GEOLOGICAL SURVEY OF CANADA
BULLETIN 412

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Energy, Mines and Resources Canada
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PREFACE

This volume of *Contributions to Canadian Paleontology* contains papers describing many different fossils from localities in eastern, western, and northern Canada.

These studies provide a basis for the precise paleontological correlations necessary for accurate dating and economic analyses of the rocks that form the sedimentary basins of Canada.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

PRÉFACE

Le présent volume des *Contributions à la paléontologie canadienne* contient des articles décrivant une grande diversité de fossiles provenant de localités de l'est, de l'ouest et du nord du Canada.

Ces études constituent une base à partir de laquelle il est possible d'établir les corrélations paléontologiques précises nécessaires à la datation et les analyses économiques précises des roches constituant les bassins sédimentaires du Canada.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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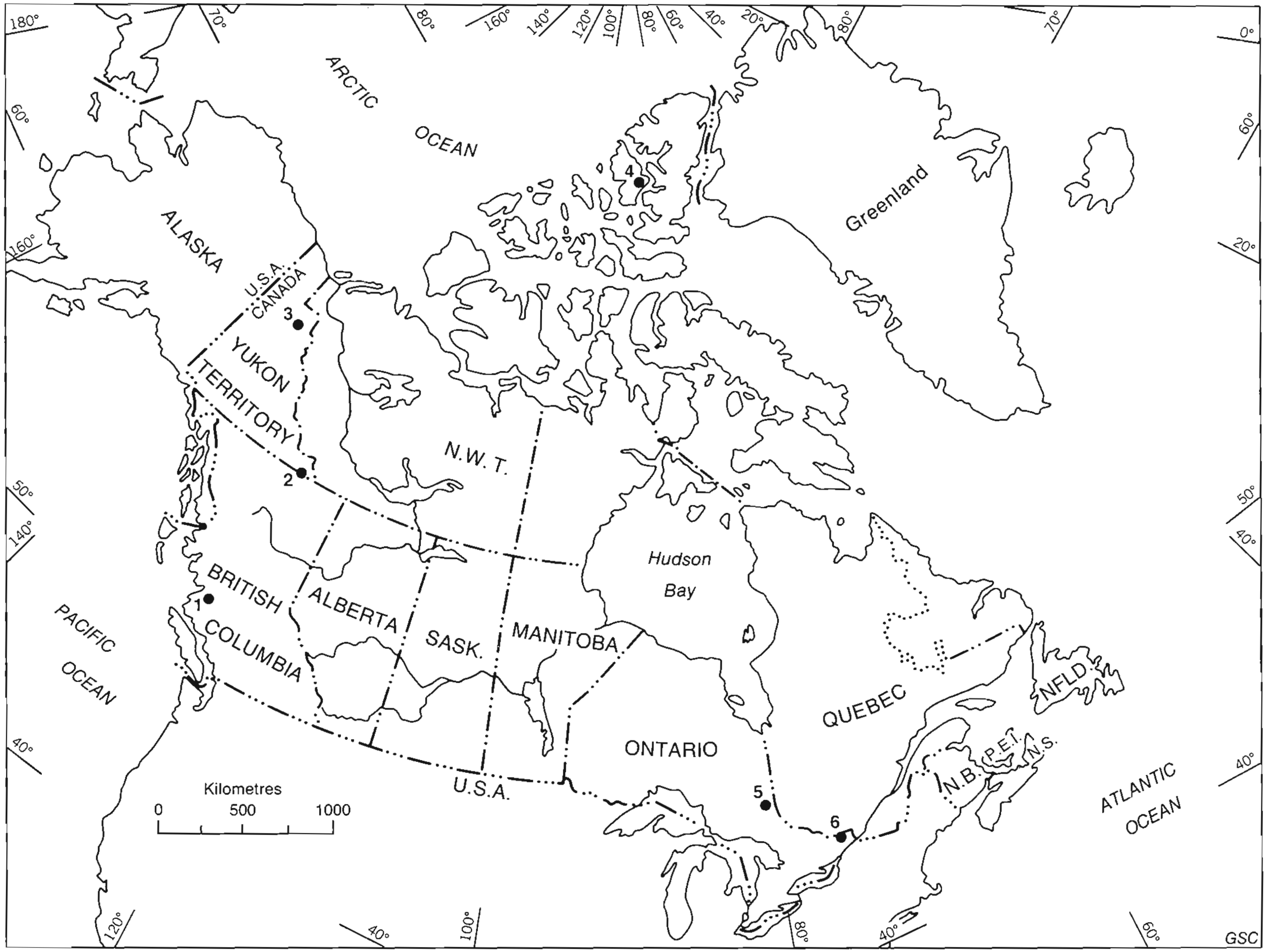

LEGEND

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MIDDLE ORDOVICIAN (CHAZYAN) STRATIGRAPHY, AND BRYOZOAN AND CONODONT FAUNAS IN THE HAWKESBURY REGION, EASTERN ONTARIO

T.E. Bolton[1], H.M. Steele-Petrovich[2], and I. Munro[3]

Bolton, T.E., Steele-Petrovich, H.M., and Munro, I., 1991. Middle Ordovician (Chazyan) stratigraphy, and bryozoan and conodont faunas, in the Hawkesbury Region, eastern Ontario. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 412, p. 1-33.

Abstract

Nodular and encrusting bryozoans *Batostoma chazyensis*, *B. lanensis*, and *Ceramoporella* n. sp., and the ramose bryozoan *Champlainopora chazyensis*, in association with the brachiopods *Mimella imperator*, *M. vulgaris*, and *Rostricellula raymondi*, define three biostromes within a shaly limestone, shale, and siltstone sequence of the lower Middle Ordovician Laval Formation located in a quarry near Hawkesbury, southeastern Ontario. This is the most westerly occurrence of these bryozoans, which are most abundant in the type biohermal Chazyan rocks of the Lake Champlain region, New York State and Vermont, and recently have been identified farther east in biohermal facies of similar age within the Mingan Formation of the Mingan Islands Archipelago, Quebec.

A small conodont fauna of 353 specimens is dominated by *Phragmodus flexuosus* morphotype A, which places it in Fauna 5 to 6 of Sweet et al., 1971. The presence of *Cahabagnathus chazyensis* in the roadcut above the quarry suggests the section is in the lower subzone of the *Pygodus anserinus* Zone and enables correlation with parts of the Crown Point and Valcour formations of the Champlain Valley.

Résumé

Les bryozoaires nodulaires et encroûtants *Batostoma chazyensis, B. lanensis* et *Ceramoporella* n. sp., et le bryozoaire branchu *Champlainopora chazyensis*, en association avec les brachiopodes *Mimella imperator, M. vulgaris* et *Rostricellula raymondi*, définissent trois biostromes à l'intérieur d'une séquence composée de calcaire shaleux, de shale et de siltstone, qui appartient à la Formation de Laval (partie inférieure de l'Ordovicien moyen), située dans une carrière proche de Hawkesbury dans le sud-est de l'Ontario. Il s'agit de l'occurrence la plus occidentale de ces bryozoaires qui sont particulièrement abondants dans les roches de type biohermal d'âge chazyen, de la région du lac Champlain, de l'État de New York et du Vermont, et ont récemment été reconnus plus à l'est dans les faciès biohermaux d'âge similaire, dans la Formation de Mingan située dans l'archipel de Mingan, au Québec.

