GEOLOGICAL SURVEY OF CANADA
BULLETIN 479

CONTRIBUTIONS TO CANADIAN PALEONTOLOGY

T.E. Bolton, B.S. Norford, S. Desbiens, H. Kurita, and D.J. McIntyre,
J.M. White, L. Marincovich, Jr., and R. Higgs

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Cover Illustration

Dorsal surface of an almost complete specimen of the Silurian trilobite, *Wallacia hendersoni* new species, from the Tegart Formation of southeastern British Columbia

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PREFACE

This volume contains five papers with studies ranging from Late Ordovician to Late Miocene. Two of the papers are taxonomic notes with biostratigraphic implications. One describes a worm-like fossil from the Collingwood Formation in Ontario, the other describes the Devonian bivalve *Prosocoelus* from several localities in northeast North America.

The other papers document new faunal collections from other parts of North America. Most of these can be correlated with fauna in other parts of the world. An extensive trilobite fauna from the Lower Silurian Tegart Formation of southern British Columbia aids precise calibration and correlation between three of the most effective biostratigraphic schemes used to zone the Silurian System. Dinoflagellates from the Upper Cretaceous Bearpaw Formation in Alberta demonstrate the applicability of these fossils for biostratigraphic determination and paleoecological analysis in a marginal marine setting. The sedimentology and paleoecology of new Late Miocene molluscs and palynomorphs from the Skonun Formation, Queen Charlotte Islands, British Columbia have allowed determination of the climate and environment at the time of deposition. These fauna are from well bores and allow precise correlation.

Studies such as these are essential for determining the stratigraphic relationships between strata in different depositional basins in North America. Because many of these basins contain oil and gas deposits, precise correlation has important economic implications.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

PRÉFACE

Le présent volume contient cinq études dont la portée s'étend de l'Ordovicien tardif au Miocène tardif. Deux articles comportent des notes taxonomiques ayant des implications biostratigraphiques. L'une décrit un fossile lombricode provenant de la Formation de Collingwood en Ontario et l'autre, le bivalve dévonien *Prosocoelus* provenant de plusieurs localités du nord-est de l'Amérique du Nord.

Les autres études documentent de nouvelles collections fauniques provenant d'ailleurs en Amérique du Nord. Elles peuvent, pour la plupart, être corrélées avec des faunes d'autres parties du monde. Une vaste faune de trilobites de la Formation de Tegart du Silurien inférieur, dans le sud de la Colombie-Britannique, facilite la datation et la corrélation de trois des schémas biostratigraphiques les plus efficaces utilisés pour zoner le Silurien. Les dinoflagellés de la Formation de Bearpaw du Crétacé supérieur en Alberta permettent de démontrer l'utilité de ces fossiles pour la détermination biostratigraphique et l'analyse paléoécologique dans un milieu margino-marin. Grâce à l'étude de la sédimentologie et de la paléoécologie de nouveaux mollusques et palynomorphes du Miocène tardif de la Formation de Skonun, dans les îles de la Reine-Charlotte (Colombie-Britannique) on a réussi à déterminer le climat et l'environnement qui existaient au moment du dépôt des sédiments. Ces faunes prélevées dans des trous de sondage permettent une corrélation précise.

De tels travaux sont essentiels pour déterminer les liens stratigraphiques qui existent entre les strates dans différents bassins sédimentaires de l'Amérique du Nord. Étant donné que nombre de ces bassins contiennent des gisements de pétrole et de gaz, la précision des corrélations a des répercussions économiques importantes.

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Sous-ministre adjoint
Commission géologique du Canada

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SPHENOTHALLUS ANGUSTIFOLIUS HALL, 1847 FROM THE LOWER UPPER ORDOVICIAN OF ONTARIO AND QUEBEC

Thomas E. Bolton[1]

Sphenothallus angustifolius *Hall, 1847 from the early Upper Ordovician of Ontario and Québec.* *In* *Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 479, p. 1-11.*

Abstract

A well preserved cluster of *Sphenothallus angustifolius* Hall, 1847 is illustrated from the Edenian–Maysvillian Collingwood Formation exposed at Bowmanville, Ontario. The genus ranges from early Ordovician to Permian. The species is now recognized in the lower Upper Ordovician black shales of the Lake St. John region, Québec, the St. Lawrence and Ottawa Lowlands, north-central New York State, the Bowmanville, Collingwood–Craigleith and eastern Manitoulin Island regions of southern Ontario, and the Upper Peninsula of Michigan. It includes a number of taxa originally assigned to *Serpulites*. Its phylogenetic affinity, cnidarian (conularid) or annelid, is still debatable. The new examples display a carbonate–apatite laminar test or 'skin', fine transverse ridges, and a primary flatness between angulate margins, but with no indication of the tubular or quadrate cross-section characteristic of worm tubes or conularids.

Résumé

Un amas bien conservé de *Sphenothallus angustifolius* Hall, 1847 est reconnu dans la Formation de Collingwood de l'Edénien-Maysvillien, qui affleure à Bowmanville (Ontario). Le genre s'étend de l'Ordovicien précoce au Permien. L'espèce est maintenant reconnue dans les shales noirs dans la partie inférieure de l'Ordovicien supérieur dans la région du lac Saint-Jean (Québec), dans les basses terres du Saint-Laurent et de la rivière des Outaouais, dans le centre nord de l'état de New York, dans les régions de Bowmanville, de Collingwood-Craigleith et de l'est de l'île Manitoulin dans le sud de l'Ontario, et dans la péninsule supérieure du Michigan. Elle inclut un nombre de taxons initialement attribués à *Serpulites*. Son affinité phylogénétique, cnidaire (conulaire) ou annélide, demeure controversée. Ces nouveaux fossiles présentent un test ou «enveloppe» laminaire de carbonate-apatite, de fines crêtes transversales et une uniformité primaire entre les marges anguleuses, mais ils ne montrent aucune indication d'une section tubulaire ou carrée caractéristique des tubes de ver ou des conulaires.

INTRODUCTION

The genus *Sphenothallus* was erected by Hall (1847, p. 261), with *S. angustifolius* Hall from the 'Utica shale', Canajoharie region of New York as the type species. He considered it to be a marine plant describing it as follows: "*Character*. Plant consisting of a stem, with diverging wedge-form leaves, or of detached leaves having this form. Leaves apparently succulent or thickened, and sometimes subcoriaceous" (ibid.). It was still placed within the Plant Kingdom by Andrews (1970).

Subsequently, Ruedemann (1898, Pl. 4, fig. 10) re-examined the type specimen, and described additional forms as *Conularia* cf. *gracilis* Hall (ibid. Pl. 2, fig. 7). Of considerable interest was the presence of 'young individuals' attached to the older 'leaves' (ibid. p. 705) on specimens of *S. angustifolius* similar to the 'supposed young' of *C. gracilis* (ibid., Pl. 1, figs. 1, 2). These young '*Conularia gracilis*' should be assigned to *Tubelloides*, according to Sinclair (1952, p. 144). The genus *Tubelloides* was introduced by Howell (1949, p. 4) for Paleozoic marine worm tubes described as 'flexuous, chitinous, smooth, with

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longitudinal marginal welt on each side and basal disc' (Howell, 1962, p. W165) that were formerly included in *Serpulites*. After further studies, Ruedemann (1916, p. 83–89) advocated *Sphenothallus* as a junior synonym of *Serpulites*. The present study shows that *Sphenothallus* is a valid genus of Late Ordovician age and that *Tubelloides* may be a junior synonym — *Serpulites* is restricted to Mesozoic worm tubes.

The genus *Sphenothallus*

The suggested phylogenetic affinities of *Sphenothallus* have included the following: hydrozoan or scyphozoan cnidarian (Moore and Harrington, 1956, p. F65, figs. 28.1, 7; *non* fig. 52.1), with a close relationship to conularids (van Iten et al., 1992), and an annelid or other 'worm' (Mason and Yochelson, 1985; Feldman et al., 1986). Although *Sphenothallus* was still regarded as a chitinophosphatic tube-dwelling organism (Fauchald et al., 1986), the absence of segmentation in enclosed soft parts of a Lower Devonian *Sphenothallus* ruled out an annelid affinity according to Fauchald and Yochelson (1990, p. 22). For the most recent review of *Sphenothallus* based on Upper Mississippian apatitic forms, refer to van Iten et al. (1992).

The genus *Sphenothallus* is now recognized in Paleozoic rocks ranging in age from Early Ordovician to Permian. Most of the recently studied material has been from middle to upper Paleozoic strata. The purpose of this note is to confirm the presence of the taxon in lower Upper Ordovician (Edenian-Maysvillian) black shales of south-central Ontario and Québec.

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X-ray Powder Diffraction Analysis performed by A.C. Roberts at the Mineralogy Laboratory, and photography by R.J. Kelley, both with the Geological Survey of Canada in Ottawa, are much appreciated. The Bowmanville specimen was collected and kindly donated to the Survey by M. Duggan, an amateur collector from Scarborough, Ontario, and the Manitoulin Island specimens by S. Desbiens, Geological Survey of Canada, Ottawa and K. Armstrong, Ontario Geological Survey, Sudbury. J.B. Waddington, Royal Ontario Museum, Toronto, and Y. Globensky, Ministère de l'Énergie et des Ressources du Québec, Montréal, lent specimens that aided in the completion of this study. The manuscript was reviewed by E.L. Yochelson (National Museum of Natural History, Washington) and A.D. McCracken (Geological Survey of Canada, Ottawa).

SYSTEMATIC PALEONTOLOGY

The GSC type material is catalogued in the National Type Collection of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Genus *Sphenothallus* Hall, 1847

Type species. *Sphenothallus angustifolius* Hall, 1847.

Sphenothallus angustifolius Hall, 1847

Plate 1.1, figures 1–7; Plate 1.2, figures 1–8;
Plate 1.3, figures 1, 2

Sphenothallus angustifolius Hall, 1847, p. 261, Pl. 68, fig. 1.
Serpulites dissolutus Billings, 1862, p. 56.
Sphenothallus angustifolius Hall. Ruedemann, 1898, p. 705, Pl. 2, fig. 7; Pl. 4, fig. 10.
Serpulites angustifolius (Hall). Ruedemann, 1916, p. 87.
Serpulites serratus Parks, 1928, p. 70, Pl. 1, figs. 29,30; textfig. 19.
Serpulites isolatus Parks, 1928, p. 71, Pl. 1, fig. 31; textfig. 20.
Sphenothallus angustifolius (Hall). Globensky, 1987, Pl. 14, fig. D.

Many randomly oriented specimens of varying length and width (hypotype GSC 108060; Pl. 1, figs. 1–3) on a surface of black calcareous shale. Skeleton thin, black and shiny, straight to slightly curved, ranging from 30 to 70 mm in length, tapered, gradually expanding to a width of 3 to 6 mm at the open (apical) end, edges distinct, normally angulate, raised above the intervening flat surfaces, which are 0.16 to 0.64 mm in width. Closely spaced, round transverse ridges are common (Pl. 1, fig. 2). Specimens may have been multilayered, as some surfaces display very fine irregular, longitudinal striae at different levels, which appear to represent the weathered 'cut-ends' of thin, irregular laminae, rather than the result of 'shrivelling' or 'postmortem wrinkling or folding' (a taphonomic feature).

No holdfast or 'adhesion disks' were observed at the ends of any of the Bowmanville specimens. Some specimens have at one end a long, fine, hair-like extension (single welt of Parks, 1928, p. 71), and in one area three individual extensions pass under the ragged edge of a *Rafinesquina* brachiopod, suggesting attachment.

A single gently curved specimen of *S. angustifolius* Hall from the Bomanville quarry (hypotype ROM 49961), over 80 mm long, gradually tapers from an adapical diameter of 0.24 mm to 7 mm at the apex. Its black 'skin' displays very close fine transverse striae, 26 to 30 in a length of 2 mm, that extend to the very edge over the bordering rods, coarse transverse ridges preserved just below surface, and locally a few coarse longitudinal lines (Pl. 1.3, fig. 1).

Excellent examples of *S. angustifolius* Hall were collected recently from the basal metre of the Collingwood Formation exposed at O'Meara Point, Sheguiandah, Manitoulin Island, Ontario. Amongst many narrow long specimens, one unique cluster of short forms (hypotype GSC 108787) with a maximum apical diameter of 1 mm displays both the coarse transverse ridges and the very fine striae, but in these specimens the striae are chevron-shaped over the border rods (Pl. 1.3, fig. 2).

A second cluster (hypotype GSC 109906) appears to consist mainly of narrow triangulate border rods. These single hollow rods, some branching, could be interpreted as being formed by tube-dwelling organisms. However, these structures more likely are the result of weathering of twisted, complete *Sphenothallus* sp., because in some areas pairs of border rods with remnants of 'skin' are preserved producing typical *Sphenothallus* outlines (Pl. 1.3, fig. 3). Caley (1936, p. 31) recorded the Vermes *Serpulites isolatus* and *S. serratus* from about 10 feet (3 m) above the base, near the top of the Collingwood Formation. The specimens were exposed at a creek connecting Bass Lake with Sheguiandah Bay and are probably the species described here.

Discussion. All specimens essentially are single planes. No form with circular, elliptical, triangular or quadrangular transverse section is evident to suggest flattening through compression of a tube. A sample of black film or 'skin' derived from the most complete specimen located in the extreme right hand corner of Pl. 1.1, fig. 1 was composed of carbonate-apatite [GSC Mineralogy Laboratory Report M92-55(1)]. According to van Iten et al. (1992, p. 137), this composition strongly supports a conularid affinity. They (ibid., p. 136) have reported *Sphenothallus* with transverse ridges from the Collingwood Shale of the Upper Peninsula of Michigan that are probably similar to those observed on the new forms herein described from the Collingwood Formation (or Collingwood Member, Lindsay Formation) at St. Marys Cement Company Quarry, lots 12-17, Broken Front Conc., Darlington Tp., Bowmanville, Ontario (Hewitt and Vos, 1972, p. 42; Derry, Michener Booth and Wahl and Ontario Geological Survey, 1989, vol. III, p. 5).

Sphenothallus angustifolius (Hall) and *S. splendens* (Hall) were recorded as Cnidaria, Conulata, by Di Vergilio (1979, p. 124) from the Utica Group, Lotbinière Formation in the northern region of the Montréal Basin. Recently, *S. angustifolius* (Hall) was illustrated by Globensky (1987, Pl. 14, fig. D; herein Pl. 2, fig. 6) from the Utica Shale [Edenian] on the Rivière Jacques-Cartier at Pont Rouge, Québec, and listed (ibid., p. 22) from the Lotbinière Formation, Sainte-Rosalie Group on the south shore of the St. Lawrence River between Pointe-au-Platon and Lotbinière village, Québec. The two clusters from Pont Rouge are characterized by strongly angulate ridged edges that preserve closely spaced adapically directed chevrons. Apical widths vary from 2.5 mm in a length of 19.5 mm to 3.4 mm in 30 mm to a maximum of 4.8 mm.

Two well preserved assemblages of *Sphenothallus angustifolius* Hall were identified during this study (hypotypes GSC 108061, 108062), in which the ridged edges are formed of sharp rods crossed by fine chevrons that are directed adapically. The specimens closely resemble those from Pont Rouge, Québec. The maximum apical width ranges from 3 to 4 mm and the length from 22 to 28 mm. The first 2 to 3 mm from the point of attachment appears to be solid, from which the bounding rods branch (Pl. 1.2, fig. 5). A single branch development of one rod is preserved in hypotype GSC 108061 (Pl. 1.2, fig. 8). In this same assemblage, some skeletons appear to be attached to a *Kionoceras* orthocone nautiloid shell (Pl. 1.2, fig. 1).

The two specimens, labelled 'Lake St. John' and presumed to have been collected by J. Richardson, are assumed to have been derived from the Maysvillian Pointe-Bleue Shales recently established by Desbiens and Lespérance (1989, p. 1189).

A number of *Serpulites* species have previously been erected, distinguished mainly on their differences in width. These species are herein considered to be synonymous with *S. angustifolius* Hall and are as follows:

1. *Serpulites dissolutus* Billings, 1862 (Pl. 1.1, figs. 6, 7).

   Skeletons thin, black and shiny, ranging in length from 56 mm (syntype GSC 1758) to 67 mm (syntype GSC 1759). Syntype GSC 1759 (Pl. 1.1, fig. 7) expands in width from 0.08 to 3.12 mm, tapering to a point that is circular rather than quadrate in cross-section; edges are defined by narrow, rounded mounds or troughs (welts), depending upon the degree of weathering, that range in width from 0.16 mm at a total width of 2.88 mm to 0.68 mm at 2.20 mm total width; surface has fine, closely spaced transverse ridges.

The wider syntype GSC 1758 (Pl. 1.1, fig. 6) gradually expands from 2.72 mm to a maximum of 5.84 mm; bounded by troughs ranging in width from 0.44 mm to 0.68 mm at a total width of 5.60 mm; outer layer or 'skin' displays fine longitudinal striae-like structures produced by multiple fracturing of the layer itself. Examples of both types of surface are preserved on the new Bowmanville forms, the narrowest of which resembles syntype GSC 1759. The types were collected from Trenton rocks by E. Billings from 3 miles (4.8 km) above Lachine, Montréal (GSC 1758), and by J. Richardson, 1852, from Lac Ouareau River (GSC 1759), Québec.

A specimen in the Royal Ontario Museum Invertebrate Palaeontology collections (ROM 98T, 23430) labelled *Serpulites dissolutus* is 45 mm long with a maximum apical width of 2.5 mm and identical to the new Bomanville forms. It was collected from the 'Trenton Group', Middle Ordovician, corner of Wrigley(?) at 'head' of Lebreton Street in Ottawa.

2. *Serpulites serratus* Parks, 1928 (Pl. 1.1, figs. 4, 5; Pl. 1.2, figs. 2–4) and *Serpulites isolatus*, Parks 1928 (Pl. 1.2, fig. 7).

Parks (1928) erected three species of *Serpulites*, two from the Upper Collingwood Formation (Maysvillian upper *Geniculograptus pygmaeus* Zone; Bergstrom and Mitchell, 1992, p. 76) of Craigleith, Ontario, and one, *S. fritzi*, from the younger Dundas Formation at Workman's Creek, Ontario. The two Craigleith specimens were differentiated on the basis of their different widths and ornamentation. The narrower *S. serratus* (syntype ROM 281UB, 24958; Pl. 1.1, figs. 4, 5) attains a length of 29 mm with an apical width of 3.0 mm. The first 7 to 8 mm of an individual consists of a 0.08 to 0.24 mm wide, single hair-like triangulate rod that subsequently divides into two rods with fine serrations common on the inside of the angular borders. The flat interarea bears fine, irregular, longitudinal striations. Similar structures are present in *Serpulites dissolutus* Billings (syntype GSC 1758), where the serrations are formed as spaces between dipping, cut laminae. The wider *S. isolatus* Parks (syntype ROM 283U, 24960; Pl. 1.2, fig. 7) possesses delicate transverse ridges. Depending on the level of weathering, specimens with both these structures preserved can be identified in the new assemblage from Bowmanville.

Parks (1928, p. 71) noted that, "In some cases, young forms seem to spring from older ones, but I am unable to state with certainty that this manner of growth is established". This feature is illustrated in Plate 1.1, figure 4. It is similar to that illustrated by Ruedemann (1898, Pl. 1, fig. 2). These 'young' forms appear to be anchored to the angulate walls rather than actually budding.

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PLATE 1.1

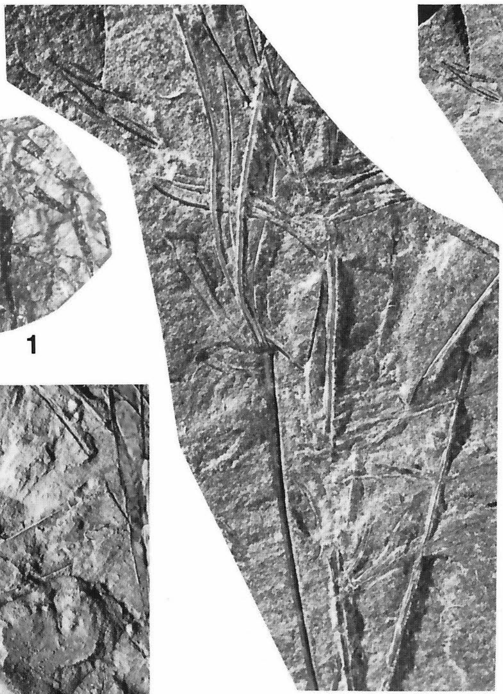
Figures 1–7. *Sphenothallus angustifolius* Hall, 1847

1–3. 1. Slab with many randomly oriented specimens, associated with trilobite pygidia *Pseudogygites latimarginatus* (Hall), graptolites and brachiopods, x1/3 (uncoated); 2. central area, showing closely spaced transverse ridges and suggested anchorage to a *Rafinesquina* brachiopod, x1 (coated); 3. uncoated slab, illustrating the uncompressed nature of overlying specimens, hypotype GSC 108060, Collingwood Formation, Bowmanville, Ontario, x0.85.

4, 5. Syntype of *Serpulites serratus* Parks, 1928 (ROM 281UB, 24958) showing the upper portion of the two specimens with anchored 'young' forms, x4, and the complete assemblage, x2, Collingwood Formation, Craigleith, Ontario.

6, 7. Syntypes of *Serpulites dissolutus* Billings 1862 showing fine longitudinal striae-like structures (syntype GSC 1758) and transverse ridges (syntype GSC 1759), x2, 'Trenton' rocks, 3 miles (4.8 km) above Lachine, Montréal, and Lac Ouareau River, Québec.

1



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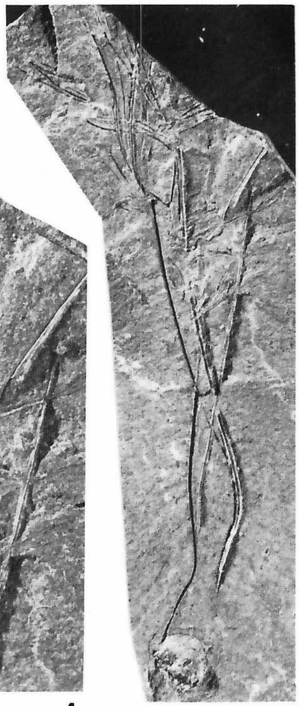

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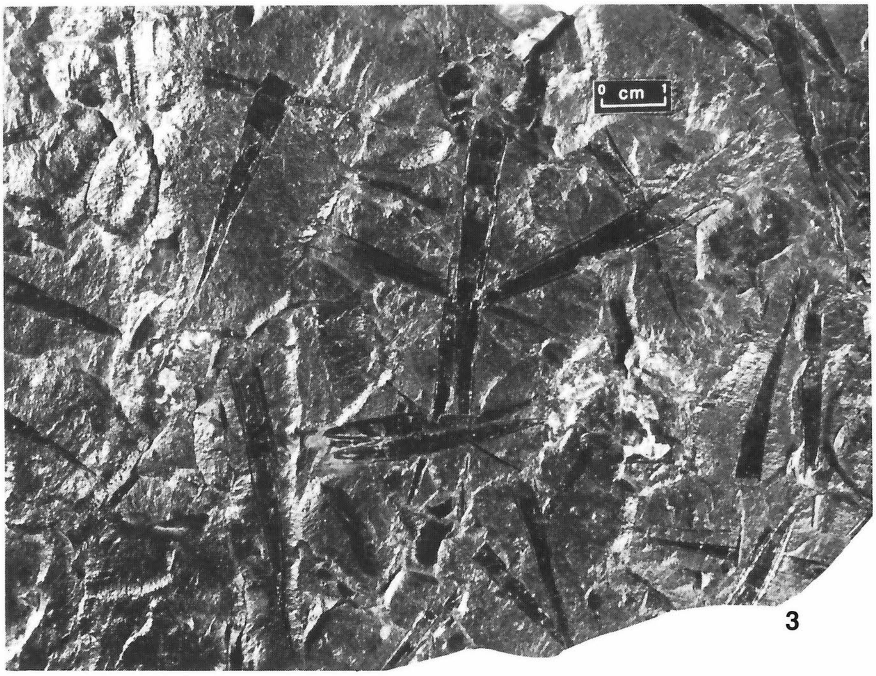

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PLATE 1.2

Figures 1–8. *Sphenothallus angustifolius* Hall, 1847

1, 8. Colony anchored to a *Kionoceras* sp. shell, x1, and upper central area illustrating well developed chevron structures on the angulate edges, x7, hypotype GSC 108061, Pointe-Bleue Shales, Lake St. John region, Québec.

2–4. Syntypes of *Serpulites serratus* Parks, 1928, ROM 281UE, x4, ROM 281UA, x2 (coated), with possible anchorage to a lingulid brachiopod, and ROM 281UD, x2, Collingwood Formation, Craigleith, Ontario.

5. Weathered assemblage illustrating the coarse ribbed edges, x2, hypotype GSC 108062, same locality as figure 1.

6. Colony figured by Globensky (1987), x2, Utica Shale, Pont Rouge, Québec.

7. Holotype of *Serpulites isolatus* Parks, 1928 showing locally fine transverse ridges, x2 (coated), ROM 283U, 24960; same locality as figures 2–4.


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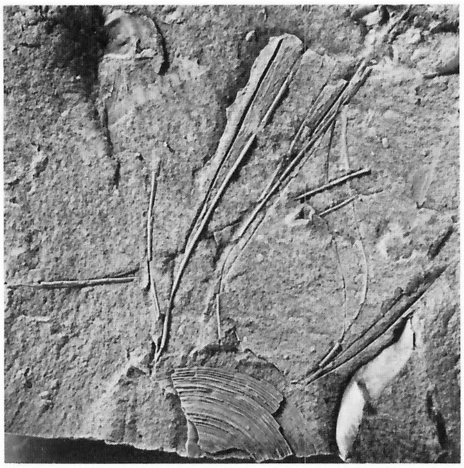
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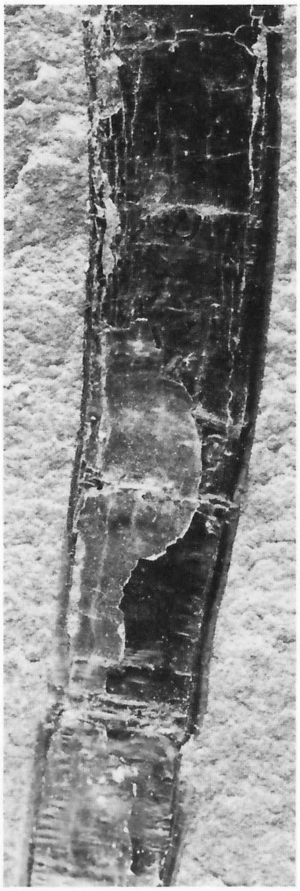
PLATE 1.3

Figures 1–2. *Sphenothallus angustifolius* Hall, 1847

1. Part of a single 80 mm long specimen in which very closely spaced, fine transverse striae are preserved, x4, hypotype ROM 49961, Collingwood Formation, Bowmanville, Ontario.
2. Cluster of small forms on which both fine striae and transverse ridges are well preserved, x4, hypotype GSC 108787, Collingwood Formation, Sheguiandah, Manitoulin Island, Ontario.

Figure 3. *Sphenothallus* sp. in which an abundance of border rods are preserved, x4, hypotype GSC 109906, same locality as figure 2.



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BIOSTRATIGRAPHY AND TRILOBITE FAUNA OF THE LOWER SILURIAN TEGART FORMATION, SOUTHEASTERN BRITISH COLUMBIA

B.S. Norford[1]

Biostratigraphy and trilobite fauna of the Lower Silurian Tegart Formation, Southeastern British Columbia. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 479, p. 13–47.

Abstract

In the Western Ranges of the Rocky Mountains, the Tegart Formation is preserved locally beneath the sub-Devonian unconformity, with a maximum thickness of 66 m. Argillaceous limestone and shale of the lower 55 m contain graptolites, conodonts and benthic macrofossils of late Telychian (Late Llandovery) age. These different groups of fossils allow correlation of the Tegart Formation within the three most effective biostratigraphic schemes that are used to zone the Silurian System. The stratigraphic association of the groups of fossils aids precise calibration between these three biostratigraphic schemes. The graptolite faunas and the conodont faunas are useful for correlation between continents and within North America; the trilobites and other benthic fossils provide correlation with carbonate rocks within North America.

The graptolite fauna represents the upper part of the *Monograptus spiralis* Zone, which is well known in central Europe, Asia, the Arctic Islands and the Yukon. The conodont fauna indicates the *Pterospathodus amorphognathoides* Zone of central Europe, Great Britain, southeastern Alaska, the Mackenzie Mountains, the Arctic Islands, Gaspé, and Anticosti Island. The lower boundary of the *Pterospathodus amorphognathoides* Zone with the underlying *Pterospathodus celloni* Zone is just above the base of the Tegart Formation. Trilobites and brachiopods dominate the shelly benthic fauna, which also has rare corals, gastropods, cephalopods and conulariids. The most precise correlation is with the faunas of trilobite assemblages e and f (within the lower *amorphognathoides* Conodont Zone) in the Whittaker–Road River transitional rocks of the Avalanche Lake region, western District of Mackenzie.

Three new species of trilobites are erected: *Paracybantyx tegartensis*, *Podowrinella rossi* and *Wallacia hendersoni*.

Résumé

Dans les chaînons ouest des Rocheuses, la Formation de Tegart est préservée localement sous la discordance sub-dévonienne, où sa puissance maximale est de 66 m. Les calcaires et shales argileux des 55 m inférieurs contiennent des graptolites, des conodontes et des macrofossiles benthiques du Télychien tardif (Llandovery tardif). Ces fossiles permettent la corrélation de la Formation de Tegart dans les trois schémas biostratigraphiques les plus efficaces utilisés pour zoner le Silurien. L'association stratigraphique des groupes de fossiles facilite la datation de ces trois schémas. Les graptolites et les conodontes sont utiles pour établir la corrélation entre les continents et entre les régions de l'Amérique du Nord; les trilobites et d'autres fossiles benthiques permettent une corrélation avec les roches carbonatées en Amérique du Nord.

Les graptolites représentent la partie supérieure de la Zone à *Monograptus spiralis*, qui est bien connue en Europe centrale, en Asie, dans l'archipel Arctique et au Yukon. Les conodontes représentent la Zone à *Pterospathodus amorphognathoides* de l'Europe centrale, de la Grande-Bretagne, du sud-est de l'Alaska, des monts Mackenzie, de l'archipel Arctique, de la Gaspésie et de l'île d'Anticosti. La limite de la Zone à *Pterospathodus amorphognathoides* et de la

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Zone à *Pterospathodus celloni* sous-jacente se trouve juste au-dessus de la base de la Formation de Tegart. Les trilobites et les brachiopodes dominent la faune benthique coquillière, qui comprend aussi de rares coraux, des gastéropodes, des céphalopodes et des conulariidés. La corrélation la plus précise est faite avec les assemblages de trilobites e et f (dans la partie inférieure de la Zone à *amorphognathoides*) dans les roches de transition Whittaker-Road River de la région du lac Avalanche, dans l'ouest du district de Mackenzie.

Trois nouvelles espèces de trilobites sont établies : *Paracybantyx tegartensis*, *Podowrinella rossi* et *Wallacia hendersoni*.

INTRODUCTION

In the western part of the Rocky Mountains (Fig. 2.1, loc. 9) the Tegart Formation is the highest Silurian unit preserved beneath a regional sub-Devonian unconformity (Norford, 1969). The site was near the outboard edge of a carbonate platform with a rapid rise of sea level at the onset of a grand cycle leading to a change from the shallow water sediments of the Beaverfoot Formation to the deeper depositional environments of the Tegart Formation. Graptolites, conodonts, trilobites, fragments of echinoderms, and rarer brachiopods, corals, cephalopods, and conulariids are present in the Tegart Formation. The presence of these different groups of fossils within the same succession provides an opportunity for refining calibration of the regional scheme of biostratigraphic zonation (based on benthic macrofossils) with schemes of intercontinental correlation based on graptolites and conodonts. Lower Silurian localities that are comparable in North America (Fig. 2.1) include the Road River Group at Prongs Creek in the northern Yukon (Raasch et al., 1961; Ludvigsen and Tripp, 1990), the transitional Road River–Whittaker rocks at Avalanche Lake, western Mackenzie (Chatterton and Perry, 1983, 1984), the interdigitation of the Cape Phillips and Allen Bay formations at Snowblind Creek, Cornwallis Island (Thorsteinsson, 1958; Thorsteinsson and Kerr, 1968) and the edge of the carbonate shelf in northern Greenland (Norford, 1972; Hurst, 1980). Each of these localities provides important contributions to the improvement of the precision of global correlation and dating of Lower Silurian rocks.

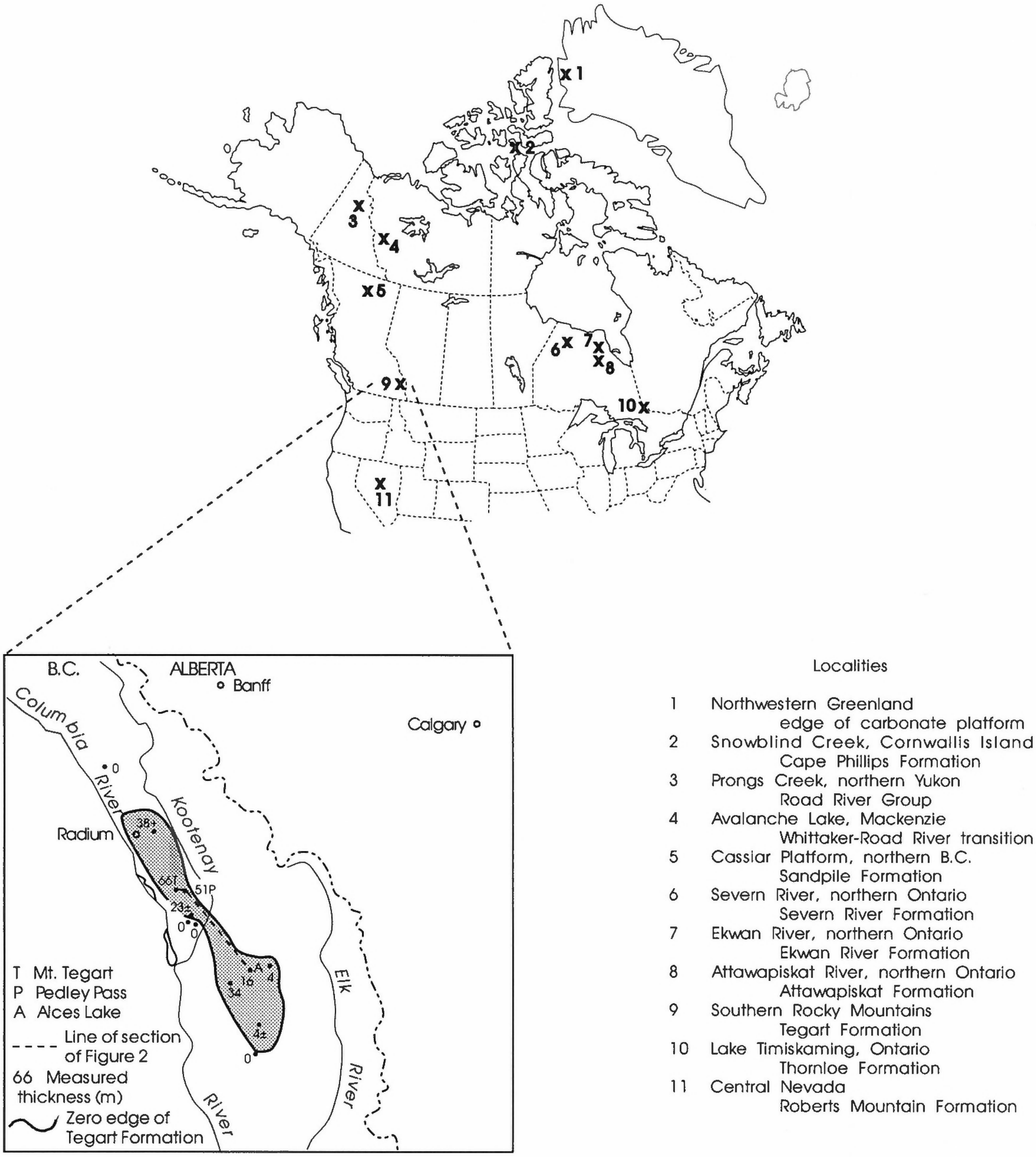
Acknowledgments

Most of the sampling of the Tegart Formation was done by B.S. Norford but important collections were made by other scientists, notably J.F. Walker, C.D. Walcott, G.B. Leech, C.G.L. Henderson and T.E. Bolton. The conodonts from the Tegart Formation and from the uppermost Beaverfoot Formation were studied by T.T. Uyeno and A.D. McCracken. Jisuo Jin kindly identified brachiopods in several of the Tegart collections and R.A. McLean a rugose coral. Several samples from the Tegart Formation were processed for acritarchs without any recovery, but rare and indeterminate chitinozoan fragments were recognized by W.A.M. Jenkins. Lars Ramsköld and G.D. Edgecombe kindly made available an advance copy of their manuscript on *Wallacia*. B.D.E. Chatterton and W.H. Fritz provided excellent suggestions on an early draft of the manuscript. B.C. Rutley took the photographs.

