

FAUNAS AND CAMBRIAN VOLCANISM ON THE AVALONIAN MARGINAL PLATFORM, SOUTHERN NEW BRUNSWICK

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ABSTRACT—The Cambrian inlier at Beaver Harbour, southern New Brunswick, is now confidently referred to the marginal platform of the late Proterozoic–Early Paleozoic Avalon microcontinent. The sub-trilobitic Lower Cambrian Chapel Island and Random Formations are unconformably overlain by the mafic volcanic-dominated Wade’s Lane Formation (new). Late Early Cambrian trilobites and small shelly taxa in the lowest Wade’s Lane demonstrate a long Random–Wade’s Lane hiatus (middle Terreneuvian–early Branchian). Latest Early–middle Middle Cambrian pyroclastic volcanism produced a volcanic edifice at Beaver Harbour that is one of three known volcanic centers that extended 550 km along the northwest margin of Avalon. Middle Middle Cambrian sea-level rise, probably in the *Paradoxides etemini* Chron, mantled the extinct volcanics with gray-green mudstone and limestone of the Fossil Brook Member. Black, dysoxic mudstone of the upper Manuels River Formation (upper Middle Cambrian, *P. davidis* Zone) is the youngest Cambrian unit in the Beaver Harbour inlier. *Lapworthella cornu* (Wiman, 1903) emend., a senior synonym of the genotype *L. nigra* (Cobbold, 1921), *Hyolithellus sinuosus* Cobbold, 1921, and probably *Acrothyra sera* Matthew, 1902a, range through the ca. 8 m.y. of the trilobite-bearing upper Lower Cambrian, and *H. sinuosus* and *A. sera* persist into the middle Middle Cambrian. *Lapworthella cornu* and *H. sinuosus* replaced the tropical taxa *L. schodackensis* (Lochman, 1956) and *H. micans* Billings, 1872, in cool-water Avalon.

INTRODUCTION

THE AVALON microcontinent is now a terrane in the Caledonian–Acadian orogen. Terminal Proterozoic volcanics and Lower Paleozoic sedimentary successions accumulated in extensional or transtensional basins on older arc successions in southern New Brunswick and other areas on the northwest margin of Avalon (Rast et al., 1976; Landing, 1996a; Barr and Kerr, 1997; Barr and White, 1999; Nance et al., 2002; Keppie et al., 2003). Detailed bio- and lithostratigraphy, sequence stratigraphy, and geochronology of this cover succession has led to reconstruction of Avalon’s geologic history and paleogeography through its insular, terminal Proterozoic–Early Paleozoic existence (Landing, 2005). The Acadian and Alleghenian orogenies fragmented the cover succession into faulted and folded inliers. However, the terminal Proterozoic–Ordovician of the inliers from Rhode Island to southern Britain shows nearly identical lithostratigraphic successions with Avalonian province biotas (Landing, 1996a; Landing and Westrop, 1998b).

A fault-bounded Cambrian inlier occurs along Buckmans Creek at the head of Beaver Harbour, southern New Brunswick (Fig. 1). Helmsteadt (1968) recorded a thick volcanic sequence and a trilobite horizon with *Paradoxides etemini* Matthew, 1883, a characteristic Avalonian middle Middle Cambrian species [see Kim et al. (2002); in this report, we use the term “*Paradoxides*” because of continuing problems with the genus- and subgenus-level taxonomy of paradoxidids (see Geyer and Landing, 2001)]. Subsequent work showed the basaltic character of the volcanics (Greenough et al., 1985; Bartsch, 2005).

Two interpretations have been proposed for this inlier. The first is that it is the west end of Avalon in New Brunswick (Greenough et al., 1985; Currie, 1988; Landing 1996a, 1996b, 2004; Currie and McNicoll, 1999; Johnson, 2001). The second is that it is a continent fragment, possibly related to the Gander terrane to the northwest, that separated from Avalon by the late Proterozoic and attained its present position by a Gander–Avalon collision in the Silurian or Devonian (van Staal et al., 1998; Barr et al., 1998, 2002, 2003; Barr and White, 1999).

A way to resolve these paleogeographic and tectonic proposals was provided by S. C. Johnson’s discovery of red limestone near

the base of the volcanics (Fig. 2). This discovery was interesting—with exception of a bed at the top of the Terreneuvian Series (i.e., the Fosters Point Formation) at Cradle Brook, 110 km northeast of Beaver Harbour (Fig. 1), red limestone is unknown in the Proterozoic–Lower Paleozoic of southern New Brunswick (Landing, 1996b). A search for fossils in the limestone and from Helmsteadt’s (1968) trilobite horizon was undertaken to provide age brackets on the volcanics. An Early Paleozoic paleogeographic synthesis of the Beaver Harbour area was a likely result of an understanding of its biotas and stratigraphy.

SECTIONS AND DEPOSITIONAL FACIES

The red limestones and Helmsteadt’s (1968) trilobite locality occur in a southwest-striking syncline (Fig. 1). Faulting and cover along the syncline axis require that the succession be described from four sections (Fig. 1, BHR-I–IV). The deformation includes bedding plane faults (Fig. 2) and a slip cleavage that deformed the fossils. A burial temperature of ca. 300°C is suggested by the opaque white color of the phosphatic fossils from section BHR-II. This color reflects heating that led to the loss of organic carbon, but did not drive off water and anneal the sclerites (i.e., Epstein et al., 1977).

BHR-I.—Section BHR-I (Fig. 2) is in the south limb of the syncline. Its base is at low tide on the west side of Woodlands Cove. A quartzite (Random Formation on Fig. 1) allows the section to be continued in the cliffs along Buckmans Creek.

Section BHR-I has three distinct intervals. The lower distinct interval (0–16.4 m) is purple and green mudstone with a silicic ash and polymict conglomerate and higher glauconitic (now chlorite), trough cross-bedded, feldspathic sandstone with dune fore-sets and wave-produced ripples with bundle-wise up-building (de Raaf et al., 1977). The second distinct interval is a white to buff, coarse-grained feldspathic quartzite (16.4–19.7 m) with bi-directional troughs that indicate tidally influenced deposition. Limonite-encrusted and -stained quartz granules and black phosphate grains lie on the quartzite’s top.

The third distinct interval comprises the rest of section BHR-I (19.7–119 m). Red basalt flows (e.g., 21–24, 28.35–32.8, 41–41.8, 43.3–44.9 m) and ignimbrites (the 103.9–119 m tuff has eutaxitic structure with welding) occur in the lower and upper

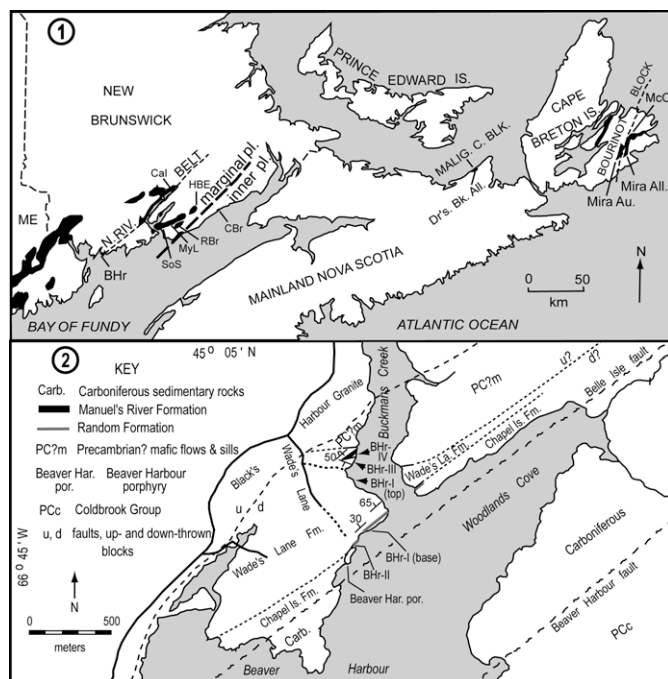


FIGURE 1—Locality maps. 1, Location of Beaver Harbour (BHR) localities at the southwest end of the Avalonian marginal platform in southern New Brunswick. Abbreviations: Cal, Caton's Island; CBr, Cradle Brook; Dr's Bk, Doctor's Brook Allochthon; Malig. C. Blk., Malignant Cove Block; ME, Maine; Mira Au., Mira Authochthon; Mira All., Mira Allochthon; MyL, Mystery Lake; RBr, Ratcliffe Brook; SoS, Somerset Street. 2, Geologic map of Beaver Harbour area showing location of sections BHR I-IV.

parts of the succession. The remainder is purplish to red basaltic "sandstone" and pebble "conglomerate" with minor red mudstone. The "sandstone" and "conglomerate" are weakly calcareous, and large, lensing patches of many beds are hyaloclastites (i.e., largely replaced by calcite). Many indicators show that the "sandstone" and "conglomerate" are pyroclastics: 1) basalt pebble strings in many "sandstones;" 2) massive "conglomerates" that suggest plinian fall deposits (i.e., unstratified, ungraded, lack of internal structures); 3) alternation of fine-grained, laminated basalt "sandstone" (possible air-fall deposits or distal surge deposits) with the massive units; 4) sandwaves and antidunes with leeside granule accumulations (e.g., 95–104 m); and 5) angular amygdaloidal boulders (to 10×20 cm at 59.3 m) isolated in basalt sand beds (see Wohletz and Sheridan, 1979). A lack of fossils or subaqueous sedimentary structures suggest subaerial tuff emplacement.

BHR-II.—This section in the small cove southeast of BHR-I (Fig. 1) is in the south limb of a southwest-plunging, parasitic anticline that has the white quartzite in its core. The section is faulted against late Proterozoic Beaver Harbour porphyry, which is likely coeval with the Blacks Harbour Granite [622 Ma; Barr et al. (2003)] (see Bartsch, 2005). Three 20–40-cm-thick red limestones are interbedded with slaty purple sandstone with basalt granule lenses (Fig. 2).

The lower limestone is a nodular lime mudstone. The upper two are trilobite-dominated pack- to grainstones with corroded hardgrounds mantled with planar-laminated and 1.0-cm-high, SH-V, limonitic stromatolites. Limonite oncolites with basalt granule-pebble cores are abundant in the upper two limestones. Similar condensed limestones characterize proximal (peritidal or intertidal) facies in the Avalonian Lower Cambrian, where upward successions from nodular mudstone to high-energy, condensed packstone are equated with shoaling-up cycles (Landing et al., 1989; Myrow and Landing, 1992; Landing and Westrop, 2004).

Section BHR-II lies above the white quartzite, and the basalt debris shows a correlation into the basalt-rich interval of BHR-I. The massive basalt (BHR-I-21–24 m) does not intervene in the 20 m interval that separates BHR-II from the white quartzite in the parasitic anticline, and the only purple sandstone in BHR-I lies between the white quartzite and the 21–24 m basalt. These data suggest that the BHR-II interval is faulted out at the base of the basalt in BHR-I. This correlation means that the BHR-II faunas bracket the onset of Beaver Harbour volcanism.

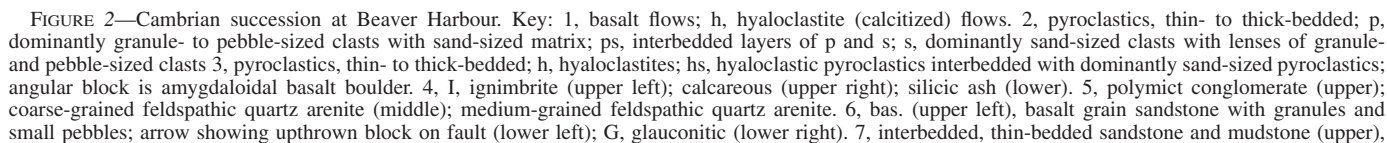
BHR-III.—This section in the north limb of the syncline begins at a fault with BHR-IV. It extends along the west side of Buckmans Creek, and ends at a dirt road that comes down to the beach (Figs. 1, 2). Most of BHR-III consists of hyaloclastites. Welded tuffs occur in the lower and upper part of BHR-III (12–19.2 and 28.4–29.8 m); the rest consists of sandwaved "sandstone" and lensing "conglomerate." A lack of fossils and subaqueous sedimentary structures suggest subaerial tuff emplacement. No obvious correlation with the BHR-I pyroclastics exists, and BHR-III may be a higher interval in the pyroclastic succession.

BHR-IV.—Fossils re-appear at the top of this overturned (dip 50° northwest) section. The base of BHR-IV is faulted against 7 m of sheared hyaloclastites, which are in turn faulted against dark green mafic flows and sills(?) of unknown age to the north. The lower 5.8 m of BHR-IV are light green hyaloclastites identical to those of BHR-III. Calcified globules formed in ash clouds or lava fountains (Hay et al., 1979) up to 1.0 mm in diameter are common. Calcification is so nearly complete that the 1.0–1.5 m interval ashes resemble neomorphic limestone. The hyaloclastites end at 5.8 m at a 10-cm-thick trilobite packstone. Hyaloclastite pebbles occur in the base of the packstone, but no volcanic component exists in higher strata. BHR-IV-5.8–8.0 is dark green-gray slaty mudstone with nodular trilobite wacke- to packstones in the lower 1.2 m. Scattered trilobite wackestone nodules occur in the top meter. This is Helmstedt's (1968) trilobite locality.

2.75 m of black, pyritiferous slaty mudstone at the top of BHR-IV are faulted against the BHR-III hyaloclastites and green-gray mudstone. An overhang at BHR-IV-10.2 is covered with uncollectable, large, articulated moldic specimens of *Paradoxides* Hawle and Corda, 1847.

CORRELATIONS

Terreneuvian series.—Despite a lack of fossils, a precise correlation can be determined for the lower 19.7 m of BHR-I. A uniform terminal Proterozoic–lowest Cambrian stratigraphy exists in the large Saint John, New Brunswick, region (ca. $1,500 \text{ km}^2$; Landing and Westrop, 1996) and in other areas on the northwest margin of Avalon [i.e., in the Antigonish Highlands of northeastern Nova Scotia and in southern Cape Breton Island, Nova Scotia (Fig. 1), and further east in the Burin Peninsula, east Newfoundland (Landing, 1996a, 2004)]. This succession, with an abrupt transition from a wave-influenced, sandstone- and mudstone-dominated shelf (Chapel Island Formation) into a massive, coarse-grained quartzite tidalite (Random Formation), is identical to that in the lower 19.7 m of BHR-I, and corresponds to the middle of the sub-trilobitic Lower Cambrian (Landing, 1996a, 2004). [The Avalonian sub-trilobitic Lower Cambrian had been designated the "Placentian Series" (see Landing et al., 1989); but this has been superseded by the global "Terreneuvian Series" for the sub-trilobitic Lower Cambrian (Landing et al., 2007). The silicic ash in BHR-I mirrors Saint John area developments, where comparable ashes occur only in the wave-deposited, fine-grained, green to purple sandstones of the middle–upper Mystery Lake Member of the Chapel Island Formation (Landing, 2004), and have a 531 Ma U-Pb zircon age (Isachsen et al., 1994). The coarse-grained sandstone tidalite that forms the upper part of the lower 19.7 m of BHR-I is identical to the Random Formation across the Avalonian platform (Landing, 1996a). The top of the Random is a sequence boundary across Avalon (Landing, 2004),



and the remanent quartz and phosphate grains at the top of the Random at BHR-I are consistent with post-Random erosion and unconformity.