Une petite faune de conodontes, représentée par 353 spécimens, est dominée par le morphotype A *Phragmodus flexuosus*, donc on la place dans la faune 5 à 6 telle que définie par Sweet et al., 1971. La présence de *Cahabagnathus chazyensis* dans la tranchée routière au-dessus de la carrière semble indiquer que la coupe stratigraphique se trouve dans la sous-zone inférieure de la Zone à *Pygodus anserinus*, et peut être mise en corrélation avec des parties des formations de Crown Point et de Valcour, situées dans la vallée de Champlain.

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INTRODUCTION

This paper will 1) review the lower Middle Ordovician stratigraphic terminology applicable in the region, 2) describe a sequence of limestone, shaly limestone, shale, and siltstone exposed in a quarry and adjacent roadcut 19.2 km east of Hawkesbury, Ontario, latitude 45°35′N, longitude 74°35′W (Fig. 1.1), and 3) describe the Bryozoa from three biostromes within the quarry section and the Conodonta from the complete stratigraphic interval of the quarry and roadcut. A study of such a sequence located between the Ottawa and Montreal basins, on the western edge of the Beauharnois Anticline, should clarify some of the stratigraphic terminology that has been adopted in the Ottawa–St. Lawrence Lowlands over the past one hundred years. Paleoecological studies are being continued and will form the basis of a future report (H.M.S.-P.).

Our knowledge of the Middle Ordovician geology of the Ottawa–St. Lawrence region is essentially based on the many works of Wilson (1921, 1932a, b, 1936, 1937, 1946, 1956) in southeastern Ontario, and Hofmann (1963, 1972), Clark (1972), and Globensky (1987) in the Montreal area, Quebec. Older contributions include the investigations of Ells (1902), Raymond (1906, 1910, 1911a, b, 1912, 1913), and Whiteaves (1908). Recently, modifications to the stratigraphy have been advanced by Williams and Wolf (1982), Williams and Rae (1983), and Williams and Telford (1986). Paleoenvironmental-paleoecological research of the Middle Ordovician rocks and fossils exposed between Pembroke and Ottawa (Steele-Petrovich, 1986, 1988) and Ottawa and the Quebec border (Steele-Petrovich, 1989, 1990) is continuing.

STRATIGRAPHIC TERMINOLOGY

The term "Aylmer formation" was introduced in the Ottawa Valley by Raymond (1905a, p. 380; 1905b, p. 362) for rocks that occur between Grenville-L'Orignal in the east and Pembroke in the northwest; these included a lower sandstone and shale member underlain by the Beekmantown formation, and an upper limestone member overlain by the Lowville limestone. Formerly, this 150- to 200-foot (46-61 m) thick sequence was assigned to the Chazy (Ells, 1902; Raymond, 1906, p. 509, 567). Each member bore a distinct fauna (Raymond, 1906, p. 557-561). The brachiopod *Camarotoechia orientalis* Billings, a Mingan Islands species, was recognized in the lower member. *Camarotoechia plena* Hall was recognized throughout the region and suggested a correlation with the upper 150 to 175 feet (46-53 m) of the type Chazy limestone of the Lake Champlain Valley, New York-Vermont. Subsequently, Raymond (1911a, p. 197; 1912, p. 353) suggested that "Aylmer" be used as a local designation to include only the 125 to 135 feet (38-41 m) of sandstone and shale capped by 20 feet (6.1 m) of impure limestone and rusty weathering dolomite (Wilson, 1936, p. 7) characterized by Chazy fossils, and present below the black shale beds containing the ostracode *Kenodontochilina*? *clavigera* (Jones, 1891) (see Copeland, 1958, p. 236; Berdan, 1984, p. J31, Pl. 11, fig. 5). The remaining fossiliferous limestones, which formed the upper part of the original Aylmer formation, were reassigned to the Pamelia/Lowville Black River division. "Aylmer formation", however, later was applied in both the Montreal region (Raymond, 1913, p. 100) and the Ottawa-Cornwall, Ontario area (Wilson, 1921, 1932a).

Wilson (1937, p. 46; 1946, p. 17) divided the Chazy of the Ottawa–St. Lawrence Lowland into the lower, shale and sandstone Rockcliffe formation, disconformably overlying the Beekmantown Oxford formation, and the upper, conformable limestone St. Martin formation, unconformably overlain by the Black River–Trenton Ottawa limestone. About 20 to 25 feet (6.1–7.6 m) of St. Martin impure limestone was recognized east-southeast of Ottawa. Cooper (1956, p. 17) considered the Aylmer formation to consist of two members, at least partly facies equivalent to each other, the Rockcliffe green shale with sandstone lenses, about 160 feet (48.8 m) thick, and the St. Martin shale, sandstone, and impure limestone, 20 to 150 feet (6.1–46 m) thick. Later, in the Montreal region, the Chazy Group Laval Formation (Hofmann, 1963, 1972; Clark, 1972, p. 56; Globensky, 1987, p. 6) was considered to consist of a westward thickening bioturbated sandstone and shale unit at the base, underlain by the Beekmantown Group; this unit, commonly called the Ste. Thérèse Member in the Montreal region, is lithologically similar to the Rockcliffe Formation of the Ottawa Valley. The overlying calcarenite and shale with lenses of crossbedded calcarenite or pure fossiliferous crystalline limestone were assigned to the Saint Martin "floating" member/lithofacies. Baird (1972, p. 18) stated that the St. Martin calcarenite member intertongues with the Rockcliffe in the eastern part of the Ottawa Embayment.

Finally, Williams and Wolf (1982), Williams and Rae (1983), and Williams and Telford (1986, p. 7) assigned all of the Chazy rocks of the Ottawa basin to the Rockcliffe Formation, and loosely subdivided it into lower unnamed and upper St. Martin members, disconformably overlain by the Ottawa Group Shadow Lake Formation. Interbedded quartz sandstone and shale are present in both members, and the upper St. Martin member is distinguished by thin interbeds of medium to coarsely

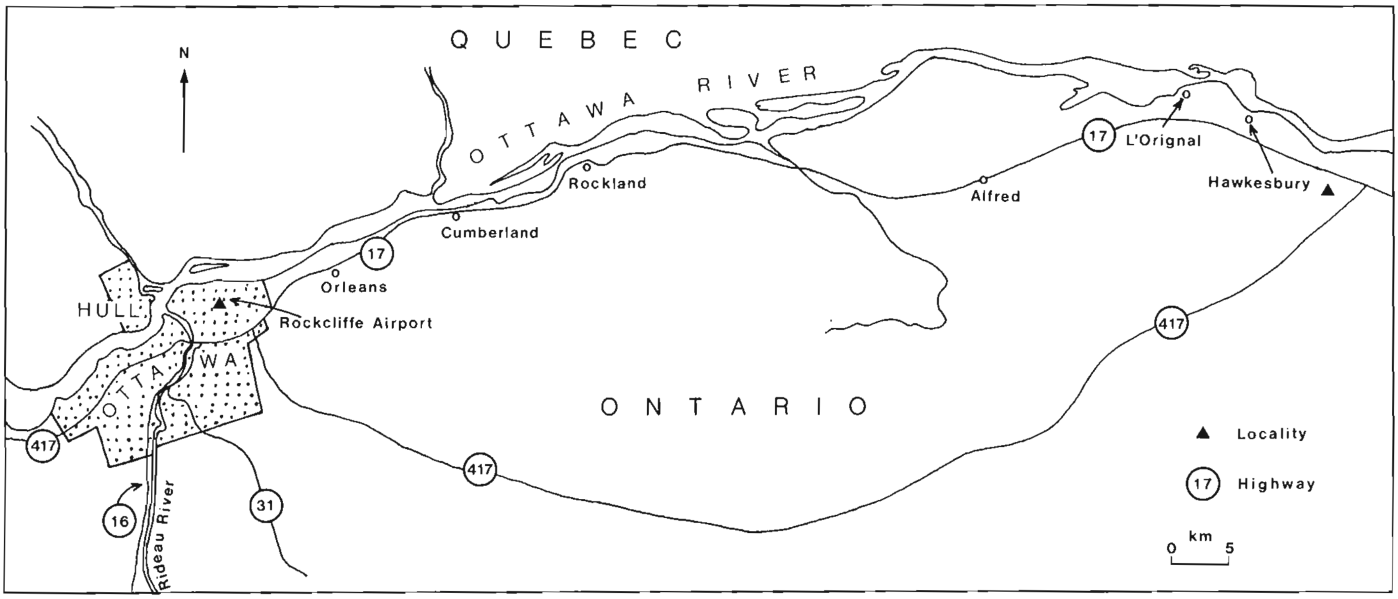

Figure 1.1. Collecting localities, Rockcliffe and Laval formations, Ottawa-Hawkesbury region, eastern Ontario.