STRATIGRAPHY

The Tegart Formation is the youngest Silurian formation in the southern Rocky Mountains (Fig. 2.1) but it is preserved only locally beneath the regional Sub-Devonian Unconformity (Fig. 2.2). The rocks were first encountered in the 1920s (Walcott, 1924, 1928; Walker, 1926), were mapped by Henderson (1954) and by Leech (1954, 1958, 1959, 1960), and were later segregated as a distinct formation (Norford, 1969). The Tegart Formation is thin throughout most of its area of preservation and only two stratigraphic sections of significant thickness are known (Fig. 2.2). The formation is 66 m thick at Mount Tegart, the type section, and 51 m thick at Pedley Pass, the standard section for the Beaverfoot Formation.

Figure 2.2 shows the successions at Mount Tegart, Pedley Pass and Alces Lake. The sections have been described in detail previously (Norford, 1969, p. 70–71, 75–77), but the thickness of Unit 5 was revised after restudy of the dip-slope portion of the Mount Tegart section (Norford, 1969, p. 76) from 41 to 36 m. The



Localities

1 Northwestern Greenland
edge of carbonate platform
2 Snowblind Creek, Cornwallis Island
Cape Phillips Formation
3 Prongs Creek, northern Yukon
Road River Group
4 Avalanche Lake, Mackenzie
Whittaker-Road River transition
5 Cassiar Platform, northern B.C.
Sandpile Formation
6 Severn River, northern Ontario
Severn River Formation
7 Ekwan River, northern Ontario
Ekwan River Formation
8 Attawapiskat River, northern Ontario
Attawapiskat Formation
9 Southern Rocky Mountains
Tegart Formation
10 Lake Timiskaming, Ontario
Thornloe Formation
11 Central Nevada
Roberts Mountain Formation

***Figure 2.1.** Locality map and distribution of the Tegart Formation.*

first two sections are only 5 km apart within the same structural panel and their successions are very similar.

Recessive limy shale and argillaceous limestone of the Tegart Formation overlie resistant limestone of the Beaverfoot Formation. The contact is conformable but represents an abrupt, substantial rise in sea level, corresponding to the start of one of the grand cycles that are a prominent feature of the Lower Paleozoic rocks of the Rocky Mountains (Aitken, 1967). Graptolites are present in these basal shales, which are succeeded by very fine grained limestones, some argillaceous, with subordinate limy shales that become progressively more sparse upward. Trilobites, brachiopods and echinoderm debris are present in the limestones, together with rare corals, cephalopods, ostracodes and conulariids. Graptolites are present in the shale interbeds but are rare and no biostratigraphically significant forms have been found in the upper parts of either of the two thickest sections. The Lower Silurian (Telychian) Tegart Formation is overlain paraconformably by the Middle Devonian (?Eifelian) Cedared Formation.

The lithotypes and faunas of the Tegart Formation indicate progressive shallowing upward from the base, but even in the uppermost beds the depositional environments appear to have been relatively deep water compared to those of the Beaverfoot Formation. Graptolites are common in the basal 25 m but rarer above. Trilobites, brachiopods and rare corals commence at 20 m above the base and continue almost to the top of the formation.

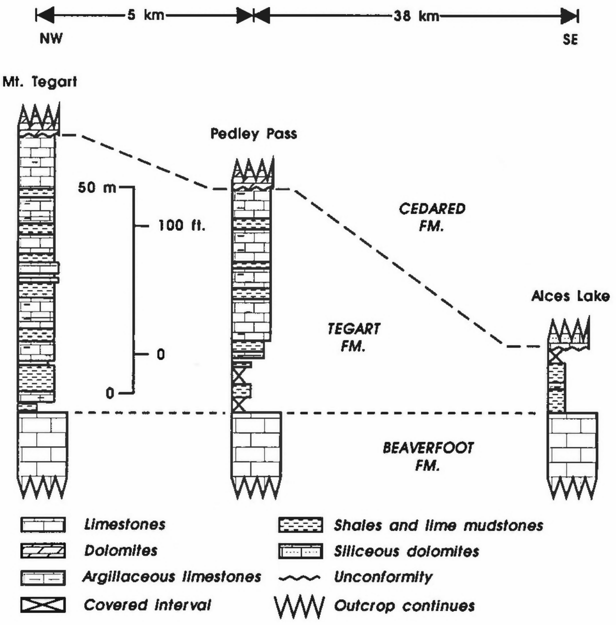


Figure 2.2. Stratigraphic profiles, Mount Tegart Section, Pedley Pass Section and Alces Lake Section.

BIOSTRATIGRAPHY

Figures 2.3 and 2.4 and Appendix A show the occurrence of taxa within the measured sections at Pedley Pass and Mount Tegart, and at other sampled localities. Species of graptolites in the lower part of the Tegart Formation indicate the *Monograptus spiralis* Zone (upper Telychian), which is well known in northern British Columbia, the Yukon, the Arctic Islands, Greenland, central and western Europe and Siberia. Some of the species are illustrated in Plate 2.5. Detailed taxonomic study of the graptolites has not been done but two local species are related to well known taxa. *Monograptus walcottorum* Ruedemann is a member of the *M. spiralis* (Geinitz) group of species and *M. columbianus* Reudemann belongs to the *M. priodon* (Bronn) group. *Stomatograptus grandis* (Suess) has been used as the index of a separate upper Telychian zone in central Europe and in the Arctic Islands but, in the Pedley Pass Section, *S. grandis* is present within the local range of the *M. spiralis* group of species and no separate biostratigraphic interval is recognized. The highest significant collection of graptolites (GSC loc. C-478) from the Tegart Formation is from near the middle of the formation and contains the following species:

Monograptus cf. *M. linnarssoni* Tulleberg
Monograptus walcottorum Ruedemann
Retiolites geinitzianus angustidens Elles and Wood.

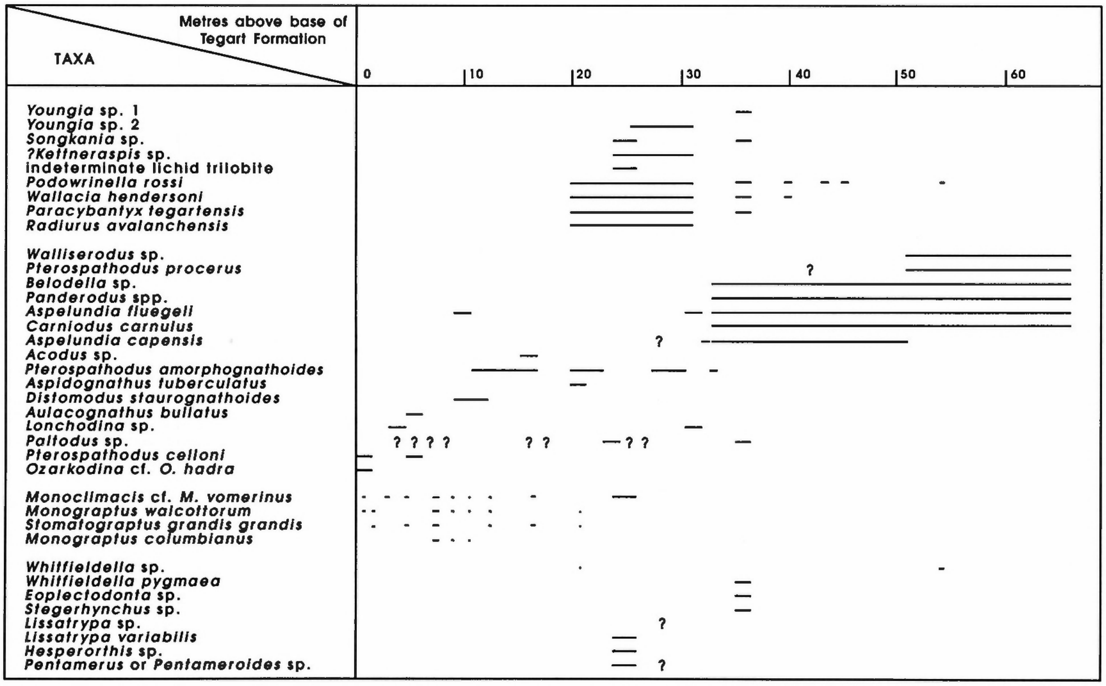


Figure 2.3. Stratigraphic ranges of trilobite, conodont and graptolite taxa, Mount Tegart Section.

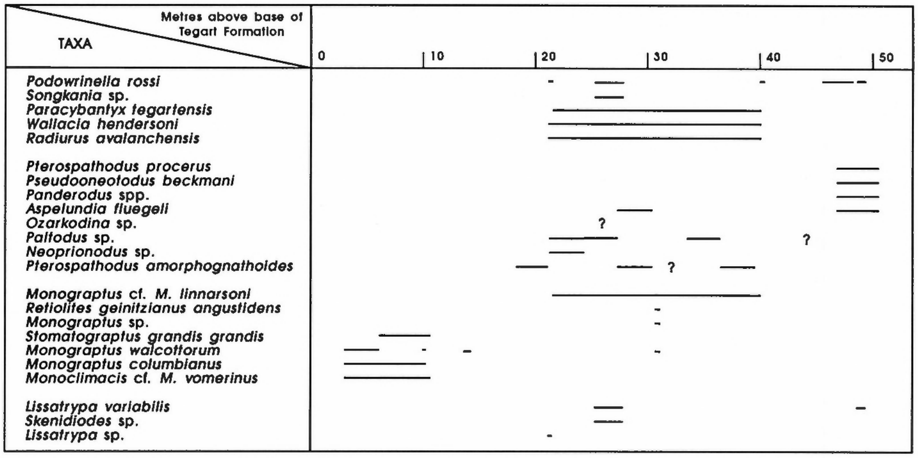


Figure 2.4. Stratigraphic ranges of trilobite, conodont and graptolite taxa, Pedley Pass Section.

This faunule can be correlated with the upper part of the *M. spiralis* Zone of Denmark (Bjerreskov, 1975) and the absence of any fragments of *Cyrtograptus* may indicate that it is older than the uppermost Telychian *C. sakmaricus-C. laqueus* Zone of northern Canada and Greenland (Lenz, 1982; Bjerreskov, 1986).

Conodonts recovered from collections from 10.7 to 66 m above the base of the formation at Mount Tegart and from 18 to 51 m above its base at Pedley Pass indicate the *Pterospathodus amorphognathoides* Zone (A.D. McCracken and T.T. Uyeno, pers. comm.; McCracken, 1991; Appendix A). In terms of the British Silurian, this zone spans the upper part of the Telychian and the lower Sheinwoodian (Fig. 2.5; Aldridge, 1972, 1975). In Norway, associated brachiopods indicate a late Telychian (C6) age for part of the *P. amorphognathoides* Zone (Aldridge, 1974). The *Pterospathodus celloni* Zone is documented in the basal 6.1 m of the Tegart Formation at Mt. Tegart and in the top 13 m of the Beaverfoot Formation at Pedley Pass (Appendix A). The boundary between the two zones thus is within the basal Tegart Formation, about 7 to 10 m above the Beaverfoot–Tegart contact and within the *Monograptus spiralis* Zone. In the Roberts Mountain Formation of Nevada (Klapper and Murphy, 1975, p. 21), the highest documentation of the *P. celloni* Zone is bracketed by occurrences of *Monograptus spiralis, Monograptus priodon* and *Retiolites geinitzianus angustidens*, which are below the lowest local occurrence of *Cyrtograptus* and indicate a correlation high within the *M. spiralis* Zone.

The *Pterospathodus amorphognathoides* Zone has an almost global distribution with documentation from Europe (Carnic Alps: Walliser, 1964, Schönlaub, 1971; Britain: Aldridge 1972, 1975; Norway: Aldridge, 1974), North America (Arctic Islands: Barnes et al., 1976; northern Yukon: McCracken, 1991; western District of Mackenzie: Over and Chatterton, 1987, McCracken, 1991; northern Greenland: Armstrong, 1982; British Columbia: McCracken, 1991; Alaska: Ovenshine and Webster, 1970; Québec: Nowlan, 1983 and Uyeno and Barnes, 1983; Ontario: Rexroad and Rickard, 1965; California: Miller, 1978; Nevada: Klapper and Murphy, 1975; Indiana and Kentucky: Nicoll and Rexroad, 1969) and Australia (Bischoff *in* Talent et al., 1975).

The only common brachiopod species in the Tegart Formation are *Lissatrypa variabilis* (Whiteaves) and *Whitfieldella pygmaea* Jin, Caldwell and Norford. In

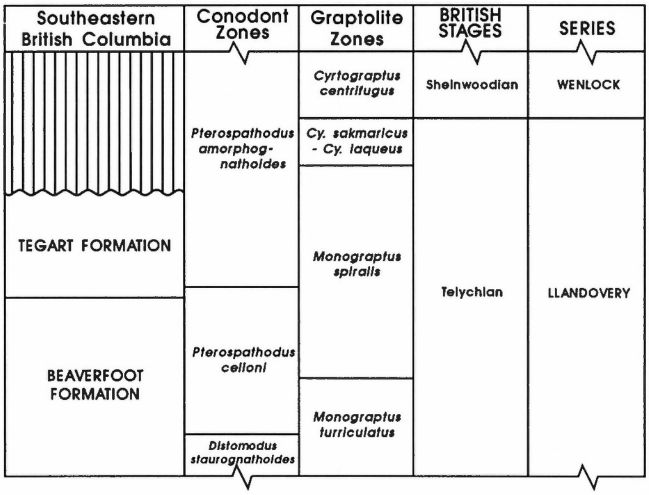


Figure 2.5. Correlation chart and biostratigraphic zones.

the Hudson Bay region, *L. variabilis* is present in the upper Telychian Attawapiskat Formation (Jin et al., in press); it also has been reported from the lower Telychian beds of the Road River Formation at Prongs Creek (Raasch et al., 1961) and from the Telychian Thornloe Formation of northern Ontario (Hume, 1925). *Whitfieldella pygmaea* was described from the upper Telychian (Attawapiskat and Ekwan River formations) of the Hudson Bay Lowlands. Rare specimens of pentamerid brachiopods probably represent *Pentamerus* or *Pentameroides* but lack of well preserved brachial valves preclude generic assignment. A few small specimens of *Dicaelosia parvifrons* Johnson, Boucot and Murphy are present in one collection; the species was described from the lower Wenlock part of the Roberts Mountain Formation of Nevada but in the Avalanche Lake region (western District of Mackenzie) its lowest occurrence is within the *P. amorphognathoides* Conodont Zone (uppermost Telychian-basal Wenlock). An Upper Telychian species of *Dicaelosia* is present in the Sandpile Formation of northern British Columbia.

The corals include the rugosan *Svetlamia*? (identified by R. A. McLean) and nondescript *Favosites* and *Aulopora*?.

TRILOBITE FAUNA

The trilobite fauna was first named the *Eophacops-Cheirurus* Fauna (Norford, 1962, 1969) but later erections of two new genera requires the change to *Podowrinella-Radiurus* Fauna, after two of the most prominent components. Preservation of the trilobites is good, but because of fine sediment tightly bonded to the shell material, manual preparation is both difficult and challenging. Ten species are represented:

Paracybantyx tegartensis n. sp.
Songkania sp.
Scotoharpes sp.
Radiurus avalanchensis Chatterton and Perry
Youngia sp. 1
Youngia sp. 2
Wallacia hendersoni n. sp.
Podowrinella rossi n. sp.
Indeterminate lichid trilobite
?*Kettneraspis* sp.

Comparison of the generic assemblage with those of the western District of Mackenzie (Avalanche Lake succession, Chatterton and Perry, 1983, 1984), northern Greenland (Lane, 1972, 1988), northern Ontario and Manitoba (Norford, 1981) and Europe shows a general Telychian to Wenlock correlation. *Podowrinella* is not known from rocks older than Telychian. Similarly for *Wallacia* but with only one of its known species younger than Telychian (Ramsköld and Edgecombe, in press). *Radiurus* has its acme in the latest Telychian. Other than the presence of *Songkania*, the assemblage has little in common with the lower Telychian (*Monograptus turriculatus* Zone) assemblage in the Road River Formation at Prongs Creek, northern Yukon (Raasch et al., 1961; Ludvigsen and Tripp, 1990). Comparison of the cheirurids with those of the Avalanche Lake succession (Chatterton and Perry, 1984) shows that *Radiurus avalanchensis* is associated with several species of *Youngia* in the Avalanche Lake faunal assemblages e, f and g. A very few cranidia of *Youngia* are present in the Tegart Formation and are inadequate for assignment to species. However, *Y.* sp. 2 has some similarities to *Y. folinsbeei* Chatterton and Perry, which is present in faunal assemblages f and g at Avalanche Lake. Similarly, *Y.* sp. 1 can be compared with *Y. boucoti* Chatterton and Perry that is restricted to assemblages e and f. Assemblages e and f are present within the lower part of the *Pterospathoides amorphognathoides* Conodont Zone at Avalanche Lake, assemblage g within the upper part of the same zone (see Over and Chatterton, 1987).

At Mt. Tegart, the trilobite assemblage occurs at 19.8 to 54.3 m above the base of the Tegart Formation (Fig. 2.3) and at 21.3 to 49.4 m at Pedley Pass (Fig. 2.4), within the *Pterospathodus amorphognathoides* Conodont Zone at both stratigraphic sections. The *Monograptus spiralis* Graptolite Zone is documented up to 20.8 m above the base at Mt. Tegart and up to 31.1 m above at Pedley Pass, with no graptolites collected from higher horizons. Thus the *Podowrinella-Radiurus* Fauna is well dated as being within the *amorphognathoides* Zone and with no evidence that it ranges higher. However one species, *Podowrinella rossi*, does range down into the *Pterospathodus celloni* Conodont Zone at Pedley Pass (Appendix A).

SYSTEMATIC PALEONTOLOGY

Prefix GSC refers to type specimens and other designated material, all stored in the type collections of the Geological Survey of Canada, Ottawa. Within the taxonomic descriptions, the occipital ring is regarded as separate from the glabella (Harrington, 1959, p. O46).

Phylum Arthropoda

Class TRILOBITA

Family STYGINIDAE Vogdes, 1890

Genus *Paracybantyx* Ludvigsen and Tripp, 1990

Paracybantyx Ludvigsen and Tripp, 1990, p. 8.

Type species. Paracybantyx asulcatus Ludvigsen and Tripp, 1990 from an Upper Silurian (probably high Ludfordian) debris flow within the Road River Group, Yukon Territory.

Paracybantyx tegartensis n. sp.

Plate 2.1, figures 1-16; Plate 2.2, figure 11;
Plate 2.3, figure 18; Figure 2.6

Material and occurrence. Five cranidia, seven pygidia, one free cheek and numerous fragments (including holotype GSC 106575, paratypes GSC 106576-106579, hypotypes GSC 106580-106583); GSC locs. 7918, 47397, 52162, 52181, 64558, 64559, C-477; mostly preserved as external surfaces but there are some internal moulds.

Derivation of name. From the Tegart Formation.

Diagnosis. A species of *Paracybantyx* with short (exsag.) lateral muscular impressions; width of pygidium about 120-130 per cent of length, border furrow virtually completely effaced on exterior of mature pygidia.

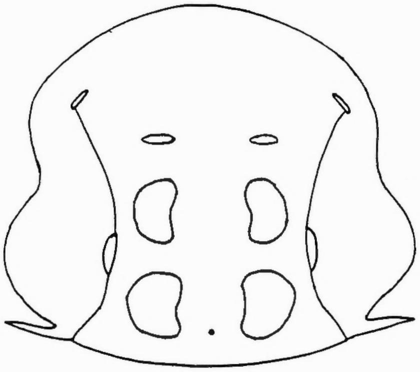


Figure 2.6. Paired glabellar muscular impressions, ***Paracybantyx tegartensis*** *n. sp. (see Pl. 2.1, fig. 1), hypotype GSC 106580; GSC loc. C-477; x3.5. Terminology of impressions follows that of Lane and Thomas (1978), the lateral impressions abut against the axial furrows and the other four pairs in order forward are the occipital, G1, G2 and G3.*

Description. Outline of cephalon suboval, much wider than long, posterior margin slightly reflexed abaxial to axial furrow. Cranidium evenly arched (tr.) but reflexed abaxial of palpebral lobe (Pl. 2.1, figs. 6, 7, 9), evenly convex (sag.). External surface almost featureless, internal moulds show more detail. Axial furrow indistinct at posterior margin (stronger on internal moulds), curves evenly forward and convergent to lateral muscular impression (Pl. 2.1, fig. 1) opposite front half of palpebral lobe, becoming divergent, gently curved and very shallow in front of palpebral lobe, undetectable beyond a faint anterior pit (Pl. 2.1, fig. 6; Pl. 2.3, fig. 18) sited slightly more than half distance (exsag.) from front of palpebral lobe to opposite front of cranidium. Large paired occipital muscle impressions (Pl. 2.1, fig. 1; Fig. 2.6) about 50 per cent larger than 1G, distant from axial furrows, posterior limits just behind axial tubercle; 1G shallow, semioval with rear parts sited opposite front third of lateral muscular impressions, more than 50 per cent longer than these, width of each of pair about a fifth of distance between axial furrows at their postion; 2G less shallow, short, transverse; 3G similar to 2G but more widely separated, very shallow and indistinct, sited slightly forward (exsag.) of anterior pit within axial furrow. Small axial tubercle on internal mould of occipital ring (Pl. 2.1, fig. 1), opposite rear of palpebral lobe (Pl. 2.1, fig. 5), which is large, raised, without rim, evenly convex in outline, extending forward to about midlength of cranidium, posterior part strongly raised above short (exsag.) but long (tr.) venterolaterally reflexed posterior area of fixed cheek that extends abaxially far beyond palpebral lobe. Facial suture straight and slightly divergent anteriorly from palpebral lobe, curving abruptly adaxially close to anterior margin and meeting it opposite anterior pit; posterior course curving abruptly laterally and ventrally from palpebral lobe, running almost transversely to reach posterior margin well abaxial of palpebral lobe. Free cheek known from one small specimen with an abrupt termination but rounded genal angle; eye not preserved. External ornament of cranidium with very fine terrace lines over most of dorsal surface, less fine near anterior margin; terrace lines also less fine on free cheek; inner layers of exoskeleton finely punctate (Pl. 2.1, fig. 1). Hypostome, rostral plate, thorax unknown.

Pygidium much wider than long, evenly convex (both sag. and tr., but with a very subtle axial keel near posterior margin) lacking trilobation, external surface with only faint traces of border furrow laterally and anterolaterally, prominent facets at anterolateral margin (Pl. 2.1, fig. 14). Doublure broad, without axial cusp or indentation. Dorsal surface almost smooth but inner layers of exoskeleton finely punctate (Pl. 2.1, fig. 8), terrace lines adjacent to margin and on doublure.

Discussion. Generic assignment is difficult in effaced trilobites and there is not full knowledge of all the skeletal parts of the Tegart species. There are similarities to the type species of *Bumastus*, *B. barriensis* (Lane and Thomas *in* Thomas, 1978) in the proportions of the cephalon and of the pygidium, but the axial furrow persists farther forward, a very shallow anterior pit is present, and the posterior part of the fixed cheek is much longer (tr.). On the only known free cheek of *Paracybantyx tegartensis* (Pl. 2.2, fig. 11), the terrace lines do not form a whorl as described in *B. barriensis* by Lane and Thomas (Thomas and Owens, 1978, Pl. 2, fig. 4) with such a configuration considered by them as a generic feature. *Cybantyx* has a longer axial furrow than *Bumastus* and the glabellar muscle impressions (Fig. 2.6; terminology of Lane and Thomas) of the Tegart species are similar to those of *Cybantyx*, except that G3 is not smaller than G2. An anterior cranidial border and associated border furrow is present in *Cybantyx*, and Ludvigsen and Tripp described *Paracybantyx* for forms lacking this feature but otherwise very similar to *Cybantyx*. The lack of this feature, together with the presence of the long axial furrow, supports assignment of the present material to *Paracybantyx*. *Paracybantyx asulcatus* is the only other described species of the genus and has a longer and proportionally wider cranidium and pygidium than *P. tegartensis*. The lateral muscular impression is longer and the pygidial border furrow is less effaced.

Family OTARIONIDAE Richter and Richter, 1926

Genus *Songkania* Chang, 1974

Type species. Songkania hanjianensis Chang, 1974 from Lower Silurian rocks in China.

Songkania sp.

Plate 2.4, figures 10, 15–18

?*Aulacoparia* sp. Norford, 1962, p. 451.
Aulacoparia? sp. Norford, 1969, p. 40.

Material and occurrence. Four incomplete cranidia, one free cheek, one incomplete pygidium (including hypotypes GSC 106611-106613), several cranidial and pygidial fragments; GSC locs. 7923, 45545, 47420, 64458, 64559, 64586, and C-477.

Comments. This rare taxon has many cranidial features in common with *Songkania* as interpreted by Ludvigsen and Tripp (1990, p. 20), but is inadequately known for comparison at the species level.

Family HARPIDAE Hawle and Corda, 1847

Genus *Scotoharpes* Lamont, 1948

Scotoharpes Lamont, 1948, p. 534.
Scotoharpes Lamont; Norford, 1973, p. 11–14.

Type species. Scotoharpes domina Lamont, 1948 from the Wether Law Linn Formation (Telychian), Scotland.

Scotoharpes sp.

Plate 2.2, figure 15

Scotoharpes sp. Norford, 1973, p. 22, Pl. 2, fig. 6.

Material and occurrence. A single specimen (hypotype GSC 27795 from GSC loc. 70516) showing part of the ventral surface of the lower lamella of the fringe (primarily the prolongation) and the ventral surface of most of one gena, an eye tubercle and the edge of the glabella.

Description. Prolongation trends almost straight rearward. Genal caeca on gena, genal roll, and very indistinctly impressed close to girder on brim of prolongation. Ornament of moderately fine pits on lower lamella, with single rows of coarser pits against girder and against external and internal rims. Girder strong, joins internal margin well in front of tip of prolongation that bears a short spine. Internal and external rims rather wide, strongly raised.

Discussion. Scotoharpes is a long-ranging genus and too little is known of the taxon to allow fruitful comparison with the described species.

Family CHEIRURIDAE Hawle and Corda, 1847

Genus *Radiurus* Ramsköld, 1983

Radiurus Ramsköld, 1983, p. 186, 188.

Type species. Radiurus phlogoideus Ramsköld, 1983 from the Lower Visby Marl (Upper Telychian), Gotland, Sweden.

Comments. Norford (1981, p. 10) mentioned that a new cheirurid genus was present in the Tegart Formation. The same genus was described by Ramsköld in 1983 based on Swedish material. Upper Llandovery taxa include the following:

Radiurus avalanchensis Chatterton and Perry, 1984, Whittaker Formation/Road River Group, District of Mackenzie; Tegart Formation, British Columbia.
R. estonicus (Männil, 1958), Velise Formation, Estonia.
R. phlogoideus Ramsköld, 1983, Lower Visby Marl, Sweden.

Possible but inadequately known additions are *Cheirurus certus* Poulsen, 1934 and *C. hyperboreus* Poulsen, 1934, both described from the Cape Schuchert Formation, Greenland. As commented by Lane (1971, p. 76, 77) concerning *R. estonicus*, and by Ramsköld (1983), the relatively unspecialized features of *Radiurus* make it a logical source for several cheirurid lineages. More pronounced inflation of the frontal lobe together with development of a small pygidial axial mucronation would lead to *Cheirurus*. Forward relocation of the palpebral lobe and development of pronounced pygidial axial mucronation would lead to *Chiozoon*. However, both *Cheirurus* and *Chiozoon* range from the Telychian into the Ludlow (Lane, 1971, 1972; Norford, 1981) and *Radiurus* has not been recorded from pre-Telychian rocks. Two species have been described from strata within the uppermost Telychian part of the *Pterospathodus amorphognathoides* Conodont Zone and the type locality of *R. estonicus* is either within the same zone or in the underlying *P. celloni* Zone.

Radiurus avalanchensis Chatterton and Perry, 1984

Plate 2.2, figures 1-10, 12-14, 16, 17

Cheirurus (Ceraurus) cf. *niagarensis* Hall; Walker, 1926, p. 33.
Cheirurus sp. Henderson, 1954, p. 75.
Cheirurus cf. *C. niagarensis* Hall; Norford, 1962, p. 451; Norford, 1969, p. 40.
Radiurus avalanchensis Chatterton and Perry, 1984, p. 27-29, Pl. 7, Textfig. 13.

Material and occurrence. Twelve fragmentary cranidia, four hypostoma, twenty pygidia, two fragmentary free cheeks, numerous fragments (including hypotypes GSC 106584-106594); GSC locs. 7918, 45545, 47397, 47420, 52162, 52181, 64559, C-472, C-473, C-477, C-60943; Tegart Formation.

Description. Cephalon much broader than long (Pl. 2.2, fig. 3), rather low but gently arched (tr.). Glabella long, slightly less than one third of width of cephalon at occipital ring, slightly raised, almost parallel sided but slightly expanded forward, with faint axial keel that fades forward. Strong axial, occipital, lateral glabellar and preglabellar furrows. Axial furrows very slightly curved and divergent forward to rear of ovoid frontal lobe where they curve evenly adaxially into preglabellar furrow; small pit in axial furrow just forward of S3. Course of lateral glabellar furrow S3 almost transverse from axial furrow, turns posteromedially and dies out well before axis; S2 transverse near axial furrow, turns less than S3 and dies out similarly adaxially; S1 posteromedial from axial furrow, reaches similar distance toward axis as limits of S2 and S3; becomes faint, broad and turns posteriorly to join occipital furrow. Lobes L3 and isolated L1 subequal in length (exsag.), L2 slightly shorter; frontal lobe large, low, broadly convex but not inflated and not overhanging border; rear of glabella with axial swelling that overhangs front of occipital furrow as it arches forward axially. Occipital ring convex, narrow abaxially. Preglabellar furrow merged with anterior border furrow except beside anterolateral corners of frontal lobe. Surface of glabella with extremely fine granules together with scattered fine granules that are irregularly concentrated axially and on the crests of the lobes (Pl. 2.2, figs. 4, 5); occipital ring with fine terrace lines and sparse fine granules.

Fixed cheek wide, low, with palpebral lobe extending from opposite mid-L3 (at axial furrow) almost to level of front of L2, joined by broad, low eye-ridge to axial furrow at S3. Lateral border furrow and almost straight posterior border furrow strong. Broad lateral and posterior borders. Fixigenal spine trends posteriorly. Between it and axial furrow, abaxial half of border narrows (Pl. 2.2, fig. 2) and is flanged against front thoracic segment. Anterior border entire, almost flat. Extremely fine granules on anterior border and on the very small triangular part of fixed cheek in front of eye-ridge; coarser but still fine granules on fixigenal spine and as local concentrations on lateral border in front of spine; both ornaments also on main part of fixed cheek together with pits of irregular size, but much larger than the granules. Facial suture runs forward from eye-ridge to opposite anterolateral corner of glabella, swings adaxially to run close to but just in front of frontal lobe and forms a subtle point axially; from rear of palpebral lobe, facial suture runs slightly forward of transverse but curves gently to be transverse at border furrow and across border. Free cheek (Pl. 2.2, fig. 10) and thoracic segments poorly known; rostral plate unknown.

Hypostome with long inflated middle body, oblique middle furrow defining small posterior lobe, posterolateral margin rounded, very short anterior border, anterior border furrow distinct axially, border furrow continues laterally into dorsally directed anterior wing; ornament of extremely fine granules.

Pygidium with prominent long spines, width (excluding spines) about twice the length. Axis with articulating half-ring, three rings and terminal piece that merges rearward with margin, axial furrow distinct except near rear margin; ring furrows incised. Pleural regions with three pairs of strong tapering spines with gently convex dorsal surfaces (Pl. 2.2, figs. 14, 17) and almost flat ventral surfaces (Pl. 2.2, fig. 13), second pair longer and stouter than others (Pl. 2.2, fig. 14); first and second pairs curving evenly rearward; no terminal mucronation but axial region of doublure with a slight swelling (Pl. 2.2, fig. 13). Interpleural furrows distinct, pleural furrows short, incised adaxially. Doublure extends under terminal piece, spines and small portion of pleural region. Pygidium ornament very finely granular.

Discussion. Radiurus avalanchensis has been reported from faunas e, f and g of the Whittaker Formation transitional to the Road River Group, within the lower part of the *amorphognathoides* Conodont Zone (Over and Chatterton, 1987). The Tegart specimens closely resemble the type suite of *Radiurus avalanchensis* except in the length of the pygidial spines, the second pair consistently being longer than the others. The glabellar ornament consists of fine granules in addition to extremely fine granules. However, the paratype cranidia are all small, as are the paratype pygidia; the holotype pygidium is larger but incomplete so that one cannot ascertain whether the second pair of spines is proportionally longer, as in the Tegart material. Both the type material and the Tegart specimens have wider and less convex cephala than *R. phlogoides*, their pygidia are lower and proportionally wider and the pygidial spines are much longer and more curved. In *R. estonicus*, lateral glabellar furrow S1 is stronger and thus lobe L1 is more strongly isolated, the pygidium is not well known, but its axis is much wider than in *R. avalanchensis*.

Genus *Youngia* Lindström, 1885

Youngia Lindström 1885, p. 49–50.
Youngia Lindström; Lane, 1971, p. 69.
Youngia Lindström; Clarkson and Howells, 1981, p. 519.
Youngia Lindström; Chatterton and Perry, 1984, p. 39–40.

Type species. Cheirurus trispinosus Young, 1868 from the Wood Burn Formation (Aeronian), Scotland.

Comments. Youngia is rare in the Tegart Formation and the material is insufficient for formal identification, but two cranidia are illustrated and described as species 1 and 2. Chatterton and Perry (1984) described seven species of *Youngia* (*boucoti, brennardi, folinsbeei, johnsoni, kathyae, steineri* and *walli*) from beds within the *Pterospathodus amorphognathoides* Conodont Zone (uppermost Telychian and basal Sheinwoodian) of the Whittaker Formation/Road River Group, District of Mackenzie. Other species of *Youngia* have been reported from rocks of similar age, including *Y. douglasii* (Lamont, 1948), Wether Law Linn Formation, Scotland; *Y. canadensis* (Billings, 1866), Chicotte Formation, Quebec; *Y. globiceps* Lindström, 1885, probably from Lower or Upper Visby Marl, Sweden; and *Y.* sp., Upper Visby Marl (lowermost Wenlock) (Bruton *in* Jaanusson et al., 1979). The acme of the genus seems to be within this episode of geological time. A few older species are known: *Y. moroides* (Marr and Nicholson, 1888) from the Rhudannian of northern England and *Y. trispinosa* (Young, 1868) and *Y.* aff. *Y. trispinosa* Lane, 1971 from the Aeronian of Scotland. A younger species is *Y. inermis* Lindström, 1885, probably from the Slite Beds (Wenlock), Sweden.

The type and several other species have long median occipital spines, but this feature is lacking in *Youngia douglasii* Lamont (Clarkson and Howells, 1981, p. 519, Pl. 80, figs, 5, 6, 11), *Youngia*? *aspera* (Weber) and *Y.*? *jakovlevi* (Weber) (according to Snajdr, 1978, p. 22). The ornament of coarse tubercles is characteristically more dense on the glabella than elsewhere on the cephalon.

Youngia sp. 1

Plate 2.4, figures 1–4, 8, 9

Material and occurrence. One incomplete cranidium (hypotype GSC 106607), GSC loc. 64558; Tegart Formation.

Description. Glabella convex both axially and transversely, projecting forward slightly ahead of and just overhanging very short anterior border (Pl. 2.4, figs. 8, 9); outline acorn-shaped, widest at midlength of lobe L2 (Pl. 2.4, fig. 1). Axial furrow strong; lateral furrow S1 strong, wide, curving rearward adaxially but (on external surface) not reaching occipital furrow to circumscribe lobe L1; S2 faint and short (Pl. 2.4, figs. 8, 9), subparallel to S1; S3 not discernible. Occipital furrow strong, broad, very deep abaxially. Occipital ring convex, long at axis, short at axial furrow, median spine apparently prominent but only the stout base is preserved. Fixed cheek small, convex laterally, midpart of its border has single, short, tapering spine that trends posterolaterally and curves adaxially near extremity; posterior border furrow strong. Palpebral lobe a high narrow rim, located opposite and close to abaxial end of S1, bordered by distinct furrow. Preglabellar field a short band that curves around glabella to merge with narrow brim-like anterior part of fixed cheek. Anterior course of facial suture outlines this brim, posterior course turns almost transverse nearly to border furrow where it curves abruptly rearward to cross border very obliquely. Ornament of evenly spaced large tubercles on glabella and occipital ring, absent on border and on all but anterolateral part of fixed cheek. Free cheeks, hypostome, thorax and pygidium unknown.

