

Small shelly fossils from the argillaceous facies of the Lower Cambrian Forteau Formation of western Newfoundland

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A diverse fauna of helcionelloid molluscs, hyoliths, and other small shelly fossils is described from limestone layers within the Forteau Formation of the Bonne Bay region in western Newfoundland. The fauna is dominated by internal moulds of various molluscs and tubular problematica, but also includes hyolith opercula, echinoderm ossicles, and other calcareous small shelly fossils preserved by phosphatisation. Originally organophosphatic shells are comparatively rare, but are represented by brachiopods, hyolithelminths, and tommotiids. The fauna is similar to other late Early Cambrian faunas from slope and outer shelf settings along the eastern margin of Laurentia and may be of middle Dyeran age. The similarity of these faunas indicates that at least by the late Early Cambrian, a distinctive and laterally continuous outer shelf fauna had evolved. The Forteau Formation also shares elements with faunas from other Early Cambrian provinces, strengthening ties between Laurentia and Australia, China, and Europe during the late Early Cambrian. Two new taxa of problematic fossil organisms are described, the conical *Clavitella curvata* gen. et sp. nov. and the wedge-shaped *Sphenopteron boomerang* gen. et sp. nov.

Key words: Helcionellidae, Hyolitha, Brachiopoda, small shelly fossils, Cambrian, Laurentia, Newfoundland.

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Introduction

In recent years, small shelly fossils from the upper Lower Cambrian of eastern Laurentia have been studied in detail from the Taconic allochthons of New York State and Quebec, and the Cambrian succession within the Caledonian region of North-East Greenland (e.g., Landing and Bartowski 1996; Landing et al. 2002; Skovsted 2004, 2006a; Malinky and Skovsted 2004; Skovsted and Holmer 2005). Lower Cambrian rocks in southern Labrador and western Newfoundland have been known to contain a rich fossil fauna since the 19th century (e.g., Billings 1861; Walcott 1886) but knowledge of this fauna is still very limited. Several studies describe the famous archaeocyath reefs of southern Labrador (James and Kobluk 1978; Kobluk and James 1979; Debrenne and James 1981; James and Klappa 1983). Problematic salterellids were described by Yochelson (1970), Peel and Berg-Madsen (1988) and Skovsted (2003), while Peel (1987) reported the helcionelloid mollusc *Yochelcionella americana* Runnegar and Pojeta, 1980. With the exception of the unpublished M.Sc. thesis of Spencer (1980), and its pub-

lished summary (Spencer 1981), no descriptions of other fossil groups have been published since the classical stratigraphical monograph by Schuchert and Dunbar (1934).

This paper describes a diverse and generally well preserved fauna of helcionelloid molluscs, hyoliths, and other small shelly fossils from the lower Forteau Formation of the Bonne Bay region in western Newfoundland (Fig. 1). In the Bonne Bay region, the Forteau Formation is dominated by shales (argillaceous facies of James and Kobluk 1978) and was deposited in an outer shelf setting lying south of the shallow water carbonate reefs of southern Labrador (James et al. 1989; Knight et al. 1995).

Institutional abbreviations.—FG, Geologisches Institut, Freiberg, Germany; MGUH, Geological Museum, Copenhagen, Denmark; NFM, Provincial Museum of Newfoundland and Labrador, St. John's, Newfoundland, Canada; NYSM, New York State Museum, Albany, New York, USA; SAMP, South Australian Museum, Adelaide, Australia; USNM, United States National Museum of Natural History, Smithsonian Institution, Washington D.C., USA.

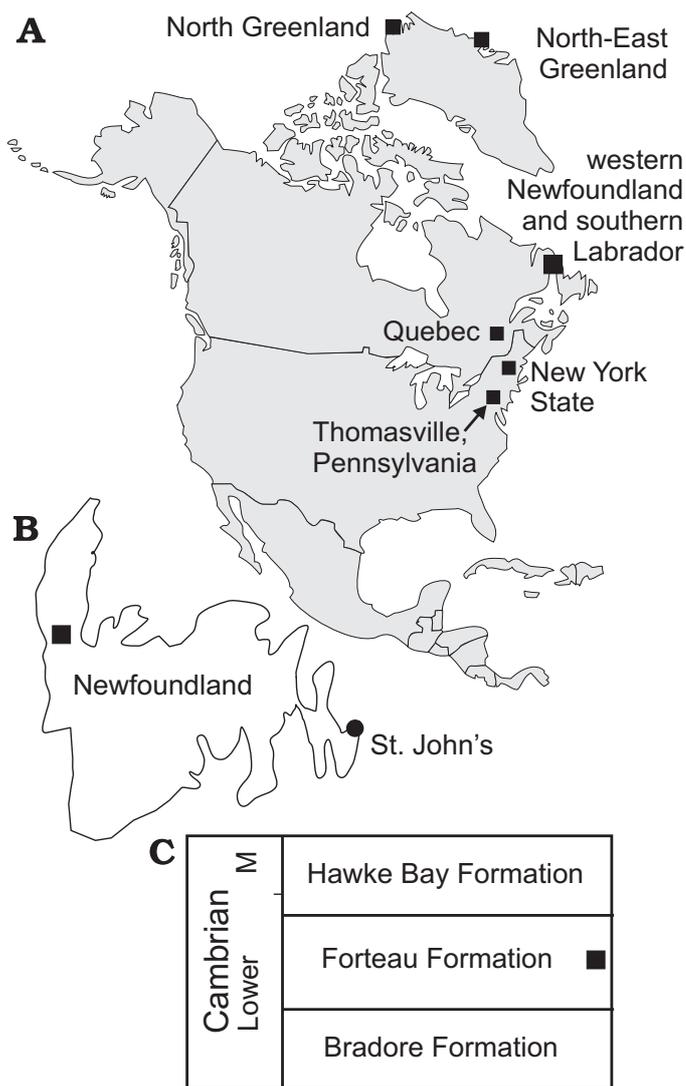


Fig. 1. Lower Cambrian localities in eastern Laurentia (A), map of Newfoundland indicating the Bonne Bay region (B) and simplified Lower Cambrian stratigraphy in western Newfoundland (C).

Geological setting

The Labrador Group (autochthonous lower Palaeozoic) of southern Labrador and western Newfoundland comprises two depositional megacycles (James and Kobluk 1978). The lower cycle is entirely Lower Cambrian while the upper cycle stretches through the Lower Cambrian to the lower Ordovician. The lower megacycle comprises basal sandstones and conglomerates (the Bradore Formation), and an upper unit of shales and limestones (the Forteau Formation) that in places includes abundant archaeocyath reefs. The Forteau Formation is overlain by the regressive Hawke Bay sandstone which forms the base of the upper megacycle.

The Forteau Formation outcrops in southern Labrador and in the Great Northern Peninsula of western Newfoundland. Two distinctive facies of the Forteau Formation can be

recognised; a shallow water carbonate facies in southern Labrador and in the northern and westernmost parts of western Newfoundland, and an argillaceous facies which outcrops east and south of the Long Range Mountains in western Newfoundland. In its argillaceous facies the Forteau Formation is up to 700 m thick and is almost entirely composed of shales and siltstones with only minor carbonate intercalations (James and Debrenne 1980). Although archaeocyath reefs are conspicuous throughout the carbonate facies of the Forteau Formation (James and Kobluk 1978), the only archaeocyaths known from the argillaceous facies belt occur in a thin basal limestone unit, the Devils Cove Member (James and Debrenne 1980). All material studied herein was derived from thin limestone layers and nodules within the shale sequence of the lower Forteau Formation in its argillaceous facies.

The Bradore and Forteau formations in southern Labrador were interpreted by Debrenne and James (1981) as a transgressive sequence representing a gradual flooding of the eastern Laurentian craton (see also Knight et al. 1995). The sediments represent a sequence of environments going from fluvial (lower Bradore Formation) via strandline (upper Bradore Formation) to shallow open shelf environments (carbonate facies of the Forteau Formation). The argillaceous facies of the Forteau Formation was presumably deposited farther away from the shore, in relatively deep open marine environments on the outer shelf (Knight et al. 1995: fig. 3.18).

Material and methods

The fossils from western Newfoundland described below were mainly derived from a limestone sample (sample JSP1982-01) collected by JSP from a road cut in the Deer Arm Member (4.6 m thick; James and Stevens 1982: 68) of the Forteau Formation, 12 km east of Rocky Harbour on Highway 73, near the head of Dear Arm, Gros Morne. This member occurs from about 110–115 m above the base of the formation. From this sample Peel (1987) described the helcionelloid mollusc *Yochelcionella americana*, Peel and Berg-Madsen (1988) illustrated internal moulds of *Salterella* cf. *S. maccullochi* and Skovsted et al. (2004) described specimens of *Triplicatella peltata* and *Triplicatella?* sp.

Additional material was derived from four samples (ICS 1421, ICS 1422, ICS 1518, and ICS 1519) collected in the same general area by Allison Robert Palmer (see Skovsted 2003). Sample ICS 1421 was collected from the basal layers of a 4 m thick limestone marker bed at about 180 m above the base of the formation (Gros Morne quadrangle, 4. 40,500 E and 54. 85,500 to 85,900 N east of Norris Point). Sample ICS 1518 was collected at the top of the same bed while ICS 1519 was collected from float material associated with the marker bed. The associated (undescribed) macrofauna of the marker bed includes species of *Wanneria*, *Bonnina*, and ptychoparioids (Allison Robert Palmer, personal communication 2003).

Sample ICS 1422 was collected from calcareous nodules at an unresolved level within a thick siltstone unit (40–110 m above the base of the formation) further north along the highway. Associated macrofossils include species of *Wanneria* and *Olenellus*? (Allison Robert Palmer, personal communication 2003).

Samples were treated with buffered 10% acetic acid. Resulting residues were sieved and the heavy mineral fraction separated using sodium polytungstate. Selected fossils were gold-coated and photographed using a Phillips Scanning Electron Microscope (SEM) at the Microscopy Unit, Evolutionary Biology Centre, Uppsala

Faunal comparisons

A late Early Cambrian (Dyeran) age for the Forteau Formation can be deduced from the presence of the trilobites *Olenellus* and *Bonnia* (Schuchert and Dunbar 1934). Two other fossil genera, the trilobite *Wanneria* and the agmatan *Salterella* have been suggested as potential index fossils for an informal medial unit of the Laurentian Early Cambrian (Fritz and Yochelson 1989; Palmer and Repina 1993). Both *Wanneria* and *Salterella* are common in the Forteau Formation, potentially indicating a mid-Dyeran age for this unit. However, the concept of *Wanneria* was extensively expanded by Lieberman (1999) and the biostratigraphical utility of this genus is presently unclear. Similarly, the stratigraphical range of *Salterella* is also unclear and, at least in North Greenland, this genus occurs in association with archaeocyath assemblages of latest Early Cambrian (late–middle Toyonian) age (Debrenne and Peel 1986; Ineson and Peel 1997; Skovsted 2006a). Nevertheless, the Hawke Bay Formation which conformably overlies the Forteau Formation in western Newfoundland is likewise Early Cambrian in age (Knight et al. 1995), and it is clear that the Forteau Formation does not represent the very latest Early Cambrian (as conventionally defined in Laurentia by the last occurrence of *Olenellus*; Palmer 1998).