crystalline limestone and silty dolostone. This redefined Rockcliffe Formation was considered equivalent to the Laval Formation. Copeland et al. (1989) assigned the clastic sequence exposed in the Rockcliffe airbase in Ottawa to the Rockcliffe Formation, but referred the purer carbonates at the top of the section to the Pamelia Formation rather than the St. Martin Formation.

Thus, the Chazyan rocks of the Ottawa-St. Lawrence Lowland have been assigned to the Aylmer, Rockcliffe, St. Martin, and Laval formations, and the Rockcliffe and Saint-Martin members. Application of the term Aylmer has been too varied, and reinstatement of the name is not recommended. Rockcliffe Formation should be applied as originally published, to the Chazyan shale-sandstone sequence in the Ottawa region, but extended to include any limestone unit (lithologically distinct from the massive limestone beds of Cap St. Martin, Montreal area) usually at or near the top replete with *Rostricellula plena*. This basically encompasses the entire sequence between the Beekmantown and Ottawa groups as used by Williams and Telford (1986). Where a St. Martin facies of *crossbedded calcarenite* is recognizable, as in the roadcut above the studied quarry, it is recommended that the term Laval Formation be adopted.

The middle part of the Laval Formation, which is characterized by argillaceous limestone, calcareous shale, and siltstone, extends as far west as the Hawkesbury area in the Ottawa Valley where it is underlain by sandstone and shale, which are typical of both the Rockcliffe Formation and the lower part (Ste. Thérèse Member) of the Laval Formation. The massive, crystalline, commonly crossbedded calcarenites of the St. Martin lithofacies also extend west to Hawkesbury. Throughout the rest of the Ottawa Valley, Chazyan rocks consist mainly of sandstone and shale of the Rockcliffe Formation, with thin limestone beds near the top in the eastern part of the distribution. The occurrence of the *Rostricellula plena* Zone (Hofmann, 1963) at the top of both the Laval and Rockcliffe formations implies their deposition at about the same time.

STRATIGRAPHY

The Chazyan rocks of this study, argillaceous limestone, calcareous shale and siltstone, and massive crystalline calcarenite are typical of the middle part of the Laval Formation of the Montreal area, including the St. Martin lithofacies (Hofmann, 1963; Clark, 1972), and are situated close to the western boundary of the Laval Formation. Sandstone and shale, typical of both the lower part of the Laval Formation and all of the Rockcliffe Formation, are faulted into the southeast corner of the quarry. The stratigraphic interval (see Steele-Petrovich, 1989, Fig. 2), detailed herein, is exposed in the western and northwestern faces of the quarry and in an adjacent roadcut, and was measured in ascending order from the base of the quarry to the top of the roadcut (Table 1.1); there is a slight stratigraphic overlap between the top of the quarry and the bottom of the roadcut. Measured units in both faces of the quarry can be traced across a drainage ditch and have been assigned the same GSC locality numbers on the two sides.

TABLE 1.1

Stratigraphic section of roadcut and northwest quarry[1] wall, Laval Formation

Collection number, thickness	Lithology
	Top of roadcut
134-2F 491-516″ (12.5-13.1 m)	Blue-grey, coarse grained, bioclastic limestone, composed mainly of bryozoan fragments with fewer brachiopod and echinoderm fragments. Fossils: *Rostricellula* sp., bryozoan concentrations – accumulation of ramose *Champlainopora* sp. encrusted by thin laminate *Batostoma* sp., which in turn are encrusted by thick multilaminar *Ceramoporella* sp. Weathers tan. GSC loc. 102973.
134-2E 385-491″ (9.8-12.5 m)	Lithologically similar to 134-2D. Contains lenses of very coarse grained echinoderm, brachiopod, and trilobite bioclastics. No crossbedding; some inconspicuous low angle microcrossbedding. Whole and partial cystoid calyces common on exposed bedding planes and vertical face. Horizontal stylolites well developed. Top surface has vertical erosion pits with elliptical cross-section, up to 14″ x 8″ (35.6 x 20.3 cm). Fossils: *Mimella* sp., *Rostricellula* sp., cf. *Canadocystis* sp. GSC loc. 102972.
134-2D 314-385″ (7.9-9.8 m)	Brown-grey, medium to coarse grained, bioclastic limestone. Composed mainly of echinoderm fragments. Weathered face brown-grey with prominent fossil fragments. Unit massive with very prominent crossbedding. Stylolites present. Abundant fossils: *Mimella imperator*, *M.* sp., *Rostricellula raymondi*, bryozoan nodules, unident. echinoderm plates. GSC loc. 102971.
134-2C 297-314″ (7.5-7.9 m)	Blue-grey, coarse grained, bioclastic limestone. Composed mainly of echinoderm plates, brachiopod and bryozoan fragments, and bryozoan nodules. Weathered face brown with prominent fossil fragments. Continuous and discontinuous shale partings present, causing unit to weather into irregular chunky plates and break locally into four beds of subequal thicknesses. Erosional lower boundary, gradational upper boundary. Fossils common: *Mimella imperator*, *Rostricellula raymondi*, bryozoan nodules. GSC loc. 102970.
	Top of quarry
134-2B (=133-4B) 283-297″ (7.2-7.5 m)	Brownish grey, coarse grained, bioclastic limestone with some pink fossil fragments. Composed primarily of echinoderm fragments, fewer bryozoan and brachiopod fragments. Highly recrystallized. Weathered face brown with fossil fragments prominent. Subhorizontal microbedding prominent, abuts against lower boundary at slight angle. Microcrossbedding minor. Boundaries sharp. GSC loc. 102969.
134-4A (=134-2A) 271-283″ (6.9-7.2 m)	Greenish grey, silty, shaly limestone with thin, irregular shale horizons. Weathers brown and crumbly. Abundant fossils: *Mimella imperator*, subspherical bryozoans (1″ [2.5 cm] diam.), *Rostricellula raymondi*, undet. gastropods. GSC locs. 102967, 102968.
133-3C (=134-1A) 231-271″ (5.9-6.9 m)	Greenish grey quartz siltstone; very thin, horizontal, discontinuous, dark reddish to greenish shale horizons common to absent. Rock parts along shale horizons. Horizontal burrows and syneresis marks common in shale. Faint evidence of microcrossbedding and climbing ripples. Vertical burrows (1-3 mm diam.) locally common. Weathered surface tan. Beds 6-8″ (15-20 cm) thick.
	Base of roadcut
133-3B 155-231″ (3.9-5.9 m)	Greenish siltstone with very thin, discontinuous, shale horizons, forming flaser bedding; faint evidence of climbing ripples. Crosslaminated siltstone lenses up to 2″ (5 cm) thick occur throughout. Weathers brownish with green tint.
133-3A 136-155″ (3.4-3.9 m)	Single dense bed of grey quartz siltstone. Weathers grey. No fossils. Concretions up to 6″ (15 cm) across at base. Contacts generally sharp, but may grade somewhat into unit above. GSC loc. 102966.
133-2J 128-136″ (3.2-3.4 m)	Greenish, shaly, silty limestone with large patches of green shale. Weathers brownish with some rust. Single bed. Contains numerous *Rostricellula* sp. and *Mimella* sp. Contacts sharp. GSC loc. 102965.