Comments. The ornament is subdued in comparison to the described species of *Youngia* and the tubercles are widely spaced. The cranidium resembles that of *Y. trispinosa* but is considerably smaller and only two pairs of lateral glabellar furrows can be detected on the external surface, which is all that is available. The Anticosti Island species *Y. canadensis* is very inadequately described (Twenhofel, 1928, p. 335, Pl. L, fig. 13) but the types and additional specimens collected by T. E. Bolton show that its cranidium is larger than that of *Y.* sp. 1, is more convex and more densely ornamented; furrows S2 and S3 are present but subdued and S1 does not meet the occipital furrow but all the specimens are external surfaces; the occipital ring shows the base of an apparently small median spine. *Youngia* sp. 1 has many similarities to *Y. boucoti* Chatterton and Perry, including the faintness of S2, but the anterior outline of the glabella is broader and the ornament of tubercles on the crandium is much less dense.

Youngia sp. 2

Plate 2.4, figures 5–7

Material and occurrence. Three fragmentary cranidia (including hypotype GSC 106608), GSC loc. 52181; Tegart Formation.

Comments. The poorly preserved material represents a species of *Youngia* with a rounded glabella and with the occipital ring tapering abaxially and bearing an apparently small axial spine that is posteriorly directed. Lateral glabellar furrow S1 is evenly curved and does not reach the occipital furrow; an unfigured specimen (internal mould) shows short S2 and S3. *Youngia* sp. 2 differs from *Youngia* sp. 1 in the outline of the glabella and in the shape and width (tr.) of the occipital ring. *Youngia* sp. 2 has similar features to *Youngia folinsbeei* Chatterton and Perry, but the available material is inadequate for detailed comparison.

Family ENCRINURIDAE Angelin, 1854

Genus *Wallacia* Lamont, 1978

Wallacia Lamont, 1978, p. 271.
Wallacia Lamont; Ramsköld amd Edgecombe, in press.

Type species. Encrinurus expansus Haswell, 1865 from the Wether Law Linn Formation (Telychian), Scotland.

Wallacia hendersoni n. sp.

Plate 2.2, figure 17; Plate 2.3, figures 1–14, 17, 19–24; Plate 2.4, figure 37

Encrinurus sp. Norford, 1962, p. 451; 1969 p. 40.

Material and occurrence. One fragmentary carapace (paratype GSC 106596), three cranidia (including holotype GSC 106595), numerous pygidia (including hypotypes GSC 106603–106606), four free cheeks (paratypes GSC 106598–106600, hypotype GSC 106597), numerous fragments; GSC locs. 7918, 45545, 47397, 47420, 52162, 52181, 64458, 64459, C-466, C-477, C-45587, C-60943; Tegart Formation.

Derivation of name. In honour of Gerry Henderson, distinguished petroleum geologist.

Diagnosis. Cranidium without genal spines and with gentle reflexion of posterior border abaxially; free cheek with numerous tubercles on its field, its precranidial lobe and its border; nonmucronate pygidium with 16 to 17 axial rings and eight pairs of pleurae.

Description. Cephalon densely tuberculate, more than twice as wide (tr.) as long (sag.); genal angles rounded. Glabella widens evenly forward to rounded front with subtle axial point; axial and occipital furrows deep, lateral glabellar furrows obsolete; border furrow shallow, anterior border without median furrow, consisting of a single row of 10 tubercles; main body of glabella with eight rows of tubercles axially (Pl. 2.3, fig. 1) together with irregularly sited smaller tubercles, abaxially three enlarged tubercles represent L2, L3 and L4; lateral lobe 1 is indiscernible. Occipital ring long, gently arched (Pl. 2.3, fig. 2), margins slightly curved. Fixed cheek broad (tr.) with pronounced border furrow and almost smooth border that broadens abaxially and turns gently posterolaterally, without fixigenal spine; five coarse tubercles against axial furrow, tubercles less coarse abaxially; palpebral lobe raised, opposite midlength of glabella (Pl. 2.3, fig. 7). Anterior branch of facial suture curves abruptly from palpebral lobe to glabella where it has a very gentle curve in front of the cranidial border to an axial obtuse junction (Pl. 2.3, fig. 3); posterior branch almost straight, crossing border furrow opposite L2. Free cheek with elevated eye, distinct anterior furrow, field of free cheek with four or five irregular rows of tubercles, gently convex procranidial lobe with three or four rows, border with two rows of coarser tubercles. Very fine granules present on borders and on occipital ring. Rostal plate and hypostome not known.

Thorax apparently with 10 segments (Pl. 2.3, fig. 7), axis low, gently arched (Pl. 2.3, fig. 9; Pl. 2.4, fig. 28), pleural regions strongly arched midway to margin, pleurae swinging rearward and strongly facetted (Pl. 2.4, fig. 37), ornament of sparse fine granules on axis and pleurae, without any axial spines or prominent axial granules (Pl. 2.3, fig. 7).

Pygidium about as long as wide, outline subtriangular but not mucronate, strongly bevelled anterolaterally by articulating facets; without axial mucronation. Axial furrows strong anteriorly, lightly impressed posteriorly, axis low, tapering evenly rearward, consisting of articulating half-ring, about 16 or 17 rings that are weaker rearward, and indistinct terminal piece; R/P ratio 1.8. (R is number of axial rings in front of posterior pair of pleurae, P is number of pairs of pleurae in front of this pair.) Narrow, slightly raised postaxial ridge disappears against conjunction of rear pair of pleurae. Pleural regions considerably wider than axis, arched in midparts, with short (ex-sag.) anterior half-pleurae and eight pairs of flat topped pleurae (first six with facetted terminations) that turn evenly rearward, rear pair trending almost straight rearward before turning together to meet before margin; interpleural furrows broad, strongly incised. Outer surface of axis and pleural regions apparently smooth (Pl. 2.3, figs. 7, 24) but ventral surface and internal moulds with finely granular ornament and faint axial tubercles on third and sixth axial rings (Pl. 2.3, figs. 21–23).

Comments. Ramsköld and Edgecombe (in press) have revived *Wallacia* for a group of species with small or no genal spines, subdued cheek tuberculation, subdued sagittal tubercles on the axis of the pygidium and low R/P ratios. *Wallacia hendersoni* resembles *W. caplanensis* (Northrop) from the Clemville Formation of Gaspé in the cranidial ornament and in the almost smooth pygidial ornament. However, *W. caplanensis* is not well known (Northrop, 1939, p. 239, Pl. 26, figs. 13–15; the types are internal moulds), the pygidium is long and narrow with a pointed rear and Northrop thought that the species might have genal spines. *Wallacia triangula* (Männil), *W. jaanussoni* Ramsköld and Edgecombe and *W. masterleei* Ramsköld and Edgecombe similarly have genal spines and mucronate pygidia.

Several Telychian species of *Wallacia* lack genal spines and have almost negligible ornament on the thorax and on the pygidium. The poorly known *W. hypolepra* (Stearn) from the Cedar Lake Formation of southern Manitoba has been described as having a spinose pygidium (Stearn, 1956, p. 122) with at least nine pairs of pleurae (Ramsköld and Edgecombe, in press). In *W. chattertoni* Ramsköld and Edgecombe (Whittaker Formation, Avalanche Lake area), the inner area of the free cheek is considerably smaller than the adjacent border, and the pygidium is broad and has a relatively convex axis. The pygidium of *W. elegantula* (Billings) from the Thornloe Formation, Lake Timiskaming, Ontario (Bolton and Copeland, 1972, Pl. X, figs. 7, 12, 15) and from the Jupiter Formation of Anticosti Island (Edgecombe and Chatterton, 1992, p. 53, 55, 56) is almost smooth but has about 28 axial rings and nine pairs of pleurae; the cranidium (Twenhofel, 1928, p. 330, 331, Pl. LVI, figs. 4, 5; Edgecombe and Chatterton, 1992, Fig. 2-1) lacks genal spines and has other similarities to the present material but the tubercles are more dense on the glabella. The pygidium of *W. laevis* (Angelin) from the Upper Visby Beds (Sheinwoodian) of Sweden is more elongate with a pronounced axial mucronation and the tubercles on the free cheek are sparse.

Family PTERYGOMETOPIDAE Reed, 1905

Genus *Podowrinella* Clarkson, Eldredge and Henry, 1977

Type species. Phacops straitonensis Lamont, 1965 from the Deerhope, Knockgardner and Ree Burn formations (Telychian and ?Wenlock), Scotland.

Comments. Eophacops, Acernaspis (*Acernaspis*), *Acernaspis* (*Eskaspis*) and *Podowrinella* have many characters in common, but others, such as the degree of impression of the pygidial furrows and of the lateral glabellar furrows are variably developed in the genera (Campbell, 1967, Fig. 7; Clarkson et al., 1977, Figs. 2, 3, 5, 6; Howells, 1982, p. 45). A critical character of *Podowrinella* is the course of the vincular furrows. In the other three genera, the furrows are located wholly on the ventral aspect of the doublure, trending subparallel to the margin rearward to the genal angle and forward to join axially in some species, but fading adaxially in others. The vincular furrows are notched in *Acernaspis* and *Eskaspis*, but smooth in *Eophacops* and *Podowrinella*. In the three described species of *Podowrinella*, *P. straitonensis*, *P. christiei* Lane and *P. rossi* n. sp., the vincular furrows are broad grooves that run obliquely across the ventral surface of the doublure and rearward reach or fade at the inner margin of the doublure in front of the genal angle. Anteriorly the vincular furrows continue onto the dorsal surface (Pl. 2.4, figs. 11–14) of the doublure that forms a spatulate projection in front of the anterior border (Pl. 2.4, figs. 13, 14). This median projection gives a more pointed cephalic outline in *Podowrinella* than in *Acernaspis*, *Eophacops* and *Eskaspis*; similarly the rear of the pygidium is more pointed in *Podowrinella* to accommodate the projection during enrollment.

The well dated occurrences of *Podowrinella* are all Telychian. *Podowrinella christiei* Lane was described from about 20 m below the top of the Odins Fjord Formation (Telychian, *Pterospathodus celloni* Conodont Zone) in northern Greenland. *Podowrinella rossi* n. sp. is a little younger (latest Telychian, *Pterospathodus amorphognathoides* Conodont Zone) within the Tegart Formation but is also present in the uppermost Beaverfoot Formation within the *P. celloni* Zone. In Scotland, *P. straitonensis* (Lamont) is well documented from the Telychian and has also been reported from the Sheinwoodian.

Podowrinella rossi n. sp.

Plate 2.4, figures 11–14, 19–27, 29–36

Eophacops aff. *E. marklandensis* (McLearn); Norford, 1962, p. 451; 1969, p. 40.

Material and occurrence. This is the most common of the Tegart trilobites and is represented by two incomplete cephala, 28 cranidia, numerous cranidial fragments, two free cheeks, 28 pygidia, numerous pygidial fragments and discrete thoracic segments, and four hypostoma that probably belong to the species (including holotype cephalon GSC 106610, hypotypes GSC 106614–106619); GSC locs. 7918, 27671, 45545, 47420, 52181, 64558, 64559, 64586, 70516, C-466, C-467, C-468, C-472, C-473, C-477, C-479, C-480, C-60934, C-60943, C-60944; Tegart Formation; also 42019, 45546, uppermost Beaverfoot Formation.

Derivation of name. In honour of Reuben J. Ross, Jr., distinguished Ordovician paleontologist and biostratigrapher.

Diagnosis. Cephalic doublure with prominent anterior projection; pygidium with strong axial, pleural, interpleural and ring furrows and eight axial rings.

Description. Cephalon about twice as wide (tr.) as long (sag.), gently arched (tr.), widest just in front of posterior border furrow (Pl. 2.4, fig. 14). Glabella low, gently convex both transversely and sagittally, expanding strongly forward, somewhat wider than long, about half as wide as cephalon, not reaching anterior margin; axial furrows well marked, almost straight; lateral glabellar furrow S1 deeply incised at axial furrow, fainter adaxially and curving forward, transverse sagittally where it is barely discernible but continuous; S2 shallow, sagittally disjunct, almost transverse but slightly curved rearward near to, but not meeting, axial furrow; S3 shallow, composed of two parts that are only very faintly connected (Pl. 2.4, figs. 14, 21), adaxial part just anterolateral of transverse, gently convex forward, abaxial part similarly convex, but anterolateral and very faint where it meets axial furrow just in front of palpebral lobe; L1 with small node against axial furrow, cut off from main part by sharply incised exsaggital furrow (Pl. 2.4, fig. 21); L2 and L3 conjunct; frontal lobe large, low, not inflated, forward part slightly depressed axially. Occipital furrow (S0) strong, deeply incised abaxially; occipital ring evenly arched (tr.). Posterior border convex, narrow adaxially, becoming broader near rear of palpebral lobe and broadest at bluntly rounded genal angle; posterior border furrow strongly marked, straight. Lateral border broad, furrow shallow and ill defined, except at junction with posterior border furrow and close in front of transect of facial suture. Fixed cheeks gently convex, almost as high as adjacent glabella, no preglabellar field. Palpebral lobe large, raised, crescentic, extending from opposite S1 to just behind junction of S3 with axial furrow; a shallow furrow (Pl. 2.4, fig. 21) is parallel to abaxial margin of palpebral lobe at about a quarter of its width from margin. Eye large, not well preserved in available material (Pl. 2.4, figs. 14, 19), probably more than 80 cylindrical lenses arranged in approximately 20 staggered files. Facial suture trends straight forward from eye, joining nearby axial furrow, curving abruptly adaxially to run almost straight along, not crossing, anterior border; posterior branch almost straight and anterior of transverse crossing lateral border furrow, at mid-border curves abruptly posterolaterally and next almost rearward to cross margin opposite abaxial elbow of border furrow. Border broad and gently convex anterolateral to glabella, narrow and convex in front of glabella and continuous sagittally behind flexed anterior doublure which forms median margin (Pl. 2.4, figs. 12–14). Cephalic doublure pronounced, about a quarter of length (sag.) of cephalon, narrow laterally; vincular furrows very strong, without any notches (Pl. 2.4, figs. 11–13), join axially on dorsal surface of doublure just in front of border. Forward the vincular furrows deepen laterally and angle across doublure to die out just in front of border; rearward they deepen laterally and angle across doublure to die out just in front of junction of posterior branch of facial suture with inner edge of doublure. Ornament of very fine granules on cephalic parts, very fine tubercles also present on anterior parts of palpebral lobes, adjacent fixed cheeks and parts of frontal lobe.

Pygidium with slightly pointed outline, wider than long, flexed transversely in midpart of pleural fields. Axis well defined, consisting of articulating half-ring, eight axial rings and a small, indistinct terminal piece. Six or seven pleural furrows and weaker, subparallel interpleural furrows, both sets strongest in midparts of pleural region, front one or two pairs just reaching margin, others do not, leaving an unfurrowed part of the field that broadens rearward; slightly raised area behind terminal piece. Ornament of very fine granules.

Comments. The new species has a more prominent median anterior projection of the cephalic doublure than *Podowrinella straitonensis* (Lamont, 1965) and *P. christiei* Lane, 1988. Compared with *P. straitonensis*, the pygidial furrows of *P. rossi* are stronger, the occipital ring is broader, and the eye and palpebral lobe are proportionally smaller. Both these species have fewer axial rings (8 and 8) than *P. christiei* (up to 18). The cephalic ornament is coarser in *P. christiei* than in *P. rossi*, with large, low tubercles on the frontal lobe.

Family LICHIDAE Hawle and Corda, 1847

Indeterminate lichid

Plate 2.3, figures 15, 16

Material and occurrence. A fragmentary cranidium (hypotype GSC 106601) and the ventral surface of a small pygidium (hypotype GSC 106602; assumed immature) that could belong to the same taxon; GSC loc. 64559; Tegart Formation.

Comments. The material is inadequate for formal description.

Family ODONTOPLEURIDAE Burmeister, 1843

Genus *Kettneraspis* Prantl and Přibyl, 1949

Kettneraspis Prantyl and Přibyl, 1949, p. 165–167.
Kettneraspis Prantyl and Přibyl, Ramsköld and Chatterton 1991, p. 357.

Type species. Acidaspis pigra Barrande, 1872 from the Acanthopyge Limestone (Middle Devonian), Czech Republic.

?*Kettneraspis* sp.

Plate 2.4, figure 28

Material and occurrence. Ventral surfaces of two free cheeks (including GSC hypotype 106609); GSC locs. 52181, 64559; Tegart Formation.

Comments. Both specimens show two spines on the anterolateral edge of the genal spine.

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APPENDIX A

Locality Data and Faunal Lists

The conodonts were studied by A.D. McCracken and T.T. Uyeno, the brachiopods by Jisuo Jin and B.S. Norford, a rugose coral by R.A. McLean, the trilobites, graptolites and tabulate corals by B.S. Norford.

Mount Tegart Section

50°27′N, 115°51′W. Tegart Formation 66 m thick
(thickness corrected from that given in Norford, 1969)

Distance above base		GSC locality
50.9–66.1 m	*Aspelundia fluegeli* (Walliser) *Belodella* sp. *Carniodus carnulus* Walliser *Panderodus* spp. *Pterospathodus procerus* (Walliser) *Walliserodus* sp.	C–60935
53.9–54.3 m	*Podowrinella rossi* n. sp. *Whitfieldella* sp.	C–60934
32.9–50.9 m	*Aspelundia capensis* Savage *A. fluegeli* (Walliser) *Belodella* sp. *Carniodus carnulus* Walliser *Panderodus* spp. *Pterospathodus procerus* (Walliser)? ?n. gen. B, n. sp. A of Over and Chatterton, 1987	C–60933
44.8 m	*Podowrinella rossi* n. sp.	C–468
43.0 m	*Podowrinella rossi* n. sp.	C–467
39.6 m	*Podowrinella rossi* n. sp. *Wallacia hendersoni* n. sp.	C–466
35.1–36.6 m	*Paltodus* sp.	C–179188
33.5–36.0 m	?*Aulopora* sp. ?*Chaetetipora* sp. *Favosites* sp. 1 ?*Svetlamia* sp. *Songkania* sp. *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Youngia* sp. 1 *Wallacia hendersoni* n. sp. *Eoplectodonta* sp. *Stegerhynchus* sp. *Whitfieldella pygmaea* Jin, Caldwell and Norford Conulariid? Undetermined gastropod	64558
32.8–33.5 m	*Pterospathodus amorphognathoides* Walliser Inarticulate brachiopod	C–179187
32.0–32.8 m	*Carniodus carnulus* (Walliser) Inarticulate brachiopod	C–179186

Distance above base		GSC locality
30.5–32.0 m	*Aspelundia fluegeli* (Walliser) *Lonchodina* sp.	C–179185
29.0.4–30.5 m	*Pterospathodus amorphognathoides* Walliser	C–179184
25.3–31.1 m	*Favosites* sp. 1 Indeterminate solitary coral ?*Kettneraspis* sp. *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Youngia* sp. 2 *Wallacia hendersoni* n. sp. ?*Lissatrypa* sp. ?Pentamerid brachiopod Chitinozoan fragments	52181
Undesignated level	*Songkania* sp.	7923
28.6–28.9 m	*Favosites* sp. 1 Undetermined colonial coral Indeterminate trilobite	C–60932
27.4–29.0 m	?*Carniodus carnulus* Walliser *Pterospathodus amorphognathoides* Walliser	C–205350
26.2–26.5 m	*Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry	C–473
25.9–27.4 m	?*Paltodus* sp.	C–205349
24.4–25.9 m	?*Paltodus* sp.	C–205348
23.8–26.0 m	?*Aulopora* sp. Indeterminate lichid trilobite ?*Kettneraspis* sp. *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Songkania* sp. *Wallacia hendersoni* n. sp. *Hesperorthis* sp. *Lissatrypa variabilis* (Whiteaves) *Pentamerus* or *Pentameroides* sp. *Monoclimacis* cf. *M. vomerinus* (Nicholson) Gastropod Straight cephalopod	64559
23.9–24.0 m	*Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry	C–472
22.9–24.4 m	Neoprioniodontiform element *Paltodus* sp.	C–205347
21.3–22.9 m	*Pterospathodus amorphognathoides* Walliser	C–205346
Approx. 19.8–23.8 m	*Favosites* sp. 2 Indeterminate solitary coral *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Wallacia hendersoni* n. sp.	7918

Distance above base		GSC locality
20.7–20.8 m	*Monograptus walcottorum* Ruedemann *Stomatograptus grandis grandis* Suess *Whitfieldella* sp.	C–471
19.8–21.3 m	*Apsidognathus tuberculatus* Walliser *Pterospathodus amorphognathoides* Walliser *P.* aff. *P. amorphognathoides* Walliser Inarticulate brachiopod	C–205345
16.8–18.3 m	Lonchodiniform and neoprioniodontiform elements ?*Paltodus* sp. Inarticulate brachiopod	C–205344
Approx. 16.2 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Stomatograptus grandis grandis* Suess	7919
15.2–16.8 m	*Acodus* sp. ?*Paltodus* sp. *Pterospathodus amorphognathoides* Walliser	C–205343
13.8–15.2 m	*Pterospathodus amorphognathoides* Walliser	C–205342
12.2–13.8 m	*Pterospathodus amorphognathoides* Walliser	C–205341
12.3–12.5 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus walcottorum* Ruedemann *Stomatograptus grandis grandis* Suess ?*Paracybantyx* sp.	C–470
10.7–12.2 m	*Distomodus staurognathoides* (Walliser) *Pterospathodus amorphognathoides* Walliser	C–205340
10.4–10.6 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann	52180
Approx. 10.1 m	*Monograptus columbianus* Ruedemann *Stomatograptus grandis grandis* (Suess)	7920
9.1–10.7 m	*Aspelundia fluegeli* (Walliser) *Distomodus staurognathoides* (Walliser)	C–205339
8.8–9.1 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedmann	C–45595
7.6–9.1 m	?*Paltodus* sp.	C–205338
Approx. 7.6 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann	7921
7.2–7.3 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann *Stomatograptus grandis grandis* (Suess)	52179
6.1–7.6 m	?*Paltodus* sp.	C–205337
4.6–6.1 m	Lonchodiform element *Aulacognathus bullatus* (Nicoll and Rexroad) ?*Paltodus* sp. *Pterospathodus celloni* (Walliser)	C–205336

Distance above base		GSC locality
Approx. 4.6 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Stomatograptus grandis grandis* (Suess)	7922
3.0–4.6 m	*Lonchodina* sp. ?*Paltodus* sp.	C–205335
2.7–3.1 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson)	C–45596
1.5–1.8 m	*Monograptus walcottorum* Ruedemann *Stomatograptus grandis grandis* (Suess) Chitinozoan fragments Indeterminate brachiopods Straight cephalopod	C–469
0.6–0.9 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus walcottorum* Rudemann	52178
0–1.5 m	*Pterospathodus celloni* (Walliser) *Ozarkodina* cf. *O. hadra* (Nicoll and Rexroad) Spathognathodontiform element	C–205334
Minus 0.4–0 m Beaverfoot	Straight cephalopod	C–205915

Pedley Pass Section

50°27′N, 115°46′W. Tegart Formation 51 m thick (Norford, 1969)

46.9–50.6 m	*Aspelundia fluegeli* (Walliser) *Panderodus* spp. *Pseudooneotodus beckmanni* (Bischoff and Sannemann) *Pterospathodus procerus* (Walliser)	C–60945
48.8–49.4 m	*Podowrinella rossi* n. sp. *Lissatrypa variabilis* (Whiteaves)	C–60944
45.5–48.2 m	*Podowrinella rossi* n. sp.	C–480
42.7–45.7 m	?*Paltodus* sp.	C–179197
40.0–40.2 m	*Podowrinella rossi* n. sp.	C–479
36.6–39.6 m	*Pterospathodus amorphognathoides* Walliser	C–179196
33.5–36.6	*Paltodus* sp.	C–179195
30.5–33.5 m	*Pterospathodus* aff. *P. amorphognathoides* Walliser	C–179194
30.8–31.1 m	*Monograptus* sp. *M.* cf. *M. linnarssoni* Tullberg *M. walcottorum* Ruedemann *Retiolites geinitzianus angustidens* Elles and Wood	C–478
21.6–40.0 m	*Paracybantyx tegartensis* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Wallacia hendersoni* n. sp. *Monograptus* cf. *M. linnarssoni* Tullberg	47397
27.4–30.5 m	Lonchodiniform element *Aspelundia fluegeli* (Walliser) *Pterospathodus amorphognathoides* Walliser	C–179193

Distance above base		**GSC locality**
25.3–28.0 m	Small gastropod Indeterminate coral *Favosites* sp. 1 *Songkania* sp. *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Wallacia hendersoni* n. sp. *Lissatrypa variabilis* (Whiteaves) *Skenidoides* sp. Indeterminate orthid and strophomenid brachiopods ?Bivalve	C–477
24.4–27.4 m	?*Ozarkodina* sp. *Paltodus* sp.	C–179192
21.3–24.4 m	*Neoprioniodus* sp. *Paltodus* sp.	C–179191
21.3–21.6 m	*Favosites* sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Wallacia hendersoni* n. sp. *Lissatrypa* sp.	C–60943
18.3–21.3 m	*Pterospathodus amorphognathoides* Walliser	C–179190
Talus from 16.50–50.6 m	*Wallacia hendersoni* n. sp.	C–45587
14.00–14.03 m	*Monograptus walcottorum* Ruedemann	52175
13.93–13.98 m	*Monograptus walcottorum* Ruedemann	52174
10.7 m	*Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann *Stomatograptus grandis grandis* (Suess)	42021
Float at 6.1–10.7 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *Stomatograptus grandis grandis* (Suess)	42022
3.0–6.1 m	*Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann	42023
Top 1.5 m of underlying Beaverfoot Formation.	?*Hibbardella* sp. ?*Panderodus* sp.	C–179189
Top 12.5 m of underlying Beaverfoot Formation.	*Aspelundia fluegeli* (Walliser) *Aulacognathus bullatus* (Nicoll and Rexroad) *A. latus* (Nicoll and Rexroad) *Belodella* sp. *Distomodus* sp. *Oulodus*? sp. *Ozarkodina* aff. *O. polinclinata* (Nicoll and Rexroad) *Panderodus* spp. *Pterospathodus celloni* (Walliser)	C–45586

Distance above base	GSC locality
2.7–5.8 m below top of Beaverfoot Formation *Podowrinella rossi* n. sp.	42019
50°08′N, 115°32′W. Alces Lake area	
Road cut at southeastern end of Alces Lake. 3.7–5.2 m above base of Tegart Formation. *Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Rudemann *Stomatograptus grandis grandis* (Suess)	45544
28.7–43.3 m below top of underlying Beaverfoot Formation. *Podowrinella rossi* n. sp. *Atrypa* (*Gotatrypa*) *gibbosa* Hall	45546
Various localities on north, northeast and southeast shores of Alces Lake, several outcrops of uncertain stratigraphic position within the Tegart Formation. "*Encrinurus*" sp. *Podowrinella rossi* n. sp. *Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann *Stomatograptus grandis grandis* (Suess) *Lissatypa variabilis* (Whiteaves) *Whitfieldella pygmaea* Jin, Caldwell and Norford Straight cephalopod	23921 27670 27671 27673 27726
50°38.5′N, 115°59.8′W. Road outcrop East of Radium	
South side of highway, 4.75 km east of Hot Pool on Sinclair Creek, Tegart Formation, from 12.8 m of beds of uncertain stratigraphic position. *Paracybantyx tegartensis* n. sp. *Podowrinella rossi* n. sp. *Radiurus avalanchensis* Chatterton and Perry *Songkania* sp. *Wallacia hendersoni* n. sp. Indeterminate ostracode *Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus columbianus* Ruedemann *M. walcottorum* Ruedemann *Stomatograptus grandis grandis* (Suess) Straight cephalopod	45545 47420 52161 52162
North side of highway, 4.70 km east of Hot Pool on Sinclair Creek, Tegart Formation. *Podowrinella rossi* n. sp. *Songkania* sp.	64586
49°58′23″N, 115°23′45″W. Ridge East of Coyote Creek	
Tegart Formation, undesignated stratigraphic position.	32335

Distance above base	GSC locality
49°58′23″N, 115°23′45″W. Ridge East of Coyote Creek (cont'd)	
Monoclimacis cf. *M. vomerinus* (Nicholson) *Monograptus walcottorum* Ruedemann Straight cephalopod	
49°53′20″N, 115°20′56″W. Divide East of Coyote Creek headwaters	
Tegart Formation, undesignated stratigraphic position. "*Encrinurus*" sp. *Monoclimacis* cf. *M. vomerinus* (Nicholson) *Monograptus walcottorum* Ruedemann	32336
About 50°11′N, 115°20″W. Ridge northeast of junction of North White River and Blackfoot Creek	
Tegart Formation, float from basal 4 m. *Dicaelosia parvifrons* Johnson, Boucot and Murphy *Lissatrypa variabilis* (Whiteaves) Undetermined brachiopods	49231
Tegart Formation, 1.2–2.1 m above base. *Monograptus* sp. *M. walcottorum* Ruedemann Undetermined brachiopods	47419
50°37″N, 115 58′W. Divide between Redstreak and Stoddart creeks	
Tegart Formation, undesignated stratigraphic position. *Podowrinella rossi* n. sp. *Scotoharpes* sp. ?*Lissatrypa* sp. Undetermined brachiopods	70516

PLATES 2.1 to 2.5

PLATE 2.1

Figures 1–16. *Paracybantyx tegartensis* n. sp.

1. Partly exfoliated cranidium (see Fig. 2.6), hypotype GSC 106580; x4; showing finely granular ornament, paired muscular impressions and axial tubercle; GSC loc. C–477.

2–4. Dorsal, anterior, lateral views of small cranidium, hypotype GSC 106581; x4; GSC loc. 52162.

5–7, 9, 10. Dorsal, lateral, lateral, tilted posterior, anterior views of holotype cranidium, GSC 106575; x3; GSC loc. 64558.

8. Ventral view of interior of small pygidium, hypotype GSC 106582; x4; showing finely granular ornament of ventral surface and a part of the doublure with terrace lines on its ventral surface; GSC loc. 52162.

11, 14. Posterior, dorsal views of mostly exfoliated pygidium, paratype GSC 106576; x3; note subtle axial keel posteriorly; GSC loc. 64558.

12. Lateral view of small, partly exfoliated pygidium, paratype GSC 106577; x3; note terrace lines on doublure; GSC loc. 64558.

13, 15, 16. Posterior, lateral, tilted dorsal views of mostly exfoliated pygidium, paratype GSC 106578; x3; GSC loc. 64558.


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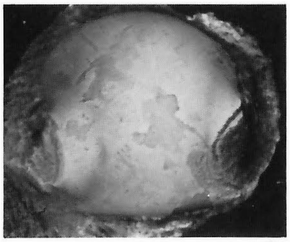
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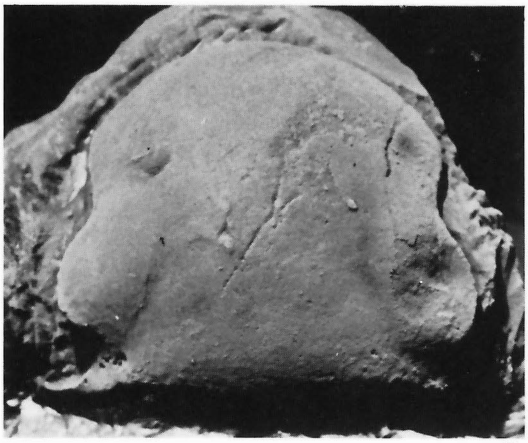
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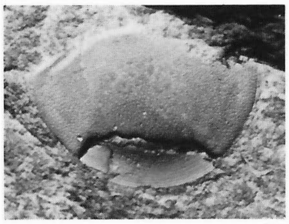
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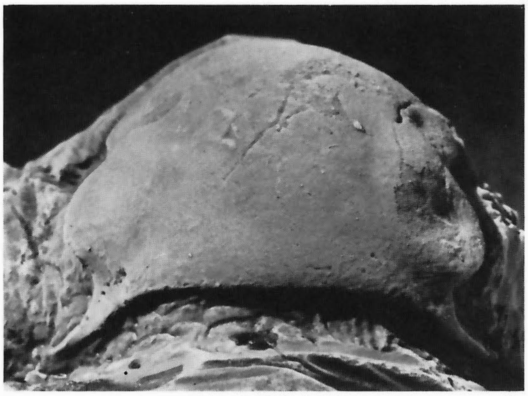
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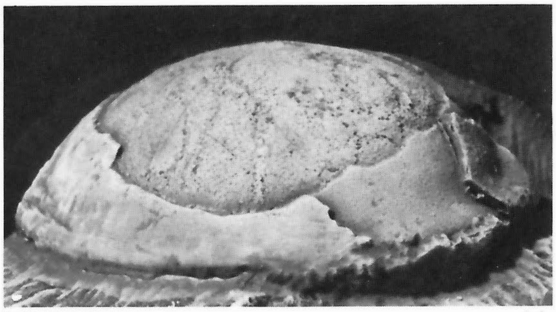
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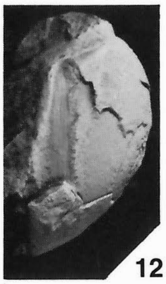
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PLATE 2.2

Figures 1–10, 12–14, 16, 17. *Radiurus avalanchensis* Chatterton and Perry

1, 4, 5. Dorsal view of incomplete cranidia, hypotypes GSC 106584, 106587, 106588; x4, x3, x4; showing external ornament; GSC locs. 64559, 47420, 47420.

2, 6 Dorsal, lateral views of fragmentary cranidium, largely exfoliated, hypotype GSC 106585; x3; GSC loc. 47420.

3, 7, 8. Dorsal, lateral, anterior views of incomplete cranidium, largely exfoliated, hypotype GSC 106586; x3; GSC loc. 7918. Also exfoliated pygidium of *Podowrinella rossi* n. sp.

9, 12. Ventral, lateral view of hypostome thought to belong to the species, hypotype GSC 106589; x3; GSC loc. C–477.

10. Dorsal view of incomplete free cheek, hypotype GSC 106590; x3; GSC loc. 47420.

13. Ventral view of incomplete pygidium, hypotype GSC 106591; x4; GSC loc. 64559.

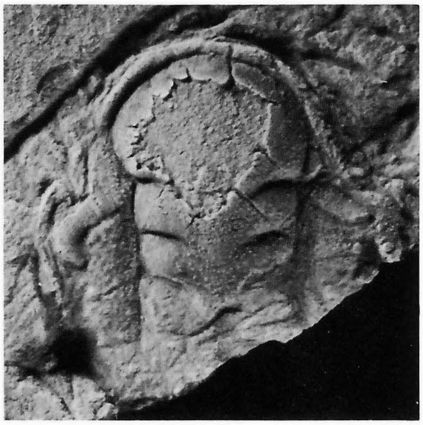
14. Dorsal view of incomplete pygidium, hypotype GSC 106592; x3; GSC loc. 64559.

16. Dorsal view of fragmentary cephalon showing genal spine, hypotype GSC 106593; x4; GSC loc. 7918.

17. Dorsal view of large incomplete pygidium, hypotype GSC 106594; x4; GSC loc. 7918. Also ventral view of several thoracic segments of *Wallacia hendersoni* n. sp. and of a pygidium of the same species with fragments of the two hindmost thoracic segments.

Figure 11. *Paracybantyx tegartensis* n. sp. Incomplete free cheek, hypotype GSC 106583; x4; GSC loc. C–477.

Figure 15. *Scotoharpes* sp. Ventral surface of incomplete lower lamella, showing parts of fringe and gena, hypotype GSC 27795; x3; GSC loc. 70516.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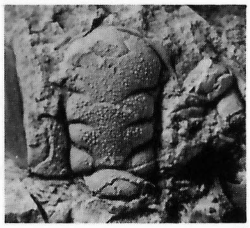
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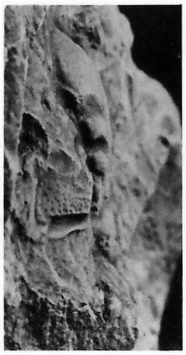
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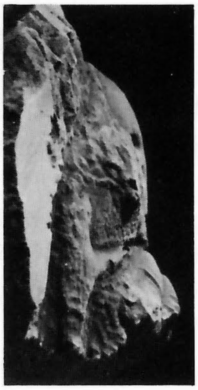
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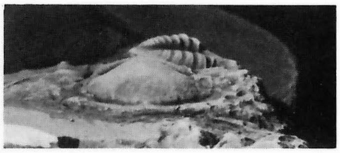
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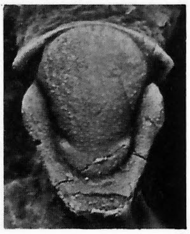
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PLATE 2.3

Figures 1–14, 17, 19–24. *Wallacia hendersoni* n. sp.

1–4. Dorsal, posterior, anterior, lateral views of cranidium, holotype GSC 106595; x3; GSC loc. 64559.

5–9. Left lateral, right lateral, dorsal, anterior and tilted anterior views of almost complete specimen, paratype GSC 106596; x3; GSC loc. 64559. See also Plate 2.4, fig. 29.

10, 14. Dorsal, lateral views of free cheek, hypotype GSC 106597; x3; GSC loc. 7918 (specimen broken after photography).

11, 17. Dorsal, lateral views of free cheek, paratype GSC 106598; x3; GSC loc. 64559.

12, 13. Dorsal views of free cheeks, paratypes GSC 106599, 106600; x3; GSC loc. 64559.