The fauna described herein from the argillaceous facies of the Forteau Formation is closely comparable to other shelf and slope faunas from eastern Laurentia (Table 1). The strongest similarities are to faunas from the Bastion Formation of North-East Greenland (summarised in Skovsted 2006a) and the Browns Pond Formation of the Taconic Allochthon in New York State (Landing and Bartowski 1996). The Browns Pond Formation was interpreted as latest early to middle Dyeran (Early Cambrian) by Landing and Bartowski (1996) and a similar age was suggested for the Bastion Formation (Skovsted 2006a). Here we conclude that the Forteau Formation was probably also deposited during the middle part of the Dyeran Stage, although it is presently difficult to constrain this informal time interval. Additional faunal comparisons within the Laurentian paleocontinent are difficult to make due to a general scarcity of data on the distribution of non-trilobite taxa. No species are shared with recently de-

Table 1. Faunal comparisons. Distribution of western Newfoundland taxa within described late Early Cambrian distal shelf and slope faunas from eastern Laurentia. Based on information in: Landing and Bartowski (1996); Landing et al. (2002); Lochman (1956); Malinky and Skovsted (2004); Skovsted (2004, 2006a); Skovsted and Holmer (2005), and Skovsted et al. (2004).

Region:	Newfound-land, Forteau Formation	NE Greenland, Bastion Formation	NE Greenland, Ella Island Formation	NY State, Browns Pond Formation	Quebec "Anse Maranda Formation"
<i>Eoobolus priscus</i>	X	X		X	
<i>Eothele</i> sp.	X				
Acrotretid indet.	X		?		?
<i>Micromitra bella</i>	X		X		
<i>Obolella crassa</i>	X	X		X	
Echinoderm morph 1	X	X	X	X	
Echinoderm morph 2	X	X	X		
<i>Calodiscus lobatus</i>	X	X	X	X	
Olenellid cephalon	X	X	X	X	
Ptychoparoid cephalon	X				
Dorypygidae cephalon	X				
Spinose trilobite fragments	X				
Hexactinellid spicules	X	X		X	
<i>Mackinnonia taconica</i>	X	X		X	X
<i>Mackinnonia</i> sp.	X				
<i>Stenothea</i> sp.	X				
<i>Yochelcionella</i> cf. <i>chinensis</i>	X			X	X
<i>Yochelcionella americana</i>	X			X	
<i>Ocuranus</i> ? sp.	X	?			
<i>Planutenia flectata</i>	X				
<i>Pelagiella</i> sp.	X	?		?	?
<i>Pojetaia runnegari</i>	X	X		X	X
<i>Parkula</i> sp.	X	?			
<i>Cupithea holocyclata</i>	X	X			
Orthothecid conchs indet.	X	X	X	X	X
Operculum A	X	?			
<i>Allathea</i> sp.	X				
<i>Triplicatella peltata</i>	X	X			
<i>Cassitella baculata</i>	X	X			
<i>Chancelloria</i> sp.	X	X	X	X	X
<i>Archiasterella</i> sp.	X				
<i>Hyoilithellus</i> sp.	X	?	?	?	?
<i>Lapworthella shodakensis</i>	X	X		X	
<i>Clavitella curvata</i>	X				
<i>Sphenopteron boomerang</i>	X				
<i>Salterella</i> sp.	X	X		?	

scribed faunas from the Lower Cambrian of the Great Basin (Skovsted 2006b; Skovsted and Holmer 2006).

On a worldwide scale, Skovsted (2006a) compared the fauna of North-East Greenland with faunas of the Botoman Stage of Siberia and its equivalents, and the Forteau Formation probably represents a similar time interval. This conclusion contrasts to the younger, Toyonian age suggested by Debrenne and James (1981) based on the archaeocyath fauna. However, the fauna documented herein stems from the lower part of the Forteau Formation in its most distal facies, and exact correlation to the archaeocyath bearing strata further to the north and west is not presently possible.

The fauna of the Bastion Formation was interpreted by Skovsted (2006a) as an outer shelf fauna. The same probably applies to most fossils of the Browns Pond Formation, although this formation was deposited on the continental slope by turbidity currents (Landing and Bartowski 1996). The similarities between outer shelf faunas of North-East

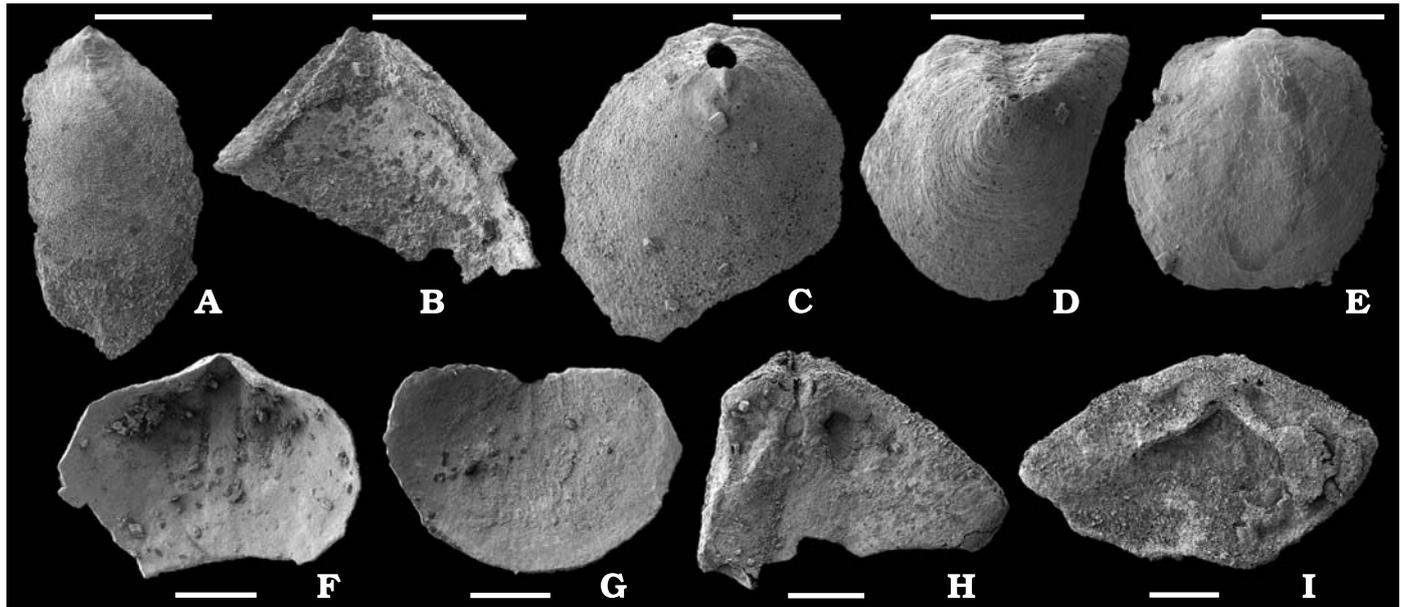


Fig. 2. Brachiopods from the Lower Cambrian, Forteau Formation (Western Newfoundland). **A, B.** *Eoobolus priscus* (Poulsen, 1932). **A.** NFM-662, exterior view of incomplete ventral valve. **B.** NFM-663, ventral valve interior with pseudointerarea. **C.** Ventral valve of *Eothele* sp., NFM-664 from ICS 1421. **D, E.** Acrotretid indet. **D.** NFM-665, ventral valve exterior. **E.** NFM-666, dorsal valve exterior. **F, G.** *Micromitra bella* (Billings, 1872). **F.** NFM-667, ventral valve interior. **G.** NFM-668, dorsal valve interior. **H, I.** *Obolella crassa* (Hall, 1847). **H.** NFM-669, fragmentary ventral valve interior. **I.** NFM-670, fragmentary dorsal valve interior. All specimens from JSP 1982-01 unless otherwise stated. Scale bars 500 μ m.

Greenland, Newfoundland and the Taconic Allochthons indicate that a distinctive fauna showing great lateral consistency had evolved in this environment by the late Early Cambrian. Unfortunately, no detailed data exist for coeval faunas in more nearshore environments. In North-East Greenland the outer shelf sediments of the Bastion Formation are overlain by shallow water carbonates of the Ella Island Formation, but this unit only contains an impoverished non-trilobite fauna yielding little information about potential depth related faunal differentiation along the Laurentian shelf (Skovsted 2006a). No shallow water sediments have been reported from the Taconic Allochthons, and Lower Cambrian non-trilobite faunas from cratonic settings in eastern Laurentia are not well known. However, the Forteau Formation includes sediments from both deep and shallow water environments, and appears to be richly fossiliferous throughout. The Forteau Formation thus offers an excellent opportunity to study and define depth related shelly faunas in eastern Laurentia.

It is noteworthy that a number of taxa represented in the late Early Cambrian of eastern Laurentia are also found on other Early Cambrian palaeocontinents, including Australia, Antarctica, North China, Mongolia, and Siberia (Skovsted 2004, 2006a). Most notably, the fauna of western Newfoundland includes taxa otherwise found in South Australia (*Eoobolus priscus* [Poulsen, 1932], *Pojetaia runnegari* Jell, 1980, *Cupithecya holocyclata* [Bengtson, 1990]) and eastern Germany (*Calodiscus lobatus* [Hall, 1847], *Pojetaia runnegari*, *Planutenia flectata* Elicki, 1994). The strongest similarities are to faunas of the early Botoman Stage of Siberia and its

equivalents. This contrasts with the generally endemic trilobite and archaeocyath faunas characteristic of this period. The wide distribution of many co-occurring fossil species representing quite different taxonomic groups (e.g., molluscs, brachiopods, hyoliths) was interpreted by Gubanov et al. (2004) and Skovsted (2004, 2006a, b) as indicative of a relative close juxtaposition of palaeocontinents in the late Early Cambrian.

Systematic palaeontology

Phylum Brachiopoda Duméril, 1806

Discussion.—Five species of brachiopods occur in the acid residues from the Forteau Formation of western Newfoundland. No detailed description of the material is given herein, but linguliforms are represented by *Eoobolus priscus* (Poulsen, 1932) (Fig. 2A, B), one unidentified eothelid (Fig. 2C) and one acrotretid species (Fig. 2D, E) as well as the pateriniid *Micromitra bella* (Billings, 1872) (Fig. 2F, G). Rhynchonelliforms are represented by *Obolella crassa* (Hall, 1847) (Fig. 2H, I). Three of the species, *E. priscus*, *M. bella*, and *O. crassa* are also found in the Taconic allochthons and in the Bastion Formation of North-East Greenland (see review in Skovsted and Holmer 2005). Eothelids and acrotretids are common in the Cambrian of Laurentia, although their taxonomy is best known from the western part of the continent (Rowell 1980; Voronova et al. 1987; Streng and Holmer 2006).