TABLE 1.1

(continued)

Collection number, thickness	Lithology
133-2I 114-128″ (2.9-3.2 m)	Biostrome 3. Greenish grey, fine grained, silty, shaly bioclastic limestone with thin, discontinuous, green, shaly horizons throughout. Weathers brownish. One bed. Abundant subspherical bryozoan colonies, shells common. Fossils: *Mimella imperator*, *Rostricellula* sp., *Batostoma lanensis*, *B. chazyensis*, *Champlainopora* sp., *Ceramoporella* n. sp. Contacts sharp. GSC loc. 102964.
133-2H 98-114″ (2.5-2.9 m)	Greenish grey, fine to medium grained, silty, shaly, bioclastic limestone with thin, discontinuous horizons of green shale throughout. Weathers brownish. One bed. Packed full of shells; subspherical bryozoan colonies rare except on top bedding plane. Fossils: *Mimella imperator, Rostricellula raymondi, Batostoma chazyensis, Ceramoporella* n. sp. Contacts sharp. GSC loc. 102963.
133-2G 76-98″ (1.9-2.5 m)	Biostrome 2. Dark green, fine to medium grained, silty, shaly, bioclastic limestone with thin lenses and horizons of dark green shale throughout. Two subequal beds separated by thin, green, shale horizon. Weathers lighter green to brownish. Abundant shells and subspherical, ellipsoidal, and disc-shaped bryozoan colonies, 2-10″ (5-25 cm) across. Fossils: *Mimella imperator, Rostricellula raymondi, Batostoma chazyensis, B. lanensis, Ceramoporella* n. sp., *Bolboporites americanus*. Contacts sharp. GSC loc. 102962.
133-2F 73-76″ (1.8-1.9 m)	Greenish grey, silty shale.
133-2E 67-73″ (1.7-1.8 m)	Fine grained, greenish grey, shaly, crystalline, bioclastic limestone with thin horizons of green shale. Shells abundant throughout. Fossils: *Mimella imperator, Rostricellula raymondi*. GSC loc. 102961.
133-2D 65-67″ (1.6-1.7 m)	Greenish grey, silty shale. No fossils.
133-2C 59-65″ (1.5-1.6 m)	Fine grained, greenish grey, shaly, crystalline, bioclastic limestone with thin horizons of green shale (up to 1 cm thick) throughout. Shells abundant throughout; horizontal fragments of branching bryozoans jammed together locally at base where shale content is high. Fossils: *Mimella imperator, Rostricellula raymondi, Champlainopora* sp. GSC loc. 102960.
133-2B 53-59″ (1.3-1.5 m)	Greenish grey, silty shale. No fossils. Lower contact sharp; upper contact sharp or gradational.
133-2A 46-53″ (1.2-1.3 m)	Biostrome 1. One bed. Fine to coarse grained, dark green, shaly, bioclastic limestone interfingered and interbedded with dark green shale. Weathers lighter green. Packed with horizontal fragments of branching bryozoans and more widely spaced subspherical bryozoans (2-5 mm across). Fossils: *Mimella imperator, Rostricellula* sp., *Champlainopora chazyensis, Batostoma chazyensis, Ceramoporella* n. sp. Contacts sharp. GSC loc. 102959.
133-1B 28-46″ (0.7-1.2 m)	Interbeds, interlaminae, and lenses of somewhat burrowed, green, fissile shale and quartz siltstone. Weathers lighter green. *Mimella imperator*, nodular and branching bryozoans. Contacts sharp. GSC loc. 102958.
133-1A 0-28″ (0-0.7 m)	Greenish grey, medium to coarse grained, very dense, bioclastic limestone. Beds massive with occasional partings of relatively continuous, very thin horizons of dark green shale. Greenish shale inclusions widely scattered throughout. Fossils: *Rostricellula* sp.; fragments of bryozoans, trilobites, green algae. Lower contact buried, upper contact sharp. GSC loc. 102957.
	Base of quarry, northwest wall

[1] Sintra Inc.-Ross Quarry (Derry Michener Booth and Wahl and Ontario Geological Survey, 1989, p. 32, 33).

PALEONTOLOGY

Fauna typical of the Lake Champlain Valley Chazyan have been traced as far northwest as Hawkesbury, Ontario, where *Bolboporites americanus* Billings, several echinoderm taxa, and the brachiopods *Mimella borealis* (Billings) and *M. imperator* (Billings) were identified (Raymond, 1906, p. 556, 567). A distinct change in faunal content was noted by Raymond (1905a, p. 362, 363) in the L'Orignal section, some 16 miles (25.7 km) west of Hawkesbury, where species appeared that were unknown in the eastern Chazyan exposures.

In the Ottawa Valley, the Chazyan beds have been characterized by the *Rostricellula plena* (Hall) fauna (Raymond, 1906, p. 568, 1911a, p. 194; Cooper, 1956, p. 17; Wilson, 1932a, p. 384). This fauna is dominated by the brachiopods *R. plena* (Hall), *R. raymondi* Cooper, *R. wilsonae* Cooper, *Mimella imperator* (Billings), *M. latistriata* (Wilson), and *Ectenoglossa*? *lyelli* (Billings). The rare pelecypod, gastropod, or trilobite also has been collected from slightly calcareous beds within the Rockcliffe Formation. The wide variety of ichnofossils present within the Chazyan terrigenous units of eastern Ontario has been documented by Hofmann (1979). Recently, a small ostracode–conodont fauna derived from a thin phosphatic dolostone bed located in the upper part of the Rockcliffe Formation east of Canadian Forces Base Ottawa (North) has been described by Copeland et al. (1989).

Bryozoa

Both encrusting and branching bryozoans are present within the Chazy beds throughout the St. Lawrence Lowlands, and are particularly abundant in the coral-bryozoan bioherms (Pitcher, 1964) of Quebec and the Lake Champlain Valley. Previous studies of the Chazyan Rockcliffe Formation, however, have rarely reported Bryozoa; Bryozoa become abundant in the Ottawa region only in the overlying Middle Ordovician Ottawa limestone (Fritz, 1957). Within the Ottawa Embayment, Ami (1902, p. 73G) listed Monticuliporidae, sp. indet., from Deschênes Mills, north side of the Ottawa River. Raymond (1906, p. 557) recognized *Stictopora* sp., *Ptilodictya* sp. and monticuliporoids from Hawkesbury, and *Monticulipora* sp. from Deschênes (ibid., p. 559). Wilson (1932a) reported many undetermined species within the Chazy (Aylmer) of Barnhart Island, New York, and Milles Roches, Ontario, belonging to a number of families (Wilson, 1937, p. 50), and Hofmann (1979, p. 56) recorded *Ropalonaria* sp. from Hawkesbury.