19, 20, 24. Lateral, rear, dorsal views of pygidium, hypotype GSC 106603; x3; note damaged right posterolateral pleural region; GSC loc. C–45587.

21, 23. Dorsal views of exfoliated pygidia, hypotypes GSC 106604, 106606; x3; GSC locs. 7918, 45545.

22. View of ventral surface of pygidium, hypotype GSC 106605; x3; GSC loc. 45545.

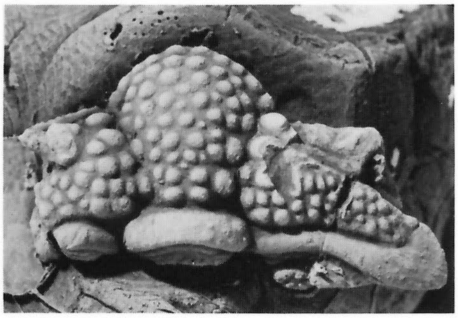
Figures 15, 16. Indeterminate lichid

15. Dorsal view of fragmentary partly exfoliated cranidium, hypotype GSC 106601; x3; GSC loc. 64559.

16. Ventral view of small pygidium that may belong to the taxon, hypotype GSC 106602; x3; GSC loc. 64559.

Figure 18. *Paracybantyx tegartensis* n. sp. Lateral view of incomplete cranidium, paratype GSC 106579; x2; note shallow pit at anterior end of axial furrow; GSC loc. 64558.

PLATE 2.3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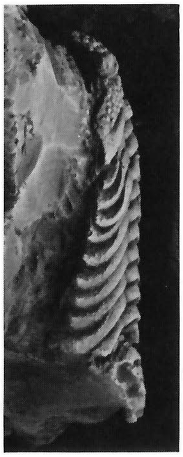
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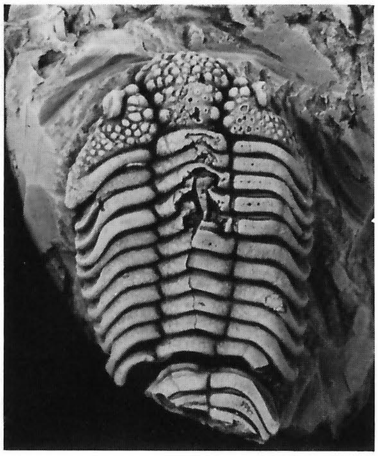
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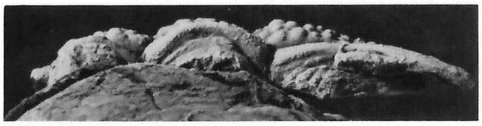
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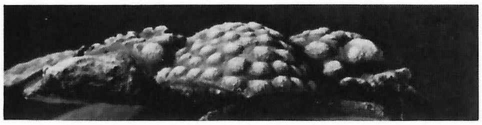
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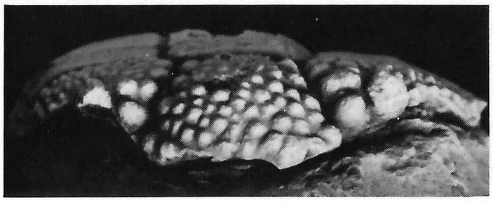
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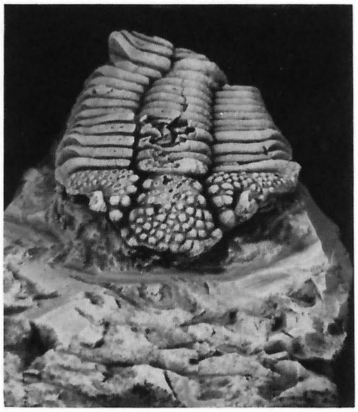
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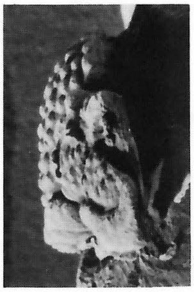
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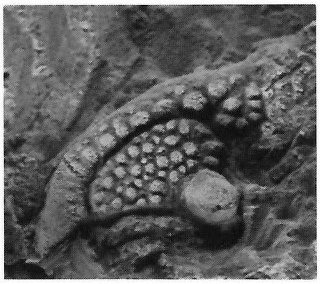
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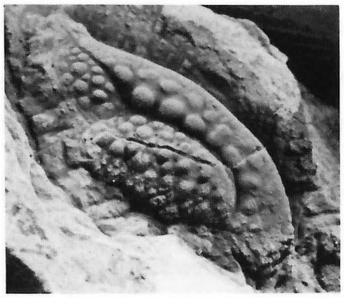
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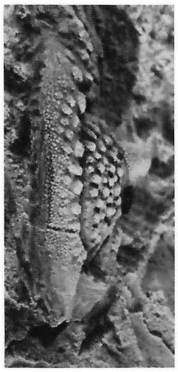
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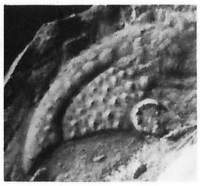
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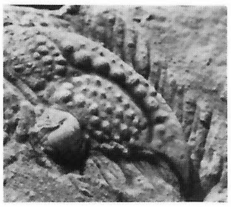
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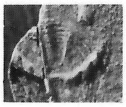
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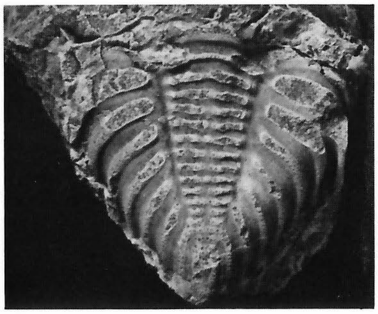
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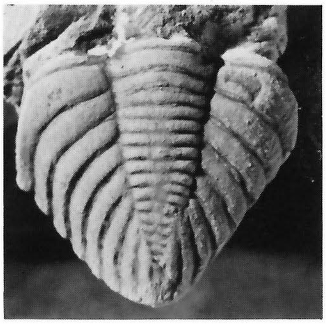
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PLATE 2.4

Figures 1–4, 8, 9. *Youngia* sp. 1. Dorsal, posterior, anterior, lateral views (fig. 2.8 same as fig. 2.4, but enlarged and with different lighting) of cranidium, hypotype GSC 106607; x3 (8, 9 x4); GSC loc. 64558.

Figures 5–7. *Youngia* sp. 2. Dorsal, lateral, anterior views of incomplete cranidium, hypotype GSC 106608; x3; GSC loc. 64558.

Figures 10, 15–18. *Songkania* sp.

10, 16, 17. Lateral, dorsal, posterior views of small pygidium, hypotype GSC 106612; x8; GSC loc. 45545.

15. Dorsal view of somewhat flattened cranidium, hypotype GSC 106611; x3; GSC loc. 64559.

18. Dorsal view of free cheek, hypotype GSC 106613; x3; GSC loc. 64559.

Figures 11–14, 19–27, 29, 30, 32–35. *Podowrinella rossi* n. sp.

11–14. Ventral, anterior, lateral, dorsal views of incomplete cephalon, holotype GSC 106610; x3; GSC loc. C-467.

19. Lateral view of incomplete free cheek and eye, hypotype GSC 106616; x8; GSC loc. 64559.

20, 21. Lateral, dorsal views of cranidium, hypotype GSC 106617; x4; GSC loc. 52181.

22, 30, 35. Lateral, posterior, dorsal views of exfoliated pygidium; hypotype GSC 106619; x3; GSC loc. 26671.

23, 27, 32. Lateral, tilted posterior, dorsal views of slightly flattened pygidium, hypotype GSC 106614; x3; GSC loc. 64558.

24, 29, 33, 34. Lateral, posterior, and two dorsal views of slightly flattened pygidium, hypotype GSC 106615; x3; GSC loc. 64558. Figures 33 and 34 same view but different lighting.

25, 26, 31, 36. Right lateral, left lateral, posterior, dorsal views of exfoliated pygidium, hypotype GSC 106618; x3; GSC loc. C-480.

Figure 28. ?*Kettnerapsis* sp. Ventral surface of incomplete free cheek, hypotype GSC 106609; x4; GSC loc. 64559.

Figure 37. *Wallacia hendersoni* n. sp. Right lateral view of almost complete specimen, hypotype GSC 106596; x4; GSC loc. 64559. Similar view to Plate 2.3, figure 6 but with different lighting to show pleurae better.


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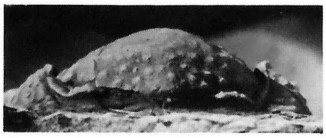
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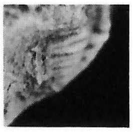
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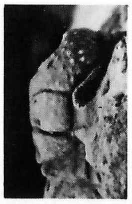
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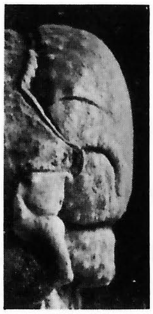
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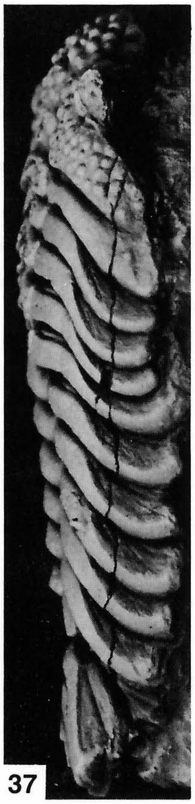
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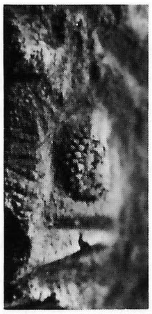
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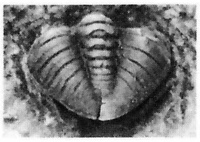
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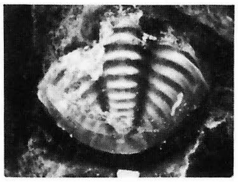
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PLATE 2.5

Illustrations of some biostratigraphically important graptolite species in the Tegart Formation.

Figures 1, 2.	*Monoclimacis* cf. *M. vomerinus* (Nicholson). Hypotype GSC 106783; x3; GSC loc. 32335. In figure 2, part of the specimen is photographed under liquid and better shows the outline of some of the thecae.
Figures 3, 4.	*Stomatograptus grandis grandis* (Suess). Hypotype GSC 106782; x3; GSC loc. 45545. Figure 3 is the counterpart of the specimen and shows in relief the median row of large pores.
Figure 5.	*Monograptus columbianus* Ruedemann. Hypotype GSC 106784; x3; GSC loc. 42022. *Monograptus columbianus* belongs to the *Monograptus priodon* (Bronn) group of species that is common in Telychian and Sheinwoodian graptolite faunas.
Figure 6.	*Retiolites geinitzianus angustidens* Elles and Wood. Hypotype GSC 106785; x3; GSC loc. C–478.
Figure 7.	*Monograptus walcottorum* Ruedemann. Hypotype GSC 106786; x3; GSC loc. 47419. *Monograptus walcottorum* belongs to the *Monograptus spiralis* (Geinitz) group of species that is a prominent constituent of Telychian graptolite faunas.


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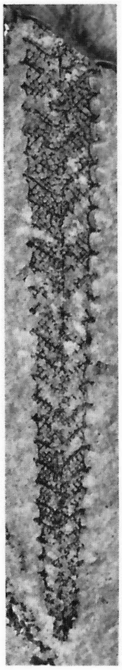
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LE BIVALVE DÉVONIEN *PROSOCOELUS* KEFERSTEIN, 1857 DANS LE NORD-EST DE L'AMÉRIQUE DU NORD

Sylvain Desbiens[1]

*Le bivalve devonien **Prosocoelus** Keferstein, 1857 dans le nord-est de l'Amérique du Nord. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 479, p. 49–65.*

Résumé

Quatre espèces du Dévonien inférieur de l'est du Canada et des États-Unis indiquent que la diffusion du bivalve rhénan *Prosocoelus* Keferstein, 1857 a atteint le côté ouest de l'océan Iapétus. Ces espèces sont décrites et une nouvelle espèce, *Prosocoelus undans* sp. nov., est érigée. *Prosocoelus* est assigné aux Carditidae Fleming et un statut générique est accordé à *Prosocoelogeton* Quenstedt du Spitsbergen. *Prosocoelus* fait sa première apparition nord-américaine dans des strates siegéniennes de la Formation de Torbrook en Nouvelle-Écosse. Il est également présent dans les formations emsiennes de York River au Québec et de Tomhegan dans le Maine. D'autres bivalves rhénans sont reconnus dans la Formation de York River. La signification paléobiogéographique de ces fossiles est discutée.

Abstract

Four Lower Devonian species from eastern Canada and the United States show that the Rhenish bivalve *Prosocoelus* Keferstein, 1857 had reached the western part of the Iapetus Ocean. These four species are described and a new species, *Prosocoelus undans* sp. nov., is established. *Prosocoelus* is assigned to the Carditidae Fleming, and the status of genus is given to *Prosocoelogeton* Quenstedt from Spitsbergen. The first North American occurrence of *Prosocoelus* is in Siegenian strata of the Torbrook Formation in Nova Scotia. The genus is also found in two Emsian formations, the York River in Quebec and the Tomhegan in Maine. Other Rhenish bivalves are recognized in the York River Formation. The paleobiogeographic significance of these fossils is discussed.

INTRODUCTION

Le bivalve *Prosocoelus* est caractéristique du Dévonien inférieur rhénan (Siegenien et Emsien) d'Allemagne (Haffer, 1959) et de Belgique (Maillieux, 1937). Quatre espèces de trois régions du nord-est de l'Amérique du Nord indiquent que la diffusion du genre a également atteint le côté ouest de l'océan Iapetus. Les localités nord-américaines sont situées dans l'est de la Gaspésie au Québec, sur la berge ouest du lac Moosehead dans le Maine et dans la vallée d'Annapolis en Nouvelle-Écosse (Fig. 3.1).

Nomenclature chronostratigraphique

La sous-commission de l'IUGS chargée de la stratigraphie du Dévonien a agréé le Lochkovien, le Praguien et l'Emsien comme étages du Dévonien inférieur. Comme *Prosocoelus* est absent des strates hercyniennes de Tchécoslovaquie et que les corrélations entre les séquences tchèque et rhénane ne sont pas bien établies, la nomenclature stratigraphique de référence rhénane est utilisée ici.

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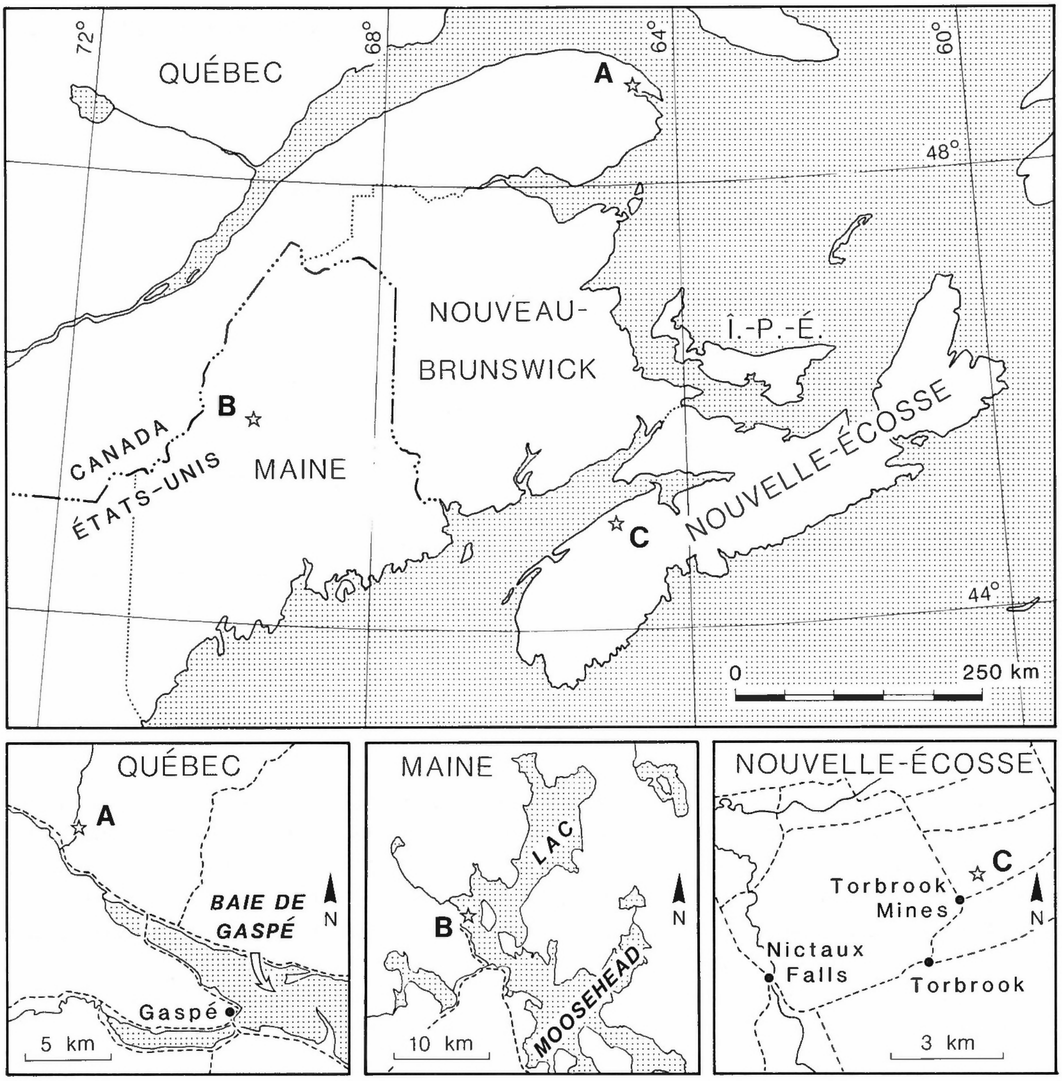

Figure 3.1. *Localisation des sites fossilifères discutés.* ***A,*** *rivière Petite Fourche au Québec, partie supérieure de la Formation de York River;* ***B,*** *pointe Baker Brook sur la berge ouest du lac Moosehead dans le Maine, Formation de Tomhegan;* ***C,*** *nord-est de Torbrook Mines en Nouvelle-Écosse, Formation de Torbrook.*

Remerciements

Je tiens à remercier Paul A. Johnston du Royal Tyrrell Museum of Paleontology en Alberta pour ses commentaires constructifs. Ed Landing du New York State Museum à Albany m'a courtoisement accordé un prêt du matériel-type du Maine. Greg Martin a préparé les moulages en latex. Cette contribution a été réalisée lors d'un stage post-doctoral à la Commission géologique du Canada à Ottawa. Le support financier du CRSNG sous forme de bourse a été grandement apprécié.

DISTRIBUTION DU GENRE *PROSOCOELUS* EN AMÉRIQUE DU NORD

Québec

L'auteur a collecté une nouvelle espèce de *Prosocoelus* dans un niveau de shale de la partie supérieure de la Formation de York River de l'est de la Gaspésie. Le niveau fossilifère est situé le long de la rivière Petite Fourche, 14 km au nord-ouest de la ville de Gaspé (Fig. 3.1A). Il a également livré les brachiopodes *Costellispirifer gaspensis* (Billings), *Globithyris*? sp. et les bivalves *Nuculites triqueter* (Conrad) et *Modiolopsis*? sp. Les brachiopodes de la Formation de York River de la région de Gaspé indiquent la Zone appalachienne à *Etymothyris* (Desbiens, 1991, 1992, et sous presse) et une corrélation avec la Formation d'Esopus dans l'État de New York (Boucot et Johnson, 1967). La Zone à *Etymothyris* est généralement corrélée avec l'Emsien (op. cit., Dutro, 1981), mais la limite inférieure de cet étage, dans l'est de l'Amérique du Nord, n'est pas fixée avec précision (Rickard, 1981). À Gaspé, la base de l'Emsien est située dans la partie supérieure du Groupe des Calcaires Supérieurs de Gaspé ou dans les strates inférieures sus-jacentes de la Formation de York River (McGregor, 1977; Richardson et McGregor, 1986; Desbiens, sous presse).

Maine

Deux espèces de *Prosocoelus*, collectées par O.O. Nylander en 1905 sur la berge ouest du lac Moosehead dans le Maine, ont été décrites par Clarke (1907, 1909). Ce dernier est inconsistant lorsqu'il signale la provenance de ces espèces. Dans sa liste faunique de la pointe Baker Brook (1909, p. 58, locs. 3454 et 3455), Clarke cite *Prosocoelus occidentalis* Clarke avec les bivalves *Modiomorpha odiata* Clarke (réillustré par Pojeta et al., 1986, Pl. 17, fig. 3), *Cypricardinia magna* Clarke et les brachiopodes *Euryspirifer atlanticus* (Clarke), *Costellispirifer perimele* (Clarke) et *Amphigenia parva* Clarke. Ces données sont compatibles avec celles de Boucot (1969) qui inclut les strates de cette localité dans la Formation de Tomhegan. Ce dernier a identifié à cet endroit (op. cit., tableau 1, loc. USGS 2750) les brachiopodes *Charionoides doris* (Hall), *Cyrtoniscus nectus* (Clarke), *Eodevonaria arcuata* (Hall) et *Amphigenia parva* qui indiquent la Zone appalachienne à *Amphigenia*. Ailleurs, Clarke (1907, p. 224 et 1909, p. 75, Pl. 16, figs. 14, 15) mentionne pourtant que *P. occidentalis* a été collectée à la pointe Tomhegan, 2 km au nord de la pointe Baker Brook [sic]. Les strates de la pointe Tomhegan appartiennent à la Formation de Tarratine (Boucot, 1969, Pl. 13), datée de la Zone à *Rensselaeria* (Boucot, 1973). Le spécimen d'*A. parva* de Clarke (1909, Pl. 18, figs. 7, 8) ne peut en conséquence provenir de la pointe Tomhegan (voir également Clarke, 1907, p. 247, 248). La présence d'une valve pédonculaire d'*A. parva* (Pl. 3.2, fig. 14) sur l'échantillon-type NYSM 9014 démontre clairement que *P. occidentalis* provient de la pointe Baker Brook (Fig. 3.1B). La seconde espèce, *P.* cf. *P. orbicularis* Beushausen, provient de la même localité que *P. occidentalis* (Clarke, 1907, p. 224, 1909, p. 75). La Formation de Tomhegan est corrélée avec les Formations emsiennes de Schoharie et de Bois Blanc de l'État de New York (Boucot et Johnson, 1967, 1968; Boucot, 1969, 1973).

Nouvelle-Écosse

Prosocoelus pesanseris (Zeiler et Wirtgen) a de plus été identifiée dans la collection GSC 873. Celle-ci a été échantillonnée par E.J. Whittaker en 1913, le long d'une voie ferrée, 1 km au nord-est de Torbrook Mines dans la vallée d'Annapolis en Nouvelle-Écosse (Fig. 3.1C). La collection contient également le gastéropode *Pedalosia* sp., le bivalve *Nuculites* sp., les brachiopodes *Vandercammenina* cf. *V. bischofi* (Giebel), *Acrospirifer*? sp. et le trilobite *Digonus* sp. Les spécimens proviennent d'un niveau de shale et de grès oolithique ferrugineux de la Formation de Torbrook. Cette formation, également connue sous les appellations de «Bear river beds», «Nictaux iron ore beds», et «Torbrook Sandstone» (Smitheringale, 1960; Taylor, 1969), est caractérisée par une faune rhénane du Gedinnien–Siegenien à possiblement Emsien (Boucot, 1960a). La distribution du genre *Prosocoelus* en Europe (Maillieux, 1937; Haffer, 1959) restreint l'âge de la collection au Siegenien–Emsien.

PALÉOBIOGÉOGRAPHIE

Chavan (1969) considère que la diffusion du genre *Prosocoelus* s'est restreinte à l'Europe moyenne et au Spitsbergen. Un statut générique est accordé à *Prosocoelogeton* du Spitsbergen. En Europe, *Prosocoelus* est répandu dans le Siegenien et l'Emsien classique d'Allemagne et de Belgique. Le genre est présent dans les Grès de Kahleberg du Harz (Keferstein, 1857; Beushausen, 1884, 1895; Dahmer, 1918, 1922) et il a été reporté à plusieurs reprises dans les Reinischen Schiefergebirge (Haffer, 1959). Il est présent dans les Siegenerschichten (Dahmer, 1936a et b, 1937), les Coblenzschichten (Beushausen, 1895; Fuchs, 1915; Richter et Richter, 1918; Mauz, 1935; Solle, 1936; Dahmer, 1940) et les Taunusquarzit (Sandberger, 1889; Beushausen, 1895). Dans l'Ardenne belge, Maillieux (1932, 1937) l'a signalé dans les Grès d'Anor, les Grès de Mormont, les Quarzophyllades de Schutbourg et l'Assise de Winenne. *Prosocoelus* a également été signalé en Chine (Liu, 1978, 1979; Zhang, 1977, 1989).

Prosocoelus est, en outre, rencontré dans trois régions du nord-est de l'Amérique du Nord. La présence de *P. pesanseris* dans la Formation de Torbrook de la vallée d'Annapolis en Nouvelle-Écosse, une espèce caractéristique des Taunusquartzit et des

Siegenerschichten (Maillieux, 1937), indique que déjà au Siegenien *Prosocoelus* était engagé dans une dispersion trans-Iapetus. Une faune rhénane de brachiopodes, incluant *Tropidoleptus* Hall, *Vandercammenina* Boucot et *Meganteris* Seuss, caractérise la Formation de Torbrook (Gedinnien–Emsien?; Boucot, 1960a, b; Isaacson et Perry, 1977). Blaise et al. (1990) ont également décrit des chitinozoaires et des restes d'échinodermes et de vertébrés d'affinités européennes de la Formation sous-jacente de White Rock (Ludlovien–Pridolien). Dans le Maine, *Prosocoelus* est associé à une faune appalachienne de brachiopodes qui indique la Formation emsienne de Tomhegan. Les bivalves du Maine n'ont pas été étudiés depuis Clarke (1909) et Williams et Breger (1916). Ils mériteraient d'être réévalués. Le genre *Prosocoelus* est également présent au Québec dans la Formation emsienne de York River. Cette dernière formation contient plusieurs taxons rhénans mélangés à une faune appalachienne (Boucot, 1975; Desbiens, 1991). Aux brachiopodes *Rhenorensselaeria* Kegel et *Mutationella* Kozlowski, s'ajoutent les bivalves *Limoptera* cf. *L. bifida* Sandberger et Sandberger, *Montanaria* sp. nov., *Radiatodonta* sp. nov., *Carydium* sp., *Schysodus*? *circularis* Beushausen, *Schysodus*? cf. *S.*? *inflata* Roemer et *Goniophora* aff. *G. exilis* Drevermann (Desbiens, sous presse et données inédites). *Nuculites triqueter* (Conrad), *Nuculites oblongatus* (Conrad) [=*N. ellipticus* (Maurer); *fide* Bailey, 1983] et *Paracyclas rugosa* (Goldfuss), des espèces répandues dans le Dévonien moyen américain (op. cit.), sont également présentes dans le Dévonien inférieur allemand et dans la Formation de York River. De plus, les espèces du Groupe d'Hamilton newyorkais *Modiella pygmaea* (Conrad), *Goniophora rugosa* (Conrad) et *Cimitaria recurva* (Conrad) apparaissent précocement en Gaspésie, dans cette même formation. Cette faune sera décrite ailleurs.

Les sédiments détritiques des Formations de York River et de Tomhegan sont issus de phases précoces de l'orogénèse acadienne en bordure du craton Laurentia. L'origine des terrains sédimentaires du sud de la Nouvelle-Écosse inclus dans la zone tectonostratigraphique de Méguma par Williams (1979) est incertaine. Selon les auteurs, on voit dans la terrane de Méguma un morceau de l'Europe de l'Ouest, de l'Afrique du Nord, du nord de l'Amérique du Sud ou d'un ancien petit craton situé entre ces derniers. Ces différentes hypothèses et leurs implications pour les reconstitutions paléogéographiques sont discutées par Keppie (1977), Schenk (1981), Bouyx et al. (1985), Kent et Keppie (1988) et Blaise et al. (1990). L'accrétion du sud de la Nouvelle-Écosse au bloc continental nord-américain était, par contre, déjà complétée ou très avancée au Dévonien inférieur (Williams, 1979; Schenk, 1981; Bouyx et al., 1985; Keppie et Dallmeyer, 1987).

Dans des études sédimentaires incorporant l'ensemble des données fauniques des Rheinisches Schiefergebirge, Fuchs (1974, 1982) relie *Prosocoelus* à des environnements sédimentaires silicoclastiques littoraux ou proches du rivage. Jensen (1975; Formation de Torbrook), Boucot (1969; Formation de Tomhegan) et Desbiens (1991 et sous presse; Formation de York River) proposent des environnements de sédimentation comparables pour les sites nord-américains. La Figure 3.2 donne la

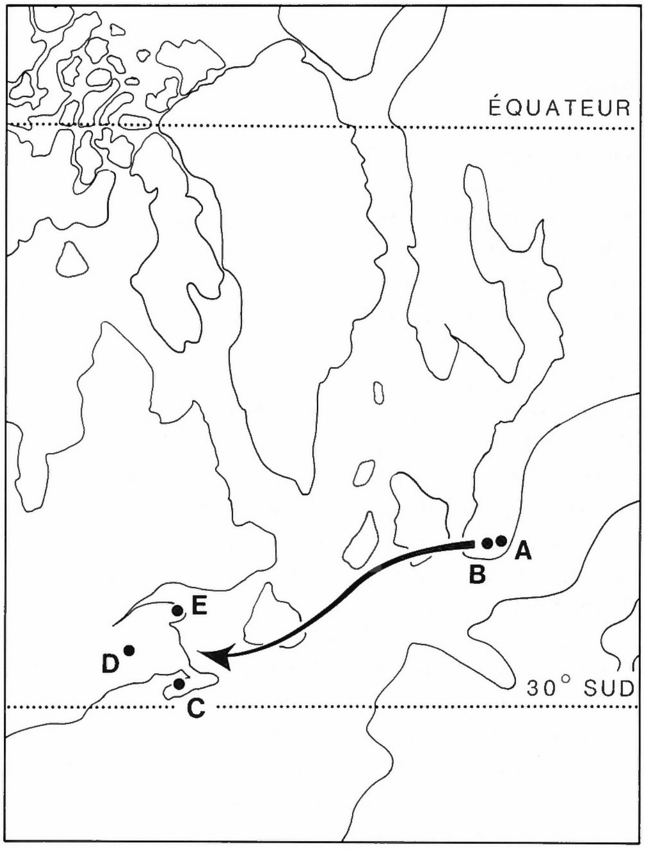

Figure 3.2. *Répartition péri–atlantique du genre* ***Prosocoelus*** *au Dévonien inférieur. La base géographique emsienne de Scotese et McKerrow (1990) est utilisée.* ***A:*** *Allemagne (Siegenien–Emsien): Keferstein (1857); Beushausen (1884, 1895); Spriestersbach et Fuchs (1909); Fuchs (1915); Dahmer (1918, 1937); Richter et Richter (1918); Mauz (1935); Solle (1936); Haffer (1959); Fuchs (1974, 1982).* ***B:*** *Belgique (Siegenien–Emsien): Maillieux (1932, 1937); Haffer (1959).* ***C:*** *Nouvelle-Écosse (Siegenien).* ***D:*** *Maine (Emsien): Clarke (1907, 1909).* ***E:*** *Québec (Emsien): Desbiens (1991).*

distribution péri-atlantique du genre *Prosocoelus*, à partir de la reconstitution emsienne de Scotese et McKerrow (1990). Sur cette reconstitution, le genre se limite aux latitudes sub-tropicales sud d'un océan Iapétus en fermeture. L'âge d'apparition de *Prosocoelus* aux différents sites suggère une migration est-ouest, de l'Europe de l'ouest vers le nord-est de l'Amérique du Nord. La diffusion du genre a été favorisée par l'étendue restreinte de l'océan Iapétus et par la présence aux mêmes latitudes, d'environnements de sédimentation comparables des deux côtés de la nappe océanique restante.

Bailey (1978, 1983) a démontré une invasion post-emsienne majeure de bivalves rhénans dans le nord-est de l'Amérique du Nord. La répartition stratigraphique de *Prosocoelus* (Siegenien et Emsien) dans les régions périphériques de l'océan Iapetus et la présence de plusieurs éléments rhénans dans la Formation de York River (Emsien) indiquent que ces migrations ont été progressives à partir du Siegenien. Les travaux de Bailey (op. cit.) sur les bivalves du Groupe d'Hamilton révèlent une augmentation marquée des immigrants au Givetien. Cet auteur favorise une route migratoire Europe-Amérique via l'Afrique du Nord. Une voie menant directement au nord-est de l'Amérique du Nord a également été utilisée par les bivalves du Dévonien inférieur. La région de Gaspé a probablement servie de relais à quelques espèces rhénanes dans leur migration vers l'État de New York, et elle a été centre d'origine de quelques espèces du Groupe d'Hamilton.

PALÉONTOLOGIE SYSTÉMATIQUE

Les spécimens-types et illustrés sont conservés à la Commission géologique du Canada à Ottawa (préfixe GSC) et au New York State Museum à Albany (préfixe NYSM).

Phylum MOLLUSCA Cuvier, 1798

Classification et méthodes. La classification supra-familiale de Pojeta (1971, 1987) est utilisée. La longueur des spécimens (L) a été mesurée parallèlement à l'axe du ligament, et la hauteur maximale (H), perpendiculairement à ce dernier.

Classe BIVALVIA Linné, 1758

Sous-classe HETEROCONCHIA Hertwig, 1895

Super-famille CARDITACEA Fleming, 1820

Famille CARDITIDAE Fleming, 1828

Discussion. Chavan (1969) assigne *Prosocoelus* aux Opinae et Morris (1978) signale sa possible affiliation aux Astartellinae. La dentition cardinale de *Prosocoelus* et des astartides paléozoïques, incluant *Cypricardella* Hall et *Eodon* Hall (voir Morris, 1978 et Pojeta et al., 1986), est restreinte à un maximum de deux dents par valve (Boyd et Newell, 1968). Par contre, la plupart des astartides du Paléozoïque possèdent de longues dents latérales postérieures et des latérales antérieures bien définies. Chez *Prosocoelus*, la dentition latérale est absente ou réduite. Un lien entre ce genre et les Opinae, une sous-famille restreinte au Mésozoïque, est peu probable. Keferstein (1857), Beushausen (1895), Krasilova (1960, 1963), Zhang (1977) et Liang (1980) considèrent *Prosocoelus* comme un Carditidae, une famille proche des Astartidae (Yonge, 1969) qui possède une dentition latérale souvent réduite ou obsolète (Chavan, 1969). Morris et al. (1991, p. 84) décrivent cette famille comme suit: «They are, we believe, essentially 'Astartidae' which have developed radial ribs, a phenomen that probably happened more than once». Stanley (1972) et Morris (1978) ont émis des doutes sur l'appartenance du genre dévonien *Carditomantea* Quenstedt aux Carditidae. *Gujocardita* Nakasawa et Newell (1968) du Permien supérieur du Japon, un genre proche de *Palaeocardita* Conrad du Triassique, est considéré par Morris (1978) comme le plus ancien carditide. *Prosocoelus* se rapproche davantage de *Gujocardita* (Nakasawa et Newell, 1968, p. 90–92, Pl. 9, figs. 1–6) et des Carditidae que des Astartidae. Ces deux genres possèdent: 1) un contour oval plus ou moins allongé; 2) un escutchéon et une lunule profonde, cette dernière moins bien définie chez *Gujocardita*; 3) un crochet prosogyre antérieur, fortement recourbé vers l'intérieur; 4) des côtes radiales, absentes de l'aire antérieure des valves; 5) une musculature faiblement anisomyaire; 6) une dentition cardinale similaire: une dent postérieure gauche allongée, peu proéminente, précédée d'une courte dent triangulaire ou conique fortement érigée; à droite, une forte dent s'insérant sous la dent postérieure gauche, et une dent plus petite, située à la bordure lunulaire ou accolée à celle-ci; 7) des nymphes bien développées, la nymphe gauche fusionnée à la dent cardinale postérieure. *Gujocardita* diffère de *Prosocoelus* par ses côtes plus nombreuses, ses fortes dents latérales postérieures et son bourrelet myophore antérieur. Quelques spécimens de *Gujocardita* possèdent une dent lunulaire gauche rudimentaire, absente chez *Prosocoelus* (Nakasawa et Newell, 1968, Pl. 9, fig. 1). *Prosocoelus* est ici assigné aux Carditidae. L'importance du hiatus temporel le séparant des carditides de la fin du Paléozoïque et du Mésozoïque suggère une documentation paléontologique incomplète. D'autre part, la similitude de *Prosocoelus* et de *Gujocardita* résulte peut-être de convergences évolutives.