Branchian series and lower wades lane formation (new).—An upper bracket on the post-Random hiatus and a lower bracket on the onset of volcanism are given by small shelly fossils and trilobites from the red limestones of BHR-II. *Torellella laevigata* (Linnarsson, 1871) and *Conotheca* sp. merely show a Lower Cambrian correlation (Fig. 3.16–3.18). *Lapworthella cornu* (Wiman, 1903; Fig. 3.1–3.13) and brachiopods similar to *Acrothyra sera* Matthew, 1902a, have long ranges—ca. 8. m.y., with appearances in the terminal Terreneuvian and a range through the Branchian Series (trilobite-bearing Lower Cambrian) in Avalon (see *Systematic Paleontology*). A sclerite of the lobopod *Microdictyon* sp. is not specifically identifiable due to heavy phosphatic overgrowth (Fig. 3.15), but represents a genus with a lowest occurrence in lower Branchian-equivalent rocks (upper Atdabanian Stage) of Siberia (Bengtson et al., 1986; correlations in Landing et al., 1989; Landing, 1992). *Strictocorniculum vanallerum* Landing, 1995, is rare in Avalon, and its recovery in the *Callavia broeggeri* Zone of eastern Massachusetts and the northern Antigonish Highlands, Nova Scotia, likely did not establish the species' upper range (see *Systematic Paleontology*).

Trilobites from the lower red limestone (Figs. 4.3, 4.4, 4.6, 4.7, 5.1–5.3, 5.5–5.8, 5.10, 5.11) are regarded as most suggestive of an upper Branchian Series correlation. The only form identifiable below the genus level is *Acanthomicmacca* sp. cf. *A. ellipsocephaloides* (Cobbald, 1910). *Acanthomicmacca* Hupé, 1953, ranges from the upper Lower Cambrian of Avalon and West Gondwana into the West Gondwanan basal Middle Cambrian. The best described species from west Avalon, *A. walcotti* (Matthew, 1899a), occurs in the upper *Callavia broeggeri* Zone [“*Dipharus Subzone*” of Bengtson and Fletcher (1983)]. *Acanthomicmacca ellipsocephaloides* was described from the “*Olenellus* limestone” at Comley, Shropshire, a unit now termed “Red *Callavia* Sandstone” and referred to the lower *Callavia* Zone (Rushton, 1974).

Ellipsocephaline gen. aff. *Ornamentaspis* is too poorly preserved for highly resolved correlation, but presence of an ellipsocephalid fits a correlation into the uppermost Lower Cambrian of Avalon and West Gondwana. A kingaspoid clade species, to which *Ornamentaspis* sp. belongs, appears just above *Protolenus* in the Hanford Brook Formation to the west in southern New Brunswick (Westrop and Landing, 2000). Thus, an ellipsocephaline suggestive of *Ornamentaspis* suggests a high position in the Avalonian Lower Cambrian, and is likely younger than known west Avalon faunas with *Acanthomicmacca*. Landing and Westrop (1996; also Westrop and Landing, 2000) suggested that *Callavia*-bearing faunas in mudstone-dominated facies might be the lateral equivalents of protolenid assemblages in sandstones. However, Landing and Westrop (1998a) also emphasized that the trilobite-bearing Lower Cambrian of Avalon typically consists of two depositional sequences—with *Callavia*-bearing faunas in the lower and ellipsocephalids in the upper. These latter data comport with a post-*Callavia broeggeri* Zone correlation of the onset of volcanism of the volcanic-dominated, lower Wade's Lane Formation (new, see Appendix).

This small shelly fossil and trilobite assemblage was previously unknown in southern New Brunswick. In the Saint John region, upper Branchian faunas include the protolenoid-bearing assemblages of the middle–upper Hanford Brook Formation (Somerset Street and Long Island Members). It is possible that the sandstones of the lower Hanford Brook (St. Martins Member) that

lack trilobites but have ostracods and lingulates are lower Branchian and represent the *Callavia broeggeri* Zone (Westrop and Landing, 2000).

These data indicate that a hiatus of comparable duration (middle Terreneuvian–middle/upper Branchian Series) occurs at the top of the Random Formation in the Saint John and Beaver Harbour regions. In both areas, an onset of volcanism is recorded in the Branchian. Thin ashes appear in the *Protolenus elegans* Zone of the middle Hanford Brook Formation (Landing and Westrop, 1996), and basaltic volcanics of the lowest Wade's Lane Formation form approximately coeval strata at Beaver Harbour.

Acadian series.—Wade's Lane Formation volcanism ceased prior to marine onlap and deposition of gray-green mudstone with trilobite wacke- and packstone. Skeletal fossils (Table 1) from BHR-IV are Middle Cambrian. A steinkern resembling the apical area of *Helcionella oblonga* Cobbald, 1921, from the lower Middle Cambrian of Shropshire, is present (Fig. 6.4, 6.5), while *Lingulella ferruginea* Salter (in Salter and Hicks, 1867) (Fig. 6.9, 6.10) appears in the middle Middle Cambrian in Avalon and Baltica (see *Systematic Paleontology*). The best biostratigraphic aid is provided by *Bradoria* sp. cf. *B. scrutator* Matthew, 1899b, as it supports a *Paradoxides etemini* Zone correlation (Fig. 8.20). The types of *B. scrutator* are from the Dugald Formation of Cape Breton Island, a unit correlated with the Fossil Brook Member (Siveter and Williams, 1997).

The deformed trilobites from BHR-IV provide a generalized age that is compatible with that provided by small skeletal taxa. The trilobites include middle Middle Cambrian paradoxidids comparable to *Paradoxides* (*Eccaparadoxides*?) that may include two species (Fig. 7). A Middle Cambrian correlation is supported by *Cotalagnostus* sp. aff. *C. lens* (Grönwall, 1902) (Fig. 4.1–4.3)—representative of a genus with an acme in slightly higher Avalonian strata (upper *P. hicksi* and *P. davidis* Zones) and coeval zones on other paleocontinents. *Kootenia* sp., *Dorypyge* spp., *Braintreeella*? sp., *Bailiella*? sp., and *Parasolenopleura*? sp. do not assist in precise correlation, but fit the suggested age.

The middle Middle Cambrian marine onlap deposits (i.e., gray-green mudstone with trilobite packstones that grade up within a meter into sparse trilobite wackestone nodules) are identical to the Fossil Brook Member of the Chamberlain's Brook Formation in the Saint John, New Brunswick, region and east Newfoundland (Landing and Westrop, 1998a, 1998b; Kim et al., 2000). In these areas, the Fossil Brook Member is a thin, unconformity-bounded depositional sequence that unconformably overlies the lower Middle Cambrian Braintree Member of the lower Chamberlain's Brook or, in Saint John, oversteps the eroded upper Lower Cambrian Hanford Brook Formation and Branchian Series (Landing and Westrop, 1996).

Overlying the Chamberlain's Brook Formation across Avalonian North America is the upper Middle Cambrian Manuels River Formation, a dysoxic black mudstone-dominated unit (Bergström and Levi-Seti, 1978; Landing, 1996a) comparable to that thrust on the Fossil Brook Member at BHR-IV. Among the poorly preserved, uncollectible (i.e., exposed on a slaty overhang), large *Paradoxides* at BHR-IV-10.2 are specimens with a quadrate pygidium with a pair of very elongate, posteriorly directed lateral spines. These are tentatively brought to *P. davidis* Salter, 1863, an upper Middle Cambrian species in Avalon (e.g., Hutchinson, 1962).

DISCUSSION

Litho- and biostratigraphic succession.—Stratigraphy and faunas show that the Beaver Harbour area was a part of the terminal



FIGURE 3—Phosphatic microfossils from lower Wade's Lane Formation, southern New Brunswick; specimens from BHR-II-1.6 unless otherwise indicated. 1–13, *Lapworthella cornu* (Wiman, 1903), Figure 7.11–7.13 from BHR-II-2.3. 1, NBMG 12551, $\times 36$; 2, broken sclerite with quadrate cross section, NBMG 12552, $\times 38$; 3, cylindrical sclerite, NBMG 12553, $\times 50$; 4, broken, broad sclerite, NBMG 12554, $\times 40$; 5, NBMG 12555, $\times 45$; 6, NBMG 12556, $\times 113$; 7, NBMG 12557, $\times 37$; 8, NBMG 12558, $\times 31$; 9, NBMG 12559, $\times 29$; 10, NBMG 12560, $\times 43$; 11–13, broken sclerites with quadrate, compressed, and sub-circular cross sections, NBMG 12561–12563, $\times 35$, $\times 22$, and $\times 23$, respectively. 14, *Strictocorniculum vanallerum* Landing, 1995, broken element, NBMG 12564, $\times 47$. 15, *Microdictyon* sp., NBMG 12565, $\times 67$. 16, *Conotheca* sp., specimen with circular cross section shows “bulges” developed along slip cleavage, NBMG 12566, $\times 43$, BHR-II-1.0. 17, 18, *Torellella laevigata* (Linnarsson, 1871), dorsal/ventral and lateral views, NBMG 12567 and 12568, $\times 22$.

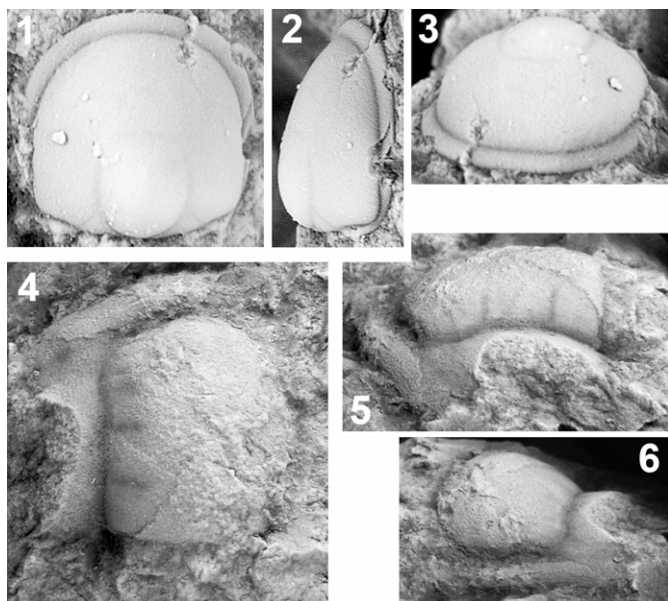


FIGURE 4—Trilobites from Beaver Harbour succession, southern New Brunswick; 1–3 from upper Chamberlain's Brook Formation (Fossil Brook Member), 4–6, from lower Wade's Lane Formation. 1–3, *Cotalagnostus* sp. aff. *C. lens* (Grönwall, 1902), cephalon, NBMG 12804a from BHR-IV-6.9, $\times 11$, dorsal, lateral and frontal views. 4–6, Ellipsocephaline gen. aff. *Ornametaspis*, incomplete cranium, NBMG 12791 from BHR-II-2.3, $\times 5.5$; dorsal, left-lateral, and frontal views.

Proterozoic–Early Paleozoic Avalon continent. This succession is comparable to “marginal platform” sequences of northwest Avalon [i.e., the Saint John, New Brunswick, area; Antigonish Highlands and southern Cape Breton Island, Nova Scotia; Burin Peninsula, east Newfoundland; and North Wales; see Landing (1996a, 1996b, 2004, 2005)]. In these regions, the oldest Avalonian cover sequence consists of of three formation-scale units: 1) uppermost Proterozoic rift–marginal marine facies, 2) Ediacaran–lower Terreneuvian, wave-dominated shelf siliciclastics, and 3) middle Terreneuvian, tidally influenced, coarse-grained quartzite. This succession is abbreviated on the “inner platform” [i.e., east Massachusetts and Rhode Island; Cradle Brook, New Brunswick; Avalon Peninsula, east Newfoundland; England and South Wales], where the oldest unit is the tidalite quartzite (Landing, 1996a, 1996b).

The succession from wave-influenced Chapel Island Formation through Random Formation tidalites at Beaver Harbour compares with that in the Saint John region (i.e., Landing, 2004). The only difference is that the lower Chapel Island and underlying Rencontre are not exposed at Buckmans Creek (Fig. 9). The Chapel Island and Random Formations represent characteristic earliest Cambrian cool-water lithofacies of the Avalon marginal platform. These units contrast with tropical carbonate platform successions on the latitudinally distant, faunally distinct north African and Iberian margins of the Gondwanan continent (Landing, 2004, 2005, and sources therein). Attempts to make Avalon a part of West Gondwana into the Ordovician (e.g., Fletcher et al., 2005) are countered by work in the Beaver Harbour area and other detailed studies of American and British Avalon (Landing, 1996a, 2004, and sources therein).

Unlike the Avalonian inner platform where the Random Formation is overlain by up to 200 m of upper Terreneuvian Series mudstone and minor limestone, the upper Terreneuvian is absent on the marginal platform, and successive major unconformities separate the Random from the two depositional sequences that comprise the lower and upper Branchian Series. The second major unconformity is demonstrated at Beaver Harbour by the recovery of upper Branchian fossils just above the Random Formation in the base of a volcanic-rich Wade's Lane Formation (Fig. 9). As suggested by Greenough et al. (1985), the onset of this volcanism was Early Cambrian.

The Cambrian of the Beaver Harbour area is not only similar, but it is largely identical, to that of the Saint John area and more distant areas in Avalon. Beaver Harbour is yet another area in Avalon for which a regionally extensive formation nomenclature is appropriate (Landing, 1996a; Landing and Westrop, 1998a, 1998b). However, where distinct local lithosomes occur, they are given different lithostratigraphic names. Thus, the laterally equivalent sandstones and mudstones of the Hanford Brook Formation and pyroclastic-dominated Wade's Lane Formation (Fig. 9) are distinguished in southern New Brunswick, but available evidence shows that they are genetically related—with prolific volcanism of the Wade's Lane Formation suggesting the source of the ashes in the middle Hanford Brook Formation (Somerset Street Member) ca. 100 km to the northeast in the Saint John area.

Most Cambrian–Ordovician units have wide geographic extent in Avalon. Imagined “tortuously-connected sub-basins controlled by features inherited from Pre-Cambrian erosion” in an Avalonian “seaway” has led to a claim that sedimentary units are geographically limited in Avalon (Fletcher et al., 2005, p. 313). This claim is belied by litho- and biostratigraphic study of terminal Proterozoic–Ordovician successions from eastern Massachusetts to southern Britain (Landing, 1996a, 1996b, 2004, 2005; Landing and Westrop, 1998a, 1998b). More appropriate in explaining the great extent of Avalonian Cambrian–Ordovician lithosomes are elongate fault-bounded depocenters with little or no syndepositional relief (e.g., Landing, 1996a, 2004).

Depositional tectonics and volcanism.—In the Beaver Harbour area, shallow marine facies with condensed limestones were deposited on the Random Formation with late Early Cambrian sea-level rise. This facies was overwhelmed by basalt flows and pyroclastics that aggraded above sea level to form a volcanic edifice.

Other volcanic edifices occur on the marginal Avalonian platform. They include late Early–Middle(?) Cambrian basalts and basalt pebble debris flows with fossiliferous upper Terreneuvian and Branchian boulders in the Antigonish Highlands, Nova Scotia (Landing and Murphy, 1991). Bimodal volcanics of the late Early–early Middle Cambrian Eskasoni and Gregwa Formations occur in southern Cape Breton Island (Landing, 1996a). The volcanic rocks of the Wade's Lane Formation are the third late Early–early Middle Cambrian volcanic edifice recognized on the Avalonian marginal platform. Ages of 522 ± 2 Ma U–Pb on the lower Eskasoni (Barr et al., 1996) and 519 ± 1 Ma on the lower *Calavia broeggeri* Zone (Landing et al., 1998) suggest overlapping ages of Eskasoni and Beaver Harbour volcanism. Trace element work on the Wade's Lane volcanics shows they are highly evolved basalts or basaltic andesites representative of within-plate tholeiites (Greenough et al., 1985; Bartsch, 2005), and indicate the rift or transtensional setting suggested by the bimodal Eskasoni volcanics.

