; GSC type collection No. 128944, sample P39160, slide 02, coordinates 19.3 × 94.9, England Finder T38/1. **4.15.** *Cycadopites* sp.: distal view of distal surface; GSC type collection No. 128945, sample P39160, slide 01, coordinates 11.0 × 103.1, England Finder K46/0. **4.16.** *Densoisporites microrugulatus*: distal view of proximal surface; GSC type collection No. 128946, sample P39160, slide 01, coordinates 19.6 × 97.3, England Finder T40/0. **4.17.** *Distaltriangulisporites perplexus*: proximal view of distal surface; GSC type collection No. 128947, sample P39160, slide 02 coordinates 20.1 × 91.5, England Finder U34/2. **4.18.** *Exesipollenites tumulus*: proximo-distal view; GSC type collection No. 128948, sample P39160, slide 02, coordinates 18.9 × 67.5, England Finder S9/4. **4.19–4.20.** *Kuylisporites* sp.: proximal view of proximal (19) and distal (20) surfaces; GSC type collection No. 128949, sample P39160, slide 02, coordinates 20.2 × 93.2, England Finder U36/0. **4.21–4.22.** *Pilosisporites trichopapillosus*: distal view of distal (21) and proximal (22) surfaces; GSC type collection No. 128950, sample P39160, slide 02, coordinates 18.9 × 96.1, England Finder S39/0. **4.23.** *Pilosisporites trichopapillosus*: distal view of proximal surface; GSC type collection No. 128951, sample P39160, slide 01, coordinates 11.0 × 97.9, England Finder K41/0. **4.24.** *Plicatella* sp.: distal view of distal surface; GSC type collection No. 128952, sample P39160, slide 01, coordinates 16.7 × 88.2, England Finder Q31/3. **4.25.** *Schizosporis reticulatus*: GSC type collection No. 128953, sample P39160, slide 01, coordinates 19.5 × 97.0, England Finder T40/0. **4.26–4.27.** *Rotverrusporites major*: upper (26) and lower (27) focal levels, view and surfaces uncertain, masked by heavy ornamentation; GSC type collection No. 128954, sample P39160, slide 01, coordinates 16.4 × 103.8, England Finder Q47/0. **4.28.** *Trilobosporites canadensis*: distal view of proximal surface; GSC type collection No. 128955, sample P39160, slide 01, coordinates 11.9 × 104.7, England Finder L48/0. **4.29.** *Trilobosporites canadensis*: proximal view of proximal surface; GSC type collection No. 128956, sample P39160, slide 02, coordinates 20.0 × 92.3, England Finder T35/3. **4.30.** *Trilobosporites canadensis*: distal view; GSC type collection No. 128957, sample P39160, slide 01, coordinates 19.5 × 96.6, England Finder T39/4.

ate, more widely spaced, and taphonomic checking is common (Fig. 7.2). Rays are composed of smooth-walled parenchyma cells, 17–25 µm high, 17–20 µm wide, and 75–250 µm long, and show 1- to 3- (rarely 4-) taxodioid pits per cross field (Figs. 7.3–7.5). Cross-field pit apertures are oval, upright, and arranged in single rows, or are oblique and randomly arranged. Ray cells are locally resin-filled. In TLV, rays are exclusively uniseriate and 1–28 (typically 7–20) cells high (Fig. 7.7–7.8). Pitting is absent on tangential tracheid walls. In TV, earlywood tracheids are 40–60 (locally –80) µm in diameter with latewood tracheids being 7–15 µm in diameter. Rays are spaced one to nine (typically four to six) tracheids apart when measured in the latewood near the ring boundary (rays commonly die out at the ring boundary, hence the importance of standardizing the location of measurement). Transverse ray walls are not pitted. Growth rings are present and described elsewhere in this paper (Fig. 7.6).