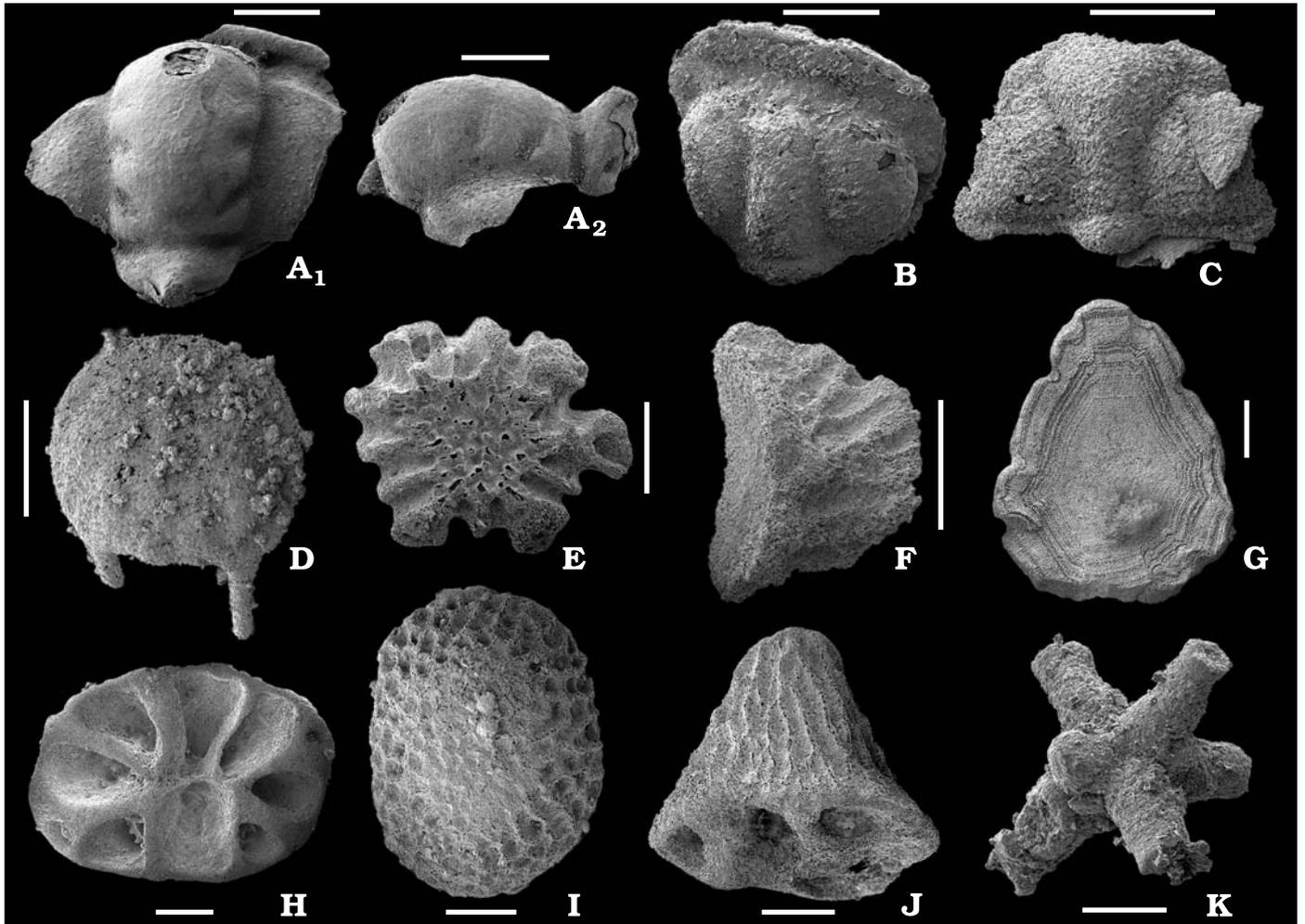


Fig. 3. Trilobites, echinoderms, and sponges from the Lower Cambrian, Forteau Formation (Western Newfoundland). A. Dorypygidae indet., internal mould of fragmentary cephalon, NFM-671 from ICS 1421; in dorsal (A₁) and left lateral (A₂) views. B. *Calodiscus lobatus* (Hall, 1847), NFM-672, dorsal view of silicified cephalon. C. Ptychoparioid indet., NFM-673 from ICS 1421, silicified cephalon. D. Olenellid indet., NFM-674 from ICS 1421, dorsal view of silicified juvenile cephalon. E–J. Phosphatised echinoderm ossicles. E. Morphotype 1, NFM-675, dorsal view. F. Morphotype 1, NFM-676, dorsal view. G. Morphotype 1, NFM-677, ventral view. H. Morphotype 2, NFM-678, ventral view. I. Morphotype 2, NFM-679, dorsal view. J. Morphotype 2, NFM-680, oblique lateral view. K. Hexactinellid spicule, NFM-681, scale bar 100 µm. All specimens from JSP 1982-01 unless otherwise stated. All scale bars except K 500 µm.

Phylum Arthropoda Siebold, 1845

Class Trilobita Walch, 1771

Discussion.—Trilobites are represented in the acid resistant residues from Newfoundland by a phosphatic mould of the cephalon of an unidentified Dorypygidae (Fig. 3A), silicified cephalons of the eodiscid *Calodiscus lobatus* (Hall, 1847) (Fig. 3B), corynexochids (Fig. 3C), and protaspid olenellids (Fig. 3D). With the exception of *C. lobatus*, no specimen can be identified to species, although a number of polymeroid trilobites have been reported from the Forteau Formation of western Newfoundland (e.g., *Wanneria logani* [Walcott, 1910], *Olenellus thompsoni* [Hall, 1859], *Bonnia parvulus* Billings, 1861, *B. columbensis* Resser, 1938, “*Conocephalites*” miser Billings, 1861, *Antagmus* sp., and other unidentified ptychoparioids; Schuchert and Dunbar [1934]; James and Kobluk [1978]; Knight and Boyce [2000]).

Morphologically diverse, flattened fossils with distinct tubercles and small spines (Fig. 7J–N) clearly represent fragmented shells of a larger animal, presumably a trilobite. Most specimens appear to be internal moulds formed between the carapace and the doublure. In particular, large curved fragments with small marginal spines may represent the cephalic margins, occasionally with the genal spine preserved (Fig. 7K). The trilobite(s) would have been covered externally with a multitude of small tubercles, preferentially along the margins of the sclerites. However, no trilobite with comparable tubercles is known from the Lower Cambrian of western Newfoundland, but the current remains are likely derived from meraspid.

Phylum Echinodermata Klein, 1734

Discussion.—Echinoderm ossicles of varying morphology

are present in all samples. The echinoderm affinity of these fossils is demonstrated by the preserved stereome ultrastructure. The composite construction of echinoderm skeletons usually precludes identification of individual taxa based only on disarticulated material but two ossicle types among the forms present in Newfoundland are sufficiently distinct to warrant individual description. Less distinct, circular, oval or irregular ossicles also occur together with the two types described below.

Morphotype 1: This type of sclerite is represented by triangular to sub-circular concavo-convex ossicles with variously indented margins (Fig. 3E–G). These sclerites are reminiscent of star-shaped sclerites of eocrinoids (compare Fig. 3E–F to pl. 1 of Ubaghs and Vizcaino 1990).

Morphotype 2: The second type of sclerite is represented by circular to oval, pyramidal ossicles with the upper (convex) surface ornamented by small depressions or undulating ridges and the lower (variously concave, convex or flat) surface with larger, irregular depressions divided by narrow ridges (Fig. 3H–J). Morphologically identical ossicles were recently described from the Bastion and Ella Island Formation of North-East Greenland (Skovsted 2006a: fig. 7.14–15) and may have potential for regional correlation.

Phylum Mollusca Cuvier, 1797

Class Helcionelloida Peel, 1991

Order Helcionellida Geyer, 1994

Family Helcionellidae Wenz, 1938

Genus *Mackinnonia* Runnegar, 1990

Mackinnonia taconica (Landing and Bartowski, 1996)

Fig. 4A.

1980 *Pollicina* sp.; Spencer 1980: 126, pl. 5: 5, 6, non pl. 5: 4, 7 (unidentified helcionelloids).

1996 *Stenotheca taconica* sp. nov.; Landing and Bartowski 1996: 753, figs. 5.5, 7–9, 10.2–3.

2001 *Aequiconus taconica* (Landing and Bartowski, 1996); Parkhaev in Gravestock et al. 2001: 138.

2002 *Stenotheca taconica* Landing and Bartowski, 1996; Landing et al. 2002: fig. 8.4.

2004 *Mackinnonia taconica* (Landing and Bartowski, 1996); Skovsted 2004: 16, figs. 3I–R, 4A–C.

Holotype: NYSM 15529. Internal mould from the uppermost Browns Pond Formation (late Early Cambrian), Claverack, New York State, USA.

Type species: *Mellopegma rosatum* Zhou and Xiao, 1984.

Material.—NFM-682 and nine additional specimens from sample JSP1982-01.

Discussion.—Straight to slightly coiled and laterally compressed helcionelloid molluscs with smooth outer shell surface combined with prominent internal rugae, are assigned to the genus *Mackinnonia* Runnegar, 1990. Most specimens of *Mackinnonia* from the Forteau Formation of Newfoundland have a sub-centrally placed apex and represent *Mackinnonia taconica* (Landing and Bartowski, 1996), also known from the Browns Pond Formation of New York State (Landing and Bartowski 1996), the “Anse Maranda Formation” of Québec (Landing et al. 2002) and the Bastion Formation of North-East Greenland (Skovsted 2004). Internal moulds of a similar morphology were reported from the Forteau Formation of Labrador as *Pollicina* sp. (Spencer 1980).

A single fragmentary internal mould (Fig. 4B) with prominent rugae has a more strongly coiled apex and a larger protoconch than typical specimens of *Mackinnonia taconica*. Large collections of *M. taconica* from Greenland show considerable variation in apical angle and expression of the internal rugae, but not in the degree of coiling or size of the protoconch (Skovsted 2004). The atypical specimen is most reminiscent of *Mackinnonia corrugata* (Runnegar, 1990) from Australia in lateral view, but the fragmentary nature of the specimen precludes specific determination.

Stratigraphic and geographic range.—Late Early Cambrian of New York State, Quebec, North-East Greenland, western Newfoundland and southern Labrador.

Genus *Stenotheca* Salter, 1872

Stenotheca? sp.

Fig. 4C.