← and $\times 33$. 19, 20, *Lingulella* sp., visceral and external views of brachial valves, NBMG 12569, $\times 36$, and NBMG 12570, $\times 36$. 21–28, *Acrothyra* sp. cf. *A. sera* Matthew, 1902a. 21, 25, 28, interior of brachial valves NBMG 12571, $\times 32$, NBMG 12575, $\times 64$, NBMG 12578, $\times 49$; 22–24, pedicle valves, respectively showing small pedicle foramen, NBMG 12572, $\times 56$, vault of broken pedicle valve shows small pedicle foramen at right center of figure, NBMG 12573, $\times 36$, and valve exterior, NBMG 12574, $\times 25$; 26, exterior of brachial valve, NBMG 12576, $\times 41$; 27, articulated specimen dominated by view of pedicle valve, NBMG 12577, $\times 49$.

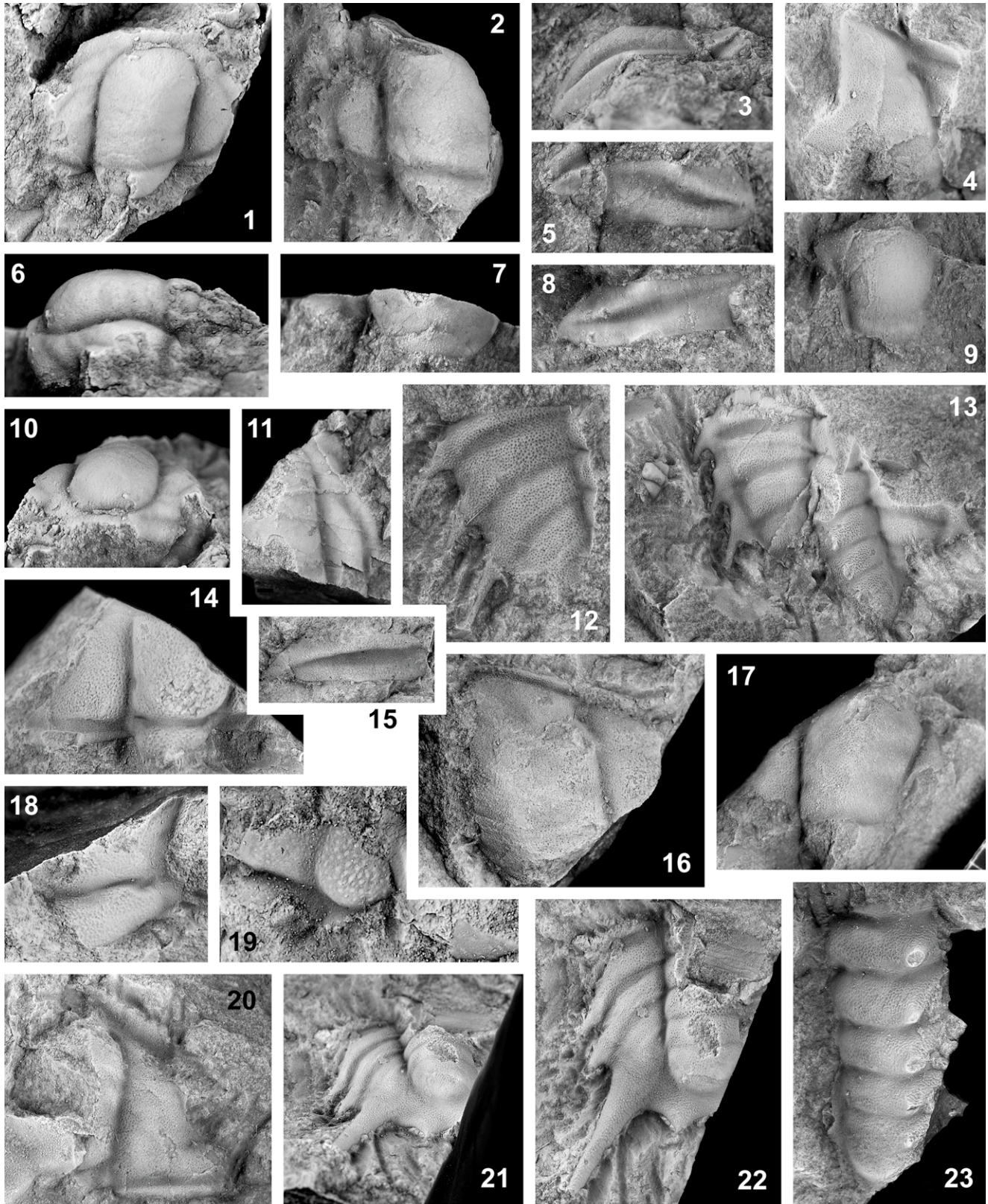


FIGURE 5—Corynexochids from Beaver Harbour succession, southern New Brunswick; 1–3, 5–8, 10, 11 from lower Wade's Lane Formation; 4, 9, 12–23 from upper Chamberlain's Brook Formation (Fossil Brook Member). 1–3, 5–8, 10, 11, *Acanthomicmacca* sp. cf. *A. ellipsocephaloides* (Cobbald, 1910) from BHR-II-1.6; 1, 6, 10, cranium NBMG 12748; dorsal, left lateral, and anterior views, $\times 7$. 2, incomplete cranium, dorsal view, NBMG 12747, $\times 6$. 3, 5, thoracic pleura, NBMG 12752a, anterior and dorsal views, $\times 5$; 7, cranial fragment with occipital ring and posterior border, NBMG 12753, $\times 9.5$. 8, thoracic pleura, dorsal view, NBMG 12750a, $\times 6$. 11, fragmentary cranium with partial glabella and right fixigena, NBMG 12746a, $\times 2.8$. 4, 9, 12, 13, 16, 17, *Kootenia*? sp. from BHR-IV-5.9. 4, fragmentary cranium with anterior part of glabella and central section of anterior border, NBMG 12785, $\times 4$; 9, tentatively assigned immature hypostome, NBMG 12774, $\times 8$; 12, partial pygidium, NBMG 12761, $\times 6.2$; 13, two incomplete pygidia (and cranium of corynexochid on left, see Fig. 8.3, 8.8), NMMG 12758a, 12758b, $\times 2.4$; 16, incomplete cranium, dorsal view, NBMG 12776, $\times 3$; cranium, dorsal view,

The transtensional environment of Cambrian bimodal volcanism extended for at least 550 km along the outer marginal platform from Beaver Harbour to Cape Breton Island, and controlled terminal Proterozoic–Cambrian deposition on the Avalonian inner platform. The development of elongate, north-northeast-trending, fault-bounded depocenters that moved sequentially to the southeast in the terminal Proterozoic–middle Terreneuvian, late Terreneuvian, and Branchian in American and British Avalon is best explained by a transtensional regime (Landing and Benus, 1988; Landing, 1996a, 2004).

Proposals that Cambrian volcanic edifices like that represented by the Bourinot Group (Eskasoni and Gregwa Formations) in Cape Breton Island were not part of or “contiguous” with Avalon (Barr and White, 1999; Barr et al., 2003) are countered by the presence of characteristic Avalon platform formations that onlap the volcanics (Landing, 1996a), or, as the Wade’s Lane Formation, under- and overlie them. The suggestion that the “Bras d’Or terrane” or “Bras d’Oria” with Cambrian volcanic edifices was related to the Gander zone of the central Appalachians (e.g., Van Staal et al., 1998; Barr et al., 2003) needs a reevaluation, as this “terrane” was simply part of Avalon.

Volcanism at Beaver Harbour ended with transgression of the middle Middle Cambrian Fossil Brook Member on subaerial pyroclastics. Coeval sea-level rise is also shown by onlap of the Fossil Brook Member across the eroded Branchian Series (Hanford Brook Formation) in the Saint John area, where the hiatus is early Middle Cambrian (Landing and Westrop, 1996; Kim et al., 2002). A major Random Formation–*Paradoxides eteminicus* Zone unconformity exists on islands with marginal platform successions in Fortune Bay, eastern Newfoundland (Landing, 1996a, p. 36), and shows the extent of Avalon middle Middle Cambrian onlap. In southeast Newfoundland, the Fossil Brook Member is a depositional sequence at the top of the Chamberlain’s Brook Formation, with 2–3-m-deep erosion of the underlying Braintree Member in east Conception Bay (Landing et al., 1988; Landing and Westrop, 1998a).

The onlap of the Fossil Brook Member provides an upper bracket on southern New Brunswick volcanism. The Fossil Brook shows no evidence for continuing volcanism at Beaver Harbour or in the Saint John area. A tentative conclusion is that the apparent unconformity between the Wade’s Lane Formation volcanics and Fossil Brook Member is comparable to the unconformity between the volcanic ash-bearing Hanford Brook Formation and the Fossil Brook in the Saint John area. By this interpretation (Fig. 9), the Wade’s Lane volcanics are the lateral equivalent of the middle Hanford Brook Formation, with the lower St. Martin’s Member correlated into the *Callavia broeggeri* Zone (discussed above).

The highest Cambrian unit at Beaver Harbour is correlative and lithologically comparable with the Manuels River Formation. With dysoxic, black mudstone-dominated deposition characterizing the upper Middle Cambrian of American and British Avalon (e.g., Landing, 1996a), this last detail of the Beaver Harbour inlier emphasizes that it is part of the terminal Proterozoic–Early Paleozoic Avalon microcontinent.

New river belt.—The Beaver Harbour area is in the “New River belt” (Johnson and McLeod, 1996; Johnson, 2001), one of several fault-bounded, northeast-trending, structural units of southern New Brunswick. To the southeast, the New River belt is separated from a “Caledonia terrane”—a local term for the

“Avalonian terrane sensu strictu” and including the Saint John area (e.g., Barr and White, 1999; Barr et al., 2002, 2003)—by Early Silurian, volcanics of the Kingston belt (Barr et al., 2002) and the terminal Proterozoic–Lower Cambrian Brookville terrane (White and Barr, 1996; White et al., 2002). Currie (1988), Currie and McNicoll (1999), and Johnson and McLeod (1996) referred the New River belt to Avalon. But, other syntheses link the New River–Brookville belts to Ganderia in the central Appalachians (Van Staal et al., 1998; Barr and White, 1999; Barr et al., 2003).

Definition of the “Avalon zone” relies on regional similarity in the terminal Proterozoic–Lower Paleozoic cover sequence (Rast et al., 1976). Our study now shows that nearly identical lithosequences and faunas exist between the southeast New River belt at Beaver Harbour, at Caton’s Island (i.e., a Rencontre–Manuels River succession) further northeast (Landing and Westrop, 1996; Fig. 1), and in the Saint John area. These similarities prove a unified Avalon terrane by the terminal Proterozoic. This synthesis was promoted by Johnson (2001), who argued that the Caton’s Island and Beaver Harbour areas in the east New River belt are Avalonian. She also noted that a structural boundary separates these areas from deep-water, late Early Cambrian rocks in the west New River belt (i.e., Mosquito Lake Road and Matthews Lake Formations) that do not easily correlate into the shallow-water, Avalon cover sequence, and proposed that the New River belt is composite (Johnson, 2001).

Contrary to the Ganderian model of Barr et al. (2002, 2003), it is likely that the various “belts” and “terrane” of the “Avalon composite terrane” are merely features limited to parts of the upper Precambrian under the Avalon cover sequence. The “belts” and “terrane” may simply reflect differences in pre-Avalonian geologic history or different depths of erosion of the basement prior to deposition of the Avalonian cover sequence (Dostal et al., 1990; Keppie and Dostal, 1991). This explanation does not explain the earliest Cambrian (ca. 540–526 Ma) calc-alkaline plutonism in the Brookville terrane with a geochemistry typical of continental margin subduction zones (White et al., 2002), while the latter tectonic setting is not readily reconciled with deposition of the Avalonian cover sequence in a transtensional regime.

CONCLUSIONS

The Beaver Harbour area has a middle Terreneuvian–upper Acadian succession characteristic of the Avalon microcontinent. As elsewhere on the Avalon marginal platform, a major unconformity separates middle Terreneuvian from higher Cambrian units, and the Random is unconformably overlain by Branchian strata. Recovery of the first Branchian microfossils and trilobites from southwest New Brunswick at Beaver Harbour dates the onset of basaltic volcanism that led to development of a volcanic edifice. Pyroclastic volcanism continued through the Branchian, and developed in a transtensional regime that extended across the Avalon platform. This transtensional regime links stratigraphic and volcanic developments of the Beaver Harbour and “Bras d’Oria” regions to the Cambrian depositional history of the Avalon marginal platform. The subaerial volcanics in the Beaver Harbour area were inundated by marine onlap and deposition of unconformably overlying middle Middle Cambrian (Fossil Brook Member) and upper Middle Cambrian (Manuels River Formation) units with Avalonian faunas.

←

NBMG 12776, ×3; 17, incomplete cranium NBMG 12779, ×3.6; 14, 15, 18–23, *Dorypyge* species A from BHR-IV-5.9; 14, immature partial cranium, note surface ornament, NBMG 12760, ×7; 15, thoracic pleura, note granular surface ornament, NBMG 12777b, ×3; 18, cranidia fragment with part of occipital ring (note surface ornament), NBMG 12771, ×3.2; 19, fragment of thoracic tergite showing bulbous lateral sectors of axial ring covered with large pustules, NBMG 12768, ×8; 20, partial cranium, NBMG 12772, ×3.5; 21, 22, incomplete pygidium, NBMG 12759, ×4; oblique posterior view and dorsal views; 23, partial pygidium, NBMG 12782, ×2.8.