Prosocoelus peut également être comparé à certains Anomalodesmata. L'apparence externe de *P. occidentalis* et de *P. undans* sp. nov. rappelle *Grammysia* De Verneuil, un genre édenté. La région cardinale de *Prosocoelus* est similaire à celle de *Permophorus* Chavan, un genre que Morris et al. (1991, Fig. 35a, b) considèrent comme un anomalodesmate convergeant vers les carditides. Le profil très allongé et les longues et fortes dents latérales postérieures de *Permophorus* sont distinctives. Les rangées de microgranules souvent visibles à la surface des anomalodesmates n'ont par été observées sur *Prosocoelus*. L'aspect finement granulaire du moule interne partiel de *P. pesanseris* illustré à la Pl. 3.2, fig. 3 résulte d'un phénomène diagénétique.

Genre *Prosocoelus* Keferstein, 1857

Espèce-type. Venus prisca Roemer, 1843 des Grès de Kahleberg du Harz en Allemagne, par désignation subséquente d'Haffer (1959, p. 157).

Diagnose. Coquille prosogyre ovoïde à sub-trapézoïdale, équivalve et fortement inéquilatérale. Crochet antérieur surplombant une lunule profonde. Mince escutchéon. Lobe antérieur court à proéminent. Valves comportant jusqu'à quatre plis radiaux ou carènes partant du crochet. Charnière portant typiquement deux dents cardinales gauches entre lesquelles s'insère une dent cardinale droite. Cardinale antérieure gauche conique, mal définie à fortement érigée. Cardinale postérieure gauche longue, mince, sub-parallèle au bord supérieur. Cardinale droite s'insérant entre les cardinales gauches, forte et faiblement recourbée. Bord lunulaire droit proéminent, formant une dent additionnelle. Dents latérales postérieures généralement absentes. Ligament opisthodète parivinculaire situé dans un sillon bordé par des nymphes bien définies. Nymphe gauche unie à la cardinale postérieure. Musculature anisomyaire à sub-isomyaire. Cicatrice adductrice antérieure ovale à circulaire, bien imprimée. Cicatrice postérieure ovale et superficielle. Ligne palléale intégripalliée.

Répartition stratigraphique. Siegenien et Emsien d'Allemagne, de Belgique, de l'est du Canada et du nord-est des États-Unis.

Espèces inclues. Prosocoelus aequivalva Richter et Richter, 1918; *P. beushauseni* Fuchs, 1915; *P. bicarinatus* Dahmer, 1922; *P. complanatus* Keferstein, 1857; *P. consobrinus* Beushausen, 1884; *P. crassinatus* Solle, 1936; *P. ellipticus* Beushausen, 1884; *P. groddecki* Beushausen, 1884 [=*P. priscus*; Haffer, 1959]; *P. occidentalis* Clarke, 1907; *P. orbicularis* Beushausen, 1884; *P. percarinatus* Richter et Richter, 1918; *P. pesanseris* (Zeiler et Wirtgen, 1851); *P. priscus* (Roemer, 1843); *P. vetustus* (Roemer, 1843); *P. undans* sp. nov.; ?*P. orientalis* Zhang, 1977; ?*P. bipleuroides* Babin, 1966.

Espèces exclues. Prosocoelus handaquiensis Liang, 1980; *P. kotanbulokensis* Krasilova, 1960; *P.* (*Prosocoelogeton*) *lenticularis* Quenstedt, 1926; *P.* sp. Khalfin (1974, Pl. 12, figs. 1, 2).

Discussion. Keferstein (1857) érigea *Prosocoelus* à partir de moules internes qu'il plaça dans trois espèces, incluant *P. priscus*. Cette dernière acquit un siècle plus tard le statut d'espèce-type, mais les détails de son anatomie externe demeurent mal connus. Un second genre, *Tripleura*, a été proposé par Sandberger (1889, p. 13) pour l'espèce *Grammysia pesanseris*. Maillieux (1932, 1937) considère que *Tripleura* est synonyme de *Prosocoelus*, mais Chavan (1969) lui donne un statut sous-générique. Il distingue *Tripleura* de *Prosocoelus* par la présence de plis radiaux chez le premier. Les moules internes de *P. priscus* suggèrent, en effet, l'absence d'ornementation radiale (Keferstein, 1857, Pl. 4, fig. 7; Beushausen, 1884, Pl. 5, fig. 9, 1895, Pl. 13, figs. 12, 13; Spriestersbach et Fuchs, 1909, Pl. 5, figs. 9, 9a, 11), mais l'exemplaire illustré à la Pl. 3.1, figs. 1–3 indique que l'espèce possède deux petites carènes partant du crochet. La trace d'une faible ornementation radiale est également visible sur un moule interne attribué à *P. priscus* par Spriestersbach et Fuchs (1909, Pl. 5, fig. 11, valve droite). La distinction de *Tripleura* et de *Prosocoelus* repose donc essentiellement sur une différence d'intensité du prosopon radial. La plupart des espèces de *Prosocoelus* ne sont connues que par des moules internes ou composites sur lesquels les caractères externes sont plus ou moins atténués ou masqués par l'épaisseur variable des coquilles. Dans ce contexte, le concept sous-générique de *Tripleura* est abandonné.

Haffer (1959) reconnaît douze espèces de *Prosocoelus* dans le Dévonien inférieur ardenno-rhénan (Siegenien et Emsien). Le patron dentaire cardinal de ces espèces varie peu (Fig. 3.3A). Elles sont distinguées par des différences du contour et du prosopon, la puissance de la coquille et les détails de l'appareil dentaire. Morris (1978, Pl. 1, fig. 2) indique une dent à la bordure lunulaire droite de l'espèce-type. D'autre part, *P. occidentalis* présente un sillon net à la limite interne de la lunule de la valve gauche (Pl. 3.2, figs. 10, 11). Ce sillon acceuillait probablement le bord lunulaire proéminent de la valve droite (Pl. 3.1, figs. 2, 3). Le spécimen de *P. priscus* illustré à la Pl. 3.1, fig. 2 ne présente aucune trace de dent latérale postérieure. La structure postéro-latérale que Morris (op. cit.) met en évidence chez cette espèce résulte possiblement d'un léger épaississement de la base du plateau d'articulation. Cependant, la trace d'une possible latérale postérieure est visible sur le lectotype de *P. occidentalis* (dpl?, Pl. 3.2, figs. 9, 11).

Le ligament de *Prosocoelus* était externe et supporté par des nymphes dont la longueur varie selon les espèces; à droite, la nymphe est séparée de la dent cardinale sous-jacente par une fossette dentaire correspondant à la cardinale postérieure gauche (Pl. 3.1, figs. 2, 3); à gauche, la nymphe est unie à la cardinale postérieure (Pl. 3.1, figs. 4, 5, Pl. 3.2, figs. 10, 11). Le sillon ligamentaire prend naissance sous le crochet, s'élargit vers l'arrière et s'étend légèrement au-delà de la limite postérieure des cardinales. Un mince escutchéon est visible dans certains cas (Pl. 3.1, fig. 5). Chez l'espèce-type, la musculature est faiblement anisomyaire et les points d'attache du manteau laissent une forte ponctuation sur la face interne des valves circonscrite par la ligne palléale (Pl. 3.1, figs. 1, 2; Spriestersbach et Fuchs, 1909, Pl. 5, figs. 9, 9a). Une forte cicatrice pédieuse accessoire de forme oblongue (non illustrée) est présente au-dessus de l'empreinte adductrice antérieure du spécimen GSC 107935, sur le côté interne du bord de la lunule.

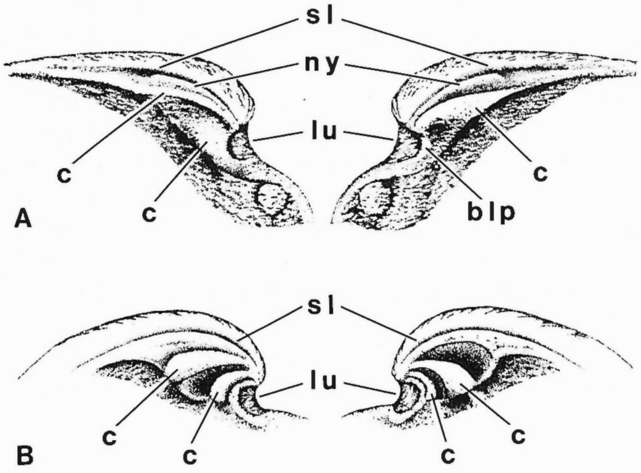

Figure 3.3. *Morphologie de la charnière de* ***Prosocoelus*** *et de* ***Prosocoelogeton****. A, patron cardinal de* ***Prosocoelus****, modifié d'après Haffer (1959, p. 157, Fig. 10), x0,6;* ***B, Prosocoelogeton lenticularis****, d'après Quenstedt (1926, p. 24, Fig. 2), x7,3; c, dent cardinale; blp, bord lunulaire proéminent, formant souvent une dent additionnelle; lu, lunule; ny, nymphe ligamentaire; sl, sillon ligamentaire.*

La similarité des charnières de *Prosocoelus* et de *Prosocoelogeton* Quenstedt, 1926 de la Formation de Ben Nevis (Gedinnien supérieur, Blieck et al., 1987; Groupe de Red Bay) du Spitsbergen a été notée par Haffer (1959). La charnière de l'espèce-type, *Prosocoelogeton lenticularis*, n'a pas été illustrée adéquatement. Cependant, le schéma qu'en a fait Quenstedt (1926, p. 24; Fig. 3.3B) diffère du patron cardinal de *Prosocoelus*. La dent cardinale antérieure gauche de *Prosocoelogeton* est plus mince, bien définie, recourbée autour de la lunule, et la cardinale postérieure, puissante, diverge nettement du bord dorsal. La cardinale droite qui s'insère entre les précédentes est, en outre, fortement recourbée et séparée du bord supérieur par une fossette dentaire beaucoup plus large que chez *Prosocoelus*. Une seconde cardinale droite, mince et recourbée autour du bord supérieur de la lunule résulte, selon Quenstedt (1926, p. 25, 26), d'un épaississement du bord de la coquille. Contrairement à *Prosocoelogeton*, la cardinale postérieure gauche de *Prosocoelus* ressemble à une pseudo-latérale, et elle est toujours plus faible (plus mince et moins proéminente) que la cardinale antérieure de forme conique (voir également Maillieux, 1937, p. 217). Ces caractéristiques justifient la distinction générique de *Prosocoelogeton*. La disposition du crochet, la morphologie de la lunule et la position du sillon ligamentaire des deux genres sont similaires, mais la présence de nymphes chez *Prosocoelogeton* est incertaine. Haffer (1959, p. 139) considère ce dernier genre comme un ancêtre possible de *Prosocoelus*.

Mode de vie. Comme *P. priscus*, la majorité des espèces de *Prosocoelus* ont une coquille compacte, robuste, au contour doucement ovoïde à sub-circulaire (Haffer, 1959, Fig. 13). Le lobe antérieur est développé, la convexité maximale est du côté dorsal et le prosopon radial est souvent marqué. Malgré une musculature faiblement anisomyaire, la taille de l'empreinte adductrice antérieure est peu réduite (Pl. 3.1, fig. 2, Pl. 3.2, fig. 6). Le bord inférieur de *P. pesanseris* et de *P. percarinatus* est concave à l'intersection des sillons rayonnants, mais il n'y a pas de sinus ventral chez les autres espèces.

La morphologie générale de *P. priscus* reflète un mode de vie endobenthique (Fig. 3.4). La ligne palléale entière suggère l'absence de siphons et indique un enfouissement peu profond. Une forte ornementation externe et une coquille épaisse favorisent le maintien d'une position stable, mais elles ralentissent l'animal dans ses déplacements (Stanley, 1970). D'autre part, le

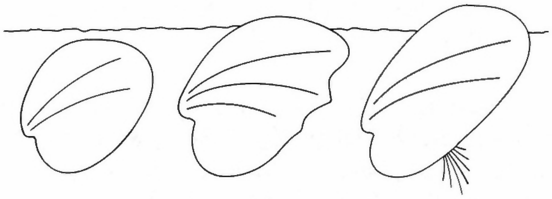

Figure 3.4. *Quelques positions de vie possibles chez* ***Prosocoelus****.*

profil allongé de certaines espèces suggère un mode de vie endobyssé. La forme de *P. crassinatus* (Haffer, 1959, Fig. 13, no. 5) rappelle l'isofilibranche *Goniophora* Phillips, et le contour sub-modioliforme de *P. occidentalis* suggère également la présence de byssus (Pl. 3.2, fig. 12).

Prosocoelus est caractéristique de sédiments silicoclastiques marins et deltaïques. Il habitait les aires boueuses littorales ou sub-littorales soumises sporadiquement à des influx de silt et de sable fin (Fuchs, 1974, 1982).

Prosocoelus pesanseris
(Zeiler et Wirtgen, 1851)

Planche 3.2, figures 1-7

1851	*Grammysia pes-anseris*, Zeiler et Wirtgen, p. 290 (*fide* Maillieux, 1932, p. 85).
1889	*Tripleura pes-anseris* (Zeiler et Wirtgen); Sandberger, p. 13.
1895	*Prosocoelus pes anseris* (Zeiler et Wirtgen); Beushausen, p. 149, Pl. 13, figs. 1-3.
?1932	*Prosocoelus* cf. *pes anseris* (Zeiler et Wirtgen); Maillieux, p. 85, Pl. 4, fig. 3.
1936a	*Prosocoelus pes anseris* (Zeiler et Wirtgen); Dahmer, p. 6, Pl. 5, fig. 12.
1937	*Prosocoelus pes anseris* (Zeiler et Wirtgen); Dahmer, p. 440, Pl. 19, figs. 1, 2.
1937	*Prosocoelus pes-anseris* (Zeiler et Wirtgen); Maillieux, p. 217, Pl. 12, fig. 14.
1959	*Prosocoelus pes-anseris pes-anseris* (Zeiler et Wirtgen); Haffer, p. 160, Fig. 13, no. 1.
1969	*Prosocoelus* (*Tripleura*) *pesanseris* (Zeiler et Wirtgen); Chavan, p. N572.
non 1936b	*Prosocoelus pes anseris* (Zeiler et Wirtgen); Dahmer, p. 640, Pl. 47, fig. 4.

Diagnose. Une espèce ornée de trois plis radiaux et de deux larges sillons doucement courbés vers le bas; pli antérieur souvent plus faible. Lobe antérieur proéminent. Bord médio-inférieur saillant à l'intersection du pli médian, concave face aux sillons. Lignes de croissances fines, uniformes sur toute la surface.

Matériel. Hypotypes GSC 107936, 107937, 107938 et 107939, 2 valves droites et 2 valves gauches plus ou moins complètes.

Répartition stratigraphique. Formation de Torbrook des environs de Torbrook Mines en Nouvelle-Écosse (GSC loc. 873). L'espèce est également présente dans les Siegenerschichten et les Taunusquartzit d'Allemagne et dans les Grès d'Anor de Belgique (Maillieux, 1937).

Description. Coquille de taille moyenne à grande, moyennement bombée, au contour transversalement ovale. Test mince. Valves ornées de trois plis rayonnants légèrement courbés, et de deux larges sillons assez profonds, bien définis sur les moules internes; pli antérieur plus faible que les suivants. Crochet prosogyre puissant, situé au quart antérieur. Bord dorsal convexe, concave en avant du crochet. Mince escutchéon fortement incliné. Bord inférieur marqué de deux sinus à l'intersection des sillons rayonnants. Bord postérieur oblique, légèrement convexe. Lobe antérieur proéminent. Lunule large, fortement concave. Lignes de croissance concentriques fines.

Charnière portant deux dents cardinales gauches et une droite. Cardinale antérieure gauche conique, située sous le crochet et pointant vers le bas; cardinale postérieure gauche mince, allongée et doucement courbée, parallèle au bord postéro-dorsal. Une cardinale droite légèrement courbée s'insère entre les précédentes. Sillon ligamentaire fin, dorso-marginal, s'étendant à peine au-delà de la cardinale postérieure gauche. Nymphe non conservée. Cicatrice adductrice antérieure développée, ovale, antérieure au crochet. Cicatrice adductrice postérieure, traces de la musculature pédieuse et ligne palléale non observées.

Mesures. GSC 107936: L partielle, 6,9 cm. GSC 107937: L, 5,5 cm; H, 3,0 cm. GSC 107938: L partielle, 5,4 cm. GSC 107939: L, 3,9 cm; H, 2,7 cm.

Discussion. La présence de trois plis radiaux est la caractéristique la plus distinctive de *Prosocoelus pesanseris*. Le matériel de Nouvelle-Écosse est indistinguable de celui d'Allemagne qu'a illustré Beushausen (1895, Pl. 13, figs. 1-3; comparer les figs. 1 et 5 de la Pl. 3.1). Le pli antérieur des spécimens canadiens est moins bien défini que les suivants. Le même phénomène est apparent sur les figures de Beushausen [1895, Pl. 13, figs. 1 (valve gauche) et 2], Maillieux (1937, Pl. 12, fig. 14) et Dahmer (1937, Pl. 19, figs. 1, 2). *P. pesanseris* se rapproche de *P. percarinatus* Richter et Richter (1918, Pl. 1, fig. 5), une espèce qui porte une quatrième carène adjacente à la troisième. Le petit spécimen que Dahmer (1936b, Pl. 47, fig. 4) assigne à *P. pesanseris* est une possible *P. percarinatus*.

Prosocoelus occidentalis Clarke, 1907

Planche 3.2, figures 9–12

1907 *Prosocoelus pes-anseris* Zeiler et Wirtgen var. *P. occidentalis* Clarke, p. 223, 2 figs. non numérotées.

1909 *Prosocoelus pes-anseris* Zeiler et Wirtgen var. *P. occidentalis* Clarke; Clarke, p. 75, Pl. 16, figs. 14, 15.

Diagnose. Une espèce allongée, sub-modioliforme, de longueur atteignant deux fois la hauteur. Lobe antérieur proéminent. Deux faibles plis radiaux. Lignes de croissance concentriques fines. Dent cardinale antérieure gauche forte et bulbeuse; cardinale postérieure gauche mince et très allongée. Possible lamelle postéro-latérale gauche peu proéminente.

Matériel. Lectotype NYSM 9014 (désigné ici), le moule interne d'une valve gauche, et le moulage original (plastotype) NYSM 9013 du moule externe du lectotype. Un moulage en latex de la charnière du lectotype est conservé à la Commission géologique du Canada à Ottawa.

Localité-type. Formation de Tomhegan à la pointe Baker Brook, sur la berge ouest du lac Moosehead dans le Maine; localités 3454 et 3455 de Clarke (1909, p. 58), équivalentes à la localité USGS 2750 de Boucot (1969, p. 27 et Pl. 30).

Description. Coquille sub-modioliforme, deux fois plus longue que haute, montrant une légère expansion postérieure. Crochet situé au cinquième antérieur. Lobe antérieur semi-circulaire proéminent. Bord postéro-dorsal sub-rectiligne, à peine convexe. Bord ventral faiblement convexe, sans sinus ventral. Escutchéon non observé. Deux faibles plis radiaux doucement courbés qui atteignent le bord postéro-ventral. Large sillon peu profond entre les plis. Intersection du sillon et du bord postéro-ventral convexe. Surface latérale antérieure adjacente au premier pli faiblement concave. Lunule profonde, sa limite interne marquée d'un sillon courbe net. Lignes de croissances concentriques fines.

Dent cardinale antérieure forte et bulbeuse. Cardinale postérieure mince et très allongée, atteignant la moitié de la longueur du bord dorsal. Possible lamelle postéro-latérale située juste en avant de l'angle postéro-dorsal, dans le prolongement du bord de la valve. Sillon ligamentaire profond. Nymphe longue et mince, surmontant directement la cardinale postérieure, et s'étendant presque jusqu'à la limite postérieure de cette dernière. Cicatrice adductrice antérieure sub-circulaire peu marquée. Cicatrice adductrice postérieure, traces de la musculature pédieuse et ligne palléale non visibles.

Mesures. NYSM 9013: L, 6,7 cm; H, 3,3 cm. NYSM 9014: L, 6,9 cm; H, 3,5 cm.

Discussion. Les détails du relief et de l'ornementation du moulage original NYSM 9013 correspondent parfaitement aux caractères du lectotype. NYSM 9013 est donc issu de la contrepartie de ce dernier. Le rétrécissement inhérent au séchage explique la taille légèrement inférieure du moulage.

La trace d'une possible lamelle dentaire postérieure (Pl. 3.2, figs. 9, 11) n'a été observée que sur un moule interne imparfait. Des spécimens additionnels sont nécessaires pour confirmer la présence de cette latérale. L'intensité des plis radiaux de *P. occidentalis* a été exagérée sur les figures de Clarke (1907, 1909). Ce dernier considérait *P. occidentalis* comme une sous-espèce de *P. pesanseris*. Les deux sont aisément différenciées par le nombre et le relief des plis radiaux et l'aspect du bord ventral. Le profil allongé distingue également *P. occidentalis* de *P. pesanseris* et des autres espèces caractérisées par deux plis (voir la discussion se rapportant à *P. undans* sp. nov.).

Prosocoelus cf. *P. orbicularis* Beushausen, 1884

Planche 3.2, figure 8

1884 *Prosocoelus orbicularis* Beushausen, p. 110, Pl. 5, fig. 8.

1909 *Prosocoelus* cf. *P. orbicularis* Beushausen; Clarke, Pl. 16, fig. 13.

Matériel. Le moulage original (plastotype) NYSM 9012 d'une valve droite.

Localité. Même localité que *P. occidentalis* (Clarke, 1907, p. 224, 1909, p. 75); Formation de Tomhegan à la pointe Baker Brook, sur la berge ouest du lac Moosehead dans le Maine.

Description. Coquille au contour ovale, presque circulaire. Crochet prosogyre situé au cinquième antérieur. Bord dorsal convexe. Courbure ventrale uniforme et prononcée. Deux plis radiaux mal définis n'atteignant pas le bord ventral. Lignes de croissances fines, mieux définies vers l'avant. Charnière inconnue. Impression de l'adducteur antérieur imprécise.

Mesures. L, 5,1 cm; H, 4,4 cm.

Discussion. Comme noté par Clarke (1909, p. 75), le contour et le faible relief des plis radiaux rapprochent le spécimen du Maine de *P. orbicularis* Beushausen (1884, Pl. 5, fig. 8).

Prosocoelus undans sp. nov.

Planche 3.2, figure 13

1991 *Prosocoelus* sp. Desbiens, p. 109, Pl. 8, fig. 19.

Étymologie. Le mot latin *undans* signifie ondoyant. Il souligne ici la nature du prosopon antérieur de l'espèce.

Diagnose. Une espèce oviforme portant deux plis obliques sub-rectilignes et un large sillon peu profond. Lobe antérieur proéminent. Fins bourrelets lamellaires concentriques en avant du pli antérieur. Lignes de croissance fines en arrière et entre les plis.

Holotype: GSC 107940, un spécimen articulé valves ouvertes.

Localité-type. Rivière Petite Fourche, 14 km au nord-ouest de la ville de Gaspé (lat. 48°56′03″N, long. 64°36′49″E); Formation de York River, à la base d'un niveau de shale gris moyen non calcareux de 2 m, 721 m au dessus de la base de la formation.

Description. Coquille oviforme allongée, peu convexe. Hauteur égale à 55 % de la longueur. Crochet prosogyre situé au cinquième antérieur. Bord dorsal faiblement convexe, concave antérieurement au crochet. Escutchéon non observé. Deux plis radiaux sub-rectilignes proéminents et un large sillon peu profond. Minces surfaces faiblement concaves en bordure antérieure du premier pli et en bordure postérieure du second. Bord postéro-ventral concave entre les plis, uniformément convexe en avant de ces derniers. Lobe antérieur proéminent, au coin supérieur sub-angulé. Prosopon antérieur constitué de fins bourrelets lamellaires concentriques régulièrement espacés qui n'atteignent pas le premier pli; lignes de croissances fines, en arrière et entre les plis. Test non conservé. Traces de la charnière et de la musculature non visibles.

Mesures. Valve droite: L, 1,9 cm; H, 1,3 cm. Valve gauche: L, 2,0 cm; H, 1,3 cm.

Discussion. Les espèces européennes *P. aequivalva* Richter et Richter (1918, Pl. 1, figs. 1–4), *P. consobrinus* Beushausen (1895, Pl. 13, figs. 6–10) et *P. bicarinatus* Dahmer, 1922 (illustrée en 1918, Pl. 39, fig. 4) possèdent également deux plis par valves. Le parcours sub-rectiligne des plis de *P. undans* sp. nov. se démarque du profil courbe des plis de ces espèces. Certains spécimens de *P. aequivalva* et de *P. consobrinus* montrent une ornementation concentrique plus accentuée vers l'avant, sans qu'elle n'atteigne toutefois l'intensité du prosopon antérieur de *P. undans* sp. nov. Les détails externes de *P. bicarinatus* sont inconnus.

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PLANCHE 3.1

aa, empreinte de l'adducteur antérieur; ap, empreinte de l'adducteur postérieur; c, dent cardinale; fd, fossette dentaire; lp, ligne palléale; lu, lunule; ny, nymphe ligamentaire; sl, sillon ligamentaire. Les flèches (fig. 3) indiquent de petites carènes partant du crochet.

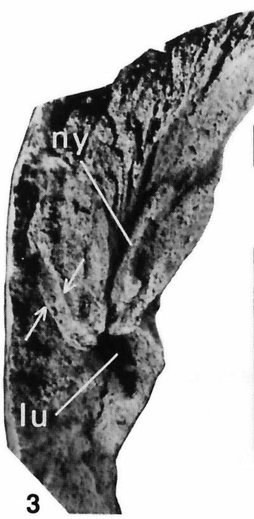
Figures 1–3. *Prosocoelus priscus* (Roemer, 1843). Grès de Kahleberg, Goslar dans le Harz, Allemagne.

1. Valve droite, hypotype GSC 107935, moule interne, x0,9.

2, 3. Moulage en latex du spécimen précédent, vues latérale interne supérieure et antéro-dorsale oblique de la région cardinale, x1,6 et x2,4.

Figures 4, 5. *Prosocoelus* sp. Grès de Kahleberg, Kahleberg dans le Harz, Allemagne.

Moulage en latex du moule interne de la valve gauche partielle GSC 108378, vues latérale interne et antéro-dorsale oblique de la région cardinale, x2,6 et x2,9.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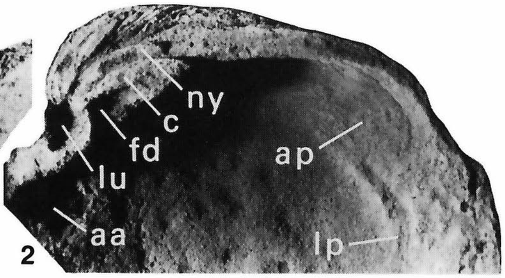
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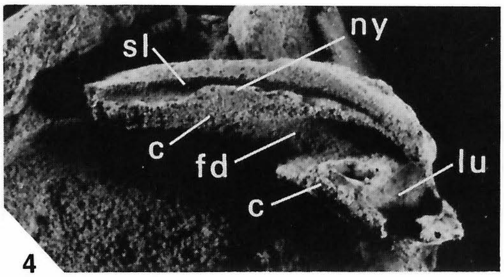
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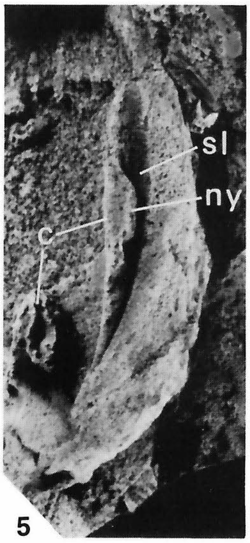
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PLANCHE 3.2

aa, empreinte de l'adducteur antérieur; c, dent cardinale; dpl?, possible dent postéro–latérale; fd, fossette dentaire; lu, lunule; ny, nymphe ligamentaire; sl, sillon ligamentaire.

Figures 1, 2. *Prosocoelus pesanseris* (Zeiler et Wirtgen, 1851). Koblenzchichten, Allemagne.

Valve gauche et charnière gauche telles qu'illustrées par Beushausen (1895, Pl. 13, figs. 3 et 1A), x1,0 et x1,0.

Figures 3-7. *Prosocoelus pesanseris* (Zeiler et Wirtgen, 1851). Formation de Torbrook, région de Torbrook Mines, Nouvelle–Écosse.

3. Valve droite partielle GSC 107936, moule interne, vue latérale, x1,0.

4, 5. Valve gauche GSC 107937, moule interne, vue latérale et vue de la charnière, x1,5 et x1,2.

6. Valve droite partielle GSC 107938, moule interne, vue latérale, x1,0.

7. Valve gauche GSC 107939 conservant une partie de la coquille, vue latérale externe, x1,6.

Figure 8. *Prosocoelus* cf. *P. orbicularis* Beushausen, 1884. Formation de Tomhegan, pointe Baker Brook sur la berge ouest du lac Moosehead, Maine.

Moulage original (plastotype) N YSM 9012 de Clarke (1909, Pl. 16, fig. 13), valve droite, vue latérale externe, x1,0.

Figures 9–11. *Prosocoelus occidentalis* Clarke, 1907. Même localité que fig. 8.

9. Lectotype NYSM 9014, valve gauche, moule interne, vue latérale, x1,0.

10, 11. Moulage en latex de la charnière du lectotype, vue antéro–dorsale très oblique et vue latérale, x1,8 et x2,0.

12. Moulage original (plastotype) NYSM 9013 du moule externe du lectotype, valve gauche, vue latérale, x1,1.

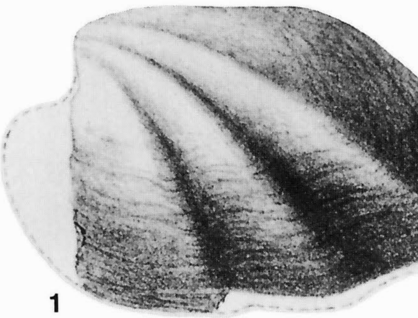
Figure 13. *Prosocoelus undans* sp. nov. Formation de York River, rivière Petite Fouche, région de Gaspé, Québec.

Holotype GSC 107940, spécimen articulé valves ouvertes, moule composite, vue latérale, x2,1.

Figure 14. *Amphigenia parva* Clarke, 1907. Même localité que fig. 8.

Valve pédonculaire associée à *Prosocoelus occidentalis* sur l'échantillon–type NYSM 9014, moule interne, x2,0.

PLANCHE 3.2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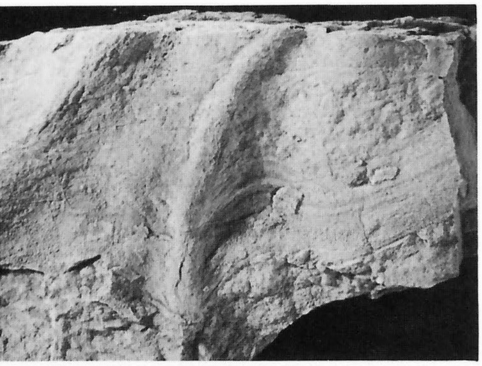
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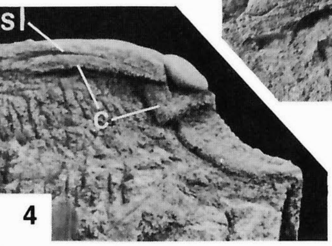

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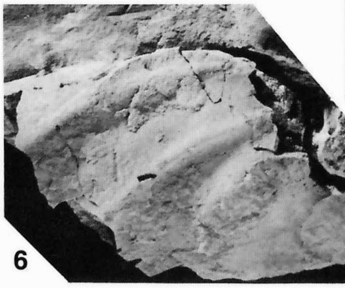

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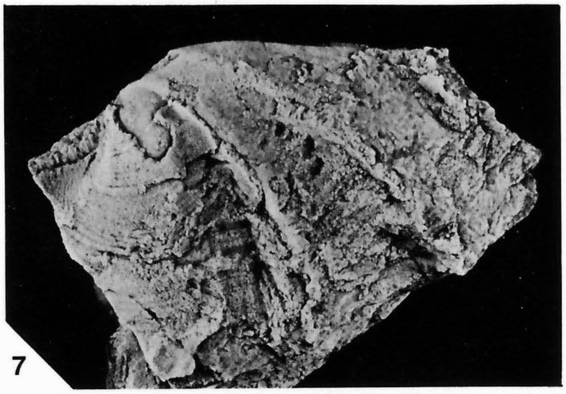
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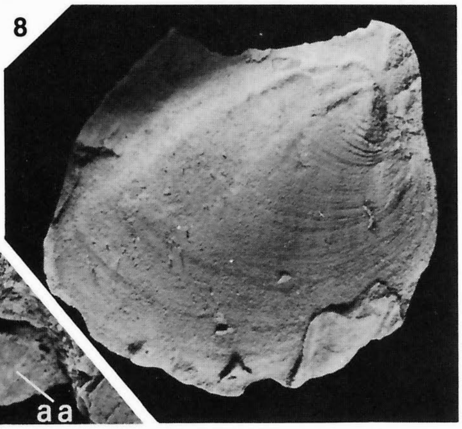
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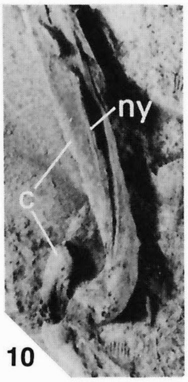

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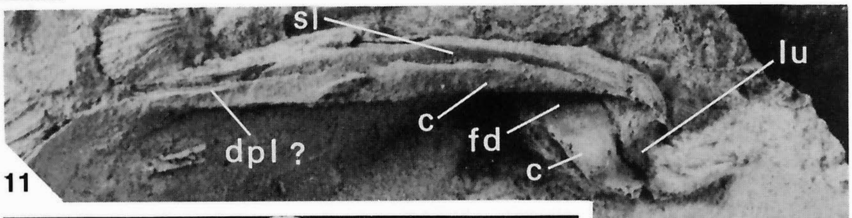

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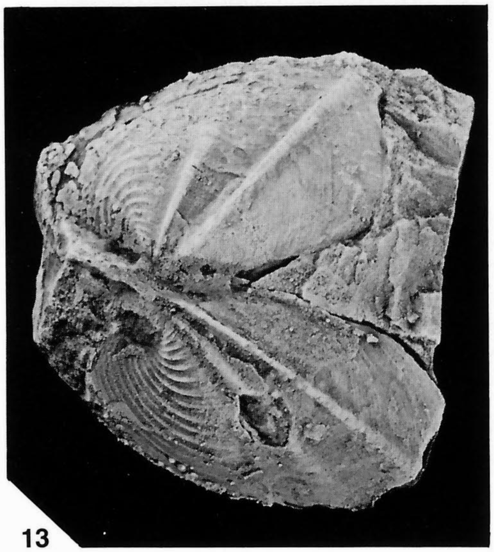
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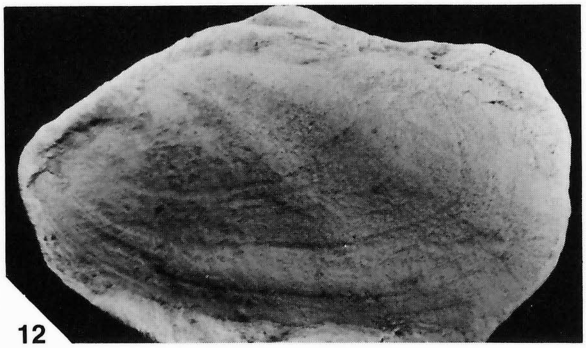
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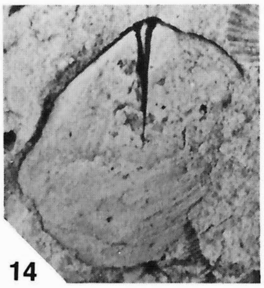
14

DINOFLAGELLATE ASSEMBLAGES AND DEPOSITIONAL ENVIRONMENTS OF THE CAMPANIAN BEARPAW FORMATION, ALBERTA

H. Kurita[1] and D.J. McIntyre[2]

Dinoflagellate assemblages and depositional environments of the Campanian Bearpaw Formation, Alberta. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 479, p. 67–83.

Abstract

Twenty-nine genera and forty-five species of dinoflagellates were recorded from the Upper Cretaceous Bearpaw Formation at surface localities in the Rocky Mountain Foothills and in the southern Alberta Plains, near Calgary, Alberta. The diverse dinoflagellate assemblages indicate that the formation is Late Campanian in the plains and the foothills of southern Alberta. The maximum western extent of the Bearpaw Sea was in the Late Campanian. Stratigraphic trends in diversity and dominance of species in the assemblages are interpreted as indicating a relatively rapid initial transgression and a gradual final regression during the period of deposition. The results demonstrate the applicability of Late Cretaceous dinoflagellates for biostratigraphic determination and paleoenvironmental analysis in a marginal marine situation.

Résumé

Vingt-neuf genres et quarante-cinq espèces de dinoflagellés ont été répertoriés dans la Formation de Bearpaw du Crétacé supérieur, à des localités en surface dans les contreforts des Rocheuses et dans le sud des plaines de l'Alberta, près de Calgary. Les assemblages variés de dinoflagellés indiquent que la formation date du Campanien tardif dans les plaines et les contreforts du sud de l'Alberta. La Mer de Bearpaw avait atteint son prolongement maximal vers l'ouest au Campanien tardif. Les tendances stratigraphiques en matière de diversité et de dominance des espèces dans les assemblages sont interprétées comme représentant une transgression initiale relativement rapide et une régression finale graduelle au cours de la période de sédimentation. Les résultats montrent l'utilité des dinoflagellés du Crétacé tardif pour la détermination biostratigraphique et l'analyse paléoenvironnementale dans un milieu margino-marin.