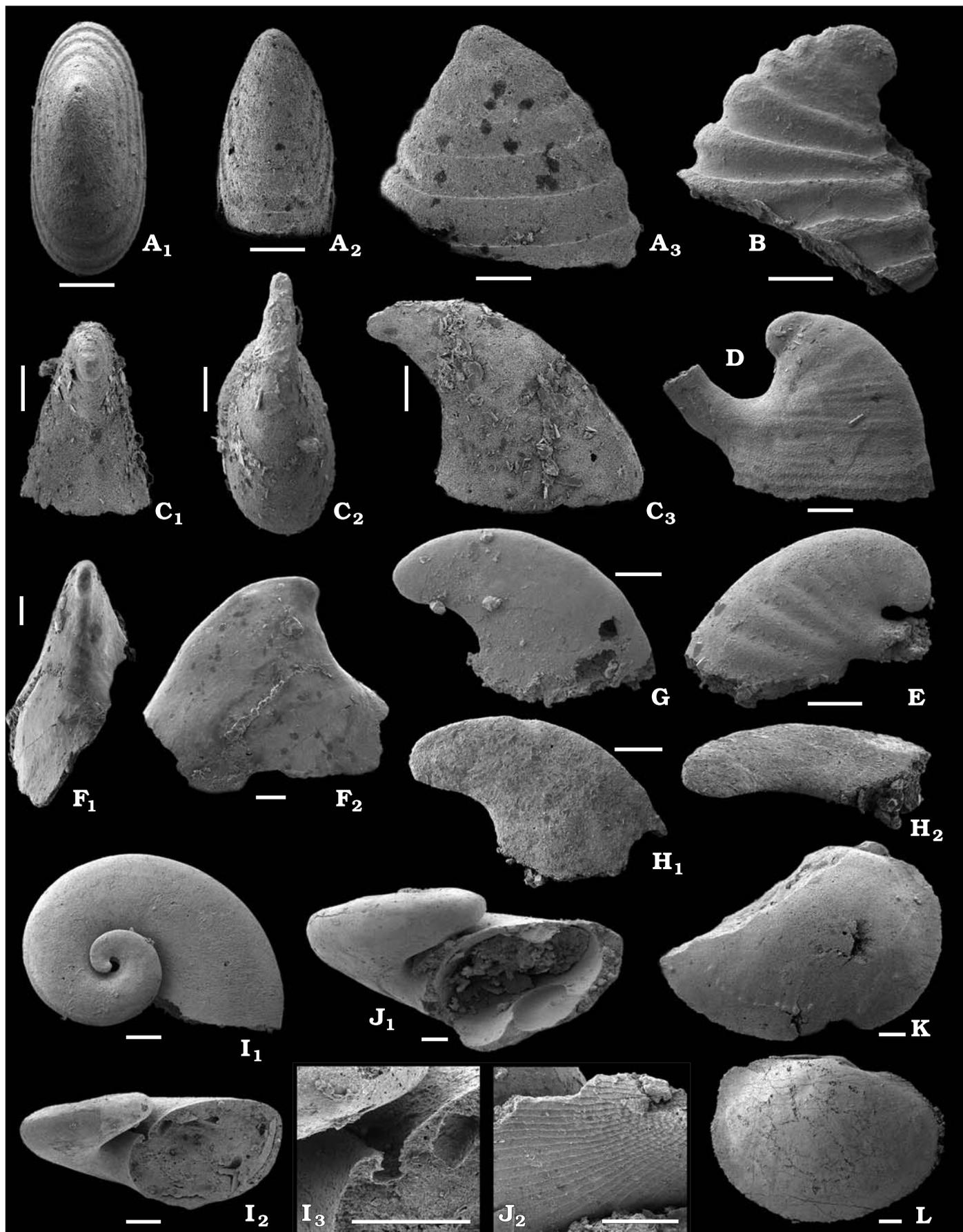
Type species: *Stenotheca cornucopia* Salter, 1872.

Material.—NFM-684 and five additional specimens from sample JSP1982-01.

Description.—Shell high, cap-shaped and laterally compressed. Coiled through about 90°. Aperture elongated oval (width about 60% of length) and lying in a single plane. The greatest elongation of the aperture is shifted about 10° anticlockwise (in dorsal view, Fig. 4C₂) from the apex. Protoconch small and cap-shaped.

Discussion.—This species is known from a few internal moulds, only one of which is reasonably complete. No evidence of the external morphology is preserved and the avail-

Fig. 4. Molluscs from the Lower Cambrian, Forteau Formation (Western Newfoundland). **A.** *Mackinnonia taconica* (Landing and Bartowski, 1996), NFM-682, internal mould; in apical view (A₁), sub-apical view (A₂), and lateral view of right side (A₃). **B.** *Mackinnonia* sp., NFM-683, lateral view of left side of internal mould. **C.** *Stenotheca* sp. internal mould, NFM-684; in apical view (C₁), dorsal view (C₂), and lateral view of right side (C₃). **D.** *Yochelcionella* cf. *chinensis* Pei, 1985, NFM-685, lateral view of right side of internal mould. **E.** *Yochelcionella americana* Runnegar and Pojeta, 1980, NFM-686, lateral view of left side of internal mould. **F.** *Ocruranus* sp., NFM-687, internal mould; in sub-apical view (F₁) and lateral view of left side (F₂). **G, H.** *Planutenia flectata* Elicki, 1994. **G.** NFM-688, lateral view of right side of internal mould. **H.** NFM-689, internal mould; in lateral view of right side (H₁) and oblique sub-apical view (H₂). **I, J.** *Pelagiella* sp. **I.** NFM-690, internal mould; in apical (I₁) and apertural (I₂) views; I₃, detail of the aperture under the spire with impression of longitudinal furrow. **J.** NFM-691, internal mould with external impression of a second specimen lodged within the aperture; in apertural view (J₁), J₂, detail of external impression of dorsum with densely set furrows. **K, L.** *Pojetaia runnegari* Jell, 1980. **K.** NFM-692, lateral view of partial internal mould with pallial muscle scars. **L.** NFM-693 from ICS 1422, lateral view of internal mould of bivalved specimen. All specimens from JSP 1982-01 unless otherwise stated. Scale bars 200 µm. →



able specimens does not preserve any small scale internal features. The slender, open coiled shell and lateral compression are reminiscent of the genus *Stenotheca*. The type species of this genus, *S. cornucopia* Salter, 1872, is not well known (Bengtson et al. 1990; Skovsted 2004), but other species referred to *Stenotheca* (see Parkhaev in Gravestock et al. 2001: 182) have extremely narrow apertures, usually with a sub-apical flexure. The specimens from Newfoundland described above are questionably referred to *Stenotheca*, although the aperture lacks sub-apical flexure and is wider than in most specimens assigned to this genus. A specimen of genus incertum et species incerta C from the Middle Cambrian of Morocco (Geyer 1986: pl. 3: 46) appears to resemble the Newfoundland material, but the available illustration precludes detailed comparison.

The slight asymmetrical coiling of the best preserved specimen may be a consequence of deformation, as indicated by occasional deformation of acrotretid brachiopods and the problematic *Salterella* sp. from the same suite of samples. Asymmetrical coiling is characteristic of some helcionelloids (e.g., *Aldanella* Vostokova, 1962, *Archaeospira* Yu, 1979, *Pelagiella* Matthew, 1895), but also occurs occasionally in otherwise planispiral species (e.g., *Oelandiella korobkovi* Vostokova, 1962; Gubanov and Peel 2000).

Genus *Yochelcionella* Runnegar and Pojeta, 1974

Yochelcionella cf. *chinensis* Pei, 1985

Fig. 4D.

Type species: Yochelcionella cyrano Runnegar and Pojeta, 1974.

Material.—NFM-685 and hundreds of additional specimens from samples ICS 1421, ICS 1518, and JSP1982-01.

Discussion.—Internal moulds of *Yochelcionella* with an erect profile in lateral view, elongated oval cross-section, apex slightly curved towards the prominent snorkel and an ornamentation of fine co-marginal ribs are reminiscent of *Yochelcionella chinensis* from the Early Cambrian Xinji Formation of Henan, North China. The specimens from western Labrador differ from the type specimen of *Y. chinensis* (Pei 1985: pl. 1) in the slightly larger protoconch, the finer and more numerous co-marginal ribs and in the shorter length of the snorkel. Two specimens from South Australia were assigned to *Y. chinensis* by Runnegar (see Bengtson et al. 1990). Similar fossils were described from New York State by Landing and Bartowski (1996) and from Quebec by Landing et al. (2002) as *Yochelcionella* sp.

Yochelcionella cf. *chinensis* differ from the co-occurring *Yochelcionella americana* in the less strongly coiled apex, the wider aperture and the fine co-marginal ribs. Although *Y. americana* may be more widely distributed in eastern Laurentia (see below), *Y. cf. chinensis* vastly outnumbers *Y. americana* in the acid residues from western Newfoundland.

Yochelcionella americana Runnegar and Pojeta, 1980

Fig. 4E.

1980 *Yochelcionella americana* sp. nov.; Runnegar and Pojeta 1980: 636, fig. 1.

1987 *Yochelcionella americana* Runnegar and Pojeta, 1980; Peel 1987: 2329, fig. 1.

1991 *Yochelcionella americana* Runnegar and Pojeta, 1980; Peel 1991: fig. 27.

Holotype: USMN 274001. Internal mould from the Lower Cambrian Vintage Dolomite, Thomasville, Pennsylvania.

Material.—NRM-686 and 50 additional specimens from sample JSP1982-01.

Discussion.—Laterally compressed internal moulds with a strongly coiled apex almost reaching the prominent snorkel and with low co-marginal ribs on the lateral sides are indistinguishable form *Yochelcionella americana* from the Lower Cambrian of Pennsylvania (Runnegar and Pojeta 1980). Specimens of *Y. americana* described by Peel (1987, 1991) were derived from sample JSP 1982-01. Parkhaev (2002) cited *Yochelcionella americana* as type species of a new genus, *Runnegarella* Parkhaev, 2002, but this is treated as a junior synonym of *Yochelcionella*.

Stratigraphic and geographic range.—Late Early Cambrian of Pennsylvania and western Newfoundland.

Genus *Ocruranus* Liu, 1979

Ocruranus? sp.

Fig. 4F.

Type species: Ocruranus filial Liu, 1979.

Material.—NFM-687 from sample JSP1982-01.

Description.—The smooth internal mould is tall and rapidly expanding, coiled through about 90°. In lateral view the supra-apical surface is convex and the sub-apical surface is concave, with both surfaces of approximately equal length. Apex of the 1.7 mm long specimen is situated posterior of mid-length and is slightly overhanging. The aperture is not preserved, but the specimen is moderately compressed laterally.

Discussion.—This single specimen resembles the problematic mollusc *Ocruranus* from the Lower Cambrian of China and Greenland. The long sub-apical surface is similar to that of *O. trulliformis* (Jiang, 1980) from China (see Qian and Bengtson 1989: fig. 69) and *O. tunuensis* Peel and Skovsted, 2005 from North-East Greenland, but the Newfoundland specimen is more compressed laterally than either of these species. The specimen also show similarities to the helcionelloid *Hispanoconus cordobaensis* Gubanov, Fernández Remolar, and Peel, 2004 from the Lower Cambrian of Spain. However, that mollusc has a teardrop-shaped cross-section and lacks an overhanging apex.

Genus *Planutenia* Elicki, 1994

Planutenia flectata Elicki, 1994

Fig. 4G, H.

1994 *Planutenia flectata* sp. nov.; Elicki 1994: 81, fig. 5-1, 12.

1994 *Planutenia inclinata* sp. nov.; Elicki 1994: 82, fig. 5-2, 13.

1996 *Planutenia flectata* Elicki, 1994; Elicki 1996: 151, fig. 2, pl. 5: 1, 2, 4.