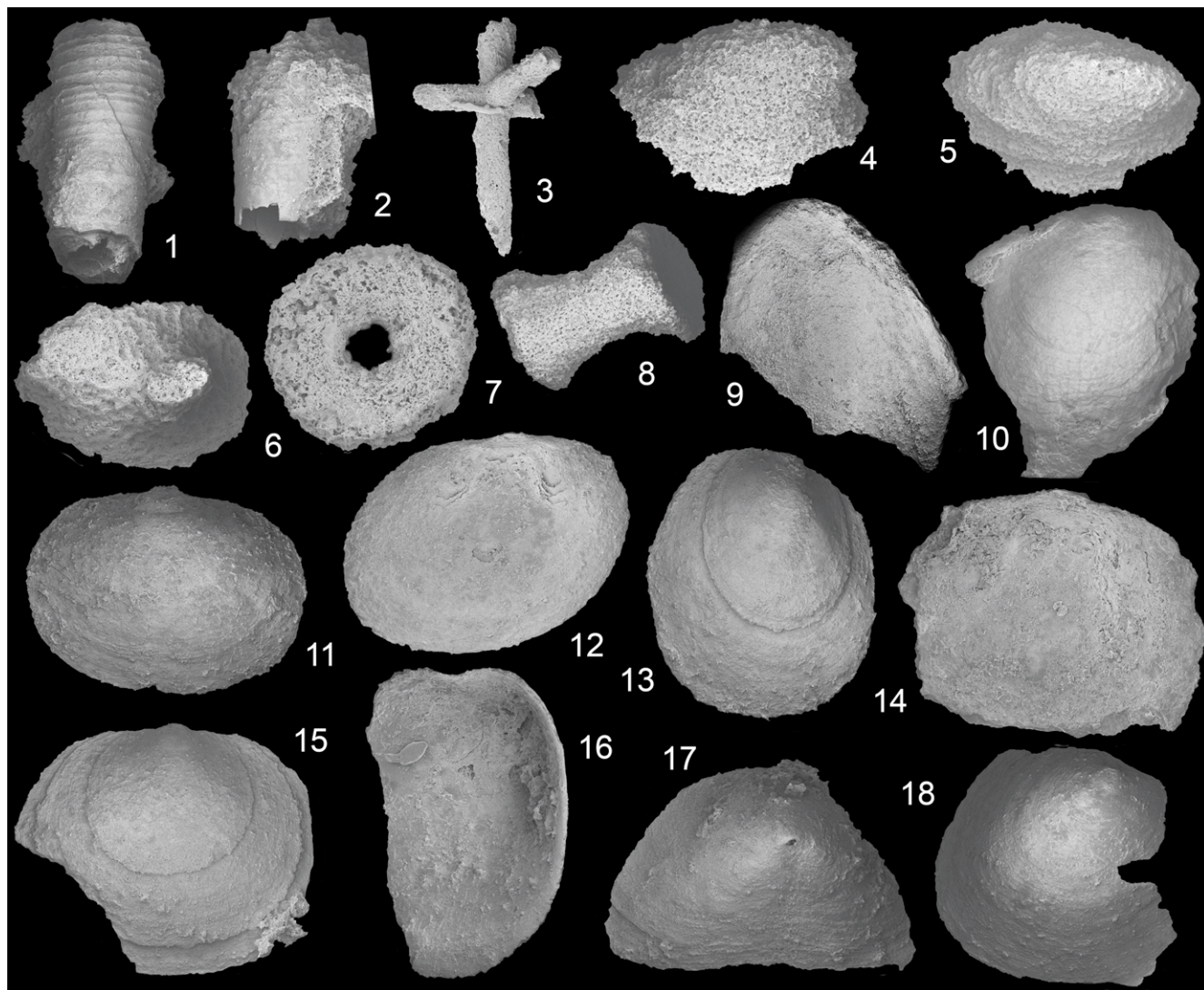


FIGURE 6—Middle Cambrian microfossils from upper Chamberlain's Brook Formation (Fossil Brook Member) of the Beaver Harbour succession, southern New Brunswick; specimens from BHR-IV-5.9, unless otherwise indicated. 1, 2, *Hyolithellus sinuosus* Cobbold, 1921, NBMG 12579 and 12580 showing prominent and obsolescent transverse ridges, $\times 35$ and $\times 22$, respectively, BHR-IV-6.9. 3, Hexactinellid hexaxon, NBMG 12581, $\times 76$. 4, 5, *Helcionella oblonga* Cobbold, 1921, dorsolateral and dorsal views of steinkern, $\times 38$, NBMG 12582. 6–8, Echinoderm sclerites; 6, dermal plate, NBMG 12583, $\times 48$; 7, columnal, NBMG 12584, $\times 109$; 8, “spindle,” NBMG 12585, $\times 38$. 9, 10, *Lingulella ferruginea* Salter in Salter and Hicks, 1867, visceral and external views of pedicle valves, NBMG 12586, $\times 26$, BHR-IV-5.9, and NBMG 12587, $\times 22$, BHR-IV-6.9. 11–18, *Acrothyra sera*? Matthew, 1902a, Figure 6.17 from BHR-IV-6.9. 11–14, brachial; 11, 12, external and visceral views of undistorted and tectonically sheared valves, NBMG 12588 and 12589, $\times 40$; 13, 14, external and visceral views of tectonically distorted and undistorted valves, NBMG 12590 and 12591, $\times 33$ and $\times 66$; 15–18, pedicle valves, Figure 6.17 specimen tectonically elongated on anterior-posterior axis, NBMG 12592–12595, $\times 33$, $\times 56$, $\times 33$, $\times 39$, respectively.

SYSTEMATIC PALEONTOLOGY

Class TRILOBITA Walch, 1771

Order AGNOSTIDA Salter, 1864

Suborder AGNOSTINA Salter, 1864

Family SPINAGNOSTIIDAE Howell, 1935

Genus COTALAGNOSTUS Whitehouse, 1936

Type species.—*Agnostus lens* Grönwall, 1902, from the Middle Cambrian *Hypagnostus parvifrons* Zone of Bornholm, Denmark; by original designation.

COTALAGNOSTUS sp. aff. *C. LENS* (Grönwall, 1902)

Figure 4.1–4.3

aff. *Agnostus lens* GRÖNWALL, 1902, p. 65, pl. 1, figs. 8, 9.

Material examined.—NBMG 12804a from BHR-IV-6.9.

Discussion.—The single cephalon is similar to those of *Lisogoragnostus* Rozova (in Lisogor et al., 1988); *Cotalagnostus*

Whitehouse, 1936; and *Hypagnostus* Jaekel, 1909—genera with a cephalon with a nearly effaced anterior glabellar lobe. Typical *Hypagnostus* species have a more distinct furrow between the anterior and the posterior glabellar lobe. The Beaver Harbour specimen is referred to *Cotalagnostus* because of the comparable development of the posterior border, and is close to cephalon of *C. lens*. Minor differences include less strongly curved lateral margins of the posterior glabellar lobe in the Beaver Harbour cephalon, a less strongly curved furrow between the anterior and posterior glabellar lobe, less well marked basal lobes, and a posteriorly narrowing cephalic border, which is more pronounced in Grönwall's and other specimens. These features are of minor importance in identification, compared with characters of the pygidium, which was not recovered.

Hutchinson (1962) described *Cotalagnostus lens* and “*C. lens* (Grönwall) subsp. *C. claudicans* Westergård” [sic] from the upper *Paradoxides hicksi* and *P. davidis* Zones of the Manuels River

TABLE 1—Acid-resistant sclerites from upper Lower and Middle Cambrian microfaunas from Beaver Harbour. Mass of sample disaggregated (kg in parentheses) below sample number. “P” indicates “presence.”

	BHr-II-0 (4.5 kg)	BHr-II-1.6 (5.5 kg)	BHr-II-2.3 (4.8 kg)	BHr-IV-5.9 (34.4 kg)	BHr-IV-6.9 (4.0 kg)	BHr-IV-7.6 (4.0 kg)
Hexactinellids						
Hexaxons				19		16
Lingulates						
<i>Acrothyra sera?</i>						
pedicle valve				21	5	1
brachial valve				57	8	1
fragments						
A. sp. cf. <i>A. sera</i>						
articulated valves	1	52	15			
pedicle valve	34	661	96			
brachial valve	25	659	155			
fragments	6	52	24			
<i>Lingulella ferruginea</i>						
brachial valve				5	6	2
L. sp.						
brachial valve		5				
fragments	2	4				
Hyolithelminthoids						
<i>Hyolithellus sinuosus</i>				25	28	6
<i>Torellella laevigata</i>	9	42	49			
Orthothecid hyoliths						
<i>Circotheca</i> sp.	2					
“Monoplacophorans”						
<i>Helcionella oblonga?</i>				1		
Tommotiids						
<i>Lapworthella cornu</i>	2	258	108			
Pseudoconodonts						
<i>Strictocorniculum vanallerum</i>		1	1			
Lobopods						
<i>Microdictyon</i> sp.		1				
Trilobites						
Pleural spines		p	p	p	p	p
Echinoderm sclerites						
Columnals				5		
Dermal plate			3	3		
Spindles			1			

Formation in southeast Newfoundland. The Beaver Harbour form differs from Hutchinson's (1962) in having a glabella with a uniform curvature of the posterior margin. Illing (1916) recorded poorly preserved *C. lens* from the Abbey Shales in Warwickshire, along with *C. rotundatus* (Grönwall, 1902), but the latter specimens are too poorly preserved for confident identification (Rushton, 1979, p. 52).

Cobbold and Pocock (1934, p. 342, pl. 44, figs. 5–8) figured material from the *Paradoxides forchhammeri* Grit [=Rushton Brook Bed of Rushton and Berg-Madsen (2002)] in Shropshire as *Agnostus lens*. Kobayashi (1939, p. 129) proposed *C. lens angustus* for these specimens, based on an additional furrow on the pygidial pleural lobes. Rushton and Berg-Madsen (2002) confirmed the identification as *C. lens lens*, and reassigned pygidia identified as *C. rotundatus* in Cobbold and Pocock (1934) to *C. lens lens*.

Order REDLICHIDA Richter, 1932

Suborder REDLICHINA Richter, 1932

Superfamily ELLIPSOCEPHALOIDEA Matthew, 1887

Family ELLIPSOCEPHALIDAE Matthew, 1887

Subfamily ELLIPSOCEPHALINAE Matthew, 1887

Ellipsocephaline genus aff. ORNAMENTASPIS Geyer, 1990

Figure 4.4–4.6

Material examined.—Cranidium NBMG 12791 from BHr-II-2.3.

Discussion.—General convexity, glabellar shape (gently tapering lateral margins that trend into strong anterolateral corners and

end in a shallow triangular front; bar-like cross-section, moderate convexity above raised lateral glabellar margins), and pattern of the three glabellar furrows (S1 slightly longer than anterior pairs, curved backward; narrower S2 and S3; faint S4) suggest reference to the kingaspidoide clade of ellipsocephaloids. Such trilobites are characterized by a mosaic of features for which information on the interior and exterior morphology is needed for confident identification. The Beaver Harbour specimen has a glabella comparable to that in *Ornamentaspis*, but the anterior part of the cranidium is shorter and has a different morphology, particularly in the sagittally narrower and raised anterior border and the pre-ocular areas. Similar forms occur in the uppermost Lower Cambrian of Baltica (see Ahlberg and Bergström, 1978, Bergström and Ahlberg, 1981). Kingaspidoide occur in the *Protolenus elegans* Zone of the Hanford Brook Formation, New Brunswick (Westrop and Landing, 2000).

Superfamily PARADOXIDOIDEA Hawle & Corda, 1847

Family PARADOXIDIDAE Hawle & Corda, 1847

Genus PARADOXIDES Brongniart, 1822

Type species.—*Entomostracites paradoxissimus* Wahlenberg, 1818, from the Middle Cambrian at Öltorp, Västergötland; subsequent designation by Barrande (1852, p. 362).

Discussion.—Reports on *Paradoxides* (Geyer, 1998; Kim et al., 2002; Rushton and Berg-Madsen, 2002) concur that its subgeneric

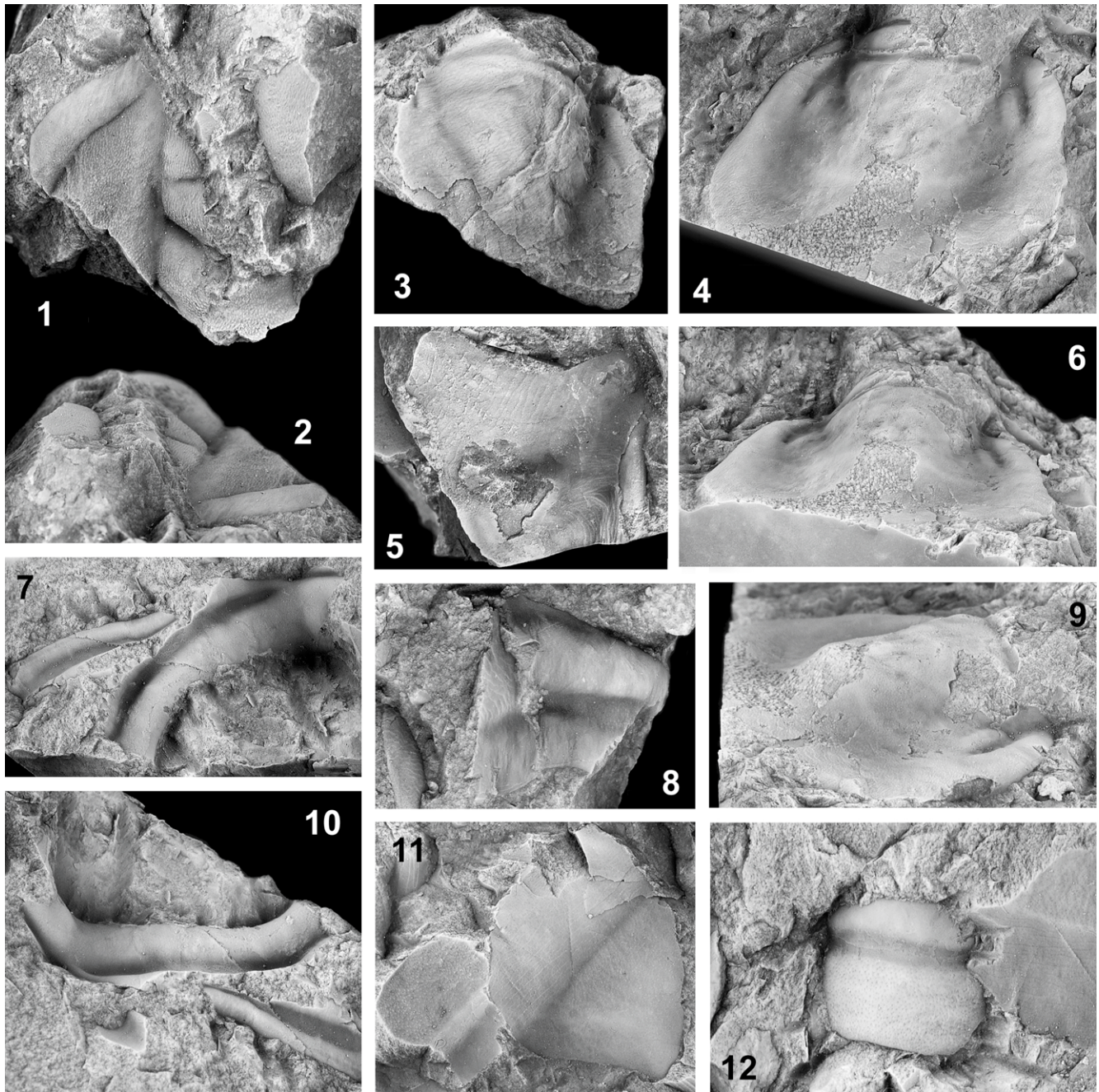


FIGURE 7.—Paradoxoidids from upper Chamberlain's Brook Formation (Fossil Brook Member) of Beaver Harbour succession, southern New Brunswick. 1–12, *Paradoxoides* (*Eccaparadoxoides*?) spp. from BHR-IV-6.9, unless otherwise indicated. 1, 2, cranial fragment showing partial glabella, left fixigena, and palpebral lobe, NBMG 12765, BHR-IV-5.9; dorsal and frontal views, $\times 3.75$. 3, incomplete pygidium, dorsal view, NBMG 12789, BHR-IV-5.9, $\times 3.1$. 4, 6, 9, incomplete hypostome, NBMG 12798; dorsal, posterior, and oblique lateral views, $\times 2.75$. 5, incomplete hypostome, dorsal view, NBMG 12803, $\times 4.75$. 7, 10, partial posterior thoracic tergite, NBMG 12797a; dorsal and anterolateral views, $\times 4$. 8, anterior thoracic tergite fragment, NBMG 12773a, BHR-IV-5.9, $\times 5.25$. 11, 12, fragments of dorsal carapace from BHR-IV-6.5; 11, NBMG 12795a with left anterior cranial wing on right (note caeca), $\times 4.25$; 12, NBMG 12794a with thoracic axial ring (center) and mold of anterolateral cranial wing (right), $\times 4.25$.

taxonomy is poorly resolved. Šnajdr's (1957) *Paradoxoides* subgenera, later raised to generic rank by some authors who proposed additional subgenera, cannot be readily distinguished if they were based on few characters. They are best treated as subgenera as long as their precise definition is pending.