The bryozoan fauna of the Quebec Chazyan, located in both the St. Martin calcarenite and shaly dolostone or dolomitic shale, has been discussed or listed by Hofmann (1963, p. 278, 282), Pitcher (1964), Toomey and Finks (1969), Clark (1972, p. 68), and Globensky (1987, p. 9). Ross (1964, Table 1; 1981) and Pitcher (1964) recognized the following fossils within the "reefs" of the Laval (Crown Point-Valcour) Formation in the Montreal region: trepostomes *Batostoma chazyensis* Ross (a Crown Point-Valcour species, Ross, 1984, Fig. 2), *B. campensis* Ross (a Day Point-Valcour species), *Champlainopora chazyensis* (Ross), *Jordanopora heroensis* Ross, the cryptostome *Chazydictya chazyensis* Ross, and the cystoporate *Ceramoporella*? sp. (*Cheiloporella* sp.). The abundant *Batostoma* and *Chazydictya*, with their sheet-like encrustations overgrowing tabulate corals, strengthened and welded together the mounds or "reef" structures.

Ramose and/or nodular and encrusting bryozoans dominate the three biostromes located in the siliciclastic-carbonate sequence of the Hawkesbury quarry. Some specimens are in growth position, others are disoriented. The lowest biostrome (No. 1) is dominated by horizontally oriented fragments of the ramose trepostome bryozoan *Champlainopora chazyensis* (Ross) and relatively small subspherical bryozoan nodules, generally less than 6 cm across, of the encrusting bryozoan species *Ceramoporella* n. sp. and *Batostoma chazyensis* Ross. Ramose bryozoans are rare from the upper two biostromes (Nos. 2, 3); these biostromes are packed with relatively large ellipsoidal to hemispherical bryozoan colonies, commonly somewhat flattened horizontally and up to 25 cm across, which are composed of the same encrusting species as in the lower biostrome. In each biostrome, the bryozoan nodules consist of a single species or intergrowing layers of up to three species. Encrusting bryozoan growth here generally begins on brachiopod shells (hypotypes GSC 91925, 91931) or fragments (hypotypes GSC 91931, 91934), although in the lower biostrome it may begin on a ramose trepostome fragment. Laminated, subspherical, free-lying bryozoan nodules develop today when colonies that have grown too large for their unattached bases topple over, or, like mobile or circumrotatory corals, are overturned in shallow water by currents and waves (Rider and Enrico, 1979, p. 313, 317; Dade and Cuffey, 1984; McKinney and Jackson, 1989, p. 190-192).

Brachiopoda

Brachiopods, commonly articulated, found in these bryozoan biostromes include *Mimella imperator* (Billings)

(Pl. 1.1, figs. 4, 6), *M. vulgaris* (Raymond) (Pl. 1.1, figs. 5, 7, 8), and *Rostricellula raymondi* Cooper (common in the middle [No. 2] biostrome—Pl. 1.2, figs. 4-9; Pl. 1.3, fig. 9; Pl. 1.6, fig. 5). *Mimella imperator* and *R. plena* have been reported previously in the Ottawa-Hawkesbury region, whereas *M. borealis*, *M. vulgaris*, and *R. raymondi* [formerly included in *R. orientalis* (Billings), a small form common to the Mingan Formation, Mingan Islands, Quebec — Pl. 1.3, figs. 4, 5-8] have been reported from the "St. Martin Formation" of the Montreal region.

Echinodermata

A small cystoid plate and *Bolboporites americanus* Billings (Pl. 1.6, fig. 8) were collected from the middle (No. 2) biostrome. *Bolboporites americanus* is an excellent index Chazyan fossil (Clark and Hofmann, 1961) present within the Day Point-Crown Point formations of the Lake Champlain region, the Laval Formation of the St. Lawrence Lowlands, and the Mingan Formation of the Mingan Islands, Quebec (Pl. 1.6, fig. 9).

Conodonta

Fourteen samples, each approximately 1.5 kg, were collected and processed for conodonts from the northwest face of the quarry and the immediately overlying roadcut. Sampling coincided with the stratigraphic units in Table 1.1, and details are given in Table 1.2. The conodont CAI value for this fauna corresponds to 3.0 of Legall et al. (1981).

The Hawkesbury fauna is dominated by *Phragmodus flexuosus* morphotype A, as defined by Bauer (1987, p. 24-26). Bauer (1987, p. 25) suggested that *P. flexuosus* morphotype B (stratigraphically below morphotype A) is representative of an interval containing the *Eoplacognathus foliaceus-E. reclinatus* transition. Accordingly, the lowest limit of *P. flexuosus* morphotype A (and the Hawkesbury section) is in the *E. reclinatus* Subzone of the *Pygodus serrus* Zone. A few specimens of *Cahabagnathus chazyensis* Bergström, in conjunction with *P. flexuosus* morphotype A, were recovered from the roadcut (St. Martin facies). *Cahabagnathus chazyensis* has only been reported from the lower subzone of the *Pygodus anserinus* Zone (Bergström, 1983, p. 54) and is characteristic of that subzone (Harris et al., 1979). The Hawkesbury section therefore is entirely in the lower subzone of the *Pygodus anserinus* Zone, or possibly may contain the *Pygodus serrus-P. anserinus* zonal boundary in the quarry.

Raring (1972) identified *Phragmodus tortus* (=*P. flexuosus*) as the dominant apparatus in the Champlain Valley Chazyan fauna. He also found *Polyplacognathus sweeti*, intermediate between *P. friendsvillensis* and *P. sweeti* (=*Cahabagnathus chazyensis*), ranging from the upper part of the Crown Point Formation through to the middle of the Valcour Formation (Raring, 1972, p. 117). On the presence of *Cahabagnathus friendsvillensis* (upper range = top of the *Pygodus serrus* Zone [Bergström, 1983, p. 42]) in the lower portion of the Crown Point Formation, Harris et al. (1979, p. 28, 29) placed the *Pygodus serrus-P. anserinus* zonal boundary near the middle of the Crown Point Formation.

The Hawkesbury section, accordingly, correlates with the Middle or Upper Crown Point and Middle Valcour formations and, based on the occurrence of *Phragmodus flexuosus*, belongs in faunal associations 5 to 6 of Sweet et al. (1971).

SYSTEMATIC PALEONTOLOGY

Phylum BRYOZOA

Order TREPOSTOMATA Ulrich, 1882

Genus *Batostoma* Ulrich, 1882

Type species. Monticulipora (Heterotrypa) implicatum Nicholson, 1881 (by monotypy).

Batostoma chazyensis Ross, 1963

Plate 1.1, figures 1-3, 9, 10; Plate 1.2, figures 1-3, 10, 11; Plate 1.3, figures 1, 2, 11; Plate 1.4, figure 1

Batostoma chazyensis Ross, 1963, p. 859, Pl. 106, figs. 1-5, 7.

Batostoma campensis Ross, 1963, p. 863, Pl. 106, figs. 6, 8; Pl. 107, figs. 8, 10; Pl. 108, fig. 9; Pl. 109, figs. 1-10; Pl. 110, figs. 1-10.