INTRODUCTION

This study describes dinoflagellate assemblages from two surface sections of the Upper Cretaceous Bearpaw Formation near Calgary, Alberta (Fig. 4.1). There have previously been few similar studies in this area. The assemblages discussed are comparable to those reported from other localities in the Western Interior of North America and show the diverse composition of Campanian dinoflagellate floras in this region. The data also permit correlations within the formation in the southern Rocky Mountain Foothills and the Interior Plains. The correlations illustrate the time and spatial extent of the Bearpaw Sea in the region. Stratigraphic trends in diversity and dominance of species in the assemblages of the limited interval studied in the plains and foothills localities are interpreted in the context of paleoenvironments. As a result, this study shows how Campanian dinoflagellates can be used for biostratigraphic determination and paleoenvironmental analysis in a marginal marine setting where there are few calcareous marine fossils.

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The Campanian-Maastrichtian boundary in the Western Interior of North America has been placed at various positions relative to ammonite zones (Fig. 4.2) but there is still considerable uncertainty about its position. Jeletzky (1968) considered the boundary to be at the base of the *Baculites baculus* Zone, a position accepted by Caldwell (1968) and Harland (1973, 1977). However, Obradovich and Cobban (1975) placed the Campanian-Maastrichtian boundary three zones lower, at the base of the *Baculites reesidei* Zone. Caldwell et al. (1978) and Harker et al. (1990) used this position of the boundary although it was not accepted by Harland (1977). Eaton (1987) considered this boundary position to be supported by the available evidence. Recent work now suggests that a position between these two boundary placements is more accurate. Hancock and Kauffman (1989) thought the boundary was most likely below the *Baculites baculus* Zone and possibly below the *Baculites eliasi* Zone. Hancock (1991) noted that the top zone of the Campanian in the Western Interior could be either the *Baculites jenseni* or *Baculites eliasi* Zone. This was reaffirmed by Hancock (1993), who stated that the Campanian-Maastrichtian boundary was no lower than the junction between the *Baculites eliasi* and *Baculites jenseni* zones. McArthur et al. (1992) agreed that the Campanian-Maastrichtian boundary may lie between the *Baculites jenseni* and *Baculites eliasi* zones and Kennedy and Cobban (1993) concluded that the base of the Maastrichtian lies above the *Baculites jenseni* Zone. The Late Campanian transgressive peak is considered (Hancock and Kauffman, 1989; Hancock, 1993) to coincide with the *Baculites cuneatus* and *Baculites reesidei* zones.

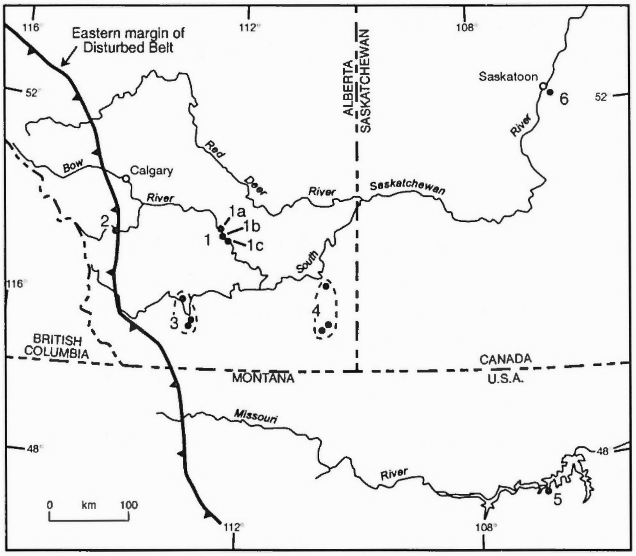
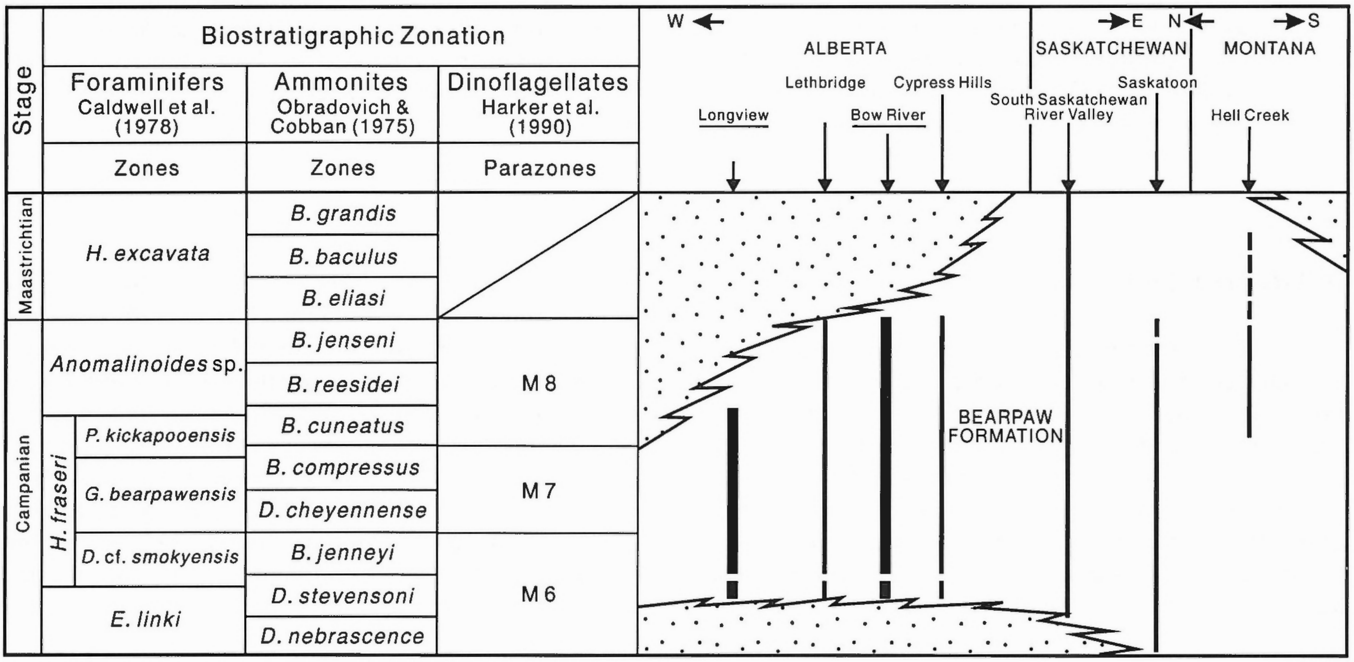


Figure 4.1. *Index map. 1, Bow River Section; 1a, Bassano South locality; 1b, Bassano Southeast locality; 1c, Bow City locality; 2, Longview Section; 3, Lethbridge area (Harland, 1973); 4, Cypress Hills area (Harland, 1973); 5, Hell Creek (Harland, 1977); 6, Goodale Farm (Harker et al., 1990).*



Stage	Biostratigraphic Zonation			
	Foraminifers Caldwell et al. (1978)		Ammonites Obradovich & Cobban (1975)	Dinoflagellates Harker et al. (1990)
	Zones		Zones	Parazones
Maastrichtian	*H. excavata*		*B. grandis*	
			B. baculus	
			B. eliasi	
Campanian	*Anomalinoides* sp.		*B. jenseni*	M 8
			B. reesidei	
	H. fraseri	*P. kickapooensis*	*B. cuneatus*	
		G. bearpawensis	*B. compressus*	M 7
			D. cheyennense	
		D. cf. *smokyensis*	*B. jenneyi*	M 6
	E. linki		*D. stevensoni*	
			D. nebrascence	

Figure 4.2. *Schematic diagram of correlation in the plains and foothills. Dotted areas indicate nonmarine strata. Lethbridge and Cypress Hills from Harland (1973); South Saskatchewan River Valley from Caldwell (1968); Saskatoon from Harker et al. (1990); Hell Creek from Harland (1977).*

For the present study of the Bearpaw Formation of southern Alberta, the position of the Campanian-Maastrichtian boundary is taken to be between the *Baculites jenseni* and *Baculites eliasi* zones, in agreement with recent interpretations. Thus strata identified as Maastrichtian by Caldwell et al. (1978) and Harker et al. (1990) are here considered to be either mainly or wholly Campanian.

The Bearpaw Formation (Hatcher and Stanton, 1903), which consists predominantly of dark grey, silty shale with a few intercalating sandstone beds, lies between nonmarine strata and represents the final major transgression of the Late Cretaceous seaway in the Western Interior. The formation is thickest in southwestern Saskatchewan and thins to the west (Caldwell, 1968). As the lower contact of the formation with underlying nonmarine strata is generally sharp and the upper contact is rather gradual, it appears that the initial transgression occurred rapidly and the final regression gradually (Russell, 1939). Caldwell (1968), however, concluded that the transgression was gradual in southwestern Saskatchewan. The maximum time span of the formation is considered Late Campanian to Early Maastrichtian in southern Saskatchewan. This is indicated by the succession from the *Didymoceras stevensoni* Zone to *Baculites grandis* Zone (ammonites; Caldwell, 1968), as well as that from the *Eoponidella linki* Zone to *Haplophragmoides excavata* Zone (benthic foraminifers; Caldwell et al., 1978) in southern Saskatchewan. To the west, near the edge of its maximum extent in Alberta, the time span of the formation is much shorter than in the plains where it is represented by the *Baculites cuneatus, Baculites reesidei, Baculites jenseni* and *Baculites eliasi* zones (Given and Wall, 1971; Wall and Rosene, 1977; Caldwell et al., 1978), most of which can be placed below the Campanian-Maastrichtian boundary as accepted here.

There have been few reports on dinoflagellates from the Bearpaw Formation (Fig. 4.1). Harland (1973, 1977) described dinoflagellates and acritarchs from the formation in the plains in southernmost Alberta, and in eastern Montana. Harker et al. (1990) studied the Bearpaw Formation near Saskatoon, Saskatchewan. Preliminary lists of dinoflagellates from some of the sections studied here were given in Wall and Sweet (1979) and McIntyre et al. (1984).

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SAMPLES

The study was conducted along two surface sections (Figs. 4.1, 4.3, 4.4). A composite section along the Bow River approximately 125 km east of Calgary, is here referred to as the Bow River section (Fig. 4.3). This comprises short sections from three localities, namely Bassano South (NE 1/4, sec. 6, tp. 20, rge. 18, W4M), Bassano Southeast (SE 1/4, sec. 24, tp. 19, rge. 18, W4M) and Bow City (lsd. 7, sec. 17, tp. 17, rge. 17, W4M). Lithology of the Bearpaw Formation at these localities was described by Byrne and Farvolden (1959). Given and Wall (1971) estimated the thickness of the formation along the section at about 170 m. Wall and Sweet (1979) reported foraminifers from the Bassano South and Bassano Southeast localities and concluded that the middle and upper part of the Bearpaw Formation in the section falls within the range of the middle *Haplophragmoides fraseri* Zone and the *Anomalinoides* sp. Zone. The age of the formation in the section is therefore considered Late Campanian. An 8.8 m section of the basal part of the Bearpaw Formation and the underlying Oldman Formation occurs at the Bow City locality. Six samples (C-72102–7) from the Bearpaw Formation and one sample (C-72101) from the Oldman Formation were examined. Two samples (C-72110, 1) from the middle of the Bearpaw Formation at Bassano Southeast were also examined. At the Bassano South locality, a 26.3 m section of the uppermost part of the Bearpaw Formation is present. At the top of the section, the formation is overlain by the Horseshoe Canyon Formation. Nineteen samples (C-72077–95) from this locality were examined.

In the southern Rocky Mountain Foothills, a roadside cut near Longview, 60 km southwest of Calgary (lsd. 2, sec. 17, tp. 18, rge. 2, W5M), provided a 58 m thick section. The Longview Section apparently covers the whole formation present in the area. The

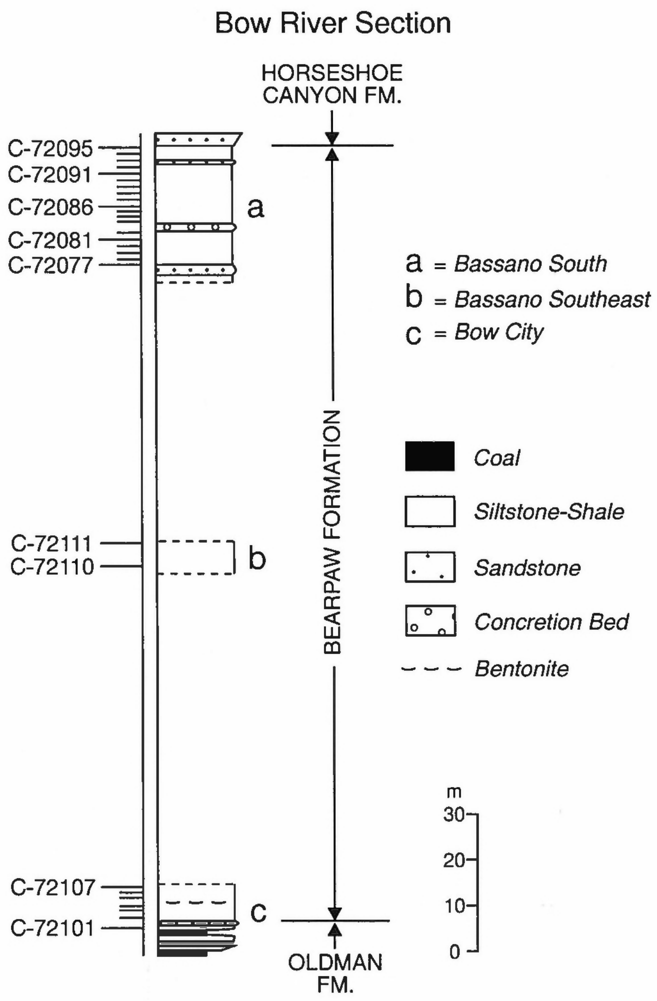

Figure 4.3. *Bow River Section: lithology and sample intervals. Lithological information provided by A.R. Sweet.*

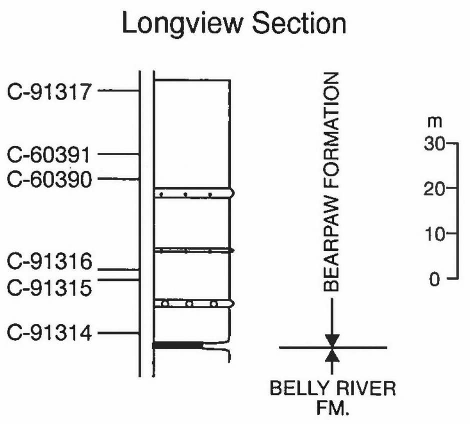

Figure 4.4. *Longview Section: lithology and sample intervals.*

lower contact with the Belly River Formation is present here, but the upper contact with the St. Mary River Formation is not exposed in this section. It is, however, present in another section 0.5 km to the east. Six samples (C-60390, C-60391, C-91314–7) from the section were analyzed. An additional sample (C-91312) from the basal part of the Bearpaw Formation near Black Diamond, 18 km north of Longview (lsd. 5, sec. 8, tp. 20, rge. 2, W5M), was also examined. At this locality, the contact between the Bearpaw and underlying Belly River Formation is exposed. These samples from the foothills area represent the northwestern outcrop edge of the Bearpaw Formation.

All material examined is deposited in the collection of the Paleontology Subdivision, Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary.

DINOFLAGELLATE ASSEMBLAGES

Results are shown in Tables 4.1 and 4.2. Twenty-nine genera and forty-five species of dinoflagellates were recorded in this study. The relative abundance of each species in a sample is shown in the tables. The generic assignment of species follows that of Lentin and Williams (1993).

Bow River Section (Fig. 4.3)

Numerous dinoflagellates were found in the basal and middle parts of the Bearpaw Formation, as well as the top of the Oldman Formation. The number of species from each sample was relatively high in these intervals. Recoveries from the uppermost part of the Bearpaw Formation were generally sparse, and the number of species relatively low. In the uppermost part of the Bow River Section (samples C-72089–95) dinoflagellates are either absent or very rare.

The following species were recorded throughout the section: *Cerodinium speciosum* subsp. *glabrum*, *Chatangiella*? *biapertura*, *Cleistosphaeridium armatum*, *Circulodinium distinctum*, *Isabelidinium belfastense*, *I.* sp., *Laciniadinium arcticum*, *L. firmum*, *Odontochitina operculata*, *Palaeoperidinium pyrophorum*, *Phelodinium kozlowskii*, *P. magnificum*, and *Spinidinium clavus*. Species restricted to the basal and middle parts of the formation include: *Chatangiella decorosa*, *C. ditissima*, *Dapsilidinium* sp. A, *Dapsilidinium.* sp. B, *Fromea fragilis*, *Hystrichosphaeridium arborispinum*, *H.* sp. cf. *H. arborispinum* sensu Harland, 1973, *Palaeohystrichophora infusorioides*, *Palaeoperidinium parvum* and *Spiniferites porosus*. The distribution of the dinoflagellate species that occur in the Bow River section is shown in Table 4.1.

In the uppermost Oldman Formation and the basal part of the Bearpaw Formation immediately above the contact, the assemblages tend to be dominated by a few species such as *Isabelidinium* sp., *Palaeohystrichophora infusorioides* and *Palaeoperidinium pyrophorum*.

Longview Section and Black Diamond Locality (Fig. 4.4)

Most samples from the Longview Section are dominated by pollen and spores and contain few dinoflagellates, except in the basal and upper parts of the section where many specimens were recorded. *Chatangiella*? *biapertura* is dominant and *Isabelidinium* sp. abundant in all the assemblages. *Chatangiella decorosa, C. ditissima, Dinogymnium longicorne, D. sibiricum, Isabelidinium belfastense, Laciniadinium arcticum, L. firmum, Palaeohystrichophora infusorioides, Palaeoperidinium*

TABLE 4.1

Occurrence of dinoflagellates in the Bow River Section

Bow River Section Southern Alberta Plains A = >25%. C = 5-25%, R = 1-5%, + = <1%																																														
Formation	Locality	GSC Locality	*Achomosphaera ramulifera*	*Callaiosphaeridium asymmetricum*	*Cerodinium speciosum* subsp. *glabrum*	*Chatangiella? biapertura*	*Chatangiella decorosa*	*Chatangiella ditissima*	*Circulodinium distinctum*	*Cleistosphaeridium armatum*	*Cleistosphaeridium diversispinosum*	*Cribroperidinium exilicristatum*	*Dapsilidinium* sp. A	*Dapsilidinium* sp. B	*Dinogymnium longicorne*	*Eucladinium spinosissimum*	*Exochosphaeridium phragmites*	*Fromea fragilis*	*Hystrichosphaeridium arborispinum*	*Hystrichosphaeridium* sp. cf. *H. arborispinum*	*Hystrichosphaeridium tubiferum* subsp. *brevispinum*	*Hystrichosphaeridium tubiferum* subsp. *tubiferum*	*Hystrichosphaeropsis* sp. cf. *H. quasicribrata*	*Isabelidinium belfastense*	*Isabelidinium* sp.	*Laciniadinium arcticum*	*Laciniadinium firmum*	*Odontochitina operculata*	*Oligosphaeridium pulcherrimum*	*Palaeohystrichophora infusorioides*	*Palaeoperidinium parvum*	*Palaeoperidinium pyrophorum*	*Phelodinium kozlowskii*	*Phelodinium magnificum*	*Pterodinium agadirense*	*Rhiptocorys veligera*	*Senegalinium obscurum*	*Spinidinium clavus*	*Spiniferites perforatus*	*Spiniferites porosus*	*Spiniferites pseudofurcatus*	*Spiniferites ramosus*	*Tanyosphaeridium variecalamus*	*Trithyrodinium evittii*	*Wallodinium luna*	Dinocysts counted
Bearpaw	Bassano South	C-72088																					+			+					+														3
		C-72087														+							+			+	+				+						+								10
		C-72086										+				+							+	+							+						+								15
		C-72085														+							+	+		+	+				+												+		15
		C-72084				+					+					+							+	+	+	+	+				+		+		+		+								29
		C-72083			R	R			R	R						R							C	C	C	R	R	R			C		R		R	R	C	R							65
		C-72082				+																	+	+																					8
		C-72081																					+	+			+									+	+								5
		C-72080				+				+						+							+	+			+										+								8
		C-72079		R	R	C						R				C						R	C	A	C	+	R								R	+	C					R		+	46
		C-72078								+		+										+	+	+	+		+								+		+					+			30
		C-72077	+		+				+	+						+					+		+	+	+		+	+			+				+		+				+				36
	Bassano Southeast	C-72111				+			C	R		C	+			R	+	C	+	R				C			R			C	C				C		R			C	R	+			99
		C-72110					R	+	C	+		R	C	R	+			R	R			C		R	C		R	R		+	R						+			C					61
	Bow City	C-72107		R	R	+			R	R		R	C	C			R	R	R	C		R		C	R	R	R	R	+	C	C	+	+					R	+						133
		C-72106		+		R			+	R			C	C				C	R	C		R		+	R		R	R	C	+	C	C	R					+	R	R	R	+			387
		C-72105	+						R		R	+	C	C				C	+	C	R		+	+	C	+		+	C		C	C	C					+	C	R		R			278
		C-72104	+			+	+		+	R	R	+	R				+	C		C		+	+		R	+	+		R	+	R	A	R		R						R	R	+		382
		C-72103	+				+		R	+	+	+	R					C		C	R	R			R	R	+	+	C	C	C	C	R		R			R		R	+	R			215
		C-72102	R				+		R	R		+	R					R		+	R	+			R	R	+	+	R	A	R	R	+	+	R	+			+	R		R			183
Oldman		C-72101							+	+	+									+		+			A	+	+	+	+	R	C	C						+				+			223

NOTE: Barren or nearly barren samples from the top of the section (GSC locs. C-72089 to 72095) are not included. Relative abundance of species: >25% = abundant (A); 5–25% = common (C); 1–5% = rare (R); <1% = present (+). Relative abundance of a single specimen and of all species from samples with less than thirty counted specimens is expressed by (+), regardless of actual percentage.

TABLE 4.2

Occurrence of dinoflagellates in the Longview Section

Longview Section Southern Alberta Foothills

A = >25%. C = 5-25%, R = 1-5%, + = <1%

Formation	GSC Locality	*Chatangiella? biapertura*	*Chatangiella decorosa*	*Chatangiella ditissima*	*Circulodinium distinctum*	*Cleistosphaeridium armatum*	*Cribroperidinium exilicristatum*	*Dapsilidinium* sp. A	*Dapsilidinium* sp. B	*Dinogymnium longicorne*	*Dinogymnium sibiricum*	*Exochosphaeridium phragmites*	*Hystrichosphaeridium tubiferum* subsp. *brevispinum*	*Isabelidinium belfastense*	*Isabelidinium* sp.	*Laciniadinium arcticum*	*Laciniadinium firmum*	*Oligosphaeridium pulcherrimum*	*Palaeohystrichophora infusorioides*	*Palaeoperidinium parvum*	*Phelodinium magnificum*	*Pterodinium* sp.	*Rhiptocorys veligera*	*Spinidinium clavus*	*Spiniferites porosus*	*Trithyrodinium evittii*	Dinocysts counted
Bearpaw	C-91317	A	C	R						+				R	C	R											60
	C-60391																		R								0
	C-60390																										0
	C-91316								+				+		+					+					+		13
	C-91315	A	C	R	R	R	R	R			R		R	R	C			R			R			R	R	R	57
	C-91314	A	R	+	+					R	+	+		+	C	R	R		R		+	+	+	R	R	+	133

parvum, *Phelodinium magnificum* and *Spinidinium clavus* are also present. The composition of the assemblages changes little throughout the section.

A few specimens of *Dinogymnium longicorne*, *Oligosphaeridium pulcherrimum*, *Phelodinium kozlowskii* and *Spiniferites ramosus* were seen in the sample from the Black Diamond locality. As the assemblage is similar to those in the Longview Section, the Bearpaw Formation at the Black Diamond locality is considered to be equivalent to at least part of the formation in the Longview Section.

CORRELATION AND AGE

Correlation of the Bow River Section with other areas (Fig. 4.2)

Harker et al. (1990) described dinoflagellate assemblages from the Bearpaw Formation at Goodale Farm near Saskatoon, central Saskatchewan. They recorded the highest occurrence of *Chatangiella decorosa*, *Fromea fragilis*, *Hystrichosphaeridium arborispinum* and *Palaeohystrichophora infusorioides* at the base of, or within, their Parazone M7, and the highest occurrence of *Palaeoperidinium parvum* in the lower part of Parazone M8. They also noted the lowest occurrence of *Phelodinium magnificum* at the base of Parazone M8, which is characterized by the appearance of microplankton taxa commonly associated with Maastrichtian and younger rocks (Harker et al., 1990). Based on the occurrence of the species discussed above, the Bow River section is correlated with the interval from the upper part of Parazone M6 to Parazone M8 in southern Saskatchewan, which is dated as latest Campanian to Early Maastrichtian (Harker et al., 1990) but is most likely Late Campanian, if the position of the Campanian-Maastrichtian boundary as discussed previously is accurate.

Harland (1973) reported dinoflagellate assemblages from the Bearpaw Formation in the Lethbridge and Cypress Hills areas, in the southern Alberta Plains. In those areas, there is little change in species composition stratigraphically throughout the formation. Most of the species recorded are common in the Bow River Section. Consequently, the age of the Bearpaw Formation in the Bow River Section is probably equivalent to that of the formation in the Lethbridge and Cypress Hills areas, where it is dated as Late Campanian (Harland, 1973). Furthermore, some of the paleoenvironmental characteristics of the assemblages from the Lethbridge and Cypress Hills areas (Harland, 1973) are similar to those recognized in the Bow River section. First, the maximum number of species recorded in samples in the basal part of the formation in both Lethbridge and Cypress Hills areas may correspond to diverse floras in the upper part of the Bow City interval of the Bow River Section. Second, poor recoveries from the uppermost interval of the formation are common to the Lethbridge, Cypress Hills and Bow River localities. The paleoenvironmental characteristics are further discussed in the following section.

Harland (1977) discussed dinoflagellates from a section of the upper part of the Bearpaw Formation at Hell Creek, eastern Montana. *Circulodinium distinctum, Odontochitina operculata* and *Oligosphaeridium pulcherrimum*, which occur in the Hell Creek Section only in the lower part, are common through the Bow River and Longview sections. *Cerodinium diebelii* and *Palaeocystodinium golzowense*, which characterize the upper part of the Hell Creek Section, are absent in the Bow River and Longview sections. Accordingly, at least part of the Hell Creek section is probably younger than the Bow River and Longview sections. The Hell Creek Section was dated as Late Campanian to Maastrichtian by Harland (1977) but Harker et al. (1990) consider it to be Early Maastrichtian.

McIntyre (1974, 1975) discussed the stratigraphic distribution of some peridinioid species from Horton River, Northwest Territories. In the Bow River and Longview sections, the following evidence is useful for comparison with the Horton River section: the sparse occurrence of *Chatangiella ditissima* and *C. decorosa*, the continuous occurrence of *Chatangiella*? *biapertura* and *Phelodinium kozlowskii* and the absence of *Laciniadinium orbiculatum* and *L. biconiculum*. This indicates that the sections examined in southern Alberta probably correspond to the lower part of Division H3 at Horton River, which is dated as Late Campanian (McIntyre, 1975).

These comparisons demonstrate that the dinoflagellate assemblages from the Bearpaw Formation in the Bow River Section are comparable to those from other areas within the Late Cretaceous Western Interior and Arctic basins, as stated by Harland (1977). The age of the Bearpaw Formation in the Bow River Section is considered, on the basis of the available evidence, as Late Campanian, and probably corresponds to the range of the *Exiteloceras jenneyi* to *Baculites eliasi* zones.

Correlation between the Bow River and Longview sections (Fig. 4.2)

The assemblages in the Longview Section contain several species that occur only in the basal and middle part of the Bearpaw Formation in the Bow River Section. Those species include *Chatangiella decorosa, C. ditissima, Dapsilidinium* sp. A, *D.* sp. B, *Palaeohystrichophora infusorioides* and *Palaeoperidinium parvum*. This suggests that the Longview Section is of Late Campanian age and should be correlated with the lower part of the formation in the Bow River Section (Fig. 4.2).

PALEOENVIRONMENTS

In the Bow River Section, changes of assemblages within short intervals in the basal and uppermost Bearpaw Formation are interpreted as being of paleoenvironmental significance. Stratigraphic changes of dinoflagellate assemblages in the 8.8 m section at the Bow City locality appear to be a good indication of rapid transgression. The assemblage from the uppermost Oldman Formation is characterized by dominance of the peridinioid species *Isabelidinium* sp. In the three samples immediately above the formation contact, the number of species in each assemblage increases, and a few peridinioid species are still dominant. In the upper part of the interval, where the number of species present has increased, this dominance declines and the ratio of gonyaulacacean forms to total population becomes relatively high. Based on the theories of dominance and gonyaulacacean ratio (Harland, 1973; Goodman, 1979), the changes suggest successive paleoenvironmental changes from embayment to open marine nearshore, then to shelf. This deepening of the depositional environment within a short interval defines the transgressive event in this area and suggests that it would have occurred relatively rapidly.

The assemblages from the uppermost Bearpaw Formation at the Bassano South locality appear to indicate a gradual regression. Relatively sparse assemblages and low number of species from each sample characterize the lower part of this interval, and the total specimens and number of species generally declines upward with slight fluctuations. This would suggest retreating marine influences through the interval.

In the middle part of the Bearpaw Formation, at the Bassano Southeast locality, paleoenvironmental characteristics of the dinoflagellate assemblages are intermediate between those from the upper part of the Bow City interval and the lower part of the Bassano South interval. This may indicate that the basal to lower part of the Bearpaw Formation in this area was deposited at the maximum transgression.

In the Longview Section, the number of species in each assemblage is lower than in the Bow River assemblages, and *Chatangiella*? *biapertura* is consistently dominant. This suggests a paleoenvironmentally more restricted marine situation, and is consistent with the marginal location of the section in the basin.

CONCLUSIONS

Results from the study of dinoflagellate assemblages from the Bearpaw Formation in the Calgary area allow biostratigraphic correlation with other areas of the Western Interior of North America and interpretation of paleoenvironments. The conclusions from this study confirm the following interpretations proposed by previous workers: 1) the Bearpaw Sea would have had its maximum western extent in the Late Campanian; 2) in southern Alberta, the basal part of the formation was deposited during a rapid transgression and the uppermost part during a gradual regression. This suggests that maximum water depth may have occurred during deposition of the lower part of the formation.

SYSTEMATIC NOTES ON SELECTED DINOFLAGELLATES

Division DINOFLAGELLATA (Butschli, 1885),
Fensome et al., 1993

Class DINOPHYCEAE Pascher, 1914

Subclass PERIDINIPHYCIDAE
Fensome et al., 1993

Genus *Hystrichosphaeridium* Deflandre, 1937,
emend. Davey and Williams, 1966

Hystrichosphaeridium sp. cf. *H. arborispinum*
Davey and Willams, 1966 sensu Harland, 1973

Plate 4.3, figure 3

1973 *Hystrichosphaeridium* cf. *arborispinum*; Harland, p. 680, Pl. 85, figs. 6, 11.

1974 *Hystrichosphaeridium* sp. cf. *H. difficile*; McIntyre, Pl. 10, figs. 4–6.

Remarks. This form is characterized by intratabular, slender, fibrous, hollow processes with irregularly and finely secate distal extremities. The secae connect with those of adjacent processes and form trabeculae, which are generally not well preserved. The operculum is detached but rarely observed. The overall morphology compares well with the forms recorded by Harland (1973). The interpreted paratabulation of the material studied here is 4', 6'', 7c, 6''', ?s, ?p, 1''''. The specimens that have processes with distinctly fenestrate distal margin and entire edge were assigned in this study to *H. arborispinum* (Pl. 4.3, figs. 2, 5).

Occurrence. This form was recorded commonly in the basal and middle part of the Bearpaw Formation in the Bow River Section.

Genus *Isabelidinium* Lentin and Williams, 1977,
emend. Marshall, 1988

Isabelidinium belfastense (Cookson and
Eisenack, 1961), Lentin and Williams, 1977

Plate 4.1, figures 16, 17

1961 *Deflandrea belfastensis*; Cookson and Eisenack, p. 71, Pl. 11, figs. 4–6.

1973 *Deflandrea korojonensis*; Harland, p. 694, Pl. 87, fig. 6.

1977 *Australiella cooksoniae*; Harland, p. 183, Pl. 25, fig. 9.

1977 *Isabelidinium belfastense*; Lentin and Williams, p. 167.

Remarks. This species is characterized by an elongated body, and smooth pericyst surface lacking any indication of paracingulum. Moderately developed shoulders on the epipericyst and well developed apical and antapical pericoels are also distinctive features. The archeopyle varies in shape from omegaform to deltaform. The specimens here compare well with the type material except for the lack of granular ornament in apical and antapical areas of the pericyst. The specimens recorded as *Deflandrea korojonensis* and *Australiella cooksoniae* from the Bearpaw Formation by Harland (1973, 1977) may also be assigned to this species, judging from their elongated body shape, smooth pericyst surface and well developed apical and antapical pericoels.

Occurrence. The species occurs rarely through the Bearpaw Formation.

Isabelidinium sp.

Plate 4.1, figures 8, 9

1973 *Deflandrea spectabilis*; Harland, p. 693, 694, Pl. 87, figs. 9, 15.

Remarks. The characteristics of this form include thin, smooth walls of both pericyst and endocyst, and weak but consistent indication of paracingulum expressed by two parallel low ridges. The epipericyst usually lacks shoulders but occasionally poorly developed shoulders are present. The endocyst outline is generally subcircular to ovoidal. The endocyst is always appressed to the pericyst in the paracingular area. The operculum of the standard hexa 2a archeopyle is usually attached posteriorly. This form is similar to *Isabelidinium cooksoniae*, but lacks the granular pericyst ornament. The specimens recorded as *Deflandrea spectabilis* by Harland (1973) may be included in this form because they lack a partite paracingulum, which is characteristic of *Chatangiella spectabilis*. *Isabelidinium* sp. differs from *Chatangiella hexacalpis*, described from the lowermost Campanian in Manitoba, in lacking an obvious partite paracingulum.

Occurrence. *Isabelidinium* sp. occurs throughout the Bearpaw Formation. It is extremely abundant in the uppermost Oldman Formation and the basal part of the Bearpaw Formation, where the paleoenvironment is presumably embayment or nearshore.

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PLATES 4.1 to 4.3

(All figures x500)

Slides containing the figured dinoflagellates are housed in the type collection of the Geological Survey of Canada, Ottawa, Ontario. For each specimen the GSC type number (GSC), GSC locality number (GSC loc. C-) and palynology slide number (P) are recorded. Stage coordinates and England Finder readings are on file with the specimens.

PLATE 4.1

Figure 1. *Palaeoperidinium pyrophorum* (Ehrenberg, 1838) Sarjeant, 1967
GSC 106620, GSC loc. C-72104, P2208-9d.

Figure 2. *Phelodinium kozlowskii* (Gorka, 1963) Lindren, 1984
GSC 106621, GSC loc. C-72106, P2208-11d.

Figure 3. *Phelodinium magnificum* (Stanley, 1965) Stover and Evitt, 1978
GSC 106622, GSC loc. C-91314, P2407-2d.

Figure 4. *Chatangiella ditissima* (McIntyre, 1975) Lentin and Williams, 1976
GSC 106623, GSC loc. C-91315, P2407-3b.

Figures 5, 6. *Chatangiella*? *biapertura* (McIntyre, 1975) Lentin and Williams, 1976
5. GSC 106624, GSC loc. C-91314, P2407-2g.
6. GSC 106625, GSC loc. C-91314, P2407-2g.

Figure 7. *Chatangiella decorosa* (McIntyre, 1975) Lentin and Williams, 1976
GSC 106626, GSC loc. C-91314, P2407-2g.

Figures 8, 9. *Isabelidinium* sp.
8. GSC 106627, GSC loc. C-91314, P2407-2g.
9. GSC 106628, GSC loc. C-72078, P2207-2d.

Figure 10. *Palaeohystrichophora infusorioides* Deflandre, 1935
GSC 106629, GSC loc. C-72101, P2208-6c.

Figure 11. *Spinidinium clavus* Harland, 1973
GSC 106630, GSC loc. C-72081, P2207-5d.

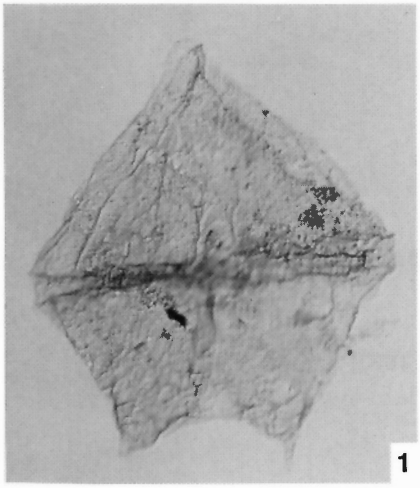
Figure 12. *Palaeoperidinium parvum* (Harland, 1973) Lentin and Williams, 1976
GSC 106631, GSC loc. C-72101, P2208-6c.