Subgenus ECCAPARADOXIDES Šnajdr, 1957

Type species.—*Paradoxoides pusillus* Barrande, 1846, from the middle Middle Cambrian Skryje Formation of Bohemia; by original designation.

Paradoxoides (*Eccaparadoxoides*?) spp.

Figure 7.1–7.12

Material examined.—The first paradoxoidid is recorded by cephalic fragments (NBMG 12765, 12781, and 12783? from BHR-IV-5.9), hypostomal fragments (NBMG 12787a from BHR-IV-5.9 and 12803 from BHR-IV-6.9), pygidia (NBMG 12789 from BHR-IV-5.9, NBMG 12798 and 12764 from BHR-IV-6.9), and tentatively assigned thoracic segment fragments (NBMG 12773a from BHR-IV-5.9; NBMG 12787b, 12797a, 12797b, 12805b, and 12805cc-6.9 from BHR-IV-6.9). The second is recorded by cephalic fragments (NBMG 12794b, 12795a) and thoracic segment fragments (NBMG 1293b, 12794a, 12794c, 12795b) from BHR-IV-6.5.

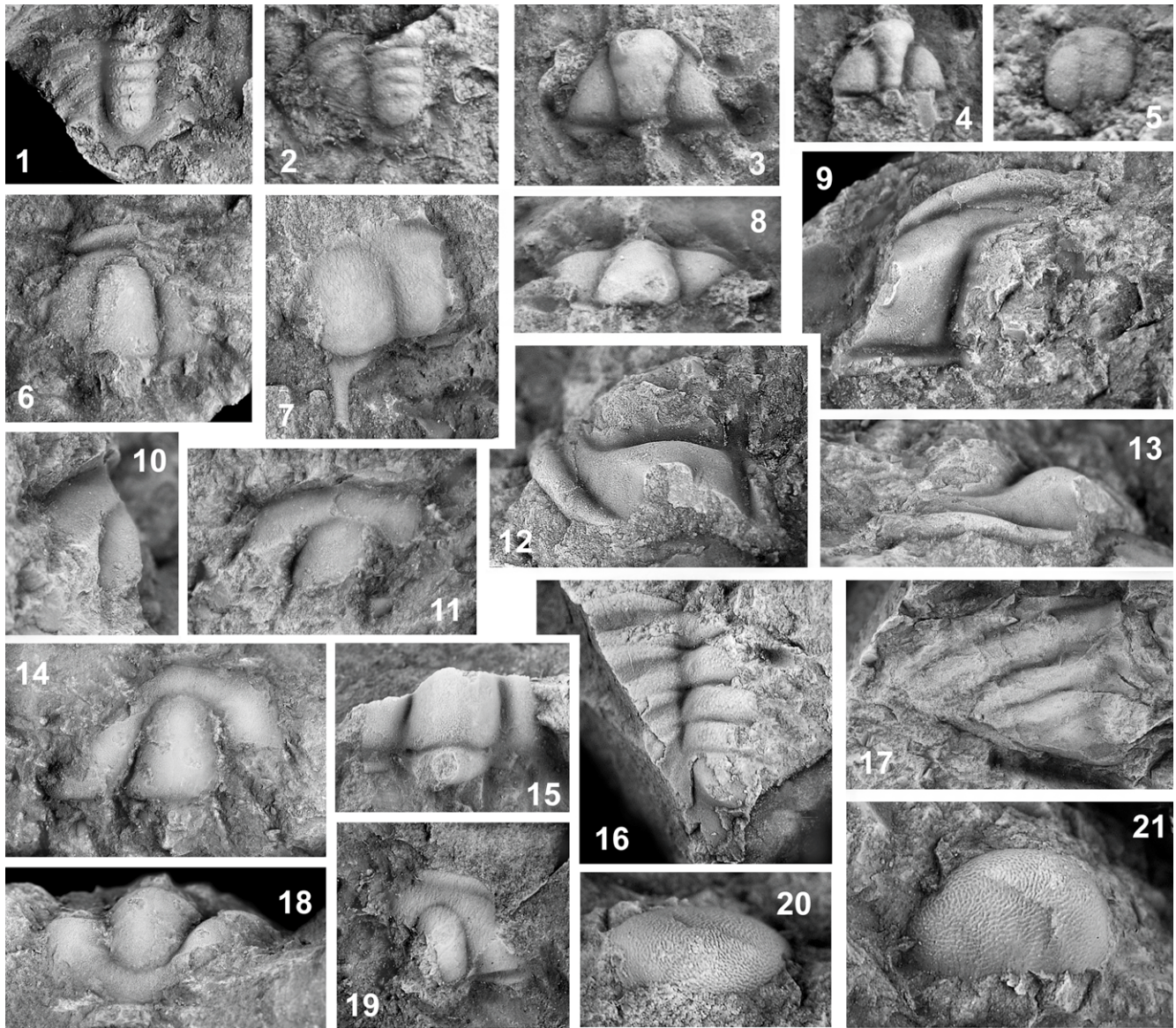


FIGURE 8—Corynexochids, ptychoparioids, and bradoriid from upper Chamberlain's Brook Formation (Fossil Brook Member) of Beaver Harbour succession, southern New Brunswick; specimens from BHR-IV-5.9. 1, 2, *Dorypyge* species B; incomplete pygidia NBMG 12770b and NBMG 12778, $\times 6.8$ and $\times 9$, respectively. 3–5, 8, Corynexochid genus and species undetermined; 3, 8, cranidium NBMG 12758c, $\times 8.5$; dorsal view and anterior views; 4, immature cranidium, dorsal view, NBMG 12763, $\times 11$; 5, protaspis NBMG 12804b, width of specimen 0.70 mm. 6, *Braintreella?* sp., cranidium NBMG 12767, $\times 6$. 7, 19, Ptychopariid genus and species B; partial cranidium, NBMG 12766, 7; and cranidium, NBMG 12777a, $\times 6$; dorsal views. 9, 12, 13, 16, *Parasolenopleura?* sp. from BHR-IV-6.9; 9, 12, 13, cranidium NBMG 12801; dorsal, left lateral, and anterior views, $\times 5.5$, $\times 7$, and $\times 5.5$, respectively; 16, fragment of posterior thorax with attached partial pygidium, NBMG 12799, $\times 3.5$. 10, 11, Ptychopariid genus and species A, cranidial fragment NBMG 12769; left lateral and dorsal views, $\times 6$ and $\times 4.8$, respectively. 14, 18, Solenopleurid genus and species undetermined, cranidium, NBMG 12788; dorsal view and anterior views, $\times 3.5$. 15, Ptychopariid genus and species C, incomplete cranidium, dorsal view, NBMG 12806a from BHR-IV-6.9, $\times 5.8$. 17, *Bailiella?* sp., partial pygidium, dorsal view, NBMG 12793a from BHR-IV-6.5, $\times 4$. 20, 21, *Bradoria* sp. cf. *B. scrutator* Matthew, 1899, right valve, NBMG 12805a, from BHR-IV-6.9, $\times 7.5$; 20, anterior view; 21, lateral view.

Discussion.—Two species of *Paradoxides* (*Eccaparadoxides*?) are likely represented in the Fossil Brook Member at Beaver Harbour. The first (Fig. 7.1–7.10) has pygidia with a distinct axis and outline. NBMG 12789 (Fig. 7.3) has an axis with an articulating half ring and well defined axial ring. The axis tapers to a narrowly rounded end, and the lateral margins seem to diverge slightly from the anterior corners. The border is recognizable only in the anterior third of the pygidium before the border furrow fades completely. The pleural fields merge into a shallow, distinct central platform surmounted by the axis. NBMG 12798 (Fig. 7.4, 7.6, 7.9) has clearly diverging lateral margins that curve inward from a point slightly posterior to the tip of the axis, pleural fields with

a distinct pleural rib on the anterior part of pygidium, and a shallow, broad depression around the posterior part of the axis. These characters are known in *P. (E.) bennetti* (Salter, 1859) and *P. (E.) etemincus* pygidia—species with great morphologic variability. Due to their recovery in fossil hash limestone, the Beaver Harbour specimens are very convex if compared with the flat material typically found in shale. NBMG 12765 (Fig. 7.1, 7.2) has strongly diverging S1 and S2, a typical feature of *P. (E.) acadicus* and *P. (E.) bennetti*, and a strongly convex palpebral lobe with relatively uniform convexity in transverse section. Other cranidial features also agree with both species. The eye ridge curvature and convexity of the fixigenae compare better with *P. (E.) acadicus*, but

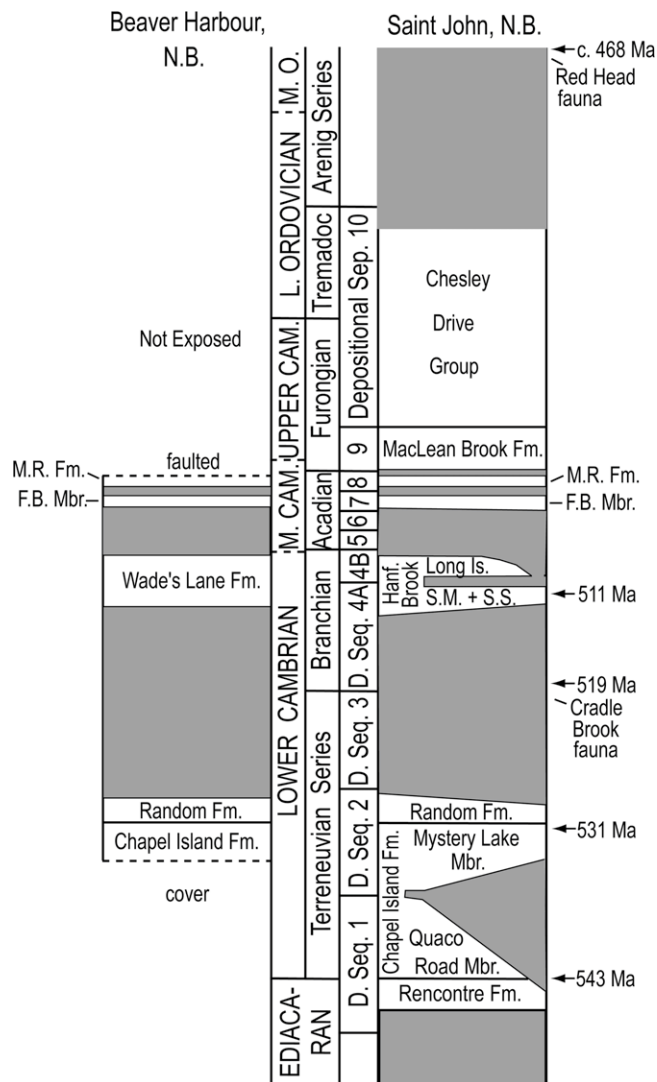


FIGURE 9—Correlation of marginal platform successions in Beaver Harbour and Saint John, New Brunswick, areas. Stratigraphic column scaled proportional to Cambrian–Ordovician geochronology (see Tucker and McKerron, 1995; Landing et al. 1998, 2003); black field = hiatus corresponding to regional sequence boundaries on Avalonian marginal platform. Abbreviations: F.B. Mbr., Fossil Brook Member of Chamberlain's Brook Formation; Hanf. Brook, Hanford Brook Formation; Long Is., Long Island Member; M.R. Fm., Manuels River Formation; S.M. = S.S., St. Martin's and Somerset Street Members. Cradle Brook and Red Head faunas in Landing (1996a) and Landing et al. (2003).

the acute angle formed by the anterior end of the palpebro-ocular ridges and glabella is not known in the latter, where this is nearly a right angle in large specimens. NBMG 12781 has a strongly convex glabella with uniform anterior curvature. The anterior border in these specimens is low and apparently narrower than in typical *P. (E.) bennetti* specimens.

Topotype *Paradoxides (E.) acadicus* from the Fossil Brook Member near Saint John, New Brunswick, appears to lack terrace lines except on the doublure (Kim et al., 2002, fig. 10). These terrace lines occur in the Beaver Harbour material. The subgenotype species *P. (E.) pusillus* (Barrande, 1846) is morphologically similar. It has terrace lines, but apparently has better developed S3 and S4 and a slightly narrower glabella.

Numerous fragments of *Paradoxides (Eccaparadoxides?)* from BHR-IV-6.5 (Fig. 7.11, 7.12) suggest a different species than in BHR-IV-5.9 and -6.9. Their features are inadequate for confident identification, but are similar to *P. (E.) etemicus* group species

(see Kim et al., 2002). Noteworthy is a fragment of the left anterior of a cranidium (Fig. 7.11). The anterior branch of the facial suture swings inward before reaching a broad, poorly defined anterior border furrow. It outlines a wide circular sector on the broad (exsag.) anterior border. The preocular area has a faint ridge (termed “ocular line” in older literature) parallel to the suture, and is covered by a caecal network. The anterior border has fine terrace lines.

Order CORYNEXOCHIDA? Kobayashi, 1935
Superfamily CORYNEXOCHIDACEA? Angelin, 1854
Family CHENGKOUIIDAE Zhu, 1980

Discussion.—The Chengkouidae [=Chengkouidae Zhu in Zhang et al. (1980)] is based on *Chengkouia* Chien and Yao, 1974, a subjective junior synonym of *Acanthomicmacca* Hupé, 1953. Despite differences such as a comparatively narrow fixigenae, long lateral glabellar furrows, and tiny, pit-like lateral glabellar furrows close to the anterolateral corners of the frontal lobe, *Chengkouia* cannot be maintained as a separate genus based on these features. Tentative evolutionary and taxonomic relationships of the Corynexochida with early *Acanthomicmacca*-type stock have been discussed by Geyer and Malinky (1997; compare Robison, 1967).

ACANTHOMICMACCA Hupé, 1953

Type species.—*Micmacca walcotti* Matthew, 1899a, from the upper Lower Cambrian basal Brigus Formation, southeast Newfoundland; original designation by Hupé (1953).

ACANTHOMICMACCA sp. cf. A. ELLIPSOCEPHALOIDES (Cobbold, 1910)

Figure 5.1–5.3, 5.5–5.8, 5.10, 5.11

cf. *Micmacca? ellipsocephaloides* COBBOLD, 1910, p. 27, 28, pl. 7, figs. 8, 9, pl. 8, fig. 1.

Material examined.—Incomplete cranidia (NBMG 12746a, 12747, 12748, 12751, 12753, 12755), a partial librigena (NBMG 12749), and thoracic pleurae (NBMG 12750a, 12750b, 12752a, 12752b); all from BHR-II-1.6.

Discussion.—*Acanthomicmacca* specimens require a mosaic of features for confident identification. The Beaver Harbour material shows a distinct posterior projection of the occipital ring, a low anterior border of moderate width, a well rounded frontal lobe, an occipital node, and dense surface granulation. These features are seen in *A. walcotti* Matthew, 1899a, a west Avalon species first described from southeast Newfoundland. This species has a stout occipital spine, as do the Beaver Harbour specimens. However, Matthew's (1899a) type of *A. walcotti* has a slightly narrower glabella and broader fixigenae.