Group II woods

Eight specimens, numbered NSM004GF047.011–013, 015, 021, 030, 033, and 034, make up a second type of wood (Fig. 8). In RLV, earlywood tracheids are characterized by uniseriate, spaced or contiguous, circular bordered pits (9–13 µm) with circular apertures (3–4 µm), and taphonomic checking is common (Figs. 8.1, 8.2). Latewood tracheid pits are rare, uniseriate, and spaced. Rays are composed of cells 22–26 µm high, 12–25 µm wide, and 70–170 µm long, and show 1–2 taxodioid, or more dominantly cupressoid, cross-field pits (Figs. 8.3, 8.5) with large oval apertures (7–10 µm). Cross-field apertures are oblique, and pits are arranged in rows. Rays are locally resin-filled (Fig. 8.6). In TLV, rays are uniseriate or rarely biseriate and 1–16 (typically <8) cells high (Figs. 8.9, 8.12). Tangential tracheid walls show irregularly arranged pits with small borders (7–8 µm) and apertures (2–3 µm). Axial parenchyma is present (cells up to 150 µm high and 25–30 µm diameter), locally resin-filled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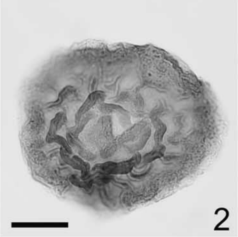
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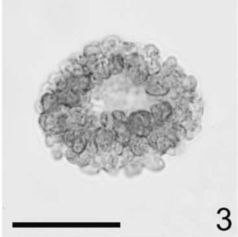
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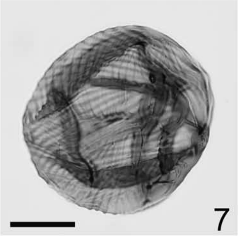
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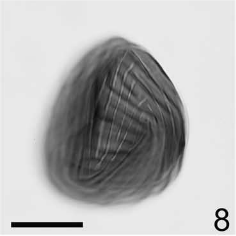
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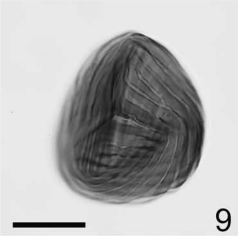
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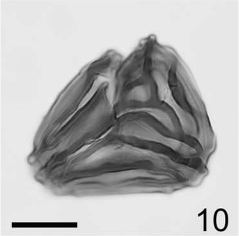
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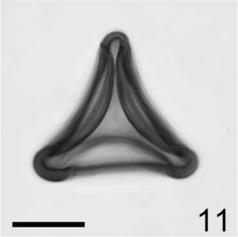
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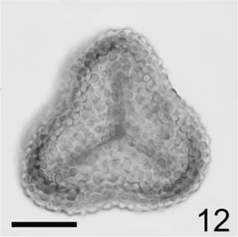
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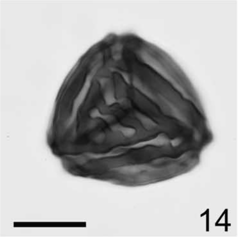
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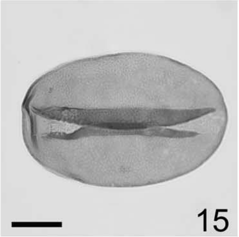
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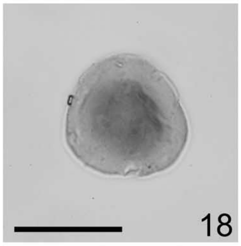
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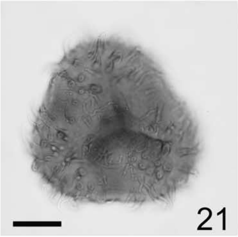
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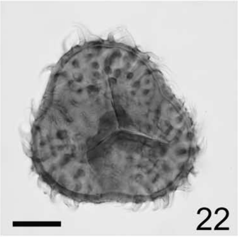
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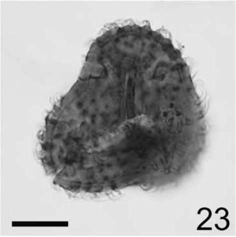
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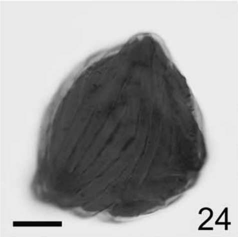
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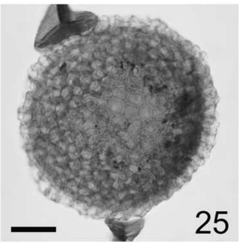
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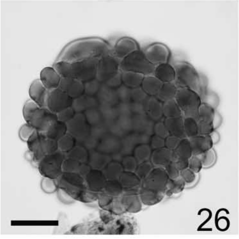
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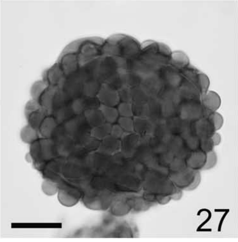
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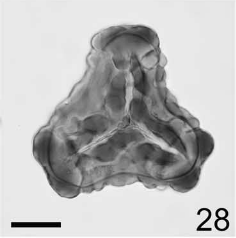
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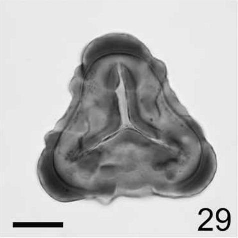
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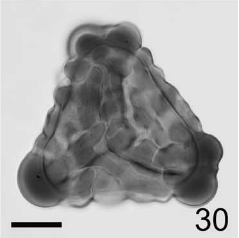
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Fig. 5. Representative palynomorphs from Bailey Quarry, sample P39161. See the caption to Fig. 4 for general details concerning microscopy, specimen repository, and sample preparation. The scale bar in all figures represents 20 µm. **5.1.** *Aequitriradites spinulosus*: proximal view of distal surface, showing hilum; GSC type collection No. 128958, sample P39161, slide 02, coordinates 17.8 × 95.7, England Finder R38/4. **5.2.** *Aequitriradites verrucosus*: distal view of distal surface, showing hilum; GSC type collection No. 128959, sample P39161, slide 02, coordinates 16.0 × 101.7, England Finder P45/3. **5.3.** *Callialasporites dampieri*: proximo-distal view; GSC type collection No. 128960, sample P39161, slide 02, coordinates 20.2 × 98.0, England Finder U41/1. **5.4–5.5.** *Cicatricosisporites* sp: distal view of distal (4) and proximal (5) surfaces; GSC type collection No. 128961, sample P39161, slide 02, coordinates 14.7 × 86.9, England Finder O29/4. **5.6–5.7.** *Cicatricosisporites* sp: distal view of distal (6) and proximal (7) surfaces; GSC type collection No. 128962, sample P39161, slide 02, coordinates 17.6 × 95.5, England Finder R38/0. **5.8–5.9.** *Cicatricosisporites* sp: distal view of distal (8) and proximal (9) surfaces; GSC type collection No. 128963, sample P39161, slide 02, coordinates 18.0 × 97.2, England Finder R40/3. **5.10.** *Classopollis classoides*: proximo-distal view; GSC type collection No. 128964, sample P39161, slide 02, coordinates 18.7 × 67.4, England Finder S9/0. **5.11–5.12**. *Concavissimisporites verrucosus*: proximal view of proximal (11) and distal (12) surfaces; GSC type collection No. 128965, sample P39161, slide 02, coordinates 15.6 × 103.2, England Finder P46/0. **5.13.** *Concavissimisporites crassatus*: distal view of distal surface; GSC type collection No. 128966, sample P39161, slide 02, coordinates 20.3 × 98.5, England Finder U41/2. **5.14.** *Deltoidospora punctata*: proximo-distal view; GSC type collection No. 128967, sample P39161, slide 02, coordinates 16.1 × 92.8, England Finder P35/4. **5.15.** *Eucommiidites minor*: proximo-distal view; GSC type collection No. 128968, sample P39161, slide 02, coordinates 19.5 × 77.8, England Finder T20/0. **5.16.** *Gleicheniidites senonicus*: proximo-distal view; GSC type collection No. 128969, sample P39161, slide 02, coordinates 20.2 × 76.7, England Finder U19/0. **5.17.** *Pilosisporites trichopapillosus*: distal view; GSC type collection No. 128970, sample P39161, slide 02, coordinates 15.3 × 104.0, England Finder P47/2. **5.18.** *Pilosisporites trichopapillosus*: distal view of proximal surface; GSC type collection No. 128971, sample P39161, slide 02, coordinates 17.0 × 99.4, England Finder Q42/4. **5.19.** *Pilosisporites delicatulus*: proximo-distal view; GSC type collection no. 128972, sample P39161, slide 02, coordinates 20.1 × 94.0, England Finder U37/1. **5.20.** *Kuylisporites* sp.: proximo-distal view; GSC type collection No. 128973, sample P39161, slide 02, coordinates 20.0 × 79.4, England Finder T22/3. **5.21–5.22.** *Rotverrusporites major*: upper (21) and lower (22) focal levels of proximo-distal view; GSC type collection No. 128974, sample P39161, slide 02, coordinates 20.2 × 90.7, England Finder U33/2. **5.23.** *Staplinisporites caminus*: proximo-distal view; GSC type collection No. 128975, sample P39161, slide 02, coordinates 17.1 × 98.2, England Finder R41/2. **5.24–5.25.** *Trilobosporites canadensis*: upper (24) and lower (25) focal levels of proximo-distal view; GSC type collection No. 128976, sample P39161, slide 01, coordinates 6.9 × 94.4, England Finder F37/0. **5.26–5.27.** *Trilobosporites canadensis*: upper (26) and lower (27) focal levels of proximo-distal view; GSC type collection No. 128977, sample P39161, slide 02, coordinates 15.0 × 104.0, England Finder O48/4. **5.28.** *Trilobosporites canadensis*: proximal view of proximal surface; GSC type collection No. 128978, sample P39161, slide 01, coordinates 12.6 × 89.3, England Finder M32/0. **5.29.** *Vallizonosporites pseudoalveolatus*: distal view of distal surface; GSC type collection No. 128979, sample P39161, slide 02, coordinates 17.0 × 94.7, England Finder Q37/4. **5.30.** *Zlivisporis cenomanianus*: oblique proximo-distal view; GSC type collection No. 128980, sample P39161, slide 02, coordinates 18.0 × 96.2, England Finder R39/3.

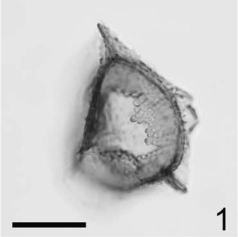
(Fig. 8.4), and especially common within the latewood (Fig. 8.11). In TV, earlywood tracheids are 22–30 µm in diameter with latewood tracheids 4–9 µm in diameter. Many latewood tracheids typically show delicate cross-walls with scalariformlike thickening, but their irregularity suggests they may be taphonomic features (Figs. 8.8, 8.10). Rays are spaced 1–11 (typically 6–8) tracheids apart when measured near the ring boundary. Transverse ray walls are locally pitted, especially in the latewood. Growth rings are present (Fig. 8.11) and described more fully in a later section.

Wood systematics

In summary, group II woods differ from those of group I by the presence of (1) axial parenchyma, (2) pitting in transverse ray walls and tangential tracheid walls, and (3) in having tracheids of smaller diameter with fewer rows of bordering pits. As our material is charcoal, a correction factor of ×1.5 was used to restore precharring anatomical dimensions in the following discussion (Jones and Chaloner 1991) and aid comparison with records of uncharred woods.

Under Kräusel's (1949) scheme, group I woods are placed in the morphogenus *Taxodioxylon* (Hartig) Gothan 1905. Relatively few Cretaceous morphospecies (n = 7) of *Taxodioxylon* have been described (Meijer 2000), although this taxon is widely encountered from pole to pole (Falcon-Lang and Cantrill 2000; Falcon-Lang et al. 2004). Our woods are closest to those of *Taxodioxylon gypsaceum* (Göppert) Kräusel 1949, especially those specimens from the Upper Cretaceous of western Canada (Ramanujam and Stewart 1969). However, those woods differ in having axial parenchyma and showing clearly defined crassulae separating bordered pits. Compared with extant conifers, our woods are similar to those members of the former "Taxodiaceae" (now absorbed into the Cupressaceae; Farjon 1998). Taxodiaceous features including very large earlywood tracheids (our specimens have ≥60 µm earlywood tracheids, rarely >100 µm, after the application of a ×1.5 correction factor) with multiseriate, opposite bordered pitting, tall rays (up to 28 cells high), and taxodioid cross-field pits (Bailey and Faull 1934; Phillips 1948). However, they lack axial parenchyma, which is common in many extant taxodiaceous conifers (Phillips 1948; Barefoot and Hankins 1982). Although they have closest affinity with certain members of the Taxodiaceae, the fossil woods could belong to the wider Cupressaceae or even the Podocarpaceae (International Association of Wood Anatomists (IAWA) Committee 2004). However, a position within the Taxodiaceae is considered most probable given the presence of taxodiaceous pollen (*Cerebropollenites*) within associated palynofloras (Balme 1995).