Types and occurrence. Hypotypes GSC 91919-91923, west end, lower (No. 1) biostrome, GSC loc. 102959; GSC 91924, 91925, north face, middle (No. 2) biostrome, GSC loc. 102962; GSC 91926, west end, lower (No. 1) biostrome, GSC loc. 103042; GSC 91927-91929, west end, middle (No. 2) biostrome, GSC loc. 103041; GSC 91931, shale bed at base of south-central exposure, GSC loc. 103044; GSC 91932, 91933, loose south-central exposure, GSC loc. 103040; GSC 91943-91945, west end, 1.25 m thick bryozoan band 0.63 m below top of lower (No. 1)

TABLE 1.2

Distribution of conodonts from the quarry and roadcut at Hawkesbury

GSC loc. 1029-	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**68**	**69**	**70**	**71**	**72**	**73**	**Total**
Belodina monitorensis Ethington and Schumacher															
compressiform element									1						
eobellodiniform? element	1														2
Indet. grandiform? element													1		1
Cahabagnathus chazyensis Bergström															
polyplacognathiform element									2				2		4
Indet. dichognathiform element													2		2
Drepanoistodus suberectus (Branson and Mehl)															
suberectiform element					1	1			1			2		1	
homocurvatiform element		2	1			2			1			5	6		
oistodiform element				1		1			1			1			27
Multioistodus compressus Harris and Harris															
cordylodiform element	1														1
Panderodus sp. cf. *P. gracilis* (Branson and Mehl)															
graciliform element	1				2				4	1		2	3		
compressiform element													1		14
Phragmodus flexuosus Moskalenko															
symmetrical phragmodiform element		4		1	3			1	1		1	11	2		
assymetrical phragmodiform element	3	7			6	3	1	2	2			7	3		
dichognathiform element	4	5	1	3	13	3	4		1	1	2	15	9	1	
subcordylodiform element	10	10	2	3	15	4	2	7	7	2	3	22	8	3	
cyrtoniodiform element	10	8		5	7	2	1	2			2	17	5	2	279
Staufferella? sp.															
symmetrical element	1		1												
asymmetrical element	5			1	1								1		10
Triangulodus alatus Dzik															
symmetrical element												1			
asymmetrical element												3	2	1	7
Indet. trichonodelliform element	1														1
Genus indeterminate	1														1
?New genus							1					4			5
Total number of specimens	**38**	**36**	**5**	**14**	**48**	**16**	**9**	**12**	**21**	**4**	**8**	**90**	**45**	**8**	**353**

biostrome, GSC loc. 104404; GSC 91948a, west end, shale unit 3.4 m above top of middle (No. 2) biostrome, GSC loc. 104412.

Description. Colonies multilaminate, nodular to hemispherical to rarely ramose in shape. In tangential section, zooecia are round to oval normally, to slightly angulate when in contact, polygonal in deep tangential sections, and petaloid when indented by acanthopores, sometimes separated by angular mesozooecia of various sizes that rarely completely surround a zooecium, walls thin; zooecia range from 0.20 to 0.44 mm in diameter, 0.24 to 0.34 mm dominating, 3 to 9 in 2 mm length, 6 to 7 usually, 3 to 20 whole zooecia in 1 mm square, 6 to 8 usually; round acanthopores are clear or with tiny dark centres, 0.02 to 0.06 mm in diameter, numbers very variable, 3 to 4 normally surrounding a zooecium, rarely 5 or 6, and ranging from 0 to 20 or more in 1 mm square.

In longitudinal section, zooecia walls are uniformally thin except where thickened by clear acanthopore rods or styles, of varying length, which occur at all levels of the zoarium; zooecia with flat to inclined to concave to convex diaphragms throughout, 1 to 5 in 1 mm length; mesozooecia long, in single to triple rows, walls indented by closely spaced horizontal diaphragms evenly spaced 8 to 10, rarely 5 or 13, in 1 mm length.

Dimensions (mm).

	GSC 91943	GSC 91945	GSC 91948a
Diameter of zooecial opening	0.24-0.28	0.24-0.28	0.24-0.34
No. of zooecia in 2 mm laterally	5-7	6-7	7-10
No. whole zooecia in 1 mm square	1-2	1-3	3
No. of diaphragms in 2 mm length in zooecium	6-9	-	8-10
No. of diaphragms in 2 mm length in mesozooecium	12-17	-	16-20
Acanthopore diameter	0.02-0.06, usually 0.04	0.04	-

Discussion. The considerable intergrading and similarity within and between individual colonies of *Batostoma chazyensis* Ross (1963b, p. 859) and *B. campensis* Ross (1963b, p. 863) are interpreted as variations within one species, and accordingly the two species are considered synonymous, with the former name having page priority (Bolton and Cuffey, in press). Separation of laminate colonies of *B. chazyensis* Ross and *B. lanensis* Ross also is difficult as there is again so much variation within each species. Inclined zooecial diaphragms and abundant mesozooecia with indented walls appear to be possible distinguishing characteristics of *B. chazyensis*; its zooecia appear to be consistently smaller, ranging from 0.11 to 0.31 mm in diameter (Ross, 1963b, Table 4) compared to 0.2 to 0.38 for *B. lanensis* (Ross, 1963b, Table 2), and its acanthopores ranging in diameter from 0.02 to 0.05 mm compared to 0.01 to 0.07 mm in *B. lanensis*, but there is considerable overlap in these characteristics. As most acanthopores range in diameter from 0.02 to 0.04 mm, and the zooecia range from 0.24 to 0.34 mm, the majority of the Hawkesbury specimens seem best allied to *B. chazyensis*.

Batostoma lanensis Ross, 1963

Plate 1.4, figures 1-6

Batostoma lanensis Ross, 1963, p. 861, Pl. 107, fig. 11; Pl. 108, figs. 1-4, 6-8.

Types and occurrence. Hypotypes GSC 91934, north face, upper (No. 3) biostrome, GSC loc. 102964; GSC 91935, 91936, loose shale blocks south-central wall, GSC loc. 103040; GSC 91937 (intergrowths with *Ceramoporella* n. sp., GSC 91937a), north face, middle (No. 2) biostrome, GSC loc. 102962.

Description. Colonies multilaminate, hemispherical in shape. In tangential section, zooecia normally are round to oval and in contact, to polygonal and completely surrounded by mesozooecia in deep tangential sections, thin walled, diameters ranging from 0.22 to 0.40 mm with rare 0.50 mm, 5 to 6 in 2 mm length, 5 to 8 whole zooecia in 1 mm square; acanthopores are clear, round, commonly 0.03 to 0.05 mm in diameter with zones of larger forms 0.06 to 0.08 mm in diameter, 18 to 20 in 1 mm square.

In longitudinal section, zooecia walls are normally thin, much thickened at all levels within the zoaria by abundant short and long acanthopores; zooecia with diaphragms horizontal to inclined near the periphery in particular, variably spaced 1 to 4 in 1 mm length; mesozooecia are abundant with horizontal diaphragms that, like the zooecial diaphragms, can extend upward at the edges to form the acanthopore walls, 6 to 10 in 1 mm length.

Discussion. The consistently large acanthopores, abundant small mesozooecia and large zooecia suggest these zoaria are closer to *B. lanensis* than to *B. chazyensis* Ross.

Genus *Champlainopora* Ross, 1970

Type species. Atactotoechus chazyensis Ross, 1963.

Champlainopora chazyensis (Ross, 1963)

Plate 1.3, figure 2; Plate 1.5, figures 1-7;
Plate 1.6, figures 1-4, 8, 9

Atactotoechus chazyensis Ross, 1963, p. 734, Pl. 107, figs. 6-10; Pl. 108, figs. 1-11.

Types and occurrence. Hypotypes GSC 91938–91940, west end, lower (No. 1) biostrome, GSC loc. 102959; GSC 91930, 91941, 91942, west end, lower (No. 1) biostrome, GSC loc. 103042; GSC 91945a–91947, west end, 1.25 m thick bryozoan band 0.63 below top of lower (No. 1) biostrome, GSC loc. 104404.

Description. Colonies ramose, up to 9.0 mm in diameter, encrusted. In tangential section, zooecia oval openings range from 0.12 to 0.22 mm in diameter, 8 to 9.5 in 2 mm length, 3 to 5 in 1 mm square; integrate walls 0.04 to 0.14 mm thick with a few round clear pores 0.02 to 0.04 mm in diameter usually located at corners; in deep tangential and transverse sections, polygonal zooecia in contact, 0.14 to 0.26 mm in diameter, with rare, small, angular mesozooecia in between zooecia.