Acanthomicmacca ellipsocephaloides from the “*Olenellus* limestone” in Shropshire has a well-rounded frontal lobe, wider fixigenae, and apparently less recurved palpebral lobes. However, the species is poorly known. The lectotype cranidium (Cobbold, 1910, pl. 8, fig. 1) is from a young individual, and the best preserved specimen is a large individual with late holaspis or gerontic features, termed by Cobbold as “var. senior,” and less recurved palpebral lobes. The best Beaver Harbour specimens are small, juvenile cranidia. It cannot be excluded that the Shropshire and Beaver Harbour forms are conspecific. Lake (1932) synonymized *A. comleyensis* (Cobbold, 1931) from the “*Callavia* sandstone” at Comley with *A. ellipsocephaloides*—with which we concur. *Acanthomicmacca? protolenoides* (Cobbold, 1931) from the “*Olenellus* limestone” has shorter palpebral lobes and a lower, narrower glabella with a well rounded frontal lobe, while *A. neltneri* Hupé, 1953, has a less convex glabella with a slightly flattened frontal lobe and less prominent anterior border. Chinese species, except *A. pustulosa* (Zhu, 1980), have narrower fixigenae.

Order CORYNEXOCHIDA Kobayashi, 1935
 Family DORYPYGIDAE Kobayashi, 1935
 Subfamily DORYPYGINAE Kobayashi, 1935
 Genus KOOTENIA Walcott, 1889

Type species.—*Bathyriscus (Kootenia) dawsoni* Walcott, 1889, from the Middle Cambrian Stephen Formation, Yoho National Park, British Columbia.

KOOTENIA? sp.

Figure 5.4, 5.9, 5.12, 5.13, 5.16, 5.17

Material examined.—Fragmentary cranidia (NBMG 12776, 12779, 12784, 12785, 12790), incomplete pygidia (NBMG 12758a, 12758b, 12761), and a fragmentary hypostome (NBMG 12774); all from BHR-IV-5.9.

Discussion.—The form is known from a number of sclerites: 1) adult cranidia slightly wider than long across center of palpebral lobes; glabella strongly convex, with conspicuously curved sides that rise above anterolateral pits; lateral glabellar furrows shallow—obsolescent; S3 distant from axial furrows; occipital ring with occipital spine; 2) hypostome ca. 1.2 times longer than wide except for anterior wings, middle body moderately convex, length/width ratio ca. 1.5; anterior lobe of middle body oviform, separated from posterior lobe by shallow, weakly defined, moderately curved middle furrow; 3) thorax segments; and 4) mature pygidium with strongly convex axis ca. 30 percent pygidium width across anterior axial ring, four or five axial rings with median node, articulating half-ring; terminal axial piece semicircular with median node, posterior end slopes steeply; pleural fields with four deep, broad interpleural furrows; at least four pairs of moderately strong, moderately long pleural spines.

An assignment to *Kootenia* is supported by the strong pygidial border and border furrow. However, the lateral pygidial border is dimpled by the extensions of interpleural furrows—a feature of *Kooteniella* Lermontova, 1940. A reference to *Kooteniella* is unlikely as incomplete cranidia from the same horizon—with punctate surface, palpebral lobe shape, and narrow anterior border—are most similar to those of *Kootenia*.

The postaxial area and the marginal spine number are not known with certainty. The morphology of the lateral border, in particular the subtle swellings anterior to the spine bases, is more typical of *Dorypyge*. However, a similar but less pronounced morphology occurs in *Kootenia moori* Lermontova (in Lazarenko, 1962) from the Siberian lower Middle Cambrian and *K. mirabile* Ergaliev (in Ergaliev and Pokrovskaya, 1977) from the upper Lower Cambrian of Kazakhstan. Also peculiar for *Kootenia* are the oblique palpebral lobes—this unusual morphology may reflect the late-middle Middle Cambrian age of the Beaver Harbour material, which suggests this is the youngest known *Kootenia*.

Genus DORYPYGE Dames, 1883

Type species.—*Dorypyge richthofeni* Dames, 1883, from the Middle Cambrian Zhangxia Formation, North China; subsequent designation by Walcott (1889, p. 443).

DORYPYGE species A

Figure 5.14, 5.15, 5.18–5.23

Material examined.—Incomplete cranidia (NBMG 12760, 12762, 12771, 12772, 12780), incomplete pygidia (NBMG 12759 and, perhaps, 12782), and tentatively assigned thoracic pleurae (NBMG 12768, 12770c, 12777b, 12786b); all from BHR-IV-5.9.

Discussion.—The Beaver Harbour specimens include three types of sclerites: 1) a cephalon with strongly convex glabella, sides curved and rise above anterolateral pits; lateral glabellar furrows obsolescent; occipital ring strongly convex, tapers toward axial furrows, covered with honeycomb-like ornament; 2) thoracic fragments with axial rings transversely strongly convex, sagittally moderately convex medial portions, separated from distinct globular lateral lobe by deep furrow; median section and lateral lobe with widely spaced, coarse granules; furrows smooth; and 3) pygidial fragments with long axis with articulating half-ring, four

axial rings, and terminal axial piece; rings highly convex transversely, moderately convex sagittally; lateral border not distinct, margin with spines and interpleural furrows; convex areas covered with granulate or honeycomb pattern, furrows finely granulated.

The co-occurring sclerites are assigned to one taxon based on their granulate and honeycomb ornament. The pygidium, particularly NBMG 12759 (Fig. 5.21, 5.22), suggests a new species. The closest similarity is with the *Dorypyge richthofeni* pygidium from the Middle Cambrian of North China (Walcott, 1913; Schrank, 1977; Zhang and Jell, 1987). Strong similarities between *D. richthofeni* and the Beaver Harbour material lie in the form of the postaxial area and posterior pygidial margin. The long posterolateral spine is more anterior in the Beaver Harbour pygidia; this results in the loss of one of the shorter marginal spines of *D. richthofeni*. The New Brunswick species has a more slender pygidium with more posteriorly directed pygidial pleurae, and finer granulation. Another similar form is *D. pergranosa* Resser and Endo, 1937, from the Zhangxia Formation, North China—a species that shares most features with *D. richthofeni*, but has distinct cranidial differences and finer granulation.

Dorypyge terneki Dean, 1982, from the Sosink Formation of southeast Turkey, is roughly coeval with the Beaver Harbour *Dorypyge*, and is similar to *D. richthofeni*. Zhang and Jell (1987, p. 56) regarded differences emphasized by Dean (1982) as intraspecific variation in *D. richthofeni* “when variation through several large populations collected from northeastern China is considered.” We do not agree, and consider *D. terneki* a valid species distinguished from *D. richthofeni* by pygidial differences—a proportionally longer terminal axial piece; short, pointed projections on the posterior margin; and finer granulation. These features are seen to a degree in some *D. richthofeni* specimens, but never in such a combination as in *D. terneki*.

Matthew (1897) described three *Dorypyge* “forms” from New Brunswick. All differ from *D. species A*, and are discussed under *D. species B*. Several *Dorypyge* species are recorded in east Avalon. Nicholas (1916) identified fragments above the Nant-y-big Mudstones in North Wales, as *D. cf. richthofeni*. The specimens were tentatively re-assigned by Westergård (1948) to *D. aenigma* (Linnarsson, 1869), but their identification remains uncertain. Cobbold (in Cobbold and Pocock, 1934) described *D. rushtonensis* from the *Paradoxides forchhammeri* Grit [=Rushton Brook Bed of Rushton and Berg-Madsen (2002)] in Shropshire. It is mainly based on a partial pygidium with four pairs of regular marginal spines and a pair of long subterminal marginal spines that distinctly diverge and are oriented in a series that matches the other marginal spines. The terminal sector of the posterior border has two faint nodes, but lacks a well developed post-axial indentation. Four axial rings and three to four pleural ribs occur in *D. rushtonensis*, and it is different from the Beaver Harbour form (see Rushton and Berg-Madsen, 2002, fig. 3e, 3f). The strong differences with *D. richthofeni* suggest questions about a referral of *D. rushtonensis* to *Dorypyge*. The surface of the Beaver Harbour material compares with that of *D. reticulata* Cobbold, 1911, from the “*Paradoxides intermedius* Grits” of Shropshire. However, *D. reticulata* and *D. lakei* Cobbold, 1911, have pygidia that suggest *Kootenia*.

DORYPYGE species B

Figure 8.1, 8.2

Material examined.—Pygidia (NBMG 12770b, 12778) from BHR-IV-5.9.

Discussion.—The small, immature(?) pygidia have a strong convex axis that measures ca. 30 percent of the width of the pygidium (except for marginal spines) across the anterior axial ring. The terminal axial piece width is slightly less than 25 percent of the pygidial width. Four axial rings and an articulating half-ring are present; the axial rings have median nodes that decrease

in size posteriorly. The posterior margin is semicircular to hyperbolic, with a pair of stout, triangular spines separated by a distance equal to the terminal axial piece width.

It is tempting to regard these as small pygidia of *Dorypyge* species A. However, differences that are difficult to explain by morphologic change with ontogeny include absence of a postaxial boss, a flat postaxial area, and the distance from the posterior margin. Matthew (1897) described three *Dorypyge* "forms" that he named *D. wasatchensis* Hall and Whitfield var. *acadica*, *D. quadriceps* Hall and Whitfield var. *valida*, and *D. horrida* from phosphatic nodules at Hastings Cove, New Brunswick. They were described from a locality stratigraphically and geographically close to Beaver Harbour, but none represents the Beaver Harbour species.

Family CORYNEXOCHIDAE Angelin, 1854
CORYNEXOCHID genus and species undetermined
Figure 8.3–8.5, 8.8

Material examined.—Cranidia (NBMG 12758c, 12763), tentatively assigned protaspis NBMG 12804b; all from BHR-IV-5.9.

Discussion.—The small cranidium (Fig. 8.4) is probably from a late meraspis. The larger specimen (Fig. 8.3, 8.8) is a mature specimen. Tentatively grouped with these specimens is a protaspis larva (Fig. 8.5) with a glabella that mushrooms anteriorly to span more than three-fourths of the transverse width of the anterior margin. The shape and length of the clavate glabella (with three pairs of faint lateral glabellar furrows in the mature specimen, S1 apparently bifurcate, S2 and S3 shallow depressions directed anteriorly from axial furrows), small palpebral lobes, short eye ridges, and the characters of the preocular fields are typical of the Corynexochidae and some Dolichometopidae. The small palpebral lobes and the position of the glabellar front with respect to the anterior border suggest the Corynexochinae or Acontheinae (which are usually blind), although a pygidium is needed for a precise assignment.

The presence of a corynexochid is unexpected as this family was earlier unknown from west Avalon. A similar cranidium was described from east Avalon as *Corynexochus pusillus* Illing, 1916, from the Stockingford Shales (*Paradoxides hicksi* Zone) in Warwickshire. Cobbold and Pocock (1934) reported *C. pusillus* from the older *P. groomii* Grit (now Quarry Ridge Grits) in Shropshire. Differences with the Beaver Harbour form include the anterior facial sutures, which diverge or are subparallel in *C. pusillus*, and the longer palpebral lobes of *C. pusillus*. The generic assignment of *C. pusillus* must be re-evaluated, and it must be determined if *C. pusillus* is based on an immature "*C.*" illingi Cobbold and Pocock, 1934, (or "*Bathyriscus pusillus*" sensu Lake, 1934) from the Quarry Ridge Grits in Warwickshire. Nicholas (1916) described *C. cambrensis* from the Nant-y-big Mudstones (*Hypagnostus parvifrons* Zone) from North Wales (see Lake, 1934, pl. 23, figs. 10–12). The *C. cambrensis* type is a mature cranidium, but is too deformed to be precisely comparable. However, there are distinct differences between the Welsh species and the Beaver Harbour material.

Order PTYCHOPARIIDA Swinnerton, 1915
Superfamily PTYCHOPARIOIDEA Matthew, 1888
Family PTYCHOPARIIDAE Matthew, 1888
Genus BRAINTREELLA Wheeler, 1942

Type species.—*Ptychoparia rogersi* Walcott, 1884, from the lower Middle Cambrian (lower Chamberlain's Brook Formation) at Braintree, Massachusetts.

BRAINTREELLA? sp.
Figure 8.6

Material examined.—Cranidium NBMG 12767 from BHR-IV-5.9.

Discussion.—An incomplete, slightly distorted cranidium is

comparable to that in *Braintreella* [e.g., glabella moderately tapers, has well rounded front, lacks well defined lateral glabellar furrows; occipital ring extends into large terminal spine; palpebral lobes relatively short, oblique to axis, obliquely upturned; eye ridges faint to obsolescent; preglabellar field slightly narrower (sag.) than anterior border, slightly sunken with respect to preocular areas; anterior border convex, elevated above preglabellar field]. Differences with *Braintreella rogersi* include a slightly narrower (sag.) preglabellar field and more distinct palpebral furrows, the direction of the eye ridges, and possibly a much stronger occipital spine. A confident identification requires better material, as other genera, such as *Xiaomajiella* Zhou (in Zhang et al., 1980) and *Yuehsienszella* Chang, 1957, from the Middle Cambrian of South China, show the same "basic" ptychoparioid features.

PTYCHOPARIID genus and species A
Figure 8.10, 8.11

Material examined.—Cranidium NBMG 12769 from BHR-IV-5.9.

Discussion.—The fragmentary cranidium shows ptychopariid characters. The anterior glabella and parts of the left fixigena, preglabellar field, and anterior border are preserved. The tapering glabella has a faintly triangular front and obsolescent lateral glabellar furrows (S3). The fixigena are distinctly convex, but broken posterior to a well developed, oblique eye ridge with a markedly sloping preocular area. The middle preglabellar field is elevated. The anterior border rises from an incised border furrow, but seems to extend as a rather flat, collar-like band along the anterior.

PTYCHOPARIID genus and species B
Figure 8.7, 8.19

Material examined.—Cranidia (NBMG 12766, 12770a, 12777a) from BHR-IV-5.9.

Discussion.—Three incomplete, slightly distorted cranidia show ptychopariid characters. They have a highly convex glabella that tapers slightly forward; three pairs of faint, slightly posteriorly directed lateral glabellar furrows; a fairly straight, deeply incised occipital furrow; and an occipital ring that extends into a long, obliquely and dorsally directed terminal spine. The fixigenae have strong posterolateral projections; the palpebral lobes are relatively short, oblique to axis, and elevated above palpebral furrows. The eye ridges are faint but thick.

The specimens resemble *Braintreella rogersi*, but this resemblance is merely an expression of plesiomorphic features of the ptychoparioid morphology. The Beaver Harbour specimens have more distinct axial furrows, wider fixigenae, more oblique palpebral lobes, less convex anterior border, and a stronger occipital spine.

PTYCHOPARIID genus and species C
Figure 8.15

Material examined.—Cranidium NBMG 12806a from BHR-IV-6.9.

Discussion.—An incomplete specimen shows the posterior of a highly convex, moderately tapering glabella. It has faint lateral glabellar furrows (S1 bifurcate; S2 short, slightly curved, more-or-less normal to axis; both originate near axial furrow) and an occipital ring with a moderately curved posterior margin with a medial spine. The fixigenae are convex, relatively narrow (less than half glabellar width), and extend into smaller posterolateral projections. The palpebral lobes are short, somewhat oblique to axis, and upturned.

Superfamily SOLENOPLURACEA Angelin, 1854
Family SOLENOPLURIDAE Angelin, 1854
Genus PARASOLENOPLURA Westergård, 1953

Type species.—*Calymene aculeata* Angelin, 1951, from the Middle Cambrian; original designation by Westergård (1953).