Under Kräusel's (1949) scheme, group II woods would be classified as *Cupressinoxylon* Göppert 1850, insofar as specimens dominantly show cupressoid cross-field pitting. This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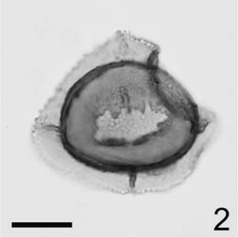
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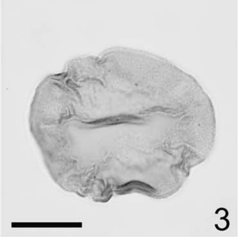
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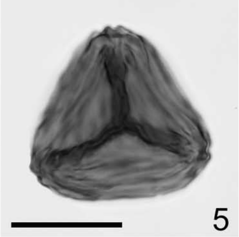
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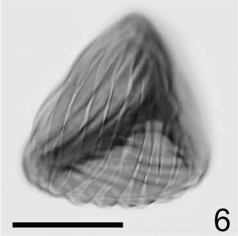
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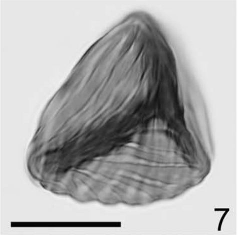
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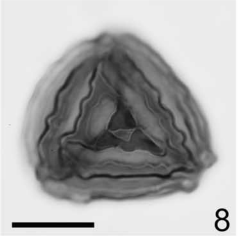
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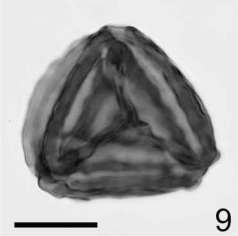
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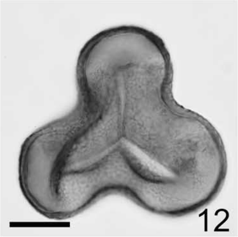
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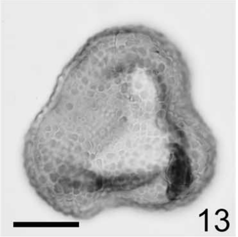
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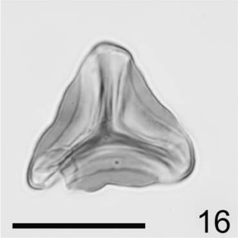
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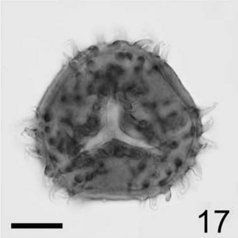
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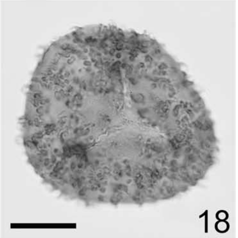
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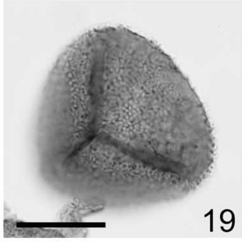
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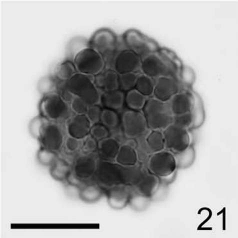
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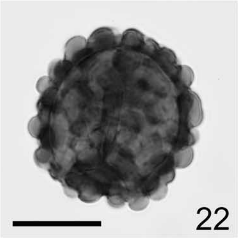
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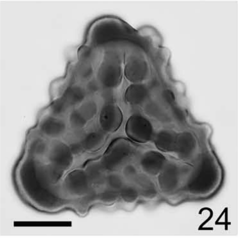
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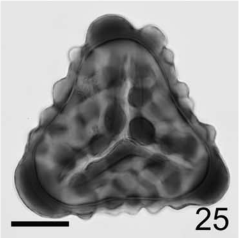
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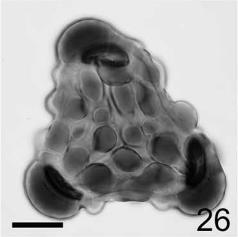
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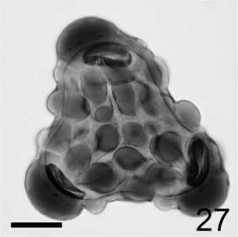
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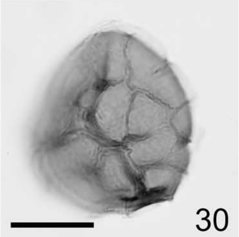
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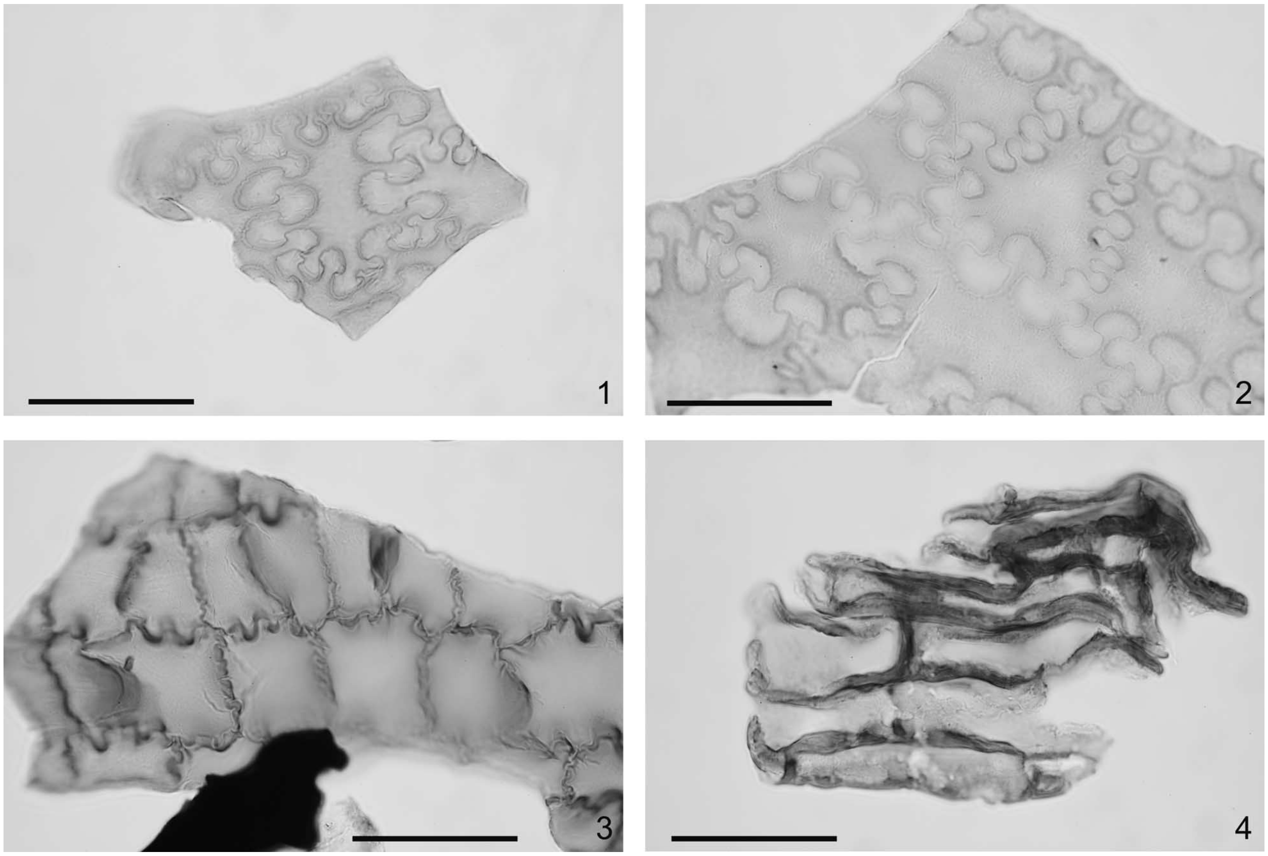
Table 3. Palynofloral assemblages from Bailey Quarry, BQ 4 (P39160 and P39161).