In longitudinal section, zooecia are slightly oblique at surface, walls are thick in exozone that is up to 1.4 mm in length; zooecia with flat diaphragms throughout, 1 to 3 in 1 mm length in axial region, 6 to 8 in 1 mm length in peripheral region; mesozooecia are slender and composed of up to 14 diaphragms in 1 mm length.

Dimensions (mm).

	GSC 91946	GSC 91947
Diameter of zooecial opening	0.16-0.20, rarely 0.28	0.16-0.20
No. of zooecia in 2 mm laterally	8-9	–
No. whole zooecia in 1 mm square	4-5	3-4
No. of diaphragms in 1 mm length in zooecium	4 to 6 in exozone, 3 in endozone	5 in exozone
No. of diaphragms in 1 mm length in mesozooecium	9-11	14
Acanthopore diameter	0.02-0.04	0.04-0.06

Discussion. An abundance of diaphragms throughout the zooecia distinguishes *C. chazyensis* from *C. kayi* Ross. The Hawkesbury zoaria are larger, the number of pores are less and the zooecial openings are less inclined at the surface than in type material of *C. chazyensis*.

Order CYSTOPORATA Astrova, 1964

Genus *Ceramoporella* Ulrich, 1882

Type species. *Ceramoporella distincta* Ulrich, 1890.

Ceramoporella n. sp.

Plate 1.3, figures 3, 4; Plate 1.4, figure 1

Cheiloporella Ross, 1981, fig. 1-9A, B.

Types and occurrence. Hypotypes GSC 91922a, west end, lower (No. 1) biostrome, GSC loc. 102959; GSC 91924a, 91937a, north face, middle (No. 2) biostrome, GSC loc. 102962; GSC 91927a, 91928a, west end, middle (No. 2) biostrome, GSC loc. 103041; GSC 91931a, shale bed loose at base of south-central exposure, GSC loc. 103044; GSC 91933a, loose shale blocks, south-central wall, GSC loc. 103040; GSC 91934, north face, upper (No. 3) biostrome, GSC loc. 102964; GSC 91948, west end, shale unit 3.4 m above top of middle (No. 2) biostrome, GSC loc. 104412.

Description. Zoaria are preserved as multilaminate encrustations within nodular colonies of *Batostoma*. Zooecia are short tubes up to 0.80 mm long and between 0.16 and 0.20 mm but up to 0.45 mm in diameter; no trace of diaphragms.

Discussion. Similar zoaria are present in the more diversified Chazyan bryozoan bioherm assemblages in the Mingan Formation of the Mingan Islands, Quebec, which will be formally named by Bolton and Cuffey (in press). In the Vermont–New York State–Montreal, Quebec areas of the Chazy Group, *Ceramoporella* n. sp. occurs within bioherms as encrustations of laminate sheets of *Batostoma chazyensis*, individual sheets that acted as sediment traps, and hemispherical colonies forming mounds (Ross, 1981, p. 10, 29).

Phylum CONODONTA

Genus *Belodina* Ethington, 1959

Type species. *Belodus compressus* Branson and Mehl, 1933.

Belodina monitorensis Ethington and Schumacher, 1969

Plate 1.7, figure 21

Multielement Taxonomy

Belodina monitorensis marginata Ethington and Schumacher, 1969, p. 455, 456, Pl. 67, figs. 1, 2, 4, 6; Textfig. 5E.

Belodina monitorensis Bergström, 1978, p. 736, Pl. 79, figs. 18, 19; Bauer, 1987, p. 12, 13, Pl. 1, figs. 10, 13, 14.

Type and occurrence. Hypotype GSC 98949, compressiform element, GSC loc. 102968; eobellodiniform? element, GSC loc. 102957.

Remarks. Of the trimembrate apparatus, only the compressiform element is represented, and that by a single specimen. An unfigured fragment probably is the remnant of the eobellodiniform. The single compressiform specimen contains four confluent denticles as illustrated in Bauer (1987, Pl. 1, fig. 14), unlike Ethington and Schumacher's (1969) description of generally (but not neccessarily) five denticles. The specimen is broad, with a well defined high heel and a low rounded costa along the lower portion of the cusp on the furrowed side. Both the figured specimen and the questionable fragment have faint longitudinal striations in the basal region.

Indet. grandiform? element

Plate 1.7, figure 22

Type and occurrence. Figured specimen GSC 98950, grandiform element, GSC loc. 102971.

Remarks. A single rastrate belodiniform (grandiform) element. The presence of a low rounded costa similar to the compressiform of *B. monitorensis* on the longitudinally furrowed side, as well as fine longitudinal stria near the base may link this element to that apparatus. The remnant, single, extraordinarily broad denticle and what appears to be the remnant of a low heel, do not, however, coincide with *B. monitorensis.*

Genus *Cahabagnathus* Bergström, 1983

Type species. Polyplacognathus sweeti Bergström, 1971.

Cahabagnathus chazyensis Bergström, 1983

Plate 1.7, figure 9

Multielement Taxonomy

Cahabagnathus chazyensis Bergström, 1983, p. 54, figs. 6 M-P (includes synonymy to 1983); Bauer, 1987, p. 14, Pl. 4, fig. 15.

Type and occurrence. Hypotype GSC 98951, polyplacognathiform element, GSC loc. 102972.

Remarks. A polyplacognathiform (stelliplanate) and an ambalodiform (pastiniplanate) element form this bimembrate apparatus. Of these, only the polyplacognathiform element is represented.

Bergström (1983) discussed the subtle differences between the stelliplanate elements of *C. chazyensis* and *C. friendvillensis*, indicating that the posterolateral process is relatively broad and crudely square as opposed to broadly rounded in the respective species. The Hawkesbury specimens have an angular posterolateral process and compare well with Bergström (1983, Figs. 6 O, P).

Genus *Dichognathus* Branson and Mehl, 1933

Type species. Dichognathus prima Branson and Mehl, 1933.

Indet. dichognathiform element

Plate 1.7, figures 10, 11

Types and occurrence. Figured specimens GSC 98952, 98953, dichognathiform elements, GSC loc. 102972.

Description. Two specimens of dichognathiform elements with broadly arched, slightly rotated (cf. oulodiform elements) processes. The anterior, adenticulate process is at an angle of less than 30 degrees to the denticulate lateral process. Main cusp is short and broadly arcuate. Denticles are discrete and peg-like. Basal cavity is broad, extends along entire base, and is posterolaterally flared beneath the cusp. Basal cavity is somewhat expanded beneath the posterior process.

Remarks. This dichognathiform element probably belongs to a *Plectodina* apparatus.

Genus *Drepanoistodus* Lindström, 1971

Type species. Oistodus forceps Lindström, 1955.

Drepanoistodus suberectus
(Branson and Mehl, 1933)

Unfigured

Oistodus inclinatus Branson and Mehl, 1933, p. 110, Pl. 9, fig. 8; Ethington and Schumacher, 1969, p. 467, Pl. 68, fig. 7.

Oistodus suberectus Branson and Mehl, 1933, p. 111, Pl. 9, fig. 7.

Drepanodus homocurvatus Lindström, 1954, p. 563, Pl. 2, figs. 23, 24, 39; Textfig. 4d; Ethington and Schumacher, 1969, p. 461.

Multielement Taxonomy

Drepanodus suberectus (Branson and Mehl). Bergström and Sweet, 1966, p. 330-333, Pl. 35, figs. 22-27 (includes synonymy to 1966).

Drepanoistodus suberectus (Branson and Mehl). Dzik, 1983, Figs. 4-10, 1-11; Bauer, 1987, p. 16, 17, Pl. 1, figs. 15-17, 22 (includes synonymy to 1987).