1996 *Planutenia inclinata* Elicki, 1994; Elicki 1996: 151, fig. 3, pl. 5: 3, 5–9.

Holotype: FG 410/3. Internal mould from the Upper Ludwigsdorf Member, Görlitz, eastern Germany.

Type species: *Planutenia flectata* Elicki, 1994.

Material.—NFM-688, NFM-689, and six additional specimens from samples ICS 1518 and JSP1982-01.

Discussion.—Laterally compressed internal moulds of helicionelloid molluscs with a strongly overhanging apex and a large, hemicircular protoconch recall *Planutenia* from the upper Lower Cambrian of eastern Germany and the probably related *Stenotheca emeiensis* Yu, 1987 from North China (Feng et al. 1994). Elicki (1994, 1996) described seven specimens of two co-occurring species of *Planutenia*, *P. flectata*, and *P. inclinata*, but the differences between these forms are very slight and are likely to be artefacts of variation or preservation. Parkhaev (in Gravestock et al. 2001) synonymised *Planutenia* with *Anabarella* Vostokova, 1962, but *Planutenia* differs from the similarly compressed *Anabarella* by its lower rate of whorl expansion and the larger protoconch.

Stratigraphic and geographic range.—Lower Cambrian of eastern Germany and western Newfoundland.

Genus *Pelagiella* Matthew, 1895

Pelagiella sp.

Fig. 4I, J.

Type species: *Cyrtolithes atlantoides* Matthew, 1894.

Material.—NFM-690, NFM-691, and thousands of specimens from samples ICS 1421, ICS 1518, ICS 1519, and JSP1982-01.

Description.—Asymmetrically coiled (through about 1–2 whorls) and rapidly expanding conch with a low spire that projects only slightly above the margin of the aperture (in apertural view). Aperture elongated oval with greatest elongation offset from the axis of coiling by approximately 70°. A distinct longitudinal furrow is present on the dorsal surface of internal moulds, and a second furrow is deeply embedded on the ventral surface, just under the spire (Fig. 4I₃). Neither furrow extends all the way to the aperture. A partial external mould of a specimen that was apparently lodged in the aperture of a larger individual (Fig. 4J₁), preserves an ornamentation of fine, aperturally arched ridges on the dorsal surface (Fig. 4J₂).

Discussion.—Internal moulds of the widespread genus *Pelagiella* Matthew, 1895 are extremely numerous in the acid residues from western Newfoundland. The generalised morphology of these specimens is shared by a host of species of *Pelagiella* from the Lower and Middle Cambrian across the world (see review by Parkhaev in Gravestock et al. 2001), and without detailed information on external shell characters any specific determination is difficult. Only two species of *Pelagiella* have been described from Lower Cambrian rocks

of eastern Laurentia, *P. primaeva* (Billings, 1872) from the Taconic Allochthon of New York, Vermont and Quebec (Lochman 1956; Landing et al. 2002) and *P. subangulata* (Tate, 1892) from North-East Greenland (Skovsted 2004). The specimens from western Newfoundland appear to differ from *P. subangulata* by the slight projection of the spire above the apertural margin in larger (adult?) specimens, but the morphology of *P. primaeva* is too poorly known to allow meaningful comparison. The Newfoundland specimens are thus left in open nomenclature.

Class Bivalvia Linnaeus, 1758

Order and family uncertain

Genus *Pojetaia* Jell, 1980

Pojetaia runnegari Jell, 1980

Fig. 4K, L.

1980 *Pojetaia runnegari* sp. nov.; Jell 1980: 234, figs. 1A–F, 2A–I, 3C–K.

1996 *Fordilla troyensis* Barrande, 1881; Landing and Bartowski 1996: fig. 6.8.

2001 *Pojetaia runnegari* Jell, 1980; Parkhaev in Gravestock et al. 2001: 201, pls 49, 50. (Synonymy to date).

2002 *Fordilla troyensis* Barrande, 1881; Landing et al. 2002: fig. 8.5.

2004 *Pojetaia runnegari* Jell, 1980; Skovsted 2004: 32, fig. 8K–Q.

Type species: *Pojetaia runnegari* Jell, 1980 (by monotypy).

Material.—NFM-692, NFM-693, and about 100 additional specimens from samples ICS 1422 and JSP1982-01.

Discussion.—Numerous internal moulds of articulated bivalves occur mainly in sample ICS 1422 from western Newfoundland. The moulds frequently preserve imprints of two hinge-teeth between the umbones; imprints of numerous small pallial muscle scars are sometimes preserved (Fig. 4K).

All available specimens are referred to *Pojetaia runnegari* Jell, 1980, the most widespread of Early Cambrian bivalves (see review by Parkhaev in Gravestock et al. 2001). The Newfoundland material includes larger specimens (up to 2.8 mm long) than collections of *P. runnegari* from its type area of in South Australia (about 1.6 mm; Jell 1980; Runnegar and Bentley 1983), and the hinge-line of many specimens is also longer. However, the Newfoundland specimens fall within the range of variation documented for *P. runnegari* from other localities (Skovsted 2004). Specimens referred to *Fordilla* Barrande, 1881 from the Browns Pond Formation of New York State (Landing and Bartowski 1996) and “Anse Maranda Formation of Quebec” (Landing et al. 2002) probably represent *P. runnegari*.

Stratigraphic and geographic range.—Early Cambrian of Australia, Mongolia, North China, South China, Transbaikalia, Germany, North-East Greenland and western Newfoundland (see also Parkhaev in Gravestock et al. 2001).

Phylum uncertain

Class Hyolitha Marek, 1963

Order Hyolithida Syssoiev, 1957

Family uncertain

Genus *Parkula* Bengtson, 1990*Parkula* sp.

Fig. 5A–C.

Type species: Parkula bounites Bengtson, 1990 (by monotypy).

Material.—Conchs: NFM-694 and 73 additional specimens from samples ICS 1421, ICS 1422, ICS 1518, ICS 1519, and JSP1982-01; Opercula: NFM-695, NFM-696, and nine additional specimens from sample ICS 1421.

Description.—The conch expands rapidly, with a triangular cross-section. The operculum has a wedge-shaped, crescentic cardinal shield and a strongly convex conical shield. One pair of short cardinal processes and one pair of narrow clavicles (diverging by about 80°) are present on the internal surface.

Discussion.—Hyolithids are represented in the Forteau Formation of western Newfoundland by internal moulds as well as silicified conchs and opercula of *Parkula* sp. Two specimens are internal moulds of the complete individual, preserving impressions of both conch, operculum and helens (Fig. 5A and one unfigured specimen). The opercula are similar to those of *Parkula bounites* Bengtson, 1990 from Australia and Greenland, but the outline is more triangular in shape and the conch appears to be more rapidly expanding than conchs of *P. bounites*. Poor preservation does not allow detailed comparison of internal morphology to that of better preserved opercula from Australia (Bengtson et al. 1990) or Greenland (Malinky and Skovsted 2004).

Order Orthothecida Marek, 1966

Family Cupithecidae Duan, 1984

Genus *Cupitheca* Duan, 1984*Cupitheca holocyclata* (Bengtson, 1990)

Fig. 5D, E.

1990 *Actinotheca holocyclata* sp. nov.; Bengtson in Bengtson, Conway Morris, Cooper, Jell, and Runnegar, 1990: 204, figs. 134–136.

2001 *Cupitheca holocyclata* (Bengtson in Bengtson, Conway Morris, Cooper, Jell, and Runnegar, 1990); Demidenko in Gravestock et al. 2001: 97, pl. 9: 1a, b.

2003 *Cupitheca holocyclata* (Bengtson in Bengtson, Conway Morris, Cooper, Jell, and Runnegar, 1990); Wrona 2003: 200, fig. 11A–F, G₃.

2004 *Cupitheca holocyclata* (Bengtson in Bengtson, Conway Morris, Cooper, Jell, and Runnegar, 1990); Malinky and Skovsted 2004: 569, fig. 12A–E.

Holotype: SAMP30845, Parara Limestone, Hose Gully, Stansbury Basin, South Australia.

Type species: Paragloborilus mirus He, 1977.

Material.—NFM-697, NFM-698, and two additional specimens from sample JSP1982-01.

Discussion.—Decollate tubular fossils are common constituents of many Lower and Middle Cambrian small shelly fossil assemblages from across the world (see review in Malinky and Skovsted 2004). Most specimens illustrated in the literature appear to represent internal moulds of limited diagnostic quality, but specimens with the external shell preserved have been described from Australia (Bengtson et al. 1990), Antarctica (Wrona 2003) and Greenland (Malinky and Skovsted 2004). The material from the Forteau Formation of western Newfoundland includes specimens with preserved external shell surfaces ornamented by narrow, densely spaced and slightly undulating growth-lines comparable to the widespread species *Cupitheca holocyclata* Bengtson, 1990.

Stratigraphic and geographic range.—Lower Cambrian of South Australia, Antarctica (glacial erratics on King George Island), North-East Greenland and western Newfoundland.

Family and genus uncertain

Orthothecid conchs indet.

Fig. 5F, G.

Material.—NFM-699, NFM-700, and four additional specimens from samples ICS 1421 and JSP 1982-01.

Description.—Hyoliths with a circular cross-section are represented in the Forteau Formation by slender conchs, either straight or gently curved. No surface ornamentation is preserved, and the apex and aperture are seldom preserved. The conchs may be partitioned internally by septa (Fig 5F). An internal mould of a single dorsally curved specimen (Fig. 5G) preserves both an impression of a gently convex apical septum and an impression of the gently concave internal surface of the operculum. The conch is curved through about 70° and the operculum possesses deep impressions of cardinal processes and narrow clavicles.

Discussion.—Although the specimens described above can not be identified on the basis of the preserved characters,

Fig. 5. Hyoliths from the Lower Cambrian, Forteau Formation (Western Newfoundland). A–C. *Parkula* sp. A. Internal mould of articulated specimen, NFM-694 from ICS 1422; A₁, lateral view; A₂, view from dorsum, insertion point of left helen indicated by arrow. B. Silicified operculum, NFM-695 from ICS 1421; B₁, interior view; B₂, oblique internal/lateral view. C. Silicified operculum, NFM-696 from ICS 1421; C₁, oblique external/lateral view; C₂, exterior view. D, E. *Cupitheca holocyclata* Bengtson, 1990. D. Lateral view of phosphatised specimen, NFM-697. E. Oblique apical/lateral view of phosphatised specimen, NFM-698. F, G. Orthothecid conchs indet. F. Lateral view of partial phosphatised specimen, NFM-699. G. Oblique apertural/lateral view of internal mould of curved articulated specimen, NFM-700 from ICS 1422. H, I. Operculum A. H. Phosphatised specimen, NFM-701; H₁, internal view; H₂, internal/ventral view. I. External view of phosphatised specimen, NFM-702. J, K. *Allatheca* sp. J. Phosphatised specimen, NFM-703; J₁, interior view; J₂, oblique interior/dorsal view. K. Phosphatised specimen, NFM-704; K₁, interior view; K₂, oblique interior/ventral view. L. *Triplicatella peltata* Skovsted, Peel and Atkins, 2004. Phosphatised operculum, NFM F-453; L₁, exterior view; L₂, dorsal? view. M, N. *Cassitella baculata* Malinky and Skovsted, 2004. M. Interior view of phosphatised operculum, NFM-705. N. Phosphatised operculum, NFM-706; N₁, exterior view; N₂, oblique dorsal?/lateral view. All specimens from JSP 1982-01 unless otherwise stated. Scale bars 500 µm.



they may represent several biological species. The conchs occur together with at least four different opercula with a circular or sub-circular cross-section (see the descriptions of Operculum A, *Allatheca* sp., *Triplicatella peltata*, and *Cassitella baculata* below). All the conchs are provisionally regarded as orthothecids because of their circular cross-section, although none of the co-occurring opercula completely complies with the morphological characteristics of orthothecids as currently defined (e.g., Marek 1967). Similar cases of hyolith-like fossils with morphologies intermediate between orthothecids and hyolithids were recently noted by Skovsted et al. (2004) and Malinky and Skovsted (2004).