Bryophytes (rare)	
Aequitriradites spinulosus (Cookson and Dettmann 1958) Cookson and Dettmann 1961	Fig. 5.1
Aequitriradites verrucosus (Cookson and Dettmann 1958) Cookson and Dettmann 1961	Fig. 5.2
Zlivisporis cenomanianus (Agasie 1969) Braman 2002	Fig. 5.30
Lycopsida (rare)	
Densoisporites microrugulatus Brenner 1963	Fig. 4.16
Densoisporites sp.	
Staplinisporites caminus (Balme 1957) Pocock 1962	Fig. 5.23
Vallizonosporites pseudoalveolatus (Couper 1958) Döring 1965	Fig. 5.29
Filicopsida (common)	
Gleicheniaceae	
Gleicheniidites senonicus Ross 1949	Fig. 5.16
Lygodiaceae	
Concavissimisporites crassatus (Delcourt and Sprumont 1955) Delcourt et al. 1963	Figs. 4.12–4.13, 5.13
Concavissimisporites verrucosus (Delcourt and Sprumont 1955) Delcourt et al. 1963	Figs. 5.11–5.12
Concavissimisporites spp.	
Impardecispora apiverrucata (Couper 1958) Venkatachala et al. 1969	
Impardecispora sp.	
Pilosisporites delicatulus Norris 1969	Fig. 5.19
Pilosisporites trichopapillosus (Thiergart 1949) Delcourt and Sprumont 1955	Figs. 4.21–4.23, 5.17–5.18
Trilobosporites canadensis Pocock 1962	Figs. 4.28–4.30, 5.24–5.28
Trilobosporites sp.	
Osmundaceae	
Baculatisporites sp.	
Rotverrusporites major (Couper 1958) Fensome in Falcon-Lang et al. herein	Figs. 4.26–4.27, 5.21–5.22
Rotverrusporites sp.	
Schizaeaceae	
Cicatricosisporites spp.	Figs. 4.7–4.10, 5.4–5.9
Crassitudisporites problematicus (Couper 1958) Hiltmann 1967	Fig. 4.14
Distaltriangulisporites perplexus (Singh 1964) Singh 1971	Fig. 4.17
Distaltriangulisporites sp.	
Plicatella sp.	Fig. 4.24
Ruffordiaspora australiensis (Cookson 1953) Dettmann and Clifford 1992	Figs. 4.4–4.5
Incertae sedis	
Biretisporites sp.	
Cibotiumspora sinuata (Couper 1953) Fensome in Falcon-Lang et al. herein	Fig. 4.6
Concavisporites toralis (Leschik 1955) Nilsson 1958	Fig. 4.11
Deltoidospora australis (Couper 1953) Pocock 1970	
Deltoidospora punctata (Delcourt and Sprumont 1955) Fensome in Falcon-Lang et al. herein	Fig. 5.14
Kuylisporites sp.	Figs. 4.19–4.20, 5.20
Coniferopsida (occasional)	
Araucariaceae	
Araucariacites? sp.	
Callialasporites dampieri (Balme 1957) Dev 1961	Fig. 5.3
Callialasporites trilobatus (Balme 1957) Dev 1961	Fig. 4.1
Cheirolepidiaceae	
Classopollis classoides Pflug 1953	Fig. 5.10
Ginkgoales	
Cycadopites sp.	Fig. 4.15
Taxodiaceae	
Cerebropollenites macroverrucosus (Thiergart 1949) Schulz 1967	Fig. 4.2
Cerebropollenites mesozoicus (Couper 1958) Nilsson 1958	Fig. 4.3

Table 3 (*concluded*).

Coniferopsida (occasional)	
Incertae sedis	
Bisaccates	
Cycadopsida (occasional)	
Bennettitales	
Exesipollenites tumulus Balme 1957	Fig. 4.18
Cycadales	
Eucommiidites minor Groot and Penny 1960	Fig. 5.15
Freshwater algal cysts (rare)	
Schizosporis reticulatus Cookson and Dettmann 1959	Fig. 4.25

Fig. 6. Cuticles from Bailey Quarry BQ 4, sample P39160. See the caption to Fig. 4 for general details concerning microscopy, specimen repository, and sample preparation. The scale bar in all figures represents 20 µm. **6.1–6.2.** Type A cuticles superficially similar to those of *Zamites tatianae* Watson and Sincock 1992: 1, GSC type collection No. 6350, sample P39160, slide 02, coordinates 17.2 × 95.6, England Finder R38/2; 2, GSC type collection No. 6351, sample P39160, slide 02, coordinates 19.8 × 92.0, England Finder T35/3. **6.3.** Type B cuticle superficially similar to those of *Ptilophyllum*, *Pseudocycas*, and *Nilssoniopteris*; GSC type collection No. 6352, sample P39160, slide 02, coordinates 19.9 × 91.6, England Finder T34/4. **6.4.** Indeterminate cuticle from plant axis; GSC type collection No. 6353, sample P39160, slide 02, coordinates 20.0 × 91.3, England Finder U34/1.

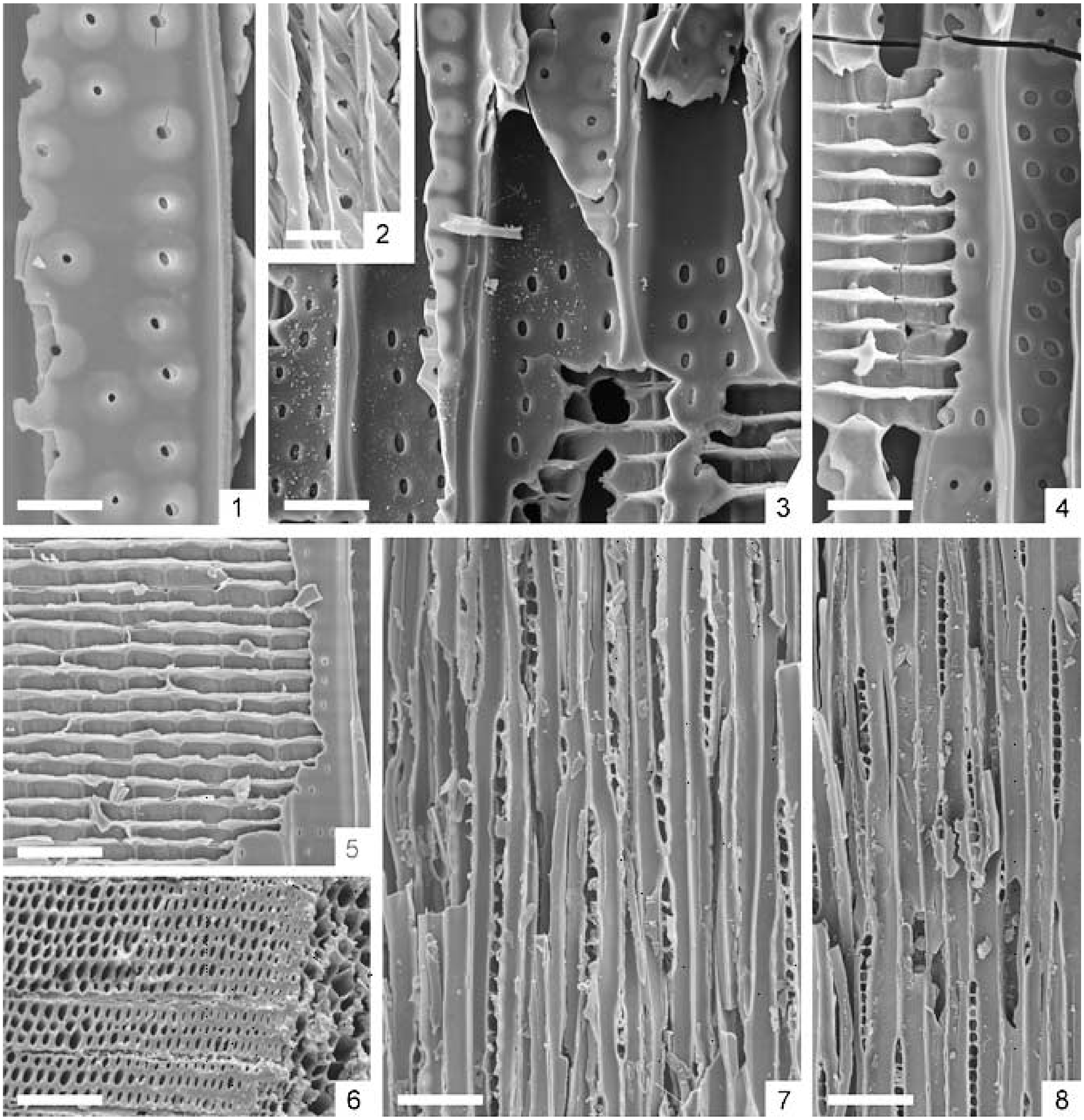


morphogenus was very diverse and widespread in Early Cretaceous times, and most commonly found in the low- to mid-paleolatitudes (Philippe et al. 2004). The family level affinity of this wood type is uncertain. However, our woods are most closely similar to woods of two conifer families, the extinct Cheirolepidiaceae (Watson 1988) and the extant Cupressaceae (Phillips 1948; IAWA Committee 2004), especially in terms of its cupressoid pits, narrow tracheids, and common resin. Of these, only the Cheirolepidiaceae is represented in the palynoflora by *Classopollis* (Balme 1995), and the *Cupressinoxylon* specimens are therefore tentatively referred to this family.