Figure 13. *Eucladinium spinosissimum* (Cookson and Eisenack, 1970) Stover and Evitt, 1978
GSC 106632, GSC loc. C-72077, P2207-1d.

Figure 14. *Laciniadinium firmum* (Harland, 1973) Morgan, 1977
GSC 106633, GSC loc. C-72079, P2207-3d,

Figure 15. *Laciniadinium arcticum* (Manum and Cookson, 1964) Lentin and Williams, 1980
GSC 106634, GSC loc. C-72101, P2208-6c.

Figures 16, 17. *Isabelidinium belfastense* (Cookson and Eisenack, 1961) Lentin and Williams, 1977
16. GSC 106635, GSC loc. C-72084, P2207-8d.
17. GSC 106636, GSC loc. C-91314, P2407-2f.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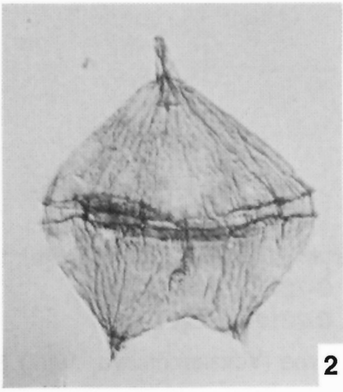
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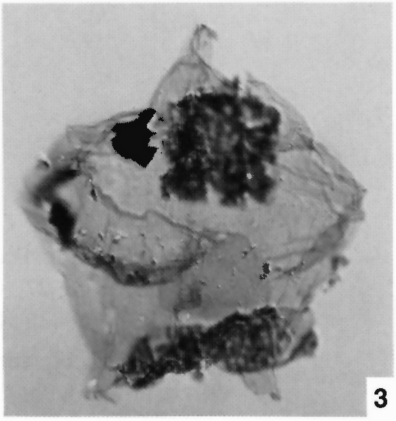
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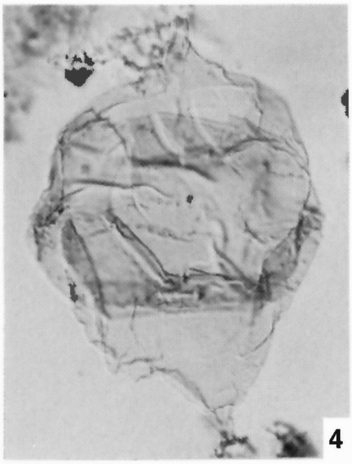
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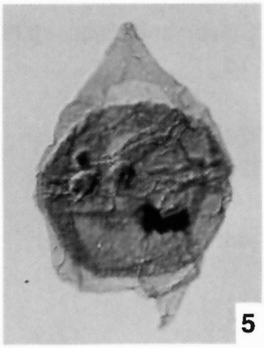
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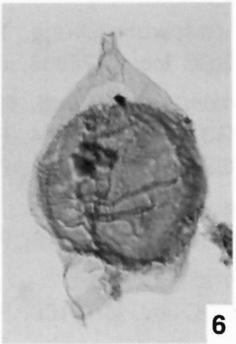
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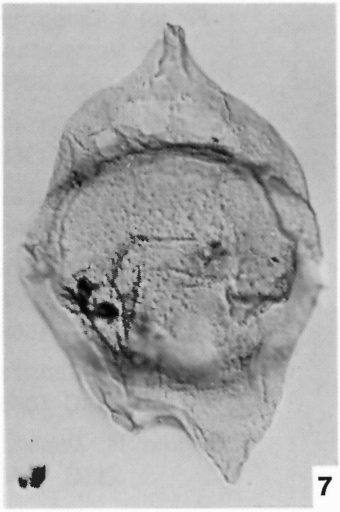
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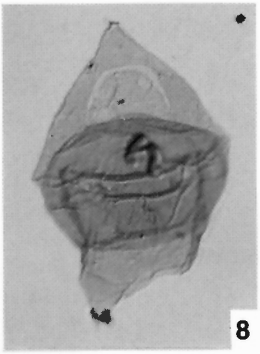
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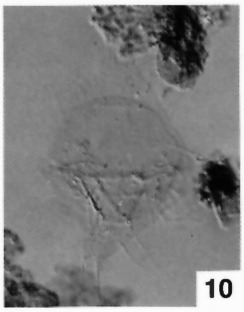
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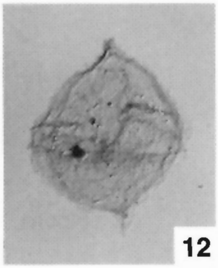
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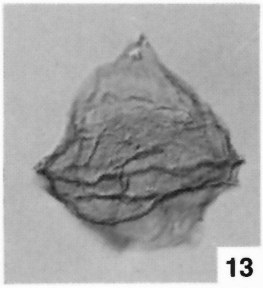
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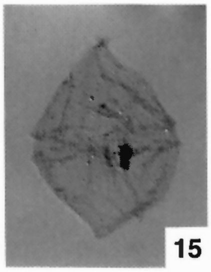
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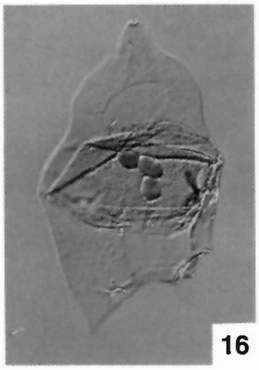
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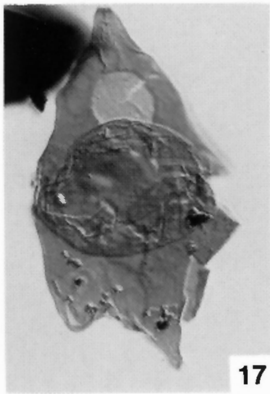
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PLATE 4.2

Figures 1, 2. *Cerodinium speciosum* subsp. *glabrum* (Gocht, 1969) Lentin and Williams, 1987
1. GSC 106637, GSC loc. C-72107, P2208-12d.
2. GSC 106638, GSC loc. C-72107, P2208-12c.

Figures 3, 4. *Dinogymnium longicorne* (Vozzhennikova, 1967) Harland, 1973; emend. Lentin and Vozzhennikova, 1990
3. GSC 106639, GSC loc. C-91317, P2407-5b.
4. GSC 106640, GSC loc. C-91314, P2407-2g.

Figure 5. *Dinogymnium sibiricum* (Vozzhennikova, 1967) Lentin and Williams, 1973; emend. Lentin and Vozzhennikova, 1990
GSC 106641, GSC loc. C-91314, P2407-2d.

Figure 6. *Circulodinium distinctum* (Deflandre and Cookson, 1955) Jansonius, 1986
GSC 106642, GSC loc. C-72077, P2207-1e.

Figure 7. *Senegalinium obscurum* (Drugg, 1967) Stover and Evitt, 1978
GSC 106643, GSC loc. C-72083, P2207-7d.

Figures 8, 9. *Trithyrodinium evittii* Drugg, 1967
8. GSC 106644, GSC loc. C-91314, P2407-2d.
9. GSC 106645, GSC loc. C-91314, P2407-2f.

Figure 10. *Dapsilidinium* sp. B
GSC 106646, GSC loc. C-91316, P2407-4d.

Figure 11. *Dapsilidinium* sp. A
GSC 106647, GSC loc. C-72102, P2208-7c.

Figures 12, 13. *Hystrichosphaeropsis* sp. cf. *H. quasicribrata* (O. Wetzel, 1961) Gocht, 1976
12. GSC 106648, GSC loc. C-72078, P2207-2d.
13. GSC 106649, GSC loc. C-72104, P2208-9c.

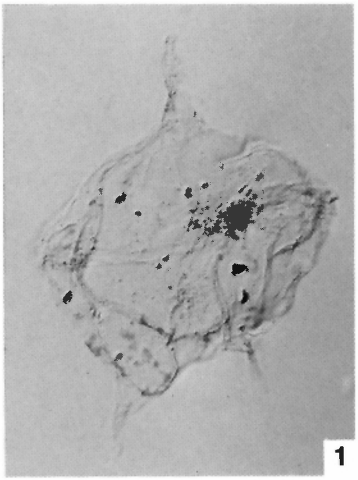
Figure 14. *Exochosphaeridium phragmites* Davey et al., 1966
GSC 106650, GSC loc. C-72107, P2208-12d.

Figure 15. *Cleistosphaeridium armatum* (Deflandre, 1937) Davey, 1969
GSC 106651, GSC loc. C-72101, P2208-6c.

Figure 16. *Cleistosphaeridium diversispinosum* Davey et al., 1966
GSC 106652, GSC loc. C-72084, P2207-8d.

Figure 17. *Callaiosphaeridium asymmetricum* (Deflandre and Courteville, 1939) Davey and Williams, 1966
GSC 106653, GSC loc. C-72106, P2208-11d.

Figure 18. *Odontochitina operculata* (O. Wetzel, 1933) Deflandre and Cookson, 1955
GSC 106654, GSC loc. C-72107, P2208-12d.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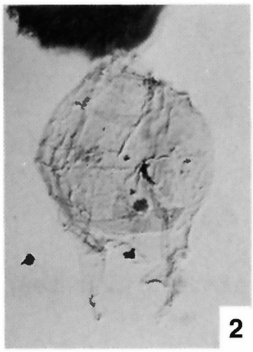
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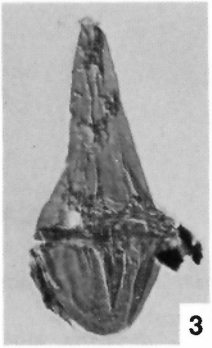
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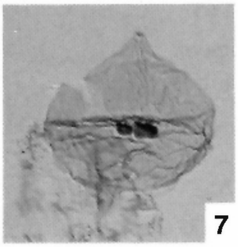
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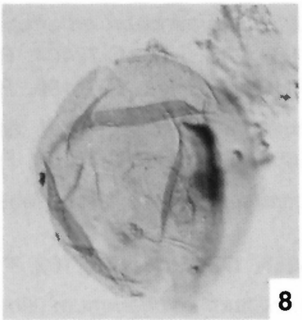
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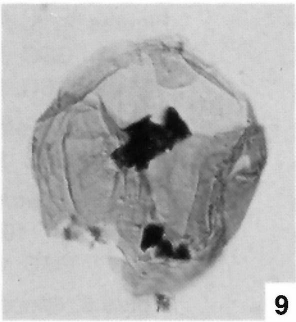
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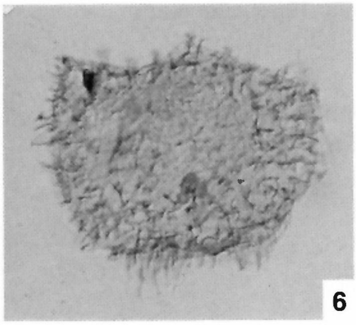
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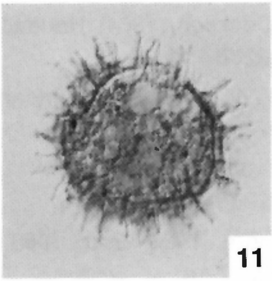
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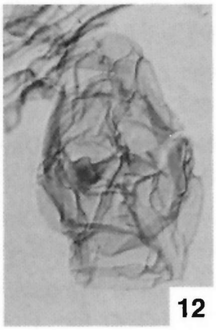
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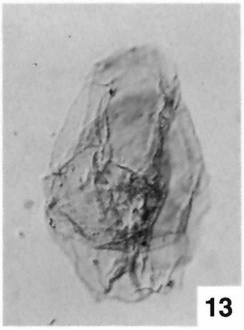
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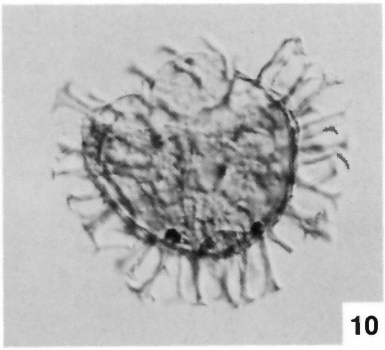
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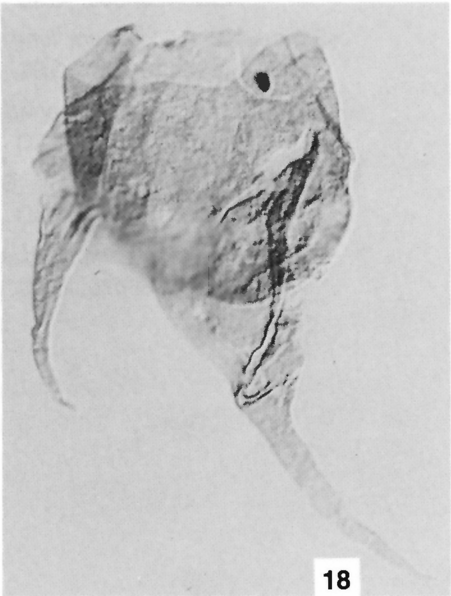
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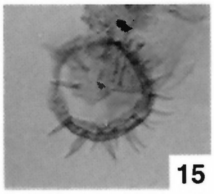
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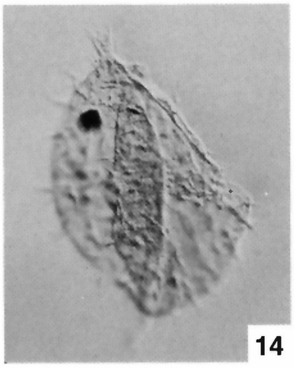
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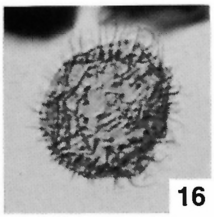
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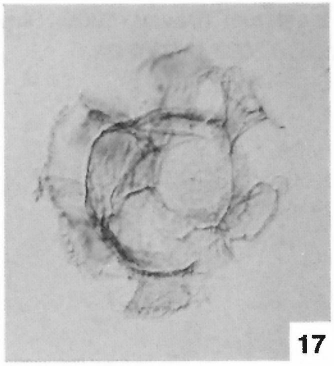
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PLATE 4.3

Figure 1. *Hystrichosphaeridium tubiferum* subsp. *tubiferum* (Ehrenberg, 1838) Deflandre, 1937; emend. Davey and Williams, 1966
GSC 106655, GSC loc. C-72106, P2208-11d.

Figures 2, 5. *Hystrichosphaeridium arborispinum* Davey and Williams, 1966
2. GSC 106656, GSC loc. C-72104, P2208-9d.
5. GSC 106659, GSC loc. C-72106, P2208-11d.

Figure 3. *Hystrichosphaeridium* sp. cf. *H. arborispinum*
GSC 106657, GSC loc. C-72106, P2208-11d.

Figure 4. *Hystrichosphaeridium tubiferum* subsp. *brevispinum* (Davey and Williams, 1966) Lentin and Williams, 1973
GSC 106658, GSC loc. C-72102, P2208-7c.

Figure 6. *Oligosphaeridium pulcherrimum* (Deflandre and Cookson, 1955) Davey and Williams, 1966
GSC 106660, GSC loc. C-72105, P2208-10d.

Figure 7. *Spiniferites pseudofurcatus* (Klumpp, 1953) Sarjeant, 1970; emend. Sarjeant, 1981
GSC 106661, GSC loc. C-72106, P2208-11d.

Figure 8. *Spiniferites porosus* (Manum and Cookson, 1964) Harland, 1973
GSC 106662, GSC loc. C-72105, P2208-10d.

Figure 9. *Spiniferites perforatus* (Davey and Williams, 1966) Sarjeant, 1970
GSC 106663, GSC loc. C-72102, P2208-7d.

Figure 10. *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854
GSC 106664, GSC loc. C-72105, P2208-10d.

Figure 11. *Achomosphaera ramulifera* (Deflandre, 1937) Evitt, 1963
GSC 106665, GSC loc. C-72077, P2207-1d.

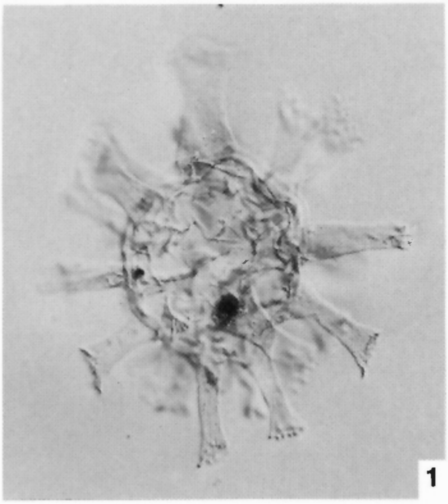
Figure 12. *Tanyosphaeridium variecalamus* Davey and Williams, 1966
GSC 106666, GSC loc. C-72078, P2207-2d.

Figure 13. *Wallodinium luna* (Cookson and Eisenack, 1960) Lentin and Williams, 1973
GSC 106667, GSC loc. C-72079, P2207-3d.

Figure 14. *Pterodinium agadirense* Below, 1981
GSC 106668, GSC loc. C-72104, P2208-9c.

Figure 15. *Fromea fragilis* (Cookson and Eisenack, 1962) Stover and Evitt, 1978
GSC 106669, GSC loc. C-72102, P2208-7c.

Figure 16. *Cribroperidinium exilicristatum* (Davey, 1969) Stover and Evitt, 1978
GSC 106670, GSC loc. C-72078, P2207-2e.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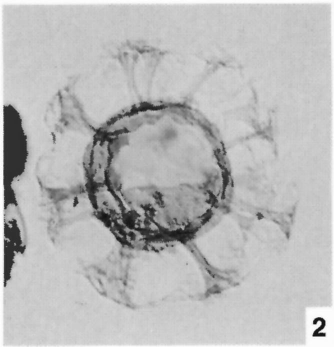
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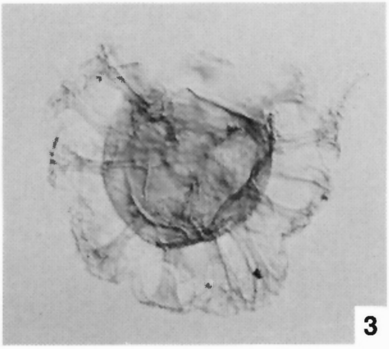
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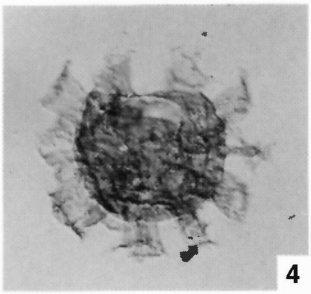
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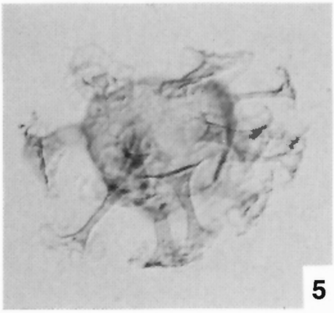
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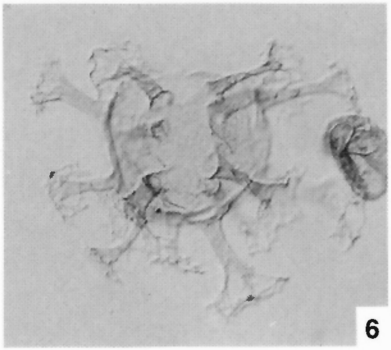
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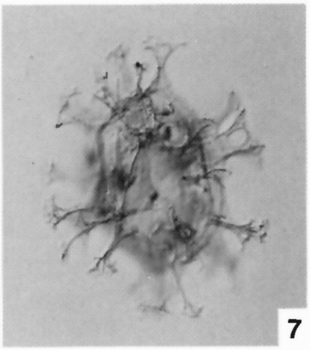
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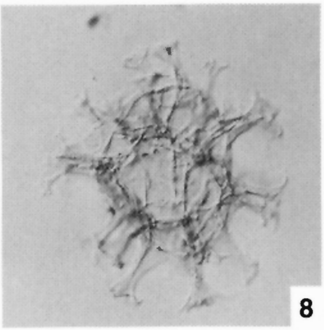
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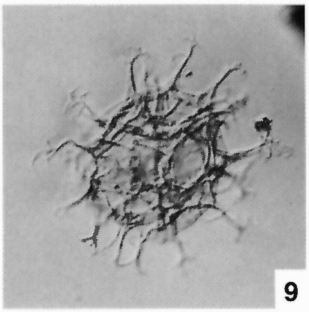
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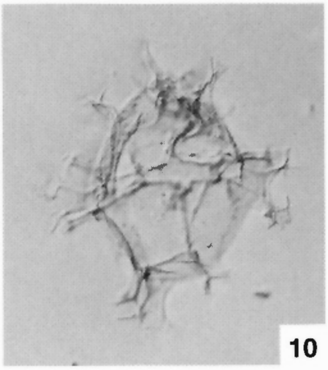
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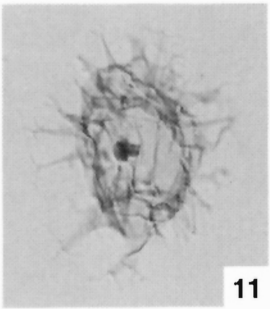
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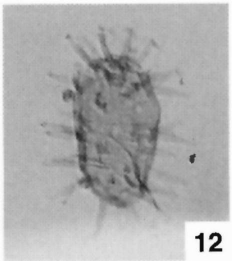
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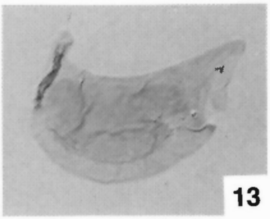
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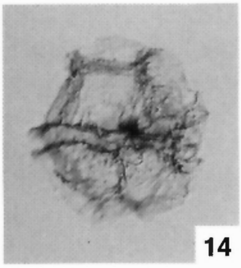
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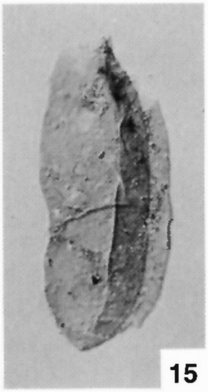
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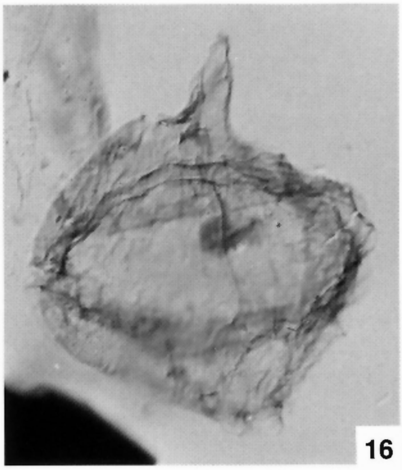
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NEW MIOCENE FOSSIL DISCOVERIES IN THE SKONUN FORMATION, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA, AND IMPLICATIONS FOR BASIN STRATIGRAPHY AND CLIMATE

J.M. White[1], L. Marincovich, Jr.[2], and R. Higgs[3]

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Abstract

New mollusc and palynomorph collections from two horizontally bedded exposures of the Skonun Formation in the Queen Charlotte Islands are reported. The fossils include the bivalve *Acila empirensis,* previously unreported from the Islands, and indicate a latest Miocene age for the sections. The sections are coeval, and probably younger than other Skonun Formation exposures, for which ages have been reported also based on molluscan collections. A cool-temperate marine environment is indicated for both the Collison Point and Yakoun River localities. Sedimentology and molluscan paleoecology indicate that the depositional environment was tidal shelf. The arboreal pollen assemblage is dominated by Pinaceae, with a few exotic broadleaf genera, suggesting a climate cooler than that represented by the Middle and Late Miocene pollen assemblage from the Tow Hill No. 1 well. It may also reflect the onset, in the Late Miocene, of the modern winter-wet, summer-dry climate. The uppermost palynological assemblages from the Tow Hill No. 1 well are considered to be older than the two sections reported here, and to be of Late Miocene, rather than Late Miocene to ?Pliocene age.

Résumé

De nouvelles collections de mollusques et de palynomorphes ont été observées dans des affleurements à litage horizontal de la Formation de Skonun, dans les îles de la Reine-Charlotte. Les fossiles comprennent le bivalve *Acila empirensis*, dont la présence dans cet archipel est reconnue pour la première fois, et ils révèlent que les coupes datent du Miocène terminal. Ces coupes sont contemporaines et sont probablement plus récentes que les autres affleurements de la Formation de Skonun dont les âges ont également été déterminés en se basant sur des collections de mollusques. Un milieu marin tempéré froid est indiqué pour les deux localités, soit la pointe Collison et la rivière Yakoun. La sédimentologie et la paléoécologie des mollusques indiquent que le milieu de sédimentation était celui d'une plate-forme tidale. L'assemblage pollinique de végétaux sylvatiques est dominé par Pinaceae et comprend quelques genres de feuillus exotiques, ce qui laisse supposer un climat plus froid que ce qu'avait indiqué l'assemblage pollinique du Miocène moyen et tardif provenant du puits Tow Hill N° 1. Il pourrait également coïncider avec le début, au Miocène tardif, du climat moderne à hiver humide et à été sec. Les assemblages polliniques supérieurs provenant du puits Tow Hill N° 1 sont considérés plus anciens que ceux des deux coupes décrites ici, et ils datent du Miocène tardif, plutôt que du Miocène tardif au ?Pliocène.

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INTRODUCTION

Most Tertiary sedimentary strata of the Queen Charlotte Islands belong to the Skonun Formation, which consists of at least 5 km of marine and nonmarine sandstone, mudstone, conglomerate and coal and offers considerable petroleum-reservoir potential (Sutherland Brown, 1968; Shouldice, 1971; Yorath, 1987; Higgs, 1991). These strata form the fill of the Queen Charlotte Basin, as defined by Shouldice (1971). They outcrop on eastern Graham Island and underlie Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Fig. 1). Onshore exposures are few and small due to a veneer of Quaternary glacial drift (Sutherland Brown, 1968). The Skonun Formation includes strata of possibly Late Oligocene age, and of Miocene and Pliocene age, based on foraminifera, palynomorphs and molluscs (Martin and Rouse, 1966; Sutherland Brown, 1968; Addicott, 1978; Champigny et al., 1981; Patterson, 1989; White, 1991). The stratigraphic relationship of Paleogene strata on Graham Island (White, 1990) to the Skonun Formation is uncertain. In adding to the biostratigraphic database, this study aids correlation and paleogeographic reconstruction of the Skonun Formation. The data also are useful for interpretations of basin evolution and west coast climatic history.

As part of a multidisciplinary basin analysis of the Queen Charlotte Islands region undertaken by the Geological Survey of Canada from 1987 to 1989 (Thompson, 1988), two of us (RH and JW) examined most of the known Skonun Formation exposures (about 15). Molluscs were recovered from two exposures, on the Yakoun River and at Collison Point (Fig. 5.1), from which megafossils had not previously been reported. Both localities yielded the bivalve *Acila empirensis,* previously unknown from the Skonun Formation. Palynomorphs were also examined from both localities. In this paper, these fossil discoveries and their sedimentological context are described, and the implications for the age and paleoclimate of the Skonun Formation are described. In this paper, RH contributed stratigraphy and sedimentology, LM contributed malacology, and JW contributed palynology. The samples yielded no foraminifera.

Acknowledgments

This paper is Contribution No. 27991 of the Geological Survey of Canada. JW thanks L. McCulloch-Smith and B. van Helden, Chevron Canada Resources, for discussions on sedimentology and palynology. We thank J. Haggart and D. H. McNeil, Geological Survey of Canada, for reviews of the manuscript.

SEDIMENTOLOGY

The sedimentology of the Skonun Formation, including the sections described in this paper, has been presented by Higgs (1989, 1991) and is abbreviated below. All Skonun Formation exposures discussed by Higgs show evidence of deposition in deltaic and/or shelf environments (op. cit.).

Yakoun River

Horizontal strata in a bare cliff on the west bank of the Yakoun River at UTM Grid Reference PQ888375 (Fig. 5.1) comprise 12 m of tabular cross-stratified, medium grained sandstone overlain by 3 m (estimated) of massive mudstone (Fig. 5.2a; Higgs, 1991). Sandstone cross-sets are 30 to 100 cm thick and foresets dip toward the north. The top few decimetres of each set contain vertical, widely spaced *Ophiomorpha* burrows. The sandstone beds contain single pebbles up to 3 cm across and one cross-set boundary is marked by a string of angular to rounded pebbles and cobbles, including a volcanic clast 50 cm long. The overlying mudstone, exposed at the cliff top, is inaccessible except as talus at the cliff base, from which molluscs and palynomorphs were recovered (Higgs, 1991).

Collison Point

A fresh exposure of 11.5 m of horizontal strata dominated by medium sandstone was examined in a recent logging road in the sea cliff at Collison Point (Figs. 5.1, 5.2b, UTM Reference PQ829629; Higgs, 1989). This section could be closely examined as the logging road cuts obliquely up section. As at Yakoun River, the sandstone is tabular cross-stratified, with northward-dipping foresets and *Ophiomorpha* burrows. The burrows are mostly vertical in the lower half of the section, but mainly horizontal in the upper half. The burrows, which have a sandy-mud lining (Frey et al., 1978; Higgs, 1989), are commonly so closely spaced that the original cross-stratification is obscured. In one interval, burrow linings volumetrically exceed the host sand, and the lithology is effectively a sandy mudstone (7.8-8.7 m, Fig. 5.2b). Bivalves and palynomorph samples were collected from a 20-cm interval within this muddy unit, and are described below. Floating pebbles (including amphibolite) and wood fragments are scattered throughout the Collison Point section (Higgs, 1989). The Collison Point beds are horizontal; the section shows no obvious tectonic disturbance.

A shallow roadcut about 50 m south of the section described above exposes conglomeratic fill in a probable channel scour into the sandstone. This short exposure is stratigraphically near the top of the 11.6 m section previously described.

PALEONTOLOGY

Molluscs

At least five species of molluscs, including four bivalves and one gastropod, are present in the two Skonun Formation collections (Table 5.1, Plate 5.1). Two of the bivalves, *Acila* (*Truncacila*) *empirensis* and *Clinocardium coosense*, are confidently identified to species, and *Patinopecten oregonensis* is tentatively identified to species. Another bivalve, *Periploma*, is

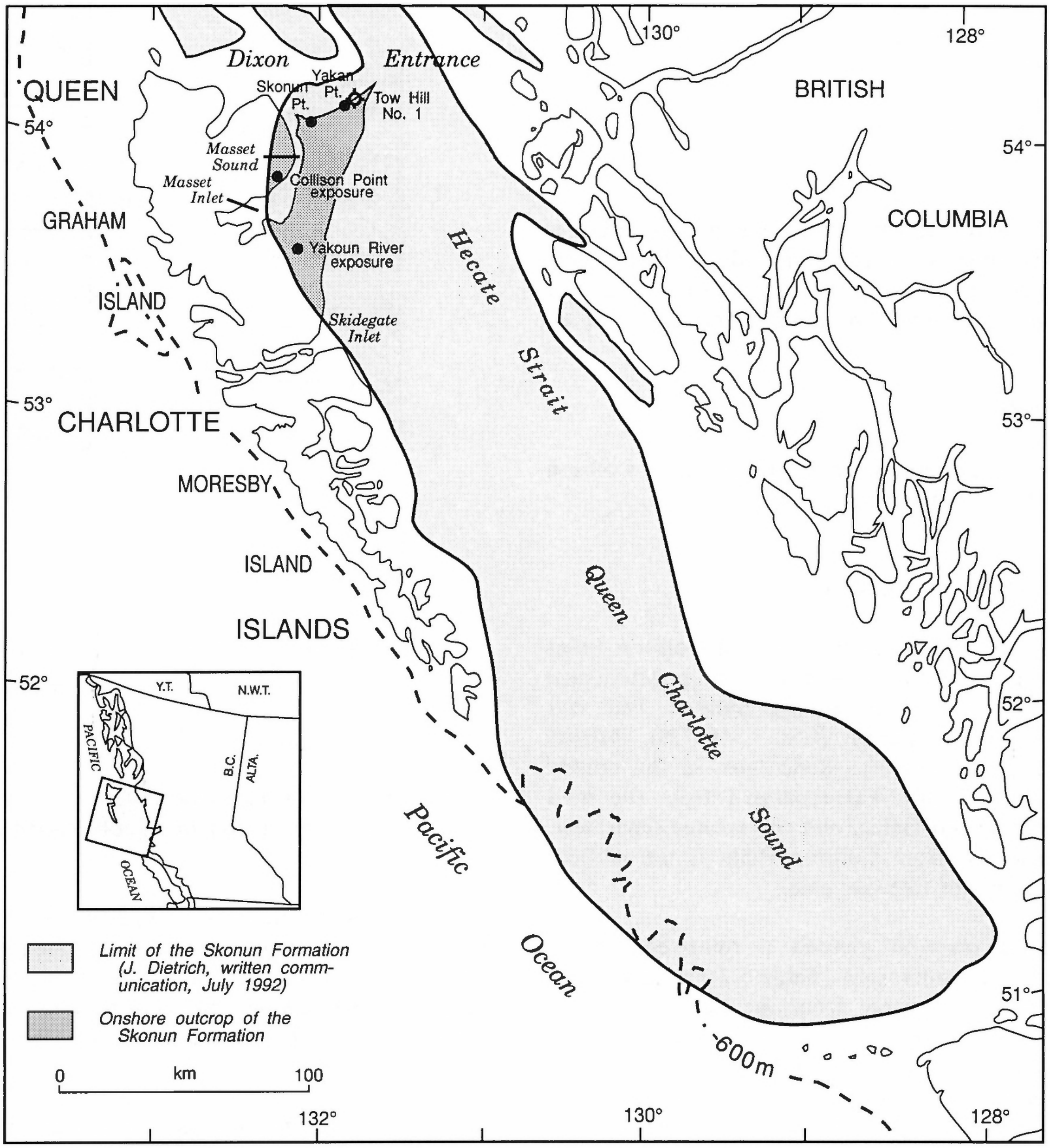

Figure 5.1. *Location map of the Queen Charlotte Islands region. The Skonun Formation outcrops are mostly covered by Quaternary drift. Apart from the two Skonun Formation exposures indicated, several other small exposures occur within the shaded area, mostly on the coast (Higgs, 1991).*

TABLE 5.1

Mollusks from two localities in the Skonun Formation

	Collison Point	Yakoun River
BIVALVES		
Acila (*Truncacila*) *empirensis* Howe	•	•
Acilia sp. indet.	•	•
Clinocardium coosense (Dall)		•
Clinocardium? sp.		•
Patinopecten sp. cf. *P. oregonensis* (Howe)	•	
Pectinidae genus indet.	•	
Periploma? sp.		•
GASTROPOD		
Turritella sp. indet.		•

identified questionably to genus. Only one gastropod is present: *Turritella* sp. indet. Reported here for the first time from the Skonun Formation are *Acila* (*Truncacila*) *empirensis*, *Periploma*? and *Turritella* sp.

Palynomorphs

Palynological samples were examined from Collison Point and Yakoun River.

Collison Point assemblage

The sandstone making up most of the Collison Point section (Fig. 5.2b) is unfavourable for palynological analysis. However, the muddy mollusc bed was sampled for palynomorphs (GSC C-166779). Detrital lignite was visible, with a hand lens, in the muddy sediment. The lignite was separated from the mud fraction during processing, and was treated separately. Wood recovered from Collison Point is uncoalified; palynomorphs are likewise pale.

The mud fraction yielded a relatively sparse collection of palynomorphs (Table 5.2), totalling 196. The arboreal assemblage from the mud fraction is dominated by Pinaceae (29.5%), including the genera *Picea*, *Pinus*, *Tsuga heterophylla*-type, *Tsuga*, and *Abies*. Only 8.6% of Taxodiaceae-Cupressaceae-Taxaceae (T-C-T) pollen occurs in the sample. The assemblage includes angiosperms and gymnosperms now exotic to the Queen Charlotte Islands, i.e., *Quercus*, *Fagus*, possibly *Corylus* and ?*Juglans*, and possibly *Podocarpus*. The coal fraction was virtually barren of palynomorphs, suggesting that the mud fraction was not significantly contaminated by recycled palynomorphs from detrital lignite. The dinoflagellate taxa *Geiselodinium* sp., and *Habibacysta tectata* sensu Head et al., 1989 were recovered from the mudstone sample.