PARASOLENOPLEURA? sp.
Figure 8.9, 8.12, 8.13, 8.16

Material examined.—Incomplete cranium NBMG 12801 and fragment of posterior thorax with partial pygidium, NBMG 12799, from BHR-IV-6.9.

Discussion.—The form is known from a cranium (transversely elongate; maximum width 10 mm; anterior moderately curved; glabella highly convex, rises slightly above genae, latter ca. 80 percent cephalic length; short, faint lateral glabellar furrows S3 and S4 apparently in anterior position, originate near axial furrows; occipital ring uniformly curved, probably with occipital node). A thorax fragment has a partial pygidium with strongly convex axis, one distinct axial ring, and a terminal axial piece with subsemicircular outline; the steeply elevated posterior margin appears to have a faint subterminal crest. The course of the facial suture, transversely broad anterior border, glabella shape, and topography and width of the fixigenae match those of *Parasolenopleura*, but the preservation does not permit an unequivocal identification.

SOLENOPLEURID genus and species undetermined
Figure 8.14, 8.18

Material examined.—Incomplete cranium NBMG 12788 from BHR-IV-5.9.

Discussion.—The cranium shows characters of the Solenopleuridae. These include: 1) a strongly tapering glabella with well-rounded, narrow (tr.) front; 2) lateral glabellar furrows apparently distinct but imperfectly preserved, with S1 clearly curved to rear from axial furrows and S2 less clearly curved; 3) fixigenae moderately convex and moderately broad; 4) preglabellar field well developed and sunken below preocular areas; and 5) surface covered with fine granules. These characters resemble those of the *Braintreella*? specimen from the same horizon, but the lateral glabellar furrow pattern indicates a reference to the Solenopleuridae.

Genus BAILIELLA Matthew, 1885

Type species.—*Conocephalites baileyi* Hartt, 1868; subsequent designation by Resser (1936).

BAILIELLA? sp.
Figure 8.17

Material examined.—Pygidial fragment NBMG 12793a from BHR-IV-6.5.

Discussion.—The left half of a large, tectonically distorted pygidial fragment has a distinct axis and pleural fields with three pleural furrows that are progressively less distinct to the rear. The border is moderately broad, moderately convex, and lacks spines. The border furrow is shallow and indistinct. This type of pygidium occurs in a number of early ptychopariids, particularly the Solenopleuridae. The relatively large size (ca. 7 mm long, originally more than 20 mm wide) suggests that it is a *Bailiella* or *Bailiaspis*—common genera in coeval west Avalon sections. The presence of only three distinct pleural ribs suggests an assignment to *Bailiella* rather than to *Bailiaspis*.

Subphylum or Class CRUSTACEA Brönnich, 1772
Order BRADORIIDA Raymond, 1935
Family BRADORIIDAE Matthew, 1902b
Genus BRADORIA Matthew, 1899b

Type species.—*Bradoria scrutator* Matthew, 1899b, from the Middle Cambrian of Cape Breton Island; subsequent designation by Ulrich and Bassler (1931).

BRADORIA sp. cf. B. SCRUTATOR Matthew, 1899b
Figure 8.20, 8.21

cf. *Bradoria scrutator* Matthew. SIVETER AND WILLIAMS, 1997, p. 22–26, 28, pl. 1, figs. 1–14, fig. 8 (with extensive synonymy).

Material examined.—NBMG 12800 and 12805a from BHR-IV-6.9.

Description.—Probable articulated specimen with right valve exposed.

Valve highly convex, weakly acuminate in latero-ventral outline; faint transverse depression just anterior to center; dorsal margin more-or-less straight with faint indentation in middle (due to compaction?); anterior, ventral, and posterior margins strongly curved; valve with meshwork of rugose ridges arranged irregularly in the center and peripherally as concentric “striation” subparallel to margin. Length almost 4 mm, height ca. 2.8 mm. Second specimen an incomplete, large (more than 9 mm) valve of moderate convexity; margins not preserved. Strong, narrow transverse depression slightly anterior(?) to center enhanced by compaction and fractured. Valve covered with honeycomb mesh of ridges irregularly to concentrically subparallel to valve margin.

Discussion.—The shape and ornamentation are comparable to those in *Bradoria scrutator*. The topotype specimens and numerous synonymous species occur in middle Middle Cambrian sandstones (Dugald Formation) in Cape Breton Island, a unit correlated with the Fossil Brook Member (Siveter and Williams, 1997). The species has concentric striae that may be abraded to produce a punctate surface. Compared with Siveter and Williams’ (1997) illustrations, the ornament of the Beaver Harbour specimens is less strictly concentric and the subcentral fold more pronounced.

Class LINGULATA Goryansky and Popov, 1985
Order LINGULIDA Waagen, 1885
Superfamily LINGULOIDEA Menke, 1828
Genus LINGULELLA Salter, 1866

Type species.—*Lingula davisii* M’Coy, 1851, from the Upper Cambrian Festiniog Formation of North Wales.

Discussion.—Many reports list Early–Middle Cambrian *Lingulella* species, but pre-Late Cambrian *Lingulella* species have been questioned (Holmer et al., 1996, p. 41, 42). However, the internal morphology and surface texture of most pre-Late Cambrian *Lingulella* valves are undocumented, and the bases for this proposal are untested. Evidence for not assigning the upper Lower and Middle Cambrian forms described below to *Lingulella* is not clear. An absence of any eobold-like, pitted or pustulose microornament in these specimens or *L. viridis* Cobbold, 1921 (Hinz, 1987; Landing, 1988) suggests that *Lingulella* appeared with the oldest trilobites in Avalon (Landing and Westrop, 2004), and that it ranged through the remainder of the Cambrian.

LINGULELLA FERRUGINEA Salter in Salter and Hicks, 1867
Figure 6.9, 6.10

Lingulella ferruginea SALTER in Salter and Hicks, 1867, p. 340, Fig. 1; WALCOTT, 1912, p. 496–500, pl. 29, figs. 1–2f, pl. 30, fig. 1, pl. 31, fig. 3–3c, pl. 35, figs. 4–4b; COBBOLD, 1921, p. 342.

Material examined.—Thirteen brachial valves from BHR-IV (Table 1).

Discussion.—With a pseudointerarea that curves anteriorly in its middle portion, gentle radial folds on the visceral surface, and posteriorly located zone of highest curvature, the brachial valves from BHR-IV are comparable to those of *Lingulella ferruginea*. This long-ranging species (middle Middle–terminal Upper Cambrian) is common in Avalon and Baltica (Walcott, 1912).

LINGULELLA sp.
Figure 3.19, 3.20

Material examined.—Five brachial valves and six fragments from BHR-II (Table 1).

Description.—Gently convex, elongately oval brachial valves with broadly obtuse posterior margin; pseudointerarea small; umbonal muscle ridge to anterior; vascular lateralia originate at anterolateral margins of umbonal ridge and distally curve laterally (Fig. 3.19).

Discussion.—Identification of this upper Lower Cambrian form is problematical. Walcott (1912, p. 511, 512) noted that non-acuminate *Lingulella*-like valves are not found below the Upper Cambrian. Subsequent reports we are aware of have not documented such forms earlier in the Cambrian. Neither Cobbold (1921) nor Hinz (1987) illustrated similar valves from coeval strata in Avalonian England.

Order ACROTRETIDA Kuhn, 1949
 Family ACROTRETIDAE Schuchert, 1893
 Genus ACROTHYRA Matthew, 1901

Type species.—*Acrotreta proavia* Matthew, 1899b, from the lower Middle Cambrian of Cape Breton Island, Nova Scotia; subsequent designation by Walcott (1912).

Discussion.—A number of upper Lower–Middle Cambrian genera similar to *Acrothyra* have been proposed (Holmer et al., 1996). The two, likely synonymous taxa discussed below are referred to *Acrothyra*, and not to *Vandalotreta* Mergl, 1988, as a weakly developed apical process encircles the foramen and does not form a low callus anterior to the foramen.

ACROTHYRA SERA? Matthew, 1902a
 Figure 6.11–6.18

?*Acrothyra signata* mut. *sera* MATTHEW, 1902a, p. 383, 384, pl. 13, figs. 3a–3f.

?*Acrothyra sera* (MATTHEW). WALCOTT, 1912, p. 718, 719, pl. 80, figs. 4–8 (includes synonymy).

?*Acrothyra comleyensis* COBBOLD, 1921, p. 348–350, pl. 23, figs. 1–8, fig. 3; HINZ, 1987, p. 51, pl. 12, figs. 16, 19.

?*Acrothyra* cf. *sera* MATTHEW. COBBOLD, 1921, p. 350, 351, 353, pl. 23, figs. 9a–18; HINZ, 1987, p. 51, pl. 12, figs. 17, 18, 20.

?*Acrotreta ophirensis* WALCOTT. HINZ, 1987, pl. 13, figs. 1–7.

Material examined.—66 brachial valves, 27 pedicle valves, and three fragments from BHR-IV (Table 1).

Description.—Morphologically variable valves similar to *Acrothyra* sp. cf. *A. sera* (described below) from the upper Lower Cambrian. Undeformed valves transversely oval (Fig. 6.14, 6.15); structural detail on visceral surface of the proclined to rarely catacline pedicle valves limited to a subtly thickened apical process that rings the foramen.

Discussion.—Many *Acrothyra* species are based on minor morphologic differences never subjected to an evaluation of their variation between individuals and with growth, or were defined by features on exceptionally preserved valves that were poorly illustrated. Walcott (1912, pl. 80) showed wide variation in toptype pedicle valves of *A. sera* from the lower Middle Cambrian Dugald Brook Formation in Cape Breton Island. These include valves with internal structures limited to a circular to quadrate callus around the foramen to those with such complex internal structures as a pedicle callus, an apical process anterior to the foramen, and short and straight to obtusely curved vascula lateralia that surround the cardinal muscle fields. These latter specimens resemble *A. ophirensis* sensu Hinz (1987) and *A. comleyensis*, and a synonymy of all of these taxa into a long-ranging (upper Lower–middle Middle Cambrian) *A. sera* is possible. Minor differences with *A. sp. cf. A. sera* include a medial furrow on the pedicle pseudointerarea (Fig. 8.16, 8.17) and prominent dorsal cardinal muscle fields (Fig. 8.12, 8.13).

ACROTHYRA sp. cf. A. SERA Matthew, 1902a
 Figure 3.22–3.28

cf. *Acrothyra signata* mut. *sera* MATTHEW, 1902a, p. 383, 384, pl. 13, figs. 3a–3f.

cf. *Acrothyra sera* (MATTHEW). WALCOTT, 1912, p. 718, 719, pl. 80, figs. 4–8 (includes synonymy).

Acrothyra cf. *sera* MATTHEW. COBBOLD, 1921, p. 350, 351, 353, pl. 23, figs. 9a–18; HINZ, 1987, p. 51, pl. 12, figs. 17, 18, 20.

Material examined.—68 articulated specimens, 791 pedicle valves, 839 brachial valves, and 82 fragments from BHR-II (Table 1).

Description.—Small/juvenile (to 1 mm wide) specimens of biconvex species; valves transversely elliptical, width ca. 130 percent of length (Fig. 3.24–3.28), weak to well defined growth lines (Fig. 3.24, 3.26). Pedicle valve weakly to strongly convex, procline to catacline (Fig. 3.23, 3.24, 3.27); apsacline specimens may be tectonically distorted (Fig. 3.22); ventral pseudointerarea weakly–strongly differentiated, gently convex–flat (Fig. 3.22, 3.24), intertrough not observed; tiny foramen posterior to umbo at top of pseudointerarea (Fig. 3.22); internal features limited to very low apical process with circular to rectangular outline (Fig. 3.22). Brachial valves weakly convex; dorsal cardinal muscle fields small, generally indistinct (Fig. 3.25, 3.28); median ridge indistinct (Fig. 3.28) or low in posterior part of valve, merges with subtle,

broad umbonal (median) buttress (Fig. 3.25), dorsal pseudointerarea ca. one third of valve width (Fig. 3.25, 3.28).

Discussion.—Despite its abundance, the taxonomy of this tiny acrotretid is problematical as a result of tectonic deformation and weak development or absence of internal shell features. The transversely oval valves, variable inclination of the pedicle pseudointerarea, and small apical callus that surrounds the foramen suggest *Acrothyra* sp. cf. *A. sera* as described from the upper Lower Cambrian of Shropshire (Cobbold, 1921; Hinz, 1987). Topotype *A. sera* from the lower Middle Cambrian of Cape Breton Island has a median groove on the ventral pseudointerarea (Walcott, 1912, pl. 80, figs. 4–8'), which was not observed on the New Brunswick specimens. Cobbold (1921, p. 351) noted the median furrow may be indistinct near the commissure, and Hinz (1987, pl. 12, fig. 17) illustrated a specimen where it is indistinct. Obsolescence of the median groove may be characteristic of *A. sera*.

Class UNCERTAIN

Order TOMMOTIIDA Missarzhevsky, 1969 (1970),
 emend. Landing, 1984

Family LAPWORTHHELLIDAE Missarzhevsky, 1966,
 emend. Landing, 1984

Genus LAPWORTHHELLA Cobbold, 1921, emend. Landing, 1984

Type species.—*Lapworthella nigra* Cobbold, 1921 (= *Stenotheca cornu* Wiman, 1903)

LAPWORTHHELLA CORNU (Wiman, 1903) emend.
 Figure 3.1–3.13

Stenotheca cornu WIMAN, 1903, p. 49, pl. 2, fig. 6.

Lapworthella nigra COBBOLD, 1921, p. 360, pl. 24, figs. 1–6.

Lapworthella dentata MISSARZHEVSKY, 1969. MATTHEWS, 1973, p. 142–146, pl. 8, figs. 1–16, pl. 9, figs. 1–12.

Lapworthella cornu (WIMAN). BENGTSON, 1980, p. 54, 55, figs. 1–2B.

Lapworthella sp. LANDING, NOWLAN, AND FLETCHER, 1980, p. 407, pl. 1, figs. 1, 2.

Lapworthella Morphotype A HINZ, 1987, p. 86, pl. 6, figs. 1–3, 6, 7, 15, 16, pl. 7, figs. 2, 6, 8–13.

Lapworthella Morphotype B HINZ, 1987, p. 86, 87, pl. 6, figs. 10–12, pl. 7, fig. 4.

Lapworthella Morphotype C HINZ, 1987, p. 87, pl. 6, figs. 4, 5, pl. 7, figs. 1, 3, 5, 7.

Lapworthella Morphotype D HINZ, 1987, p. 87, pl. 6, figs. 9, 13, 14.

Material examined.—308 sclerites from BHR-II (Table 1).

Emended diagnosis.—*Lapworthella* species with moderately sized sclerites (generally less than 2 mm long, rarely to 3 mm); apical angle 5°–30°, rarely to 60°; straight, recurved, to slightly helicoid; with lenticular, circular, to quadrate cross sections; apically inclined transverse ridges (6–22/mm) with apically directed nodes (12–25/mm), faint interridge growth lines, almost obsolescent radial ridges, and apically directed granulose nodes on some element tips.

Description.—Sclerites with lenticular–quadrate–circular cross sections, are straight–curved, have weak to strong transverse ridges spaced 6–22/mm (Fig. 3.1, 3.6, 3.8, 3.9) and apically directed, subtle to prominent nodes; length to 2 mm or more (Fig. 3.1, 1.94 mm long); apical angles up to 60° (Fig. 3.4, 40°).