Growth patterns

Growth patterns in the woods were also qualitatively studied to elucidate paleoclimate (Fig. 9) (Creber and Chaloner 1984). Twenty specimens of radius <18 mm (typically 5–10 mm) were sufficiently uncompressed in TV to examine growth

Fig. 7. Fossil wood preserved as charcoal from Bailey Quarry, *Taxodioxylon* sp. (Group I). All specimens stored in the Nova Scotia Museum. **7.1.** Uni- to tri-seriate, subopposite bordered pits, RLV, NSM004GF047.032; scale: 35 µm. **7.2.** Checking, RLV, NSM004GF047.017; scale: 25 µm. **7.3.** Upright taxodioid cross-field pitting, RLV, NSM004GF047.001; scale: 45 µm. **7.4.** Taxodioid cross-field pitting, RLV, NSM004GF047.001; scale: 40 µm. **7.5.** Long, thin-walled ray cells, RLV, NSM004GF047.001; scale: 60 µm. **7.6.** Marked growth ring boundary with thick-walled latewood, TV, NSM004GF047.018; scale: 175 µm. **7.7.** Tall, uniseriate rays, TLV, NSM004GF047.004; scale: 175 µm. **7.8.** Tall, uniseriate rays, TLV, NSM004GF047.005; scale: 150 µm.



patterns. Sixteen specimens are *Taxodioxylon* and four are *Cupressinoxylon*. Both morphotaxa show similar growth patterns, although rings in *Taxodioxylon* are generally more marked. The most distinct rings show a gradual decline in tracheid diameter (by up to 90%–95%) over the terminal 10–25 cells, and a concurrent increase in the cell wall thickness (<4–6 µm) to typically twice that of earlywood cell wall thickness (<2–3 µm). Tracheid size abruptly increases and cell wall thickness decreases at the start of the adjacent growth increment resulting in an asymmetrical boundary: these features resemble true growth rings. Other rings are weakly developed, defined only by a slight decline in tracheid diameter (by up to 40%–50%) but no change in cell wall thickness. Subsequent increase in tracheid diameter is gradual, resulting in a symmetrical profile; such features are usually termed growth interruptions (Schweingruber 1992, 1996). In

Fig. 8. Fossil wood preserved as charcoal from Bailey Quarry, *Cupressinoxylon* sp. (Group II). All specimens stored in the Nova Scotia Museum. All images are SEM micrographs. **8.1.** Uniseriate bordered pits, RLV, NSM004GF047.011; scale: 25 μm. **8.2.** Checking, RLV, NSM004GF047.030; scale: 25 μm. **8.3.** Cupressoid and taxodioid cross-field pits, RLV, NSM004GF047.034; scale: 30 μm. **8.4.** Axial parenchyma in latewood with crystalline content, TLV, NSM004GF047.011; scale: 30 μm. **8.5.** Taxodioid cross-field pits, RLV, NSM004GF047.021; scale: 20 μm. **8.6.** Resin-filled ray, RLV, NSM004GF047.012; scale: 40 μm. **8.7.** Rays with wavy walls, RLV, NSM004GF047.033; scale: 60 μm. **8.8.** Axial parenchyma and small cross-walls with irregular scalariformlike thickening in latewood (arrow), RLV, NSM004GF047.012; scale: 25 μm. **8.9.** Axial parenchyma (arrow), TLV, NSM004GF047.030; scale: 150 μm. **8.10.** Cross-walls in latewood (arrow), TV, NSM004GF047.021; scale: 60 μm. **8.11.** Axial parenchyma (arrows), TV, NSM004GF047.012; scale: 100 μm. **8.12.** Short, locally biseriate rays, TLV, NSM004GF047.012; scale: 100 μm.

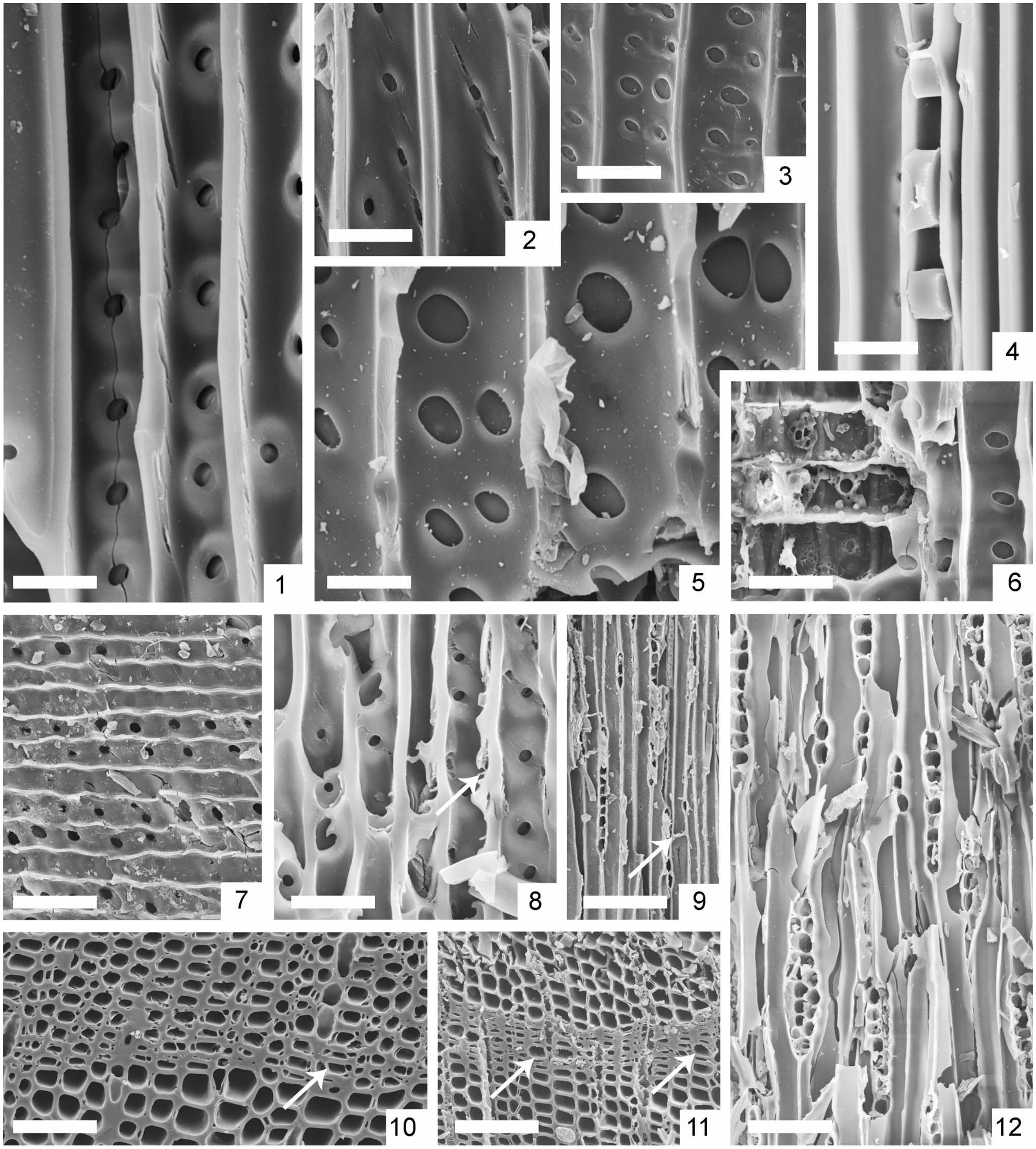
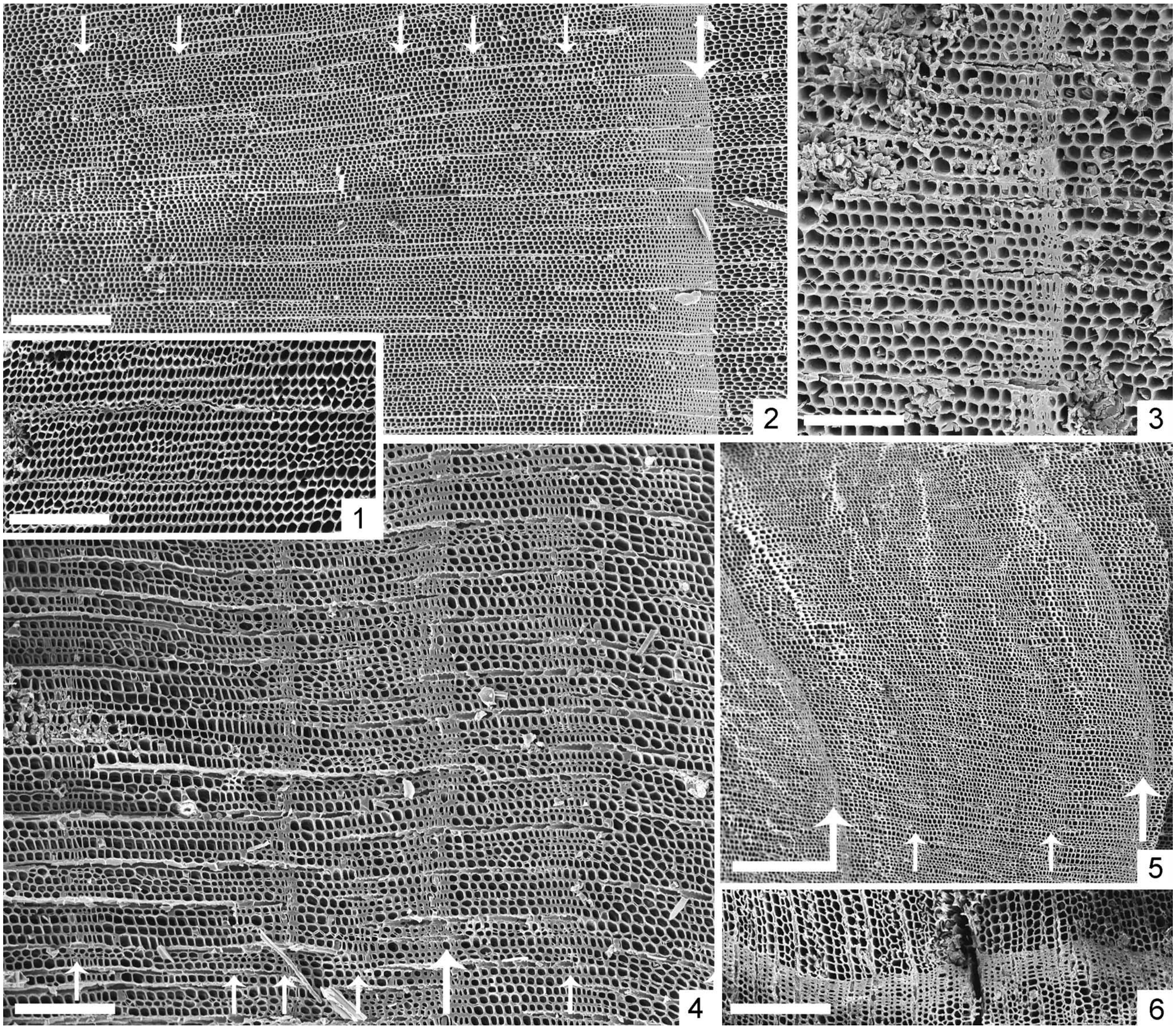