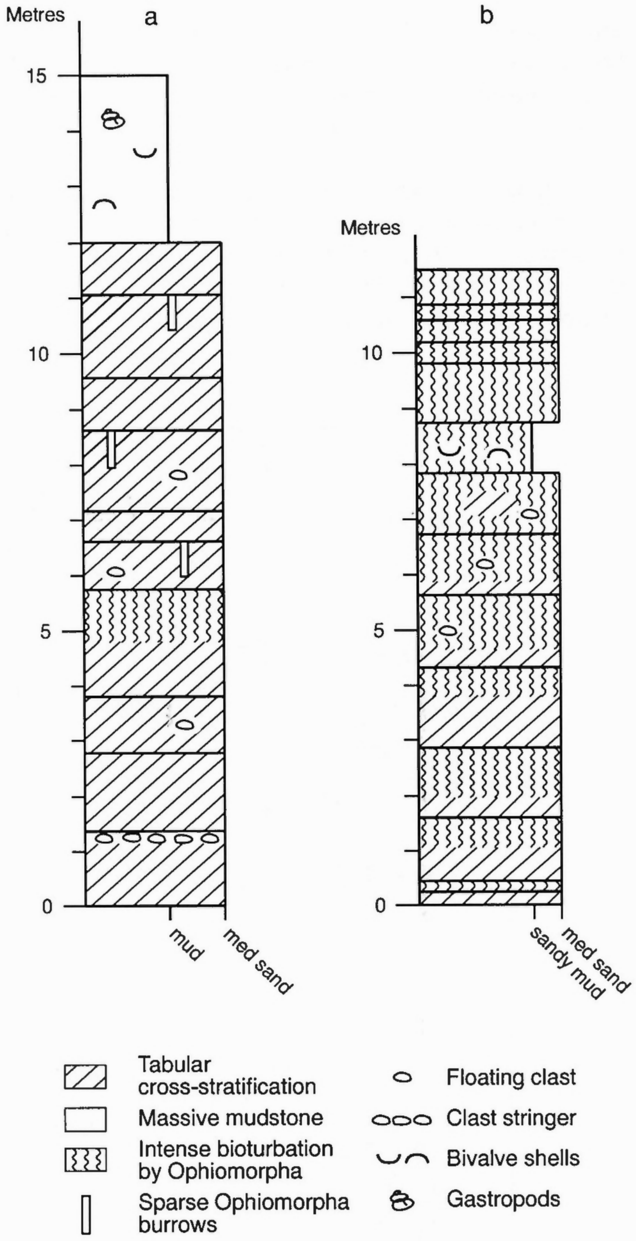

Figure 5.2. *Sedimentological logs of measured sections: (a) Yakoun River; (b) Collison Point.*

This palynomorph assemblage can be compared to an apparently sparse assemblage described from Collison Point by Martin and Rouse (1966). Their lithostratigraphy reports 4.6 m (15 ft.) of section of which the lower 2.8 m (9 ft.) is sandstone enclosing

TABLE 5.2

Palynological assemblages derived from Collison Point (GSC C-166779) and Yakoun River (GSC C-129754)

TAXON	Collison Point (%)	Yakoun River (%)
ALGAE AND DINOFLAGELLATES		
Inaperturate algal cysts	4.6	17.2
Habibacysta tectata Head et al., 1989	x	9.0
Geiselodinium sp.	0.5	
Operculodinium centrocarpum sensu Wall and Dale, 1968		0.6
Trinovantedinium sp.		0.3
?Dinoflagellates		8.4
Total algae and dinoflagellates	**10**	**82**
FUNGI		
Brachysporisporites sp.	0.5	
Fractisporonites sp.	3.8	
Microsporonites sp.	0.5	
Monoporisporites sp.	1.0	
Polyporisporites sp.	0.5	
Pycnidium fragment	1.0	
FILICALES		
Athyrium filix-femina type	1.1	
Deltiodospora sp.	0.5	0.8
Laevigatosporites sp.	12.9	13.8
Lycopodium annotinum-type	0.5	
Osmunda irregulites Martin and Rouse, 1966	x	
Osmunda sp.		1.3
Polypodiaceae	1.1	
Polypodiaceae–Dennstaedtiaceae Form 1 Martin and Rouse, 1966	3.2	0.4
Polypodiaceae–Dennstaedtiaceae Form 2 Martin and Rouse, 1966	0.5	1.3
Polypodiaceae–Dennstaedtiaceae Form 3 Martin and Rouse, 1966	1.6	
Selaginella sinuites Martin and Rouse, 1966	1.6	0.8
Sphagnum sp.		0.4
CONIFERALES		
Abies sp.	1.6	1.3
Picea sp.	5.9	9.6
Pinus sp.	1.6	11.3
Pinus koraiensis-type		x
Pinaceae undifferentiated	11.3	5.9
Tsuga heterophylla-type	3.2	3.8
Tsuga sp.	5.9	1.3
Podocarpus-type	x	0.8
Taxodiaceae–Cupressaceae–Taxaceae	8.6	10.5
cf. *Sciadopitys*		0.4
ANGIOSPERMAE		
Cyperaceae	1.6	0.4
Gramineae	0.5	x
Aceraceae		0.4
Alnus sp. (4 pore)	1.1	2.9
Alnus sp. (5 pore)	3.8	2.5
Alnus sp. (6 pore)	0.5	0.8
Betula sp. (>20 μm)		3.4
Betula sp. (≤20 μm)	1.1	0.4
Caryophyllaceae cf. *Cucubalus*		x
Chenopodiaceae		x
Compositae, Tubuliflorae	x	
Corylus-type	0.5	
Ericaceae	0.5	0.8
cf. *Fagus* sp.	2.2	
Fagus granulata Martin and Rouse, 1966		0.4
Fraxinus sp.		x
?*Juglans* sp.	1.1	
cf. *Nyssa* sp.		0.4
Onagraceae	x	
Pterocarya sp.		0.8
Quercus granopollenites Rouse, 1962	0.5	1.3
cf. *Quercus* sp.	0.5	x
Tricolporopollenites sp.	0.5	1.7
Tricolporopollenites sp.	0.5	0.4
Triporopollenites sp.	1.6	2.1
Ulmus/Zelkova		0.4
Umbelliferae	0.5	
OTHER		
Indeterminable palynomorphs	13.4	17.2
Total pollen and spores	**186**	**239**

'x' indicates that the taxon was observed but not counted, or observed in the screened fraction of the residue.
Pollen and spore percentages are calculated on the basis of total pollen and spores; algal percentages on the basis of total pollen and spores plus algae and dinoflagellates.

three siltstone beds, and the upper 1.8 m (6 ft.) is conglomerate. This does not match the 11.5 m section described here. Their section might be from a sea cliff exposure of sandstone capped by conglomerate channel fill. If so, their sandstone and siltstone beds would probably be stratigraphically equivalent to the upper half of our 11.5 m section, but likely did not include the mollusc bed reported here.

The study by Martin and Rouse (1966) showed an even greater dominance of Pinaceae genera (53.5%) and a low relative abundance of the T–C–T pollen (3.5%). Martin and Rouse identified the palynomorphs *Podocarpus, Cedrus, Pterocarya, Corylus* and *Quercus,* which do not now occur on the Queen Charlotte Islands. Considering that their samples and those reported here are probably from different beds, the assemblages are similar in the dominance of Pinaceae pollen, the low representation of T–C–T pollen, and the sparse representation of now exotic genera. Differences in percentages may be partly explained by differential sorting, which can occur in neritic environments (Cross et al., 1966; Traverse and Ginsberg, 1966; Heusser and Balsam, 1977).

Yakoun River sample

A palynological sample was taken from the matrix of a mollusc cast from Yakoun River section (GSC C-129754), from which a count of 321 palynomorphs was obtained. The sample is also dominated by the Pinaceae genera that occur in the Collison Point section, and which constitute 33.2% of the terrestrial assemblage. T–C–T and cf. *Sciadopitys* pollen make up 10.9% of the assemblage. Several of the angiosperm and gymnosperm taxa that occur in Yakoun River do not occur in Collison Point, including *Fagus granulata* Martin and Rouse, 1966, *Fraxinus* sp., cf. *Nyssa, Pterocarya* and *Ulmus/Zelkova*. Algae are more abundant in the Yakoun River than in the Collison Point assemblage, including the taxa *Habibacysta tectata*, Head et al., 1989 and *Operculodinium centrocarpum* sensu Wall and Dale, 1968.

DISCUSSION

Correlation and age

The association of the fossils with the burrowed tidal foresets is certain at Collison Point because the continuity of sedimentation between the sandier and muddier beds could be traced. In contrast, the transition from the sandstone to mudstone at Yakoun River appears abrupt and may indicate some disconformity. Nonetheless, the similarities between both sections in terms of sedimentology, current direction, mollusc and palynomorph assemblages, and lack of tectonic deformation implies that they are penecontemporaneous, or at least indistinguishable in age on the basis of available data.

Molluscs

Addicott (1978) considered molluscs from other exposures of the Skonun Formation in northeastern Graham Island to represent the Wishkahan Stage of the U.S. Pacific Northwest molluscan biochronology (early late Miocene) and to be a warm water fauna. The assemblage from the two sections reported here are interpreted to be of Late Miocene age, but not coeval with the previously reported molluscan assemblages.

At the time of Addicott's report, the Wishkahan Stage was thought to be early Late Miocene, and the succeeding Graysian Stage to be late Late Miocene, based on the earlier work of Addicott (1976). However, a reassessment of the U.S. Pacific Northwest molluscan sequence with reference to planktic microfossils (Allison, 1978) indicated that the combined Wishkahan and Graysian stages have an age range of late Middle Miocene to Late Miocene. Subsequent studies of diatoms from Wishkahan and Graysian faunas in Oregon and Washington suggest that the two stages are coeval, at least in part (Barron and Armentrout, 1980; Barron, 1981), and confirm the combined age range of late Middle Miocene to Late Miocene.

The Skonun mollusc fauna described by Addicott (1978) is most similar in species composition to that of the type Empire Formation at Coos Bay and the Empire Formation exposed near Cape Blanco, southwestern Oregon. The Empire Formation near Cape Blanco contains molluscs determined by Addicott (1983) as Late Miocene in age. The same author noted that diatoms and silicoflagellates associated with poorly preserved, not age-diagnostic, molluscs in the upper part of this section are of late Late Miocene age. Addicott (1983) also observed that many molluscs of the Empire Formation near Cape Blanco are present only in Wishkahan/Graysian (late Middle Miocene to Late Miocene) faunas or range into younger faunas, but not into older (Newportian Stage) faunas. This association with younger faunas supports the interpretation that the age of the Empire Formation near Cape Blanco, and of the correlative Skonun

Formation, is within the Late Miocene, part of the Wishkahan/Graysian stage. Diatom florules from both the type Empire Formation and the Empire Formation near Cape Blanco were considered by Barron (1981) to be of late Late Miocene age, or about 6.5 to 8.0 Ma. Together, this evidence suggests that the Skonun fauna described from northeastern Graham Island by Addicott (1978) is of late Late Miocene age.

The present collections from Yakoun River and Collison Point (Table 5.1) clearly support a Wishkahan/Graysian age for the Skonun Formation. The bivalve *Acila* (*Truncacila*) *empirensis*, previously unknown from the Skonun Formation, is reported in Wishkahan through Moclipsian (late Middle Miocene to Pliocene) faunas in the U.S. Pacific Northwest (Addicott, 1976) and in the Late Miocene Tachilni Formation fauna in southwestern Alaska (Marincovich, 1983). *Patinopecten oregonensis* is known elsewhere only in Wishkahan/Graysian faunas of Oregon and Washington (Addicott, 1976). *Clinocardium coosense* was described from the Wishkahan/Graysian Empire Formation and there are no reliable records from other formations. *Periploma*, questionably identified here, is notably absent from Neogene faunas of Washington and Oregon, but common in Miocene and older faunas from the Gulf of Alaska to Japan (Kanno, 1971; Marincovich, 1980). An age assignment within the late Miocene portion of the Wishkahan/Graysian molluscan stages is compatible with the known age ranges elsewhere of the molluscs from Collison Point and Yakoun River.

All of the Yakoun River and Collison Point Skonun molluscs are known from the upper Miocene part of the Yakataga Formation exposed in the Lituya district of southeastern Alaska (L. Marincovich, Jr., unpublished data), whereas only three of the five Skonun taxa are present in well studied, warm-water faunas to the south of the Queen Charlotte Islands. The Yakataga Formation in the Lituya district contains cold-temperate molluscs associated with glaciomarine lithotypes, including dropstones (Plafker and Addicott, 1976). Yakataga faunas in the Lituya district do not contain relatively warm-water bivalves such as *Protothaca* and *Pseudocardium* cited by Addicott (1978) in an unpublished list of Lituya district bivalves identified by F.S. MacNeil (L. Marincovich, Jr., unpublished data).

The relatively warm-water Skonun Formation fauna with southern affinities noted by Addicott (1978) is most likely to have lived during the warmest interval of the Late Miocene. Barron and Baldauf (1990) note that the Late Miocene thermal maximum occurred between 6.6 and 7.6 Ma, based on North Pacific planktic microfossil data and oxygen isotope values. This age range coincides closely with the 6.5 to 8.0 Ma age cited by Barron (1981) for Empire Formation diatom florules. The colder water Skonun fauna noted here (discussed below) may have lived either before or after that late Miocene thermal optimum. Marine glaciation in the northeastern Gulf of Alaska began in the early Middle Miocene (15 to 16 Ma), based on molluscan faunas in the Yakataga Formation (Marincovich, 1990a, b), or in the Late Miocene, based on foraminifera (Lagoe et al., 1993). Coal or cold northern water probably influenced marine faunas in British Columbia, Washington and Oregon both before and after the late Miocene climatic optimum.

Palynomorphs

The palynomorph assemblage from Collison Point can be compared with Middle to Late Miocene assemblages from the Tow Hill No. 1 well (Fig. 5.1; White, 1991), and with Miocene to Pliocene assemblages from southern Alaska.

Gramineae, Compositae and Ericaceae, which occur at Collison Point and/or Yakoun River, first appear in the middle Miocene in the Tow Hill No. 1 well (White, 1991), and persist to the present. There is, however, a significant difference between the palynomorph assemblage in the Tow Hill No. 1 well and those from Collison Point and Yakoun River. T-C-T pollen dominates the upper Tow Hill assemblages (approx. 30%) with Pinaceae pollen making up about 10% of the total (White, 1991). The converse is true of the Collison Point and Yakoun River assemblages. This suggests a more modern flora at Collison Point and Yakoun River and thus an age younger than the Late Miocene to (?)Early Pliocene age estimated by White (1991) for the upper Tow Hill assemblages.

Onagraceae pollen, found at Collison Point, were reported by Leopold (1969) as first occurring in the Late Miocene to Early Pliocene of southern Alaska. The absence of Onagracean pollen in the Tow Hill No. 1 well (White, 1991), suggests an age older than Late Miocene for these strata.

Evidence of the age of the Collison Point and Yakoun River asssemblages is also derived from the percentage of "exotic" taxa, i.e., taxa that no longer live on the Queen Charlotte Islands. A characteristic of late Neogene floras in southern Alaska is the loss of exotic genera (Wolfe et al., 1966). Palynomorphs representing exotic arboreal taxa make up only about

3% of the Collison Point assemblage, i.e., *Podocarpus*-type, *Fagus* and *Quercus*. Likewise, the arboreal taxa cf. *Sciadopitys*, *Fagus granulata* Martin and Rouse, 1966, *Fraxinus*, cf. *Nyssa*, *Pterocarya* and *Ulmus/Zelkova* make up about 4% of the Yakoun River floral assemblage. Thus, the Collison Point and Yakoun River pollen assemblages suggest both an age younger than the upper strata in the Tow Hill No. 1 well, and a correlation with the Late Miocene to Late Pliocene of southern Alaska (Leopold, 1969), although the Queen Charlotte assemblages are not dominated by Betulaceae, as is the Alaskan Clamgulchian assemblage (Wolfe et al., 1966).

In the Atlantic realm, *Habibacysta tectata* occurs in the Middle Miocene of Baffin Bay, through the Upper Pliocene of the North Atlantic and possibly occurs as late as the middle Pleistocene in the Labrador Sea (Head, 1993). In the Pacific realm, *H. tectata* has been identified in the Pliocene of the Bering Sea as *Filisphaera filifera* (Matsuoka and Bujak, 1988), but is now identified as *H. tectata* (Head, 1993). The Atlantic range is consistent with a Late Miocene age for both sections, but would also permit a Pliocene to middle Pleistocene age. This second record of *H. tectata* from the Pacific also extends its range there into the Late Miocene.

Summary

The molluscan, palynomorph and dinoflagellate assemblages are consistent with a late Late Miocene age for both the Collison Point and Yakoun River sections. The composition of the molluscan fauna, however, indicates that these assemblages were not coeval with the Late Miocene Skonun Formation molluscan assemblage reported by Addicott (1978). The modern aspect of the pollen assemblage and its difference from that recovered from upper strata in the Tow Hill No. 1 well (this report; White, 1991) points to an age younger than the Skonun Formation outcropping at Skonun Point and Yakan Point, and that penetrated by the Tow Hill No. 1 well.

Addicott (1978) reported molluscs of Wishkahan/Graysian age predominantly from Skonun and Yakan points, both of which have anticlinal structures with steeply dipping beds (MacKenzie, 1916; Sutherland Brown, 1968). In contrast, the Yakoun River and Collison Point outcrops show no evidence of deformation, suggesting that these sections are younger.

We conclude that the Collison Point and the Yakoun River sections are probably of latest Miocene age, postdating the Late Miocene thermal maximum (6.6 to 7.6 Ma; Barron and Baldauf, 1990). The evidence suggests that the age of these sections lies between 5.3 and 6.6 Ma.

Depositional environment

The presence of *Ophiomorpha* in sandstones of the Yakoun River section suggests a marine environment (Frey et al., 1978). An offshore marine shelf is inferred, based on the lack of evidence for shoreface or beach deposition, and on the inner- to mid-shelf molluscan fauna in the overlying mudstone (see below). The cross-stratification indicates that the shelf was subjected to a current strong enough to move large dune-like bedforms in medium sand. This current was probably of tidal origin; other Skonun exposures show unequivocal evidence of tides, namely, double mud drapes and herringbone cross-stratification (Higgs, 1989, 1990). Hence, the inferred environment was a tide-dominated shelf floored by straight-crested sand dunes colonized by *Ophiomorpha* (probably shrimps — see Frey et al., 1978). A similar setting was inferred for Eocene deposits in Belgium (Houthuys and Gullentops, 1988). Modern offshore tidal sand dunes are also well known (Belderson et al., 1982). The consistent northward dip of the foresets at Yakoun River, and the lack of evidence for reversed (southward) transport (e.g., reactivation surfaces), suggest that the sand transport fields for the ebb and flood tides were separate (Higgs, 1990).

The clasts in the sandstone are probably dropstones. They might have been deposited from the roots of drifted trees, but one of us (RH) favours the interpretation that they were deposited from icebergs (Higgs, 1989, 1991) for four reasons: 1) the lack of conclusive evidence in the literature for tree-rafted clasts in offshore deposits, fossil or modern; 2) a thick glaciomarine succession with ice-rafted dropstones in the Miocene–Pliocene of southeastern Alaska (Plafker and Addicott, 1976; Marincovich, 1990a, b; Lagoe et al., 1993); 3) an increase in elevation of the Coast Mountains of British Columbia in the Late Miocene (Parrish, 1983), perhaps creating the necessary elevation for alpine glaciation and 4) the cold-temperate environment indicated by the molluscs.

The abrupt upward change from sandstone to mudstone at 12 m (Fig. 5.2a) may indicate a shift in tidal current pathway, leading to an abrupt decrease in tidal current velocity. The molluscs and palynomorphs were collected from the mudstone section. Dropstones were not observed, either due to their absence, or because the section could only be examined in talus.

In summary, the depositional environment of the Yakoun River section is interpreted as a high energy and, subsequently, a low energy tidal shelf.

The sediments at Collison Point strongly resemble those at Yakoun River, and are likewise interpreted as tidal-shelf deposits. At Collison Point, however, one could observe lithological gradation between the cross-stratified sandstones and the enclosed mud beds, which yielded the age-diagnostic mollusc casts and palynomorphs.

Paleoecology

Depth

The habitats of modern analogues of the Skonun molluscs (Table 5.1) imply an inner- or mid-shelf environment for the Yakoun River and Collison Point localities. The taxon with the narrowest bathymetric range is *Periploma* (questionably identified here), which lives in depths of 20 to 90 m in the northeastern Pacific (Keen and Coan, 1974). Modern *Turritella* species also have an upper depth limit of 20 m in the same region, with a lower limit of 185 m. Depth ranges in the modern northeastern Pacific of the other Skonun molluscs are: *Acila* (*Truncacila*), 10–1280 m; *Clinocardium*, 0 to 200 m; *Patinopecten*, 5 to 185 m. Even though *Acila* (*Truncacila*) ranges into relatively deep water, all Skonun taxa are most common in the shallower parts of their modern depth ranges. In addition, it is well known that these taxa occur together elsewhere only in relatively shallow, inner- to mid-shelf environments. Comparable faunas are those of the upper Miocene Empire Formation of Oregon (Dall, 1909; Addicott, 1983) and coeval parts of the Yakataga Formation of the northeastern Gulf of Alaska (Kanno, 1971; Addicott et al., 1978). The combination of modern depth ranges of Skonun taxa and their occurrences in better studied faunas elsewhere suggests depths of 20 to 50 m for the Yakoun River and Collison Point faunas. This is consistent with the sedimentological evidence for a tidal-shelf setting (see above).

Paleoclimatology

Marine temperature

The Skonun collections described in this paper imply a colder environment than the Skonun molluscan fauna of 29 taxa studied by Addicott (1978). *Acila* (*Truncacila*), *Periploma*? and *Turritella* were not cited by Addicott (1978) from the Skonun fauna. *Periploma*? and *Turritella* are also unknown from the coeval Empire Formation of Oregon (Dall, 1909; Addicott, 1983), although common in cold-temperate Miocene faunas from the Gulf of Alaska (Kanno, 1971; Addicott et al., 1978). Addicott (1978) did cite species of the relatively warm water bivalves *Anadara*, *Pseudocardium*, *Saxidomus*, *Protothaca*, and *Securella*, and the gastropods *Megasurcula* and *Tectonatica* from the Skonun. These taxa are well known in warmer-water faunas to the south, such as the Empire Formation (Dall, 1909; Addicott, 1983), but are absent in colder-water faunas northward (Kanno, 1971; Addicott et al., 1978; L. Marincovich, Jr., unpublished data). The possible presence of *Periploma* at Yakoun River also suggests a northern affinity and a cold-temperate environment. A study of the modern marine distribution of the dinoflagellate *Operculodinium centrocarpum* indicates that it is ubiquitous in cool temperate water, and common in subarctic and arctic water (Mudie, 1992).

Terrestrial vegetation and climate

The Late Miocene was a time of global cooling and climatic oscillation (Hodell et al., 1986; Miller et al., 1987; Barron and Baldauf, 1990). Indeed, the Messinian salinity crisis of the latest Miocene has been attributed to glacioeustatic sea level change associated with the expansion of Antarctic glaciation (Adams et al., 1977; Hodell et al., 1986). Ruddiman and Kutzbach (1990) have shown, using their Global Circulation Model, that the presence of high altitude plateaux in Tibet and western North America in the last 10 Ma profoundly affected global atmospheric circulation. The model indicated that summer winds along the west coast of North America would have shifted from westerly to northerly and, consequently, that dry air subsidence would have increased, resulting in drier summers. Wolfe and Hopkins (1967) provided evidence from fossil leaf margins for the onset of a definite summer-dry climate in the Pacific Northwest between 10 and 2 to 3 million years ago. There is, therefore, good reason to expect significant vegetation change in Late Miocene to Pliocene pollen assemblages from the Queen Charlotte Basin.

The Collison Point and Yakoun River sediments were deposited in a shallow marine environment, and the pollen assemblages most likely reflect regional vegetation (Heusser and Balsam, 1977). The lignites, shales and siltstones of the Tow Hill well (Sutherland Brown, 1968), in which dinoflagellates have been found below 590 m (White, 1991), were probably deposited in a distal floodplain, estuarine or shallow marine environment. The similarity of altitude satisfies

Axelrod's (1966) criterion for the determination of secular trends in vegetation. In the Tow Hill well the Pinaceae pollen is always less, generally much less, than two thirds of the T–C–T pollen (White, 1991). The switch in dominance of the arboreal assemblage from T–C–T pollen in the Tow Hill well to Pinaceae pollen in Collison Point and Yakoun River suggests a change in the forest ecology of the Queen Charlotte region within the Late Miocene. The Collison Point and Yakoun River assemblages have a distinctly more modern aspect than the Tow Hill assemblages.

The T–C–T assemblage comprises spherical and generally unornamented palynomorphs, often split or papillate, which could be produced by species in the Taxodiaceae, Cupressaceae, or Taxaceae families. (A Taxodiaceae cone was observed in core in the Tow Hill No. 1 well at 187.9 m.) The Pinaceae, including *Picea* sp., *Pinus* sp., *Abies* sp., *Tsuga* sp. and *Tsuga heterophylla*-type pollen, dominate the assemblages from the latest Miocene sections considered here. The large number of species and broad ecological tolerances of the T–C–T families and the Pinaceae precludes detailed interpretation of the climatic significance of the ecological shift. However, the modern distribution of these families (Hora, 1980) shows that the Pinaceae grow at higher latitudes in the Northern Hemisphere than do the other families, indicating greater tolerance of cool temperatures and probably of dryness.

Waring and Franklin (1979) have noted that the modern evergreen coniferous forests of the Pacific Coast of northwestern America are unique amongst temperate forests of the world, which are normally dominated by deciduous hardwoods. They proposed that the modern Pacific Northwest forests are best explained as an adaptation to the modern winter-wet, summer-dry climate of the West Coast, under which evergreen needle or scale-like leaves confer an advantage. Summer drought may have contributed significantly to the loss of broadleaf angiosperms in the Late Miocene assemblage studied here. However, the transition from T–C–T to Pinaceae domination of the pollen assemblages may be attributable more to climatic cooling than to summer dryness.

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PLATES 5.1 to 5.2

PLATE 5.1

Molluscs from Yakoun River and Collison Point.
All specimens were whitened with ammonium chloride before photography.

Figures 1–3. *Acila* (*Truncacila*) *empirensis* Howe, x1.5.

1. Left valve, GSC 98095.
2. Right valve, GSC 98096.
3. Nearly complete right valve (on left) and fragment of external mould of another right valve (on right), GSC 98097.

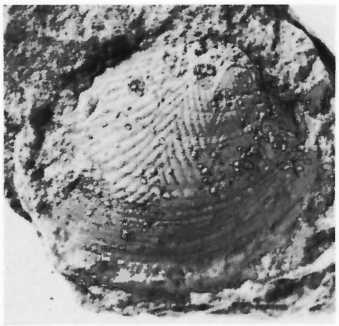
Figure 4. *Patinopecten* cf. *P. oregonensis* (Howe), x1, GSC 98098.

Figure 5. *Periploma*? sp., x1.5, left valve, GSC 98099.

Figure 6. *Turritella* sp., x1.5, latex impression, GSC 98100.

Figure 7–8. *Clinocardium coosense* (Dall).

7. Articulated and open valves, x1, right valve (on left); left valve (on right), GSC 98101.
8. Left valve, x1.5, GSC 98102.



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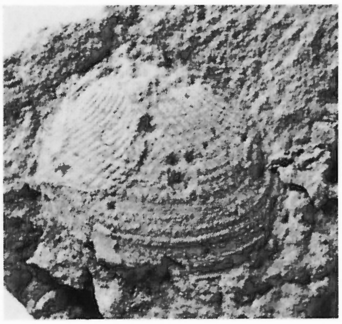

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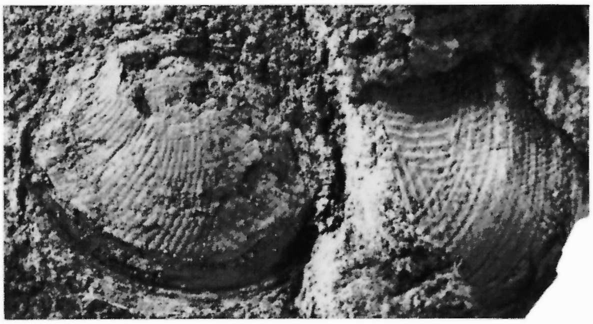

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PLATE 5.2

Palynomorphs identified in the Collison Point (GSC loc. C-166779) and Yakoun River (GSC loc. C-129754) sections. Coordinates are from Zeiss Axiophot stage 45-35-02, and Universal England Finder. All magnifications x1000 unless otherwise indicated.

Figure 1. *Tsuga heterophylla*-type, GSC 98052, P3330-1C, 80.2x6.3, U 18/3, GSC loc. C–166779 (note microspines).

Figure 2. *Picea* sp., GSC 98053, P3330-1B, 80.7x18.8, G18/2, GSC loc. C-166779, x500.

Figure 3. *Abies* sp., GSC 98054, P3330-1B, 86.0x22.70, C24/3, GSC loc. C-166779, x500.

Figure 4. *Podocarpus*-type, GSC 98055, P3330-1D, 82.5x14.7, L20/3, GSC loc. C-166779.

Figure 5. *Tsuga* sp., GSC 98056, P3330-1B, 88.5x22.4, C26/4, GSC loc. C-166779, x500.

Figure 6. Taxodiaceae-Cupressaceae-Taxaceae, GSC 98057, P3330-1D, U24/2, GSC loc. C-166779.

Figure 7. ?*Juglans* sp., GSC 98058, P3330-1B, 86.5x19.7, F24/3, GSC loc. C-166779.

Figure 8. Onagraceae, GSC 98059, P3330-1D, 94.4x14.3, M32/2, GSC loc. C-166779.

Figure 9. cf. *Fagus* sp., GSC 98060, P3330-1B, 88.7x9.8, Q26/4, GSC loc. C-166779.

Figure 10. Compositae, Tubuliflorae, GSC 98061, P3330-1D, 96.7x19.0, G34/2, GSC loc. C-166779.

Figure 11. *Habibacystata tectata* Head et al., 1989, GSC 98062, P3330-1D, 91.9x12.6, O30/1, GSC loc. C-166779.

Figure 12. Gramineae, GSC 98063, P3696-1A, 80.0x20.1, F17/2, GSC loc. C-129754.

Figure 13. Cyperaceae, GSC 98064, P3696-1A, 98.0x3.0, x36/3, GSC loc. C-129754.

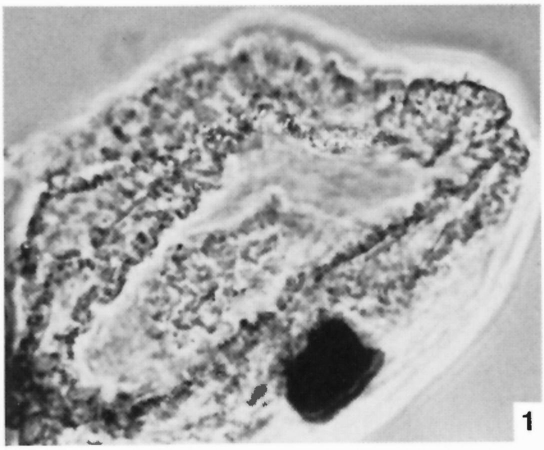
Figure 14. *Ulmus/Zelkova*, GSC 103717, P3696-1A, 98.0x22.2, D36/1, GSC loc. C-129754.

Figure 15. *Pterocarya* sp., GSC 103718, P3696-1A, 98.3x15.6, K36/4, GSC loc. C-129754.

Figure 16. *Operculodinium centrocarpum* Wall, 1967, GSC 103719, P3696-1A, 100.2x19.2, G38/2, GSC loc. C-129754.

Figure 17. *Habibacystata tectata* Head et al., 1989, GSC 103720, P3696-1A, 98.0x5.3, V36/3, GSC loc. C-129754.

PLATE 5.2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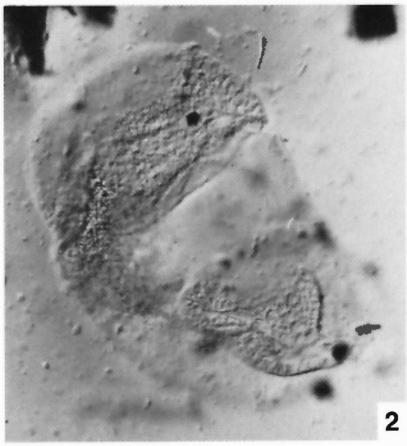
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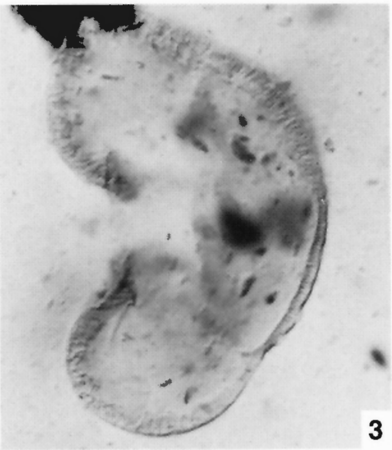
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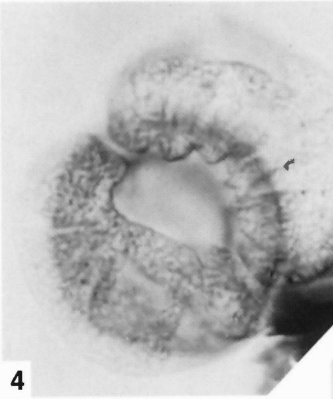
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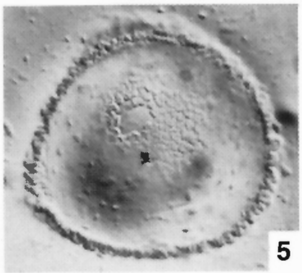
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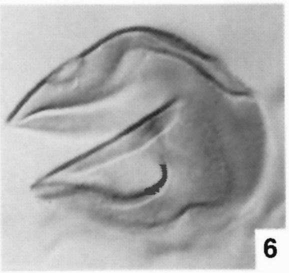
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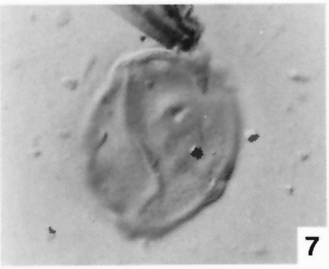
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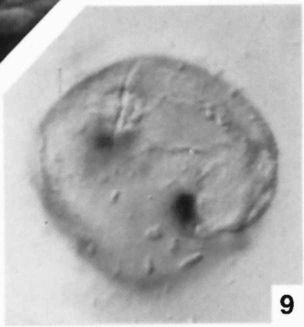
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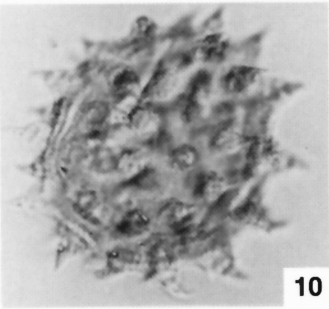
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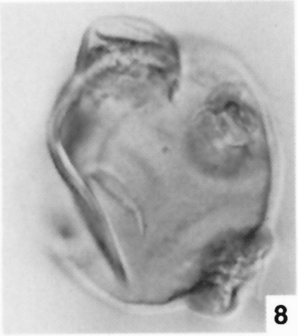
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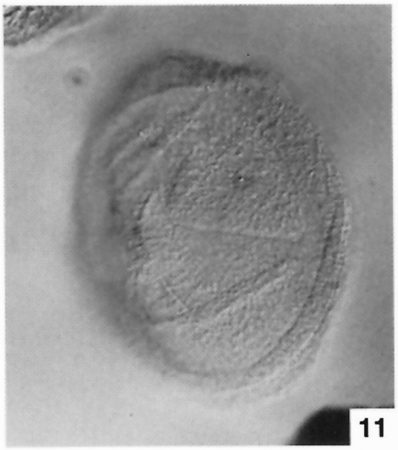
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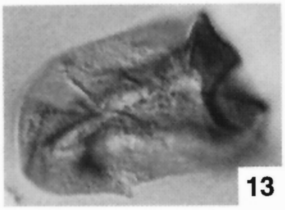
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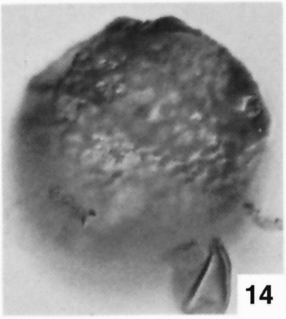
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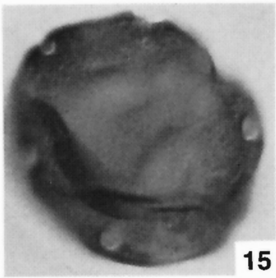
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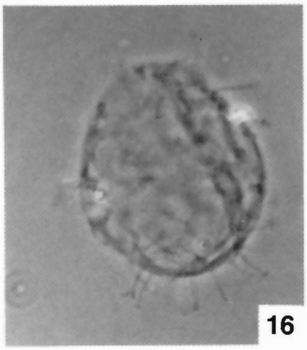
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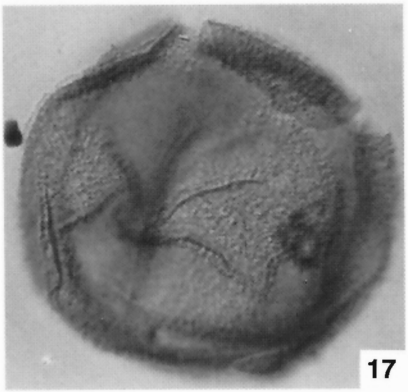
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