The operculum of the mould of the single complete individual (Fig. 5G) is comparable to Operculum A, described below, in the presence and relative position of the cardinal processes and clavicles and (at least occasionally) in the concave shape of the operculum. It differs from this form by the relatively small and thin clavicles inserted between the cardinal processes and by the apparently complete separation of cardinal processes and clavicles. The mould, however, is twice as wide as the largest specimen of Operculum A, and the differences may be related to ontogeny.

Family uncertain

Operculum A

Fig. 5H, I.

Material.—NFM-701, NFM-702, and nine additional specimens from sample JSP1982-01.

Description.—Circular to transversely oval operculum (diameter 0.8 to 1.4 mm), often with a gently concave external surface. The initial part of the operculum is displaced towards the dorsal edge. External ornamentation of faint concentric growth lines. The smooth, usually convex, internal surface has a pair of prominent cardinal processes close to the dorsal edge. These diverge slightly (by approximately 35°) and have rounded tips. Thin, blade-like clavicles diverge from the base of the cardinal processes, forming an angle of about 60°. The clavicles are fused to the cardinal processes for up to about 2/3 of their length.

Discussion.—Operculum A from the Forteau Formation of western Newfoundland is closely comparable to “Operculum A” of Malinky and Skovsted (2004) from the Bastion Formation of North-East Greenland, and may represent the same taxon. However, the conch is not known from either area, and the incomplete preservation of all specimens from both Newfoundland and Greenland precludes a more formal description of the species. Operculum A is similar to the operculum of an internal mould of a hyolith specimen described above under the heading “Orthothecid conchs indet.” (Fig. 5G), but differs from this form by the fusion of the clavicles to the bases of the cardinal processes.

The association of well developed cardinal processes and clavicles in a hyolith operculum without a strong dorso-ventral differentiation on the exterior and with a near circular shape in “Operculum A” from North-East Greenland was

considered unusual by Malinky and Skovsted (2004), who nevertheless assigned the fossil provisionally to the Hyolithida.

Family Allathecidae Missarzhevsky, 1969

Genus *Allatheca* Missarzhevsky, 1969

Type species: *Allatheca corrugata* Missarzhevsky, 1969.

Allatheca sp.

Fig. 5J, K.

Material.—NFM-703, NFM-704, and 29 additional specimens from sample JSP1982-01.

Description.—Circular to sub-rectangular operculum, 0.6 to 1.0 mm in diameter. External surface convex with concentric growth lines around a sub-central summit. Dorsal and ventral regions are not clearly differentiated. The internal surface is divided by a sharply defined furrow into a relatively narrow marginal region and a circular to sub-triangular central region bounded by a concentric ridge raised above the marginal zone. The floor of the marginal region is smooth and slope slightly outwards. The concentric ridge is differentiated into a curved dorsal edge with two weakly defined swellings, a straight ventral edge, and more strongly developed lateral edges that sometimes slightly overhang the marginal zone of the operculum.

Discussion.—The circular to sub-rectangular opercula described above resemble opercula of *Allatheca* sp. from the Tommotian Stage of Siberia (Rožanov et al. 1969: pl. 11: 4, 8; Meshkova 1974: pl. 11: 12; Dzik 1994: fig. 15) in having a thickened central region with ridges raised above the interior surface and in lacking cardinal processes. *Allatheca* is also known to occur in the Lower Cambrian of Sweden and England (Rožanov et al. 1969: 139–140) as well as eastern (Avalonian) Newfoundland (Landing 1988). The conch of *Allatheca* is a slowly expanding cone with densely set growth lines, straight or slightly curved dorso-ventrally and has a circular to sub-circular cross-section (Landing 1988; Missarzhevsky 1989).

The current specimens can only be compared in detail to specimens from Siberia due to lack of data on the internal morphology of opercula from other areas. The material from the Forteau Formation differs from the Siberian specimens in terms of its sub-rectangular shape and by the lack of radial ribs on lateral parts of the concentric ridge. The difference in age between the Siberian (Tommotian) and Newfoundland (Dyeran, Botomian-equivalent) material is also considerable. Hyolith opercula of apparently identical morphology from strata of Aftonian equivalent age in northwest China were referred to *Neogloborilus* Qian and Zhang, 1983 (Qian et al. 2001). In terms of morphology and age, the Chinese specimens are more compatible with the Newfoundland opercula. However, *Neogloborilus* is presently poorly understood and its relationship to *Allatheca* remain to be resolved. The new material from Newfoundland is here referred to the better known genus *Allatheca*.

Allatheca sp. differs from the widespread *Hyptiotheca* Bengtson, 1990 (see review in Malinky and Skovsted 2004) by the presence of cardinal processes and well defined furrows and rooflets in *Hyptiotheca*, and by the more strongly developed, overhanging edges of the central region in *Allatheca* sp. A concentric ridge raised above the internal surface is also present in the opercula of *Conotheca australiensis* Bengtson, 1990, but this species also has a pair of well defined cardinal processes and the ridge is more strongly differentiated into clavicles. Opercula of *Petrasothecha minuta* Landing and Bartowski, 1996 from the Taconic Allochthon of New York differ from *Allatheca* sp. by the dorso-lateral rather than ventro-lateral position of the concentric ridge. The small swellings on the dorsal edge of the concentric ridge in *Allatheca* sp. are situated in approximately the same position as the cardinal processes of *Hyptiotheca* and *Conotheca*, and this form could be viewed as intermediate between the orthothecid-like *Conotheca* and the hyolithid-like *Hyptiotheca*. Dzik (1994) derived all younger orthothecid hyoliths from *Allatheca*. No conch from western Newfoundland can presently be associated with *Allatheca* sp.

Family uncertain

Genus *Triplicatella* Conway Morris, 1990

Triplicatella peltata Skovsted, Peel, and Atkins, 2004

Fig. 5L.

2004 *Triplicatella peltata* sp. nov.; Skovsted et al. 2004: 1279, figs. 2P–S, 3G–O, 4A–C.

Holotype: MGUH 27078 from the Aftenstjernesø Formation of Løndal, western Peary Land, North Greenland.

Type species: *Triplicatella disdoma* Conway Morris, 1990.

Material.—NFM F-453 and one additional specimen from sample JSP1982-01.

Discussion.—Skovsted et al. (2004) referred four specimens from the Forteau Formation of western Newfoundland to the problematic hyolith genus *Triplicatella*. Two specimens were considered to be opercula of *T. peltata*, a species also recognised in samples from North and North-East Greenland. The remaining two specimens (not illustrated here) are incompletely preserved opercula and were only tentatively referable to *Triplicatella*. No additional specimens from western Newfoundland have been found.

Stratigraphic and geographic range.—Lower Cambrian of North Greenland, North-East Greenland and western Newfoundland.

Genus *Cassitella* Malinky and Skovsted, 2004

Cassitella baculata Malinky and Skovsted, 2004

Fig. 5M, N.

2004 *Cassitella baculata* sp. nov.; Malinky and Skovsted 2004: 574, fig. 15.

Holotype: MGUH 27130 from the upper Bastion Formation of Albert Heim Bjerge, Hudson Land, North-East Greenland.

Type species: *Cassitella baculata* Malinky and Skovsted, 2004.

Material.—NFM-705, NFM-706, and 12 additional specimens from sample JSP1982-01.

Discussion.—Cap-shaped, circular shells with an eccentrically placed apex and two thick, widely diverging internal ridges were described from the upper Bastion Formation of North-East Greenland as *Cassitella baculata* by Malinky and Skovsted (2004). Similar cap-shaped fossils from the Forteau Formation of western Newfoundland are referred to the same species, although most specimens are incompletely preserved.

Stratigraphic and geographic range.—Lower Cambrian of North-East Greenland and western Newfoundland.

Phylum and class uncertain

Order Chancelloriida Walcott, 1920

Family Chancelloridae Walcott, 1920

Genus *Chancelloria* Walcott, 1920

Chancelloria sp.

Fig. 6A, B.

Type species: *Chancelloria eros* Walcott, 1920.

Material.—NFM-707, NFM-708, and about 100 additional sclerites and isolated rays from samples ICS 1421, ICS 1518, ICS 1519, and JSP1982-01.

Discussion.—Small sclerites with one straight central ray and five to six slender marginal rays (5-6+1) that curve gently away from the basal facet. The basal facet has tightly set and relatively small foramina. All specimens are internal moulds; no specific assignment is possible, although the generalised morphology agrees well with sclerites of *Chancelloria* Walcott, 1920.

Genus *Archiasterella* Sduzy, 1969

Archiasterella sp.

Fig. 6C, D.

Type species: *Archiasterella pentactina* Sduzy, 1969.

Material.—NFM-709, NFM-710, and 10 additional specimens from samples ICS 1421, ICS 1519, and JSP1982-01.

Discussion.—Sclerites with four marginal rays only (4+0), three of which lie in the plane of the basal facet, while the fourth ray curves strongly away (by at least 60°) from this plane. The basal facet has tightly set and relatively large basal foramina. The recurved sagittal ray of these chancelloriid sclerites suggests affinity to *Archiasterella* Sduzy, 1969. Several species of *Archiasterella* have been proposed based only on the number of rays, and Vassiljeva and Sayutina (1993) proposed *A. tetraspina* for sclerites of *Archiasterella* with a total of four rays. Given the variability in sclerite configuration and ray number which has been demonstrated to occur in the scleritomes of chancelloriids (Qian and Bengtson 1989; Janussen et al. 2002), including *Archiasterella* (Randell et al. 2005), we consider this practice to be unreliable. All specimens of *Archiasterella* from Newfoundland are fragmentary internal moulds and are thus left in open taxonomy.