Fig. 9. Growth patterns in charred fossil woods from Bailey Quarry. All specimens stored in the Nova Scotia Museum. All images are SEM micrographs. Large arrows, growth ring boundary; small arrows, growth interruption. **9.1–9.3.** *Taxodioxylon*, **9.4–9.6.** *Cupressinoxylon*. **9.1.** Wood lacking growth rings, TV, NSM004GF047.018; scale: 150 µm. **9.2.** Widely spaced growth rings and multiple subtle interruptions, TV, NSM004GF047.020; scale: 450 µm. **9.3.** Asymmetric growth ring boundary, TV, NSM004GF047.032; scale: 75 µm. **9.4.** Multiple growth interruptions and subtle growth rings, TV, NSM004GF047.013; scale: 250 µm. **9.5.** Small diameter twig showing strongly curved growth ring boundaries and growth interruptions, TV, NSM004GF047.021; scale: 400 µm. **9.6.** Large diameter trunk showing inverted and fluted curvature to growth ring boundary, TV, NSM004GF047.034; scale: 300 µm.



our woods, the distinction between true rings and growth interruptions (here collectively referred to as growth features) is artificial because a continuum exists between the two. The spacing between adjacent growth features is remarkably variable, ranging from 0.18–4.96 mm (n = 76), or 0.27–7.44 mm when the ×1.5 correction factor is applied. Adjacent rings of growth features show extreme fluctuations in spacing, the mean sensitivity of the population being 0.606 (N = 76).

Interpretation

We have described a cluster of four new recognized outliers of putative Cretaceous sediments at Avondale, Bailey Quarry, and Wentworth 4A Quarry near Windsor, Nova Scotia, along with the previously recognized McKay Settlement site. Sediments at all these sites share a very similar geological context, facies, and petrology, and in addition, one site, Bailey Quarry, contains rich plant assemblages comprising palynomorphs, cuticles, and wood.

Biostratigraphy

A Cretaceous age can be unequivocally determined only for the Bailey Quarry site. The two palynological samples from BQ 4 (P39160 and P39161) contain an abundance of spore taxa, some of which are age-indicative Lower Cretaceous taxa (Table 1; cf. Burden and Hills 1989) and lack angiosperm pollen, a characteristic that generally indicates a pre-Albian age in this area of the North Atlantic (Crane and

Lidgard 1989). Based on evidence mainly from western North America (Burden and Hills 1989), *Aequitriradites verrucosus* (Fig. 5.2), *Distaltriangulisporites perplexus* (Fig. 4.17), and *Plicatella* (Fig. 4.24) have their first appearance datum in the Valanginian; while *Trilobosporites canadensis* (Figs. 4.28–4.30 and 5.24–5.28) has a Hauterivian last appearance datum. Assemblages therefore indicate a provisional Valanginian–Hauterivian age for BQ 4. This determination is supported by fern assemblages that contain a diversity of *Cicatricosisporites* types (sensu lato: striate fern spores without radial projections), rare *Plicatella* (one specimen found), and no *Appendicisporites*; later Barremian–Aptian assemblages typically have a greater diversity of *Plicatella* and *Appendicisporites* species (Burden and Hills 1989). The age determination is also consistent with the presence of bennettite cuticles in the BQ 4 samples, which indicate a general Jurassic–Cretaceous age (Watson and Sincock 1992).

Determination of a provisional Valanginian–Hauterivian age for BQ 4 is important because these represent some of the oldest sediments of the Chaswood Formation. Chaswood Formation sediments of comparable age are known only from poorly documented sites at Milford Quarry and Diogenes Brook (Table 1). Palynomorph assemblages from the Chaswood Formation[4] are best known from dark clays and lignites of the middle member at Shubenacadie Basin (Stea and Pullan 2001), where they indicate a Barremian–Albian age. Lithologies in the lower and upper members in this basin are less suitable for palynomorph preservation, so assemblages at BQ 4 may be either stratigraphically below the type section of the Chaswood Formation or represent its lower part.

The other palynological sample from Bailey Quarry, BQ 1 (P39159), may also be of Cretaceous age, but it is overwhelmingly dominated by Carboniferous palynomorphs. The single specimen of *Cicatricosisporites* indicates a general Mesozoic (or possibly Cenozoic) age, but could represent contamination. Similar samples of “Cretaceous-looking” sediment at the West Indian Road pit (Gobeil 2002) have yielded overwhelmingly or entirely Carboniferous palynomorph assemblages (R.A. Fensome, unpublished data; palynomorph assemblage dated as possibly late Tournaisian *Colatisporites decorus – Schopfites claviger* Zone by J. Utting (personal communication, 2000)). This material has been interpreted as possible debris-flow deposits at the base of the Cretaceous succession (Gobeil et al. 2006). The BQ 1 sample occurs in a precisely similar geological context, just above the basement contact. Sediments at BQ 2 – BQ 3 are considered broadly coeval with those of BQ 4 because they all share the same taxa of conifer woods, although the woods themselves have no independent biostratigraphic significance.

A Cretaceous age for the remaining deposits at Avondale, Wentworth 4A Quarry, and McKay Settlement Quarry, cannot, at present, be confirmed because these deposits have yet to yield palynomorphs. As noted above, palynological samples containing Quaternary assemblages, collected at Wentworth 4A Quarry, were extracted from an outcrop adjacent to the putative Cretaceous outcrops. Whereas the sampled deposits are certainly of Quaternary age, these data have no bearing on the age of the lithologically distinct lignite-bearing sand nearby, the age of which remains unconfirmed. That said, sediments at Avondale, Wentworth 4A Quarry, and McKay Settlement Quarry are all of closely similar geological context, facies, and petrography to those of Bailey Quarry, and we consider a Cretaceous age highly probable. However, deposits could have formed during other periods of the Mesozoic and Cenozoic, and Quaternary deposits are common in sinkholes across the area (e.g., Godfrey-Smith et al. 2003). The identification of a Quaternary deposit adjacent to a probable Cretaceous outlier in the Wentworth 4A Quarry highlights the problem of assessing ages based on degree of consolidation and lithology.