Discussion.—*Lapworthella* sclerites formed a multielement, unimembrate external sclerotome (Landing, 1984). Species-level taxonomy is based on unique features of some sclerites [e.g., granulation between major ridges in *L. filigrana* Conway Morris and Fritz, 1984; closely spaced, non-nodose transverse ridges and radial ridges in *L. ludvigseni* Landing, 1984].

A number of species with sclerites with nodose transverse ridges are named from the upper Lower–lower Middle Cambrian. Hinz (1987) proposed that most of these are synonymous, and based on sclerites from a variable sclerotome. Others (Bengtson, 1980; Landing, 1984; Landing et al., 1989) used the density of structural elements (ridge and node spacing) and sclerite size for species differentiation. Bengtson (1980) re-interpreted Matthew's (1973) report of *Lapworthella dentata* from Avalonian England. He showed that these "*L. dentata*" sclerites [10–23 nodes/mm,

minor terraces between major ridges, and large size (to ca. 2.0 mm)] are comparable to *L. cornu* sclerites from Baltica. Siberian *L. dentata* sclerites have the dense nodes (25–45/mm) and small size of its senior synonym, the Laurentian *L. schodackensis* (Lochman, 1956) (Landing, 1984; Landing et al., 1995).

Hinz (1987) named four stratigraphically overlapping, upper Lower Cambrian *Lapworthella* “morphotypes.” These morphotypes are synonymized with *L. cornu* based on a 10–25/mm spacing of their apically inclined nodes (see Hinz, 1987, pl. 6, figs. 5, 11, 13; pl. 7, fig. 2; the 60 nodes/mm in pl. 6, fig. 14, reflects a reported “×150” magnification, but comparison of pl. 6, fig. 14, with pl. 6, fig. 13 indicates a correct ×55 magnification]. In addition, they have the fine interridge lines of *L. cornu*.

Hinz (1987) reported “Morphotypes C and D” from the *Lapworthella* Limestone—the topotype horizon of *L. nigra*. Cobbold (1921) did not report nodes in *L. nigra*. However, nodes are lost by pre-burial abrasion and obscured by phosphatic overgrowths (Landing, 1984; Hinz, 1987), a likely development in the phosphatic *Lapworthella* Limestone (see Rushton, 1974, p. 97). Cobbold’s (1921) specimens were cracked out of the matrix, and this would militate against node preservation and recognition. More importantly, bulk processing by Matthews (1973) and Hinz (1987) of the *L. nigra* type horizon yielded only nodose sclerites referable to *L. cornu*.

The data support: 1) synonymy of Matthew’s (1973) “*Lapworthella dentata*,” Hinz’s (1987) Morphotypes A–D, Cobbold’s (1921) *L. nigra*, and the Beaver Harbour sclerites with *L. cornu*; 2) the distribution of *L. cornu* in cool-water successions in Baltica and across Avalon from Shropshire to New Brunswick; 3) and a range of *L. cornu* through the ca. 8 m.y. of the trilobite-bearing Lower Cambrian (Landing et al., 1998). *Lapworthella cornu* appears in Avalon in the Lower Comley Sandstone, an uppermost sub-trilobitic Lower Cambrian unit (Hinz, 1987; Landing, 1996a, fig. 7, Shropshire column). *Lapworthella cornu* sclerites have an apical angle up to 60° (Matthews, 1973, pl. 8, fig. 8), and a length to 3 mm (Cobbold, 1921). Irregularly distributed, apically inclined, granular nodes can cover sclerite tips (Hinz, 1987, pl. 6, figs. 6, 7).

Comparison.—*Lapworthella schodackensis* (=“*L. dentata*”) sclerites from the upper Lower Cambrian of Siberia and Laurentia have a denser node spacing and smaller size [to 1.6 mm long (Missarzhevsky, 1969, p. 193; Landing, 1984)]. *Lapworthella vandali* Landing et al., 1995, from the lower Middle Cambrian of West Gondwana has large (to 4 mm), elongate (apical angles 6–15°) sclerites readily distinguishable from *L. cornu*, but its node spacing (10–21.5/mm) overlaps. East Gondwanan species from the upper Lower Cambrian of South Australia have small (0.5–0.6 mm long) sclerites, with *L. fasciculata* Conway Morris and Bengtson (in Bengtson et al., 1990) having interridge fasciculae that extend onto the ridges to produce a nodose appearance. The stubby sclerites of *L. puttapisensis* Bengtson and Conway Morris (in Bengtson et al., 1990) have closely spaced nodes that form a tuberculate texture on the ridges.

Order PSEUDOCORNODONTIDA Landing, 1995
Family STRICTOCORNICULIDAE Landing, 1995
Genus STRICTOCORNICULUM Landing, 1995

Type species.—*Strictocorniculum vanallerum* Landing, 1995; type specimen *Rhombocorniculum* n. sp. Landing, 1988, from the upper Lower Cambrian (*Callavia broeggeri* Zone) Brigus Formation of eastern Massachusetts.

STRICTOCORNICULUM VANALLERUM Landing, 1995
Figure 3.14

Rhombocorniculum n. sp. LANDING, 1988, p. 687, fig. 11.6.
Strictocorniculum vanallerum LANDING, 1995, p. 487, 488, fig. 5.1–5.3.

Material examined.—Two fragments from BHR-II (Table 1).

Discussion.—The species is represented by slowly expanding,

tube-like fragments with thick walls (internal cavity ca. 50 per cent of element diameter), circular cross section, and finely rhomboid surface ornament visible through a drusy phosphatic coating. The elements are readily distinguished from those of other pseudoconodonts. Slender elements of *Rhombocorniculum cancellatum* (Cobbold, 1921) are curved and typically have a lateral sulcus (Landing et al., 1980). *Rushtonites spinosus* Hinz, 1987, has curved, thin-walled elements (see Hinz, 1987, pl. 11, figs. 16, 17). Other occurrences of *S. vanallerum* are from the *Callavia broeggeri* Zone in Avalonian Massachusetts and Nova Scotia (Landing, 1988, 1995).

Order HYOLITHELMINTHES Fisher 1962
Family HYOLITHELLIDAE Walcott, 1886
Genus HYOLITHELLUS Billings, 1872

Type species.—*Hyolithellus micans* Billings, 1872, from the upper Lower Cambrian of the Taconian allochthons of southern Québec.

HYOLITHELLUS SINUOSUS Cobbold, 1921
Figure 6.1, 6.2

not *Hyolithellus micans* BILLINGS. MATTHEW, 1899a, p. 109, 110, pl. 4, fig. 1a–1d.
?not *Hyolithellus micans* BILLINGS. GRABAU, 1900, 658, 659, pl. 32, fig. 12.
Hyolithellus micans BILLINGS. COBBOLD, 1921, p. 361, 362, pl. 24, figs. 19–21.
Hyolithellus micans var. *pallidus* COBBOLD, 1921, p. 362, pl. 24, fig. 23.
Hyolithellus micans var. *robustus* COBBOLD, 1921, p. 362, pl. 24, fig. 22.
Hyolithellus? *sinuosus* COBBOLD, 1921, p. 362, pl. 24, fig. 24.
Hyolithellus? *tortuosus* COBBOLD AND POCKOCK, 1934, p. 321, pl. 40, fig. 4.
Hyolithellus cf. *micans* BILLINGS. BRASIER, 1984, p. 236, 237, Figure 1s–1x;
HINZ, 1987, p. 69, 70, pl. 13, figs. 15–18, pl. 14, figs. 3, 4, 12, 14, 15;
LANDING, 1988, Figure 6.1, 6.7.

Material and occurrence.—59 specimens from BHR-IV (Table 1).

Description.—Gently tapering (ca. 3°), thin-walled, straight to curved phosphatic tubes, circular cross section, diameter to 5 mm; weak to strong transverse annulations closely but irregularly spaced (average ca. 0.05 mm), aperturally inclined.

Comparison.—Over ten *Hyolithellus* species have been named (Bengtson et al., 1990, p. 187) based on minor differences in simple phosphatic tubes with circular cross sections (i.e., presence/absence of transverse annulations; their average spacing, regularity/irregularity of spacing, relative height, and inclination to aperture; rate of conch expansion; presence/absence of curved conchs; maximum size). One problem has been the lack of adequate illustrations of the genotype *H. micans*. Restudy of *H. micans* from its type region in Laurentia (Landing and Bartowski, 1996; Landing et al., 2002; Skovsted, 2006) shows *H. micans* had straight to subtly bent conchs with a low rate of expansion (ca. 2°), and low, aperturally inclined, obsolescent to regularly spaced (average spacing ca. 0.1 mm) transverse annulations. These annulations were illustrated by Walcott (1886, pl. 14, figs. 2, 2a; 1890, pl. 79, figs. 1, 1a). Skovsted (2006) noted maximum conch diameters of 2 mm.

The first report of *Hyolithellus micans* in Avalon was from the sub-trilobitic Lower Cambrian of eastern Massachusetts (Shaler and Foerste, 1888). This report was based on the more rapidly expanding (ca. 4°), calcareous conchs of “*Ladatheca*” *cylindrica* (Grabau, 1900)—a conclusion shown by the lack of *H. micans* and presence of “*L.*” *cylindrica* with resampling of Shaler and Foerste’s (1888) locality (Landing, 1988, p. 685). Matthew (1899a) reported abundant *H. micans* at the top of the subtrilobitic Lower Cambrian at Smith Point, eastern Newfoundland. These specimens in the New Brunswick Museum are referable to the calcareous problematicum *Coleoloides typicalis* Walcott, 1889. Restudy of Matthew’s locality showed that the “plentiful” specimens that “stand at various angles” to the substrate (Matthew, 1899a, p. 108) are in situ *C. typicalis* conchs (Landing et al., 1988, p. 50, fig. 31).

Nearly smooth conchs reported as *Hyolithellus* cf. *micans* from

the top of the sub-trilobitic Lower Cambrian in England include strongly curved specimens (see Brasier, 1984, fig. 1u, 1v). These curved conchs are comparable to Cobbold's (1921) annulated form *H. sinuosus* from slightly older sandstones in Shropshire (*Obolella groomi* Beds) and to the seemingly identical *H. ? tortuosa* Cobbold and Pocock, 1934, from the overlying *Acrothele prima* Shale (see correlations in Landing, 1996a, fig. 7). Grabau (1900) reported *H. micans* in red limestone boulders from eastern Massachusetts. The lithology and associated faunas (Grabau, 1900, p. 610) indicate the top of the Avalonian Terreneuvian Series (i.e., Fosters Point Limestone). His difficulty in distinguishing these conchs from "*L.*" *cylindrica* and comparison with Shaler and Foerste's (1888) *H. micans* (discussed above) suggest they are referable to "*L.*" *cylindrica*.

Straight to curved tubes are present in Cobbold's (1921) *Hyolithellus micans* from the upper Lower-middle Middle Cambrian of Shropshire. Hinz's (1987) *H. cf. micans* from Cobbold's (1921) sections is a form not referable to *H. micans* as they occur with straight to curved *H. sinuosus*-like conchs with aperturally inclined, irregularly spaced ridges (ca. 0.06 mm average spacing) that are obsolescent to prominent. Similarly, *H. cf. micans* from the Branchian Series of east Massachusetts (Landing, 1988, fig. 1.1, 1.7) has straight to curved conchs with closely and irregularly spaced ridges—features not present in *H. micans*. The middle Middle Cambrian specimens from Beaver Harbour (Fig. 8.1, 8.2) have the same obsolescent to prominent, irregularly spaced ridges, with an average spacing of ca. 0.05 mm—half the 0.1 mm spacing in *H. micans* (e.g., Skovsted, 2006, Fig. 11.10–11.12). Large fragments from Beaver Harbour indicate a conch diameter of 5 mm, a measurement comparable to that reported for *H. micans robustus* from approximately coeval strata in Shropshire, and greater than the 2 mm maximum diameter in *H. micans* (Skovsted, 2006).

Discussion.—*Hyolithellus micans* characterized tropical Laurentia and Australia [i.e., *H. cf. micans* of Bengtson et al. (1990)], and a species with straight-curved conchs and irregularly, more closely spaced ridges occurred in Avalon. Cobbold (1921) reported this species as high as strata coeval with the Fossil Brook Member. The best name for this Avalonian species seems to be *H. sinuosus*. Likely synonyms are the large, Middle Cambrian *H. micans rugosus* and the upper Lower Cambrian, annulated, straight *H. micans pallidus*. The Australian *H. filiformis* Bengtson (in Bengtson et al., 1990) has straight to curved conchs, but has regularly spaced ridges and a maximum diameter (0.2 mm) much less than in *H. sinuosus*.

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APPENDIX

Wade's Lane Formation (new).—The Wade's Lane Formation (new) is a distinctive lithologic unit on the Avalon marginal platform in southwest New Brunswick. It is a volcanic-dominated succession of flows and subaerial pyroclastics with marine volcanoclastic sandstone, granule conglomerate, and limestone in its lower part. It is unconformably underlain by the Random Formation and presumably unconformably overlain by the Fossil Brook Member at its type section. The 102.7-m-thick type section (Fig. 2, BHR-I) was measured through the south limb of the syncline just west of the confluence of Buckmans Creek and Woodlands Cove in Charlotte County. Inclusive of the higher pyroclastics of BHR-III and those under the Fossil Brook Member in BHR-IV, the formation is at least 147.5 m thick.

The formation is named for Wade's Lane, which runs roughly north–south (Figure 1). A path from No. 30 Wade's Lane gives access to BHR-I and -II. "Wade's Lane Formation" is proposed for much of the stratigraphic interval referred to as the "Buckmans Creek Beds" or "Buckmans Creek Formation" (designations abandoned). Currie (1988) emphasized the volcanics along lower Buckmans Creek, and named the "Buckman (sic) Creek Beds" for all of Helmstedt's (1968) "Fossil Brook Formation" [in which he included the Chapel Island–Manuels River Formations of this report]. Johnson and McLeod (1996) and Barr et al. (2003) used "Buckmans Creek Beds" and "Buckmans Creek Formation" as a map unit for the Chapel Island–Manuels River Formation interval, even though "Buckmans Creek" was never formally defined for unequivocal use (e.g., North American Commission on Stratigraphic Nomenclature, 1983, Article 9). Rather than create a homonym by redefining "Buckmans Creek" for a volcanic-dominated unit—which would require restricting it by changing its upper and lower boundaries by excluding the Chapel Island, Random, and Manuels River Formations and Fossil Brook Member and their lithologies—it is best to propose a new name for much of the interval. As there are few locally appropriate geographic names, and "Woodlands Cove" and "Beaver Harbour" are used for stratigraphic units in New Brunswick, "Wade's Lane Formation" is selected.

The Wade's Lane Formation spans the later part of the late Early Cambrian Branchian Epoch. Middle or upper Branchian trilobites at its base suggest an age younger than 519 Ma (see Landing et al., 1998). The abrupt Wade's Lane pyroclastic–Fossil Brook marine facies contact shows that the volcanism ended before or in the middle Middle Cambrian. The presence of volcanic ashes in the Somerset Street Member of the Hanford Brook Formation in the Saint John area (Landing and Westrop, 1996) suggests the lateral equivalency of the Hanford Brook and Wade's Lane, and the Hanford Brook–Fossil Brook and presumed Wade's Lane–Fossil Brook unconformities are equated (Figure 9). With a lack of fossils in the upper Wade's Lane, samples were collected from BHR-III for U-Pb zircon geochronology. As might be expected in basaltic volcanics, no zircons were recovered.