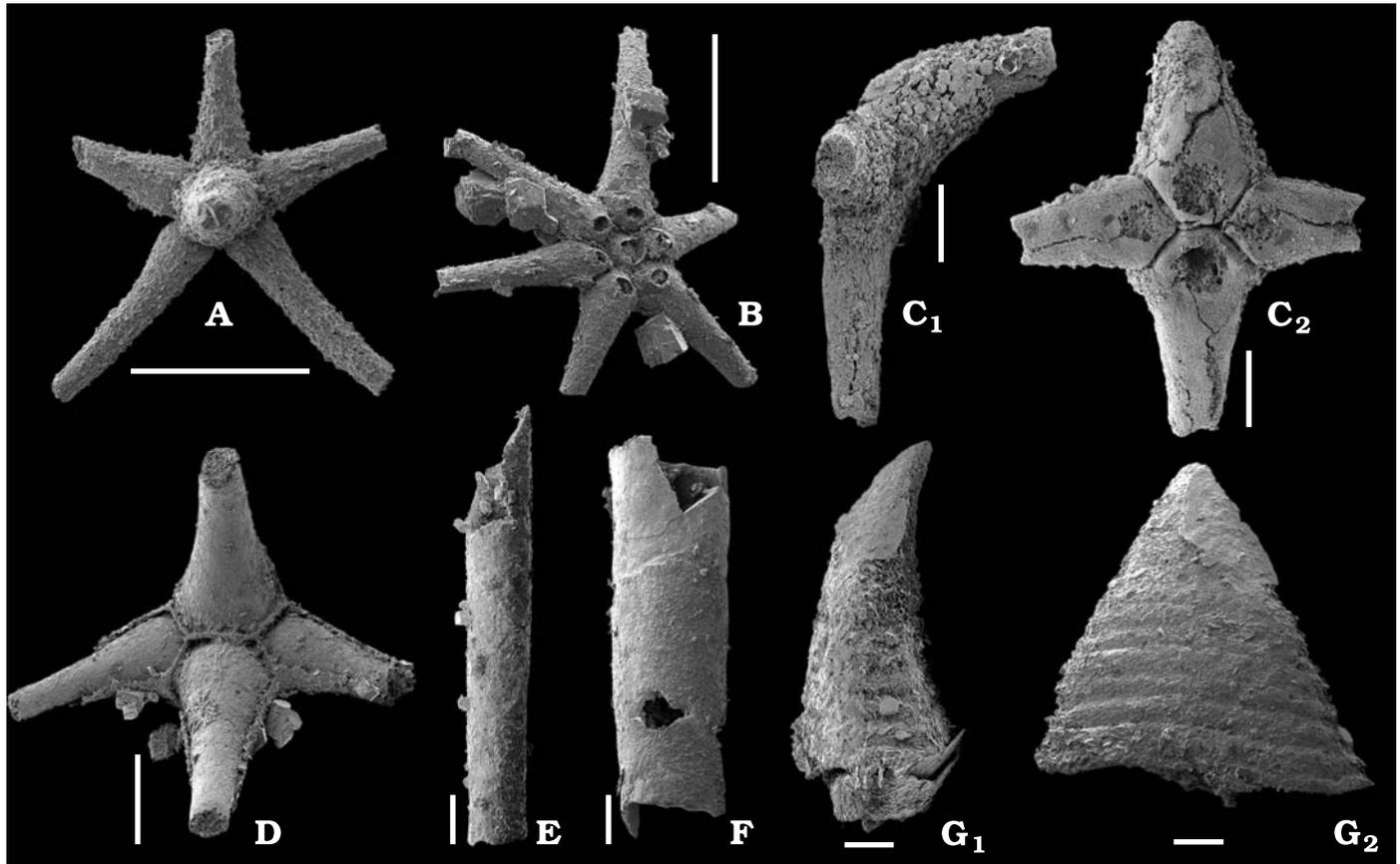


Fig. 6. Problematic taxa from the Lower Cambrian, Forteau Formation (Western Newfoundland). **A, B.** *Chancelloria* sp. **A.** Phosphatic internal mould, NFM-707; **B.** Phosphatic internal mould viewed from basal facet, NFM-708. **C, D.** *Archiasterella* sp. **C.** NFM-709 from ICS 1421, phosphatic internal mould; **C₁,** lateral view; **C₂,** viewed from basal facet. **D.** NFM-710, oblique view of phosphatic internal mould. **E, F.** *Hyolithellus* sp. **E.** NFM-711. **F.** NFM-712. **G.** *Lapworthella shodakensis* (Lochman, 1956). NFM-713, dorso-ventrally flattened sclerite; in lateral (**G₁**) and dorsal (**G₂**) views. All specimens from JSP 1982-01 unless otherwise stated. Scale bars 200 μ m.

Phylum and class uncertain

Order Hyolithelminthida Fisher, 1962

Family Hyolithellidae Walcott, 1886

Genus *Hyolithellus* Billings, 1872

Hyolithellus sp.

Fig. 6E, F.

Type species: *Hyolithes micans* Billings, 1871.

Material.—NFM-711, NFM-712, and eight additional specimens from samples ICS 1421, ICS 1519, and JSP1982-01.

Discussion.—Straight fragments of phosphatic tubular fossils with circular cross-section. The tubes expand only very slowly, but neither termination is preserved. The straight tubular morphology suggests affinity to the type species, *Hyolithellus micans* Billings, 1871, which is known to occur widely in eastern Laurentia (see review in Skovsted 2006a). The apparent lack of surface ornamentation may corroborate this view, but all specimens are covered with diagenetic minerals and the lack of ornamentation may be a consequence of preservation.

Phylum and class uncertain

Order Tommotiida Missarzhevsky, 1970

Family Lapworthellidae Missarzhevsky, 1966

Genus *Lapworthella* Cobbold, 1921

Type species: *Lapworthella nigra* Cobbold, 1921.

Lapworthella shodakensis (Lochman, 1956)

Fig. 6G.

1956 *Stenotheopsis shodakensis* sp. nov.; Lochman 1956: 1394, pl. 4: 1, 2.

1984 *Lapworthella shodakensis* (Lochman, 1956); Landing 1984: 1395, figs. 2A–O, 3D, 5A–E.

1996 *Lapworthella shodakensis* (Lochman, 1956); Landing and Bartowski 1996: fig. 9.18, 19

2006 *Lapworthella shodakensis* (Lochman, 1956); Skovsted 2006a: 1103, fig. 10.14–17.

Holotype: USNM 125749, Cambridge, New York State.

Material.—NFM-713 from sample JSP1982-01.

Discussion.—*Lapworthella shodakensis* is common in the Lower Cambrian of the Taconic Allochthon (Landing 1984), but also occurs in the Bastion Formation of North-East

Greenland. Although details of surface ornamentation are obscured by diagenetic minerals, rare lapworthellid sclerites from the Forteau Formation of Newfoundland appear identical to specimens of *L. shodakensis* from the Bastion Formation in the rapid lateral expansion and the coarsely annulated surface.

Stratigraphic and geographic range.—Late Early Cambrian of New York, North-East Greenland and western Newfoundland.

Phylum, class, order, and family uncertain

Genus *Clavitella* nov.

Derivation of the name: From Latin *claves*, nail.

Type species: *Clavitella curvata* sp. nov. (by monotypy).

Diagnosis.—Small, gently curved and tapering cone-shaped fossils with circular cross-section. Adapical termination with a circular aperture in a single plane normal to the long axis of the fossil. Apical end partly filled by secondary deposits, but an asymmetrically placed, narrow tubular cavity runs through the secondary deposits along the supra-apical margin.

Clavitella curvata sp. nov.

Fig. 7A–C.

Holotype: Phosphatic internal mould NFM-715 (Fig. 7B) from sample JSP1982-01.

Derivation of the name: For the curved shape of the fossils.

Additional material.—NFM-714, NFM-716, and six additional specimens from sample JSP1982-01.

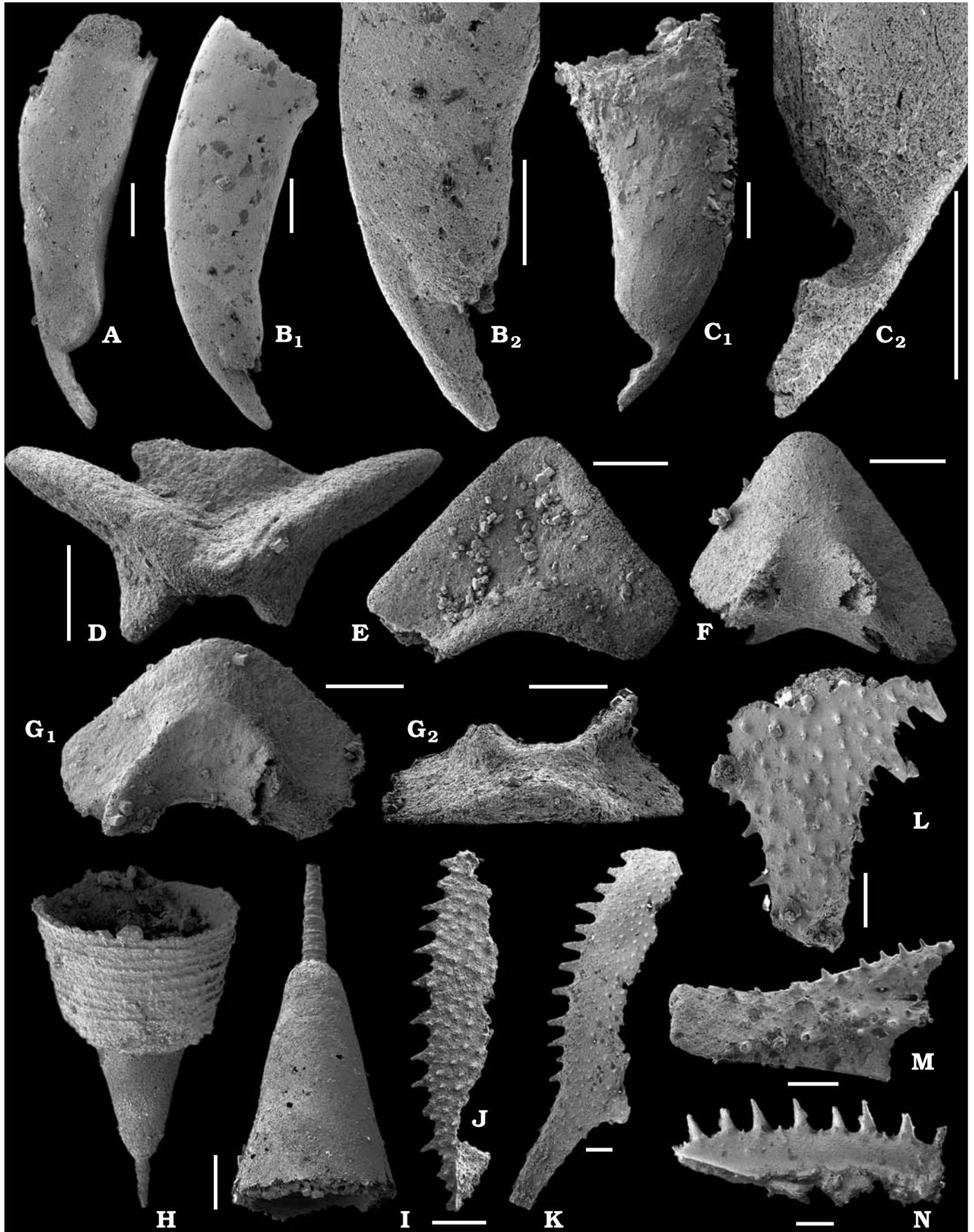
Diagnosis.—Same as for the genus.