Paleoenvironment and karstic setting

There are three characteristic facies at our localities. The first facies comprises up to 7 m thick successions of quartz-rich, granule- to pebble-gravel and pebbly sand, commonly found directly resting on gypsum basement or infilling fissures. Gravels have subrounded to angular clasts up to 10 mm in diameter in a sandy matrix, contain minor quantities of brown clay, locally cemented by gypsum, fossil wood, and cryptic low-angle stratification. The second facies consists of up to 4 m thick successions of very fine- to coarse-grained quartz-rich sand with sparse quartz pebbles, lignite clasts, and thin clay lenses. The relationship of this second lithology to the underlying gypsum is not observed, and these finer grained sediments may rest on basement rocks or coarser Cretaceous strata. The third facies consists of green to brown clays, occurrences of which are present in BQ 3 material, and are up to 5.7 m thick in Core 685.

The apparent absence of marine fossils within these sediments, and the abundance of plant fossils at Bailey Quarry, strongly suggests a terrestrial environment, in common with other Chaswood occurrences. Sediment grade (fine sand to gravel) and moderate sorting further indicate high-energy conditions. The occurrence of planar to low-angle stratified sand and gravel at BQ 1, and possible cross-strata at Avondale, suggest deposition from downstream migrating bar forms or as bedload sheets within gravel- and sand-bed river channels (Miall 1996). A well-exposed succession at the West Indian Road pit (Table 1) has been interpreted as braided-fluvial (Gobeil et al. 2006), and a comparable environment is envisaged for the Windsor localities, although the two dimensional nature of our exposures precludes assessment of fluvial style and planform. Clay fabrics oriented in domains (Brewer 1976; seen in petrographic thin section) may imply that some sandy bars were subject to soil formation.

The Cretaceous fluvial deposits in our study are preserved in a variety of “trenches”, hollows, and fissures in the gypsum, interpreted as a karstified paleosurface. Although the features observed on the present-day surface may have formed at any time from the Pennsylvanian (Boehner 1985) to the recent (Martinez and Boehner 1997), gypsum in Core 685 shows deep paleoweathering beneath the Cretaceous contact, suggesting that karst formation was, in part, Mesozoic or earlier in age. We limit this interpretation to the Windsor area alone and note that other basal Chaswood deposits in tectonic basins are clearly not karst-related (Stea and Pullan 2001). While it would be invidious to make comprehensive interpretations from a few, small localities, useful comparisons can be drawn with modern karst (Jennings 1985) and paleokarst occurrences worldwide (James and Choquette 1988). Because gypsum is more soluble than calcite, Windsor evaporites should have been highly prone to karstic development, although numerous factors influence karstification, not just bedrock solubility (Elorza and Santolalla 1998).

In the study area, narrow bodies of sediment with steep margins penetrate up to 36 m below the inferred paleosurface in Core 685 and at BQ 4. Although their three-dimensional form is not known, their occurrence within steeply dipping Windsor Group strata implies a linear form. At Gays River (Table 1), a similar "trench" less than 100 m wide and nearly 2 km long was cut into the Windsor Group along a faulted carbonate–evaporite contact. The Gays River trench contains 90 m of semi-consolidated gravel, sand, clay, and minor lignite, and yielded Early Cretaceous palynomorphs (Akande and Zentilli 1984; Davies et al. 1984). The Cretaceous strata at Gays River are faulted (Akande and Zentilli 1984), suggesting a complex relationship among karst development, deformation, and sedimentation. These narrow, linear features may represent karst valleys (gorges or possibly blind valleys in which drainage passes below the surface), or may form part of tower karst where dissolution of broad karstic plains generates pinnacles and ridges (Pelechaty et al. 1991). Although topographic relief associated with the gypsum might in part represent later diapiric movement, diapirs are sharply truncated by Cretaceous strata in offshore successions, suggesting that halokinetic deformation had largely ceased by late Mesozoic times (MacLean and Wade 1992; Pascucci et al. 1999); however, we acknowledge the possibility that some deformation might have occurred after deposition of the Cretaceous strata onshore. We also consider it unlikely that field relationships reflect Quaternary glaciotectonic deformation, although this phenomenon is present in the region; where observed, the Cretaceous–Carboniferous contact is unquestionably an undisturbed sedimentary surface.

Depressions a few metres deep in the Windsor Group paleosurface, filled with alluvium at Avondale and BQ 2, probably represent the deposits of small sinkholes or solution dolines (Jennings 1985), although their three-dimensional form is not known. Fissure fills that penetrate up to 8 m below the inferred paleosurface at Avondale represent the piping of sediment down solution-widened joints (grikes) or fractures. At BQ 1 and in the Wentworth 4A Quarry, horizontally bedded alluvium may fill broader surface depressions, possibly shallow gorges or narrow poljes. Muddy intervals at BQ 4 and in Core 685 are probably the deposits of floodplains or small lakes within the karstic terrain. Lakes and ponds commonly occupy sinkholes and dry valleys in modern karstic terrains (Jennings 1985; Martinez and Boehner 1997; Elorza and Santolalla 1998), or occupy depressions oriented at high angles to the main drainage lines, where fluvial input is reduced (Pelechaty et al. 1991).

Although some of the Cretaceous sediments may have originated in subterranean settings such as cave networks (e.g., Sando 1988; Pelechaty et al. 1991; Simms 1994), the stratigraphic position of boulders in the sequence makes this unlikely. Gypsum and mudstone boulders underlie or border sediments at Avondale and BQ 4, but only small fragments were observed interstratified at higher levels in the thicker occurrences, with no indication of major breccia horizons that might signify cave-roof collapse. Consequently, we infer that the Cretaceous sediments formed in association with surface drainage.

Although it might seem improbable that the small Cretaceous outliers near Windsor formed part of drainage networks, the similarity in facies and mineralogy of the deposits to those of the broader basins (Dickie 1986; Pe-Piper et al. 2005*a*, 2005*b*, 2005*c*; Gobeil et al. 2006) implies that the new occurrences were linked to through-going river systems. The sands are somewhat more feldspathic and less rich in lithic grains than sands in some other onshore deposits, but their feldspathic nature accords broadly with the basal Chaswood sands in the Elmsvale Basin (Pe-Piper et al. 2005*c*). Gobeil et al. (2006) documented a southerly paleoflow for sands in the West Indian Road pit, and suggested source rocks in the Cobequid Highlands, to the north of the main belt of Nova Scotia exposures, for some of the petrographic components. The "floating" fabric of the gypsum-cemented sand and gravel in our samples suggests early cementation from sulphate-charged groundwater, prior to intensive compaction. Such early cementation, as well as accumulations of clay, may have reduced the permeability of the karstic surface, allowing rivers to flow from the Cobequid Highlands without passing into subterranean drainage.

In modern gypsum karst areas such as the Gállego valley of Spain (Benito et al. 1998), solution-induced subsidence is currently taking place beneath fluvial cover (covered karst), assisted by subsurface flow through the porous alluvium. Consequently, the area is characterized by syndepositional tilting of evaporite bedrock, rapid changes in thickness of alluvium over short distances, and angular unconformities within the alluvium, with up to 190 m of solution-related subsidence recorded in Quaternary terrace deposits. The alluvium exhibits abundant examples of both brittle and ductile deformation, whereas the underlying bedrock is undeformed. However, we consider it unlikely that the Cretaceous sediments near Windsor represent remnants of alluvial sheets that subsided during covered karst formation because neither cemented nor unconsolidated sediments are markedly deformed. This, in turn, implies that the karst developed primarily in an uncovered (exposed) mode (as suggested for a Proterozoic example by Pelechaty et al. 1991). Although syndepositional and (or) postdepositional deformation is seen elsewhere in the Chaswood Formation of Nova Scotia, this is primarily related to tectonism (Stea and Pullan 2001; Pe-Piper and Piper 2004; Piper et al. 2005; Gobeil et al. 2006).

Paleoecology and paleoclimate

Fossil assemblages at Bailey Quarry permit insight into the vegetation ecosystems that surrounded these Early Cretaceous karst valleys near Windsor. Palynological samples reveal the existence of forests of conifers, ginkgos, bennettites, and cycads, characterized by a diverse understory of ferns, lycopods, and bryophytes — a typical pre-angiosperm Mesozoic vegetation. Ferns were by far the most abundant and diverse group, and included a variety of forms found in subtropical to tropical environments today, including the Gleicheniaceae, Lygodiaceae, Osmundaceae, and Schizaeaceae (Van Konijnenburg-van Cittert 2002). Modern representatives of the Lygodiaceae are commonly climbing ferns, and their occurrence in our deposits may imply a scrambling habit against steep karst surfaces. Extant members of the Schizaeaceae prefer drier sites or disturbed riparian settings, and such niches may have been widespread on well-drained gypsum bedrock and adjacent braided drainages in Cretaceous Nova Scotia.

Although charred ferns are not found at our sites (probably a taphonomic bias in the allochthonous assemblage), fern charcoal is abundant at other Chaswood Formation localities (Calder et al. 1998; Scott and Stea 2002), and in fact is widespread throughout the Lower Cretaceous fill of the North Atlantic (Alvin 1974; Collinson et al. 1999). Members of the fern family Gleicheniaceae are commonly found in a charred state, and may have formed fire-prone thickets in open sites (Van Konijnenburg-van Cittert 2002). Another fire-prone group was the conifers, represented by members of the Araucariaceae, Taxodiaceae, and Cheirolepidiaceae in our material; these were probably canopy-forming trees. The extinct Cheirolepidiaceae is a particularly interesting group (Watson 1988), displaying an array of xeromorphic features (Watson and Alvin 1996), and thought to be especially fire-prone (Alvin et al. 1981).

Nothing appears to have been preserved of the faunal ecosystems that presumably inhabited these vegetated karst valleys in Cretaceous Nova Scotia. However, some insights may be gained from a brief review of the diverse fossil assemblages found in the Berriasian–Barremian Wealden Group of southern England, which was deposited on the opposite, but closely adjacent, side of the North Atlantic rift (Allen et al. 1998). Associated with a similar paleoenvironment (though not karst terrain; Wright et al. 2000), it contains molluscs (Radley and Barker 2000), insects (Sukatsheva and Jarzembowski 2001), fish, reptiles, and mammals (Sweetman 2006), among others. Dinosaurs were an especially prominent component of the megafauna (Insole and Hutt 1994). As in the Chaswood Formation, conifers, bennettites, and ferns dominated Wealden vegetation (Watson and Alvin 1996; Batten 1998), so it is probable that the two regions had a similar fauna.

Further insights into terrestrial paleoecology, and paleoclimate inferences, may be derived from analysis of growth patterns and taphonomic features preserved in the conifer woods at Bailey Quarry. The presence of growth rings with asymmetric boundaries indicates the occurrence of environmental stress sufficient to induce sustained dormancy in the vascular cambium of the canopy-forming conifers (Falcon-Lang 2003). Symmetrical growth interruptions also indicate stresses triggering temporary cessation of growth. Extreme variability in the spacing of these growth features, even within individual samples (mean sensitivity, 0.6), probably rules out summer/winter seasonality in temperature as a plausible causal mechanism.

In Early Cretaceous times, Nova Scotia lay at paleolatitude of 35°–40°, and under Cretaceous greenhouse conditions, even mid-latitude settings like this experienced a humid subtropical climate (White et al. 2001; Paleomap 2002). Under such conditions, the most likely cause of the observed growth features would be water stress, triggered by aperiodic droughts of variable intensity, and further accentuated by the hydrological vagaries of the karstic terrain (Jennings 1985). Erratic droughts of this kind are common in the subtropics today, and trees produce similar growth features, one or multiple “rings” forming each year (Ash 1983; Jacoby 1989). Taphonomic features such as checking lend additional support to the inference of water stress, indicating that wood sometimes became sufficiently dry to allow the microfibril structure of the tracheid walls to split (Jones 1993). Similar paleoclimate inferences have been made for growth patterns in araucarian woods in the Chaswood Formation at Vinegar Hill (Falcon-Lang et al. 2003) and elsewhere in the North Atlantic region (Francis 1987; Collinson et al. 1999).

Sedimentary evidence represents a second important source of paleoclimatic data for the Chaswood Formation. In Nova Scotia, the South Mountain Batholith of granitoid rocks is deeply altered to saprolite (decomposed and (or) disaggregated rock weathered in place) beneath Quaternary strata south and west of Windsor (O’Beirne-Ryan and Zentilli 2003; Ryan et al. 2005). Although the timing of saprolite formation is constrained only as post-Triassic and pre-Pleistocene, these regolith occurrences imply warm and humid conditions during the Mesozoic, in accord with the presence of abundant kaolinite and compositionally mature quartz-rich sands within the Chaswood Formation generally (Stea and Pullan 2001; Pe-Piper et al. 2005*c*). Paleosols identified as oxisols and ultisols in the Chaswood Formation at Elmsvale are also characteristic of the subtropical belt today (Stea and Pullan 2001; Pe-Piper et al. 2005*a*), and karst is best developed under humid climates (Jennings 1985; Choquette and James 1988), although evaporite karst may represent much drier conditions (Elorza and Santolalla 1998).

Paleobotanical data (widespread fires, growth interruptions) and palaeosols suggest a seasonally dry climate that may be consistent with recent computer modelling of the Early Cretaceous climate of the North Atlantic (Haywood et al. 2004). Models predict a subtropical climate where summer temperatures were sufficiently hot to trigger droughts (Allen et al. 1998), despite year-round high rainfall (Haywood et al. 2004). This unusual aspect of the climate was probably linked to a much-accelerated hydrological cycle in the Cretaceous greenhouse world (White et al. 2001). Year-round humidity would account for the deep paleoweathering observed in Nova Scotia, whereas the occurrence of edaphic droughts would stress vegetation and trigger fires.

Conclusions

(1) New outliers of the Cretaceous Chaswood Formation are described from near Windsor, Nova Scotia. The Bailey Quarry site is assigned a provisional Valanginian–Hauterivian age based on palynofloras, and therefore represents one of the oldest known onshore Cretaceous deposits in the Maritimes. Other deposits at Avondale, Wentworth 4A Quarry, and McKay Settlement, which share a similar geological context, facies, and petrographic character, are probably broadly coeval, although there is presently no biostratigraphic proof.

(2) Cretaceous sediments, which are composed of mature quartz sands, gravels, and clays, are preserved on a paleosurface of karstified gypsum, and were laid down in karst valleys, sinkholes and fissures, up to 36 m deep in places. The sediments represent the deposits of sand- and gravel-bed rivers and local floodplains or lakes. The petrographic similarity of the sands and gravels with extrabasinal materials in larger, fault-bounded basins in the region suggests that, despite their karstic setting, the

small outliers were originally connected to through-going drainage systems.

(3) Analysis of charred fossil wood, cuticles, and palynofloras indicate that the karstic areas were covered by fire-prone forests of conifers, bennettites, cycads, and ginkgos with a diverse fern-dominated understory. Growth ring patterns in conifer woods imply a humid subtropical climate punctuated by occasional droughts that may have been accentuated by the hydrological character of the karstic environment.

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Appendix A. Cretaceous localities near Windsor, Nova Scotia

Quarry coordinates are designed by the mining company to provide very precise positions for localities.

Avondale (section on Avon River)

Location:

~45°01′36′′N; 64°07′48′′W.

Grid reference on NTS sheet 21H/01 (1 : 50 000 scale): 108864.

Bailey Quarry

Locations:

BQ 1, 45°01′24′′N; 64°03′48′′W; BQ 4, 45°01′10′′N; 64°02′59′′W.

Shown for each locality below are grid references of localities on NTS sheet 21H/01 (1 : 50 000 scale). These are followed in parentheses by numbers that refer to a grid referenced to the Nova Scotia coordinate monument system, Zone 5, Central Meridian at 64°30′ west longitude, as used by the Nova Scotia Land Surveyors (NSMTM79).

Localities:

BQ 1, 161854 (N: 4987140, E: 5534393); BQ 2, 166859 (N: 4986975, E: 5535343); BQ 3, 171859 (N: 4986986, E: 5535639); BQ 4, 172857 (N: 4986701, E: 5535467); Core 685, 173853 (N: 4986504.6, E: 5535543.8); GSC Locality Number D4308 (for palynomorph samples).

Wentworth 4A Quarry

Location:

~44°58′32′′N; 64°04′58′′W.

Grid reference of locality on NTS sheet 21A/16 (1 : 50 000 scale): 145810 (N: 4981830, E: 5532892).

McKay Settlement Quarry

Location:

~45°00′03′′N; 63°57′30′′W (south of pit pond).

Grid reference of locality on NTS sheet 11E/04 (1 : 50 000 scale): 243835.

Appendix B. Taxonomic proposals

The following new combinations for names of miospore taxa are proposed (by R.A. Fensome).

Cibotiumspora sinuata (Couper 1953) comb. nov. (= *Trilites sinuatus* Couper 1953, p. 31; pl. 3, figs. 24–25); *Deltoidospora punctata* (Delcourt and Sprumont 1955) comb. nov. (= *Concavisporites punctatus* Delcourt and Sprumont 1955, p. 25, pl. 1, fig. 8; pl. 2, fig. 2); *Rotverrusporites major* (Couper 1958) comb. nov. (= *Leptolepidites major* Couper 1958, p. 141, pl. 21, figs. 7–8.