Description.—Gently curved, cone-shaped fossils (1.0–1.6 mm long) with circular cross section (0.4–0.8 mm in diameter). For most of its length the cone tapers slowly, adapically, while its curvature frequently increases slightly towards the modified apex (Fig. 7A). The apex is reduced to a narrow spine, formed as a continuation of the supra-apical, convex, wall of the fossil (as seen in lateral view), while the sub-apical, concave side is constricted, apparently by some kind of thickening or septation within the original shell interior (Fig. 7A, B₁, C₁). The spine-like apical extension sometimes tapers to a bluntly rounded point (Fig. 7B₂), but is usually equidimensioned through much of its length (up to 0.4 mm long, about 0.1 mm in diameter; Fig. 7A). In one specimen it expands slightly at about mid-length (Fig. 7C₂). The sub-apical thickening usually produces a gently rounded (but sometimes irregular) termination to the conical part of the internal mould and is continuous with, or forms a small angle to, the sub-apical wall, resulting in a sigmoidal profile (Fig. 7A). The adapical termination lies in a single plane, representing a simple circular aperture. The surface of the internal mould is usually smooth, although faint furrows may be present close to the junction of the cone and the apical extension (Fig. 7B₂). However, several specimens are partly covered by diagenetic minerals (Fig. 7C₁).

Discussion.—These unusual fossils are all internal moulds formed by diagenetic infilling of calcium phosphate into open cavities within the original, presumably calcareous, shell. The characteristic constriction of the apex probably reflects secondary secretion of shell material in the apical part of the cone; the apical spine at the supra-apical margin probably represents a narrow, tubular cavity that penetrated or was overlain by the secondary deposits. The nature of the secondary deposits is not clear. In most specimens there is no indication of annulations or other types of ornamentation on the surface of the apical extension, and the structure appears to reflect a simple tubular continuation of the internal cavity through a solid deposit of secondary shell material. In a single specimen, the apical extension has a distinct swelling at about mid-length (Fig. 7C), perhaps indicating that the apex was divided into distinct compartments by the repeated formation of septa. However, the lack of diagenetic phosphatic infilling of the chambers between septa indicates that these space, if present, were probably completely sealed off by shell material from the tubular extension of the cavity.

The morphology of *Clavitella curvata* is at least superficially reminiscent of the internal cavity of the problematic *Salterella* Billings, 1861. *Salterella* is present in the Forteau Formation of Labrador (Billings 1861) and western Newfoundland (Peel and Berg-Madsen 1988; Skovsted 2003), and it is very common in the residue that yielded all known specimens of *Clavitella*. The shell of *Salterella* consists of a simple cone of calcium carbonate with a circular cross-section, partly filled with laminated deposits composed of alternating calcareous and agglutinated layers. The laminated deposits surround a straight central canal and a cone-shaped apertural cavity (Yochelson 1977). Moulds of the cone are usually smooth, while those of the central canal are coarsely annulated (see Fig. 7H, I). *Clavitella* differ from internal moulds of *Salterella* in that the apical extension lies along the supra-apical margin, and by the lack of regular annulation on the apical spine. However, cone-shaped fossils referred to *Salterella pulchella* (Billings, 1861) are gently curved in similar fashion to the present material (Lochman 1956). This taxon was originally described from the Forteau Formation of Labrador (Billings 1861), but has also been reported from Quebec, Vermont, and New York (Walcott, 1886; Lochman 1956). Its internal morphology is poorly known.

The apical extension of *Clavitella* is also superficially similar to the infilled siphuncle of nautiloid cephalopods. The earliest known cephalopods are the plectronoceratids that appear in the Upper Cambrian (e.g., Chen and Teichert 1983; Peel 1991). These early cephalopods, exemplified by *Plectronoceras* Ulrich and Foerste, 1933, have an eccentrically placed siphon adjacent to the sub-apical wall. *Clavitella* differs from early cephalopods by the supra-apical position of the apical spine. Furthermore, there is no strong evidence that the shell was actually divided into compartments by septa. The apical part of the shell may have been filled with massive deposits of secondary shell material. The small size and Early Cambrian age of the present fossils is also difficult



to reconcile with the size and age of the earliest undoubted cephalopods.

The simple curved conchs of the hyolith *Petrasothecca minuta* Landing and Bartowski, 1996 from the Taconic Allochthon of New York resemble the fossils described above in both size and curvature. However, the apices of the two conchs of *P. minuta* illustrated by Landing and Bartowski (1996: fig. 6.10–11) appear to be simple cones. No opercula identical to those of *P. minuta* were found in the samples from western Newfoundland. In general, *Clavitella* is similar to the conchs of certain orthothecid hyoliths with circular cross-section (e.g., *Conothecca* Missarzhevsky, 1969). The fossils also occur in western Newfoundland together with several circular or sub-circular hyolith (or hyolith-like) opercula without a known associated conch (e.g., *Allatheca* sp., *Triplicatella peltata*, *Cassitella baculata*, and *Operculum* A). The apical parts of hyolith conchs are also known to be frequently constricted by septa, but these septa are not known to over grow an extension of the main shell cavity, as seen in *Clavitella*.

Occurrence.—Lower Forteau Formation of the Bonne Bay Region, western Newfoundland.

Phylum, class, order, and family uncertain

Genus *Sphenopteron* nov.

Derivation of the name: From Greek *sphenos*, wedge and *pteron*, wing.

Type species: *Sphenopteron boomerang* sp. nov. (by monotypy).

Diagnosis.—Deltoid fossils with a rounded anterior (arbitrarily defined) corner and two trailing flanks. The dorsal (arbitrarily defined) surface is concave, while the ventral surface is convex and crested with one inclined blade-like projection on each flank.

Discussion.—The deltoid fossils described above are difficult to interpret biologically. The generally flattened shape of the (presumed) dorsal surface suggests that *Sphenopteron boomerang* may have functioned as dermal sclerites on some larger animal, with the blade-like projections on the ventral surface providing sites of attachment for soft tissues. The triangular shape with a posterior embayment is not incompatible with this interpretation as the sclerites, if arranged in alternating rows, could form an imbricating pattern. However, the lack of growth-lines or other types of ornamentation may indicate that the structures did not grow by marginal accretion, unless they were completely embedded in soft tissue (in

the manner of sponge-spicules), allowing new shell material to be deposited simultaneously on all surfaces.

The triangular shape of *Sphenopteron* is also vaguely reminiscent of some hyolith opercula, and the ventral projections could be compared to hyolith clavicles. However, *Sphenopteron* differ from typical hyolith opercula in lacking incremental growth. *Sphenopteron* also shows some resemblance to certain echinoderm ossicles, but does not preserve any trace of the stereome ultrastructure that is usually preserved in co-occurring echinoderm plates (see Fig. 3E–J).

Sphenopteron boomerang gen. et sp. nov.

Fig. 7D–G.

Holotype: Phosphatised specimen, NFM-717 (Fig. 7D), from sample JSP1982-01.

Derivation of the name: From the boomerang-shape of the fossil in dorsal view.

Diagnosis.—Same as for genus.

Additional material.—NFM-718, NFM-719, NFM-720, and six additional specimens from sample JSP1982-01.

Description.—Roughly triangular or wedge-shaped fossils, in plan view, formed by two elongated, wing-like structures or flanks. The (arbitrarily defined) dorsal surface is shallowly concave (Fig. 7E), and the ventral surface is convex (Fig. 7F, G₁). In dorsal outline bilateral symmetry is evident, and the two straight, leading edges of the wings meet at an angle of 65–90°, forming a rounded, “anterior”, termination. The “posterior” margin is slightly curved towards the anterior. Viewed from the anterior (Fig. 7D), the lateral wings are inclined at about 30° above the horizontal plane and the curved posterior margin is elevated above the rest of the dorsal surface. The ventral surfaces of the lateral wings are convex and crested with blade-like projections (Fig. 7G₁). The projections are elongated towards the posterior and overhang the posterolateral slope of the wings (Fig. 7G₂). Both dorsal and ventral surfaces lack any type of distinct ornamentation.

Discussion.—See generic discussion above.

Phylum, class, and order uncertain

Family Salterellidae Walcott, 1886

Genus *Salterella* Billings, 1861

Type species: *Salterella maccullochi* (Murchison, 1859).

Salterella sp.

Fig. 7H, I.

← Fig. 7. Problematic taxa from the Lower Cambrian, Forteau Formation (Western Newfoundland). **A–C**. *Clavitella curvata* gen. et sp. nov. **A**. NFM-714, lateral view of phosphatic internal mould. **B**. NFM-715, phosphatic internal mould (holotype); B₁, lateral view; B₂, detail of apical part. **C**. NFM-716, phosphatic internal mould with partial siliceous crust; C₁, lateral view; C₂, detail of apical part. **D–G**. *Sphenopteron boomerang* gen. et sp. nov. **D**. NFM-717 (holotype), anterior? view of phosphatised specimen. **E**. NFM-718, dorsal? view of phosphatised specimen. **F**. NFM-719, ventral? view of phosphatised specimen. **G**. NFM-720, phosphatised specimen; G₁, ventral? view, G₂, oblique anterior view (ventral side uppermost). **H, I**. *Salterella* sp. **H**. NFM-721 from ICS 1421, oblique lateral/apertural view of partial silicified shell surrounding phosphatic internal mould. **I**. NFM-722 from ICS 1421, lateral view of phosphatic internal mould (aperture downwards). **J–N**. Spinose trilobite fragments. **J**. NFM-723, dorsal? view, morphotype 1. **K**. NFM-724, dorsal? view, morphotype 1 with terminal spine. **L**. NFM-725, dorsal? view, morphotype 2. **M**. NFM-726, dorsal? view, morphotype 3. **N**. NFM-727; ventral? view, morphotype 1. All specimens from JSP 1982-01 unless otherwise stated. Scale bars D–G 500 µm, all others 200 µm.

Material.—NFM-721, NFM-722, and thousands of additional specimens from samples ICS 1421, ICS 1422, ICS 1518, ICS 1519, and JSP 1982-01.

Discussion.—Internal moulds and partly preserved conchs of *Salterella* are extremely numerous in acid residues from the Forteau Formation of western Newfoundland. Internal moulds of the apical cavity and central canal of *Salterella* were described by Peel and Berg-Madsen (1988), while Skovsted (2003) described internal moulds and associated sliced external shells. Three species of *Salterella* have been described from this area, *S. maccullochi*, *S. pulchella*, and *S. clarkii* (Yochelson 1977; Fritz and Yochelson 1989), but specimens from acid residues are not readily identified as to species (see discussion in Skovsted 2003). Occasional specimens with oval rather than circular cross-section are interpreted as tectonically deformed. *Salterella* was included in the new Phylum Agmata by Yochelson (1977; see also Yochelson and Kisselev 2003), but the status of this grouping has been questioned by other authors (e.g., Hagadorn and Waggoner 1992).

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