Types and occurrence. Unfigured hypotypes GSC 98954, suberectiform elements, GSC loc. 102973; GSC 98955, homocurvatiform element, GSC loc. 102972; GSC 98956, oistodiform element, GSC loc. 102971.

Remarks. The apparatus consists of two drepanodiform (homocurvatiform and suberectiform) elements and one oistodiform element. There is considerable variation (gradational) in the shape and expansion of the base of the homocurvatiform elements at Hawkesbury. Such variation was also suggested by Carnes (1975, p. 129-132; as reported in Bauer, 1987, p. 16, 17), who divided homocurvatiform elements into three distinct, intergradational forms based on the character of the base.

Genus *Multioistodus* Cullison, 1938

Type species. Multioistodus subdentatus Cullison, 1938.

Multioistodus compressus
Harris and Harris, 1965

Plate 1.7, figure 8

Multielement Taxonomy

Neomultioistodus compressus Harris and Harris, 1965, p. 43, 44, Pl. 1, figs. 7a-c.

Multioistodus compressus Harris and Harris. Ethington and Clark, 1982, p. 58, 59, Pl. 6, fig. 8 (includes synonymy to 1982).

Type and occurrence. Hypotype GSC 98957, cordylodiform element, GSC loc. 102957.

Remarks. Ethington and Clark (1982) thoroughly discussed this five-member apparatus, of which a single hyaline cordylodiform element occurs in the Hawkesbury samples. The specimen differs from their description in that the anterior aboral knob does not project anteriorly, but rather is erect.

Genus *Panderodus* Ethington, 1959

Type species. Paltodus unicostatus Branson and Mehl, 1933.

Panderodus sp. cf. *P. gracilis*
(Branson and Mehl, 1933)

Plate 1.7, figures 19, 20

Paltodus compressus Branson and Mehl, 1933, p. 109, Pl. 8, fig. 19.

Paltodus gracilis Branson and Mehl, 1933, p. 108, Pl. 8, figs. 20, 21.

Multielement Taxonomy

Panderodus gracilis (Branson and Mehl). Bergström and Sweet, 1966, p. 355-359, Pl. 35, figs. 1-6 (includes synonymy to 1966).

Types and occurrence. Hypotypes GSC 98958, graciliform element, GSC loc. 102957; GSC 98959, compressiform element, GSC loc. 102972.

Remarks. The few specimens of *Panderodus* in the Hawkesbury samples show some variations but are similar to the bimembrate *P. gracilis* apparatus, containing graciliform and compressiform elements.

Genus *Phragmodus* Branson and Mehl, 1933

Type species. Phragmodus primus Branson and Mehl, 1933.

Phragmodus flexuosus Moskalenko, 1973

Plate 1.7, figures 1-5

Multielement Taxonomy

Phragmodus flexuosus Moskalenko, 1973, p. 73, 74, Pl. XI, figs. 4-6; Harris, Bergström, Ethington and Ross, 1979, Pl. 2, figs. 1-4; Bauer, 1987, p. 24, 25, Pl. 3, figs. 10, 14, 15, 18, 20, 24; Textfig. 8A.

?*Phragmodus flexuosus* Moskalenko. Ethington and Clark, 1982, p. 79-82, Pl. 9, figs. 2, 3, 5-7, *non* fig. 4.

Phragmodus sp. A, Sweet, Ethington and Barnes, 1971, p. 173, 174, Pl. 2, figs. 3-6.

Types and occurrence. Hypotypes GSC 98960, symmetrical phragmodiform element, GSC loc. 102961; GSC 98963, asymmetrical phragmodiform element, GSC loc. 102971; GSC 98961, cyrtoniodiform element, GSC loc. 102972; GSC 98964, subcordylodiform element, GSC loc. 102958; GSC 98962, dichognathiform element (Pb), GSC loc. 102957.

Remarks. The *Phragmodus flexuosus* apparatus was extensively described and discussed by Ethington and Clark (1982) as well as by Bauer (1987). In her original description of the apparatus, Moskalenko (1973) included both an oistodiform (geniculate) and a cyrtoniodiform (dolabrate) element. In the Hawkesbury samples, only the cyrtoniodiform element is present. Harris et al. (1979, p. 23) found the apparatus containing a cyrtoniodiform element to be stratigraphically the younger. Ethington and Clark (1982, p. 81) suggested that the *P. flexuosus* apparatus containing an oistodiform element occurs in association with conodonts of the *Eoplacognathus suecicus* Subzone, the apparatus containing a cyrtoniodiform element occurs with conodonts of the *E. foliaceus* Subzone, and that future subdivision of this species is dependant on further work in the type area in Siberia. They (1982, p. 80) also divided the phragmodiform elements into three groups: those having a keeled anterior margin and commonly asymmetrical lateral costae as well as a posterior keel and process; those lacking one of the lateral costae; and completely symmetrical phragmodiform elements with rounded anterior margins and equally developed costae on either side. The Hawkesbury samples contain all three types of phragmodiform elements, however, the first two are transitional, and are not separated here.

Bauer (1987, p. 24-26) further subdivided the cyrtoniodiform element-containing apparatus based on the presence of either a single or two dichognathiform elements. The two dichognathiforms differ in the angle between the anterior adenticulate keel and lateral process, the Pa element enclosing a 10 to 20 degree angle and the Pb element, a 70 to 80 degree angle. He termed the apparatus containing two dichognathiform elements *P. flexuosus* morphotype A, whereas morphotype B contained one dichognathiform element. Bauer also noted that morphotype B preceded morphotype A in the section. Although the Hawkesbury samples contain *P. flexuosus* morphotype A, the Pa and Pb elements are transitional and are not subdivided. Plate 1.7, figure 3 shows the Pb element.

Genus *Staufferella* Sweet, Thompson and Satterfield, 1975

Type species. Distacodus falcatus Stauffer, 1935.

Staufferella? sp.

Plate 1.7, figures 14-16

Multielement Taxonomy

Semiacontiodus sp. nov. Dzik, 1983, Fig. 3-3.

Staufferella sp. Bauer, 1987, Pl. 5, figs. 12-14.

Types and occurrence. Figured specimens GSC 98965, symmetrical element, GSC loc. 102957; GSC 98966, 98967, asymmetrical element, GSC loc. 102957.

Diagnosis. The apparatus consists of one bilaterally symmetrical and two variably asymmetrical hyaline coniform elements. Surfaces have fine longitudinal striations, basal cavities are fairly deep and bases are generally subcircular in cross-section. The posterior face of the symmetrical element contains a midline longitudinal groove. Asymmetrical elements have variably developed lateral carinae and a slight lateral twisting of the distal portion of the cusp.

Description. The symmetrical element is gently recurved and somewhat basally depressed. The anterior surface is broadly rounded, forming symmetrical lateral costae that taper both toward the cusp tip and the basal margin. No prominent basal alae are developed. The posterior face is broadly bicarinate, resulting in a distinct but neither wide nor deep midline groove. The asymmetrical elements are recurved to strongly recurved. Posterior and anterior faces are variably rounded with distinct, generally rounded lateral carinae. In at least one specimen, there are no lateral carinae, and in another, one of the carinae is not as rounded, forming a sharp edge along most of the cusp. Basal and cross-sections of all elements are subcircular.

Remarks. This apparatus is tentatively placed into *Staufferella* on the basis of the rather deep basal cavities, the longitudinal striations, and the hyaline nature of the conodonts. Also, the few Hawkesbury specimens closely resemble Bauer's (1987) illustrations and description of *Staufferella* sp. Sweet et al. (1975, p. 43, 44) stated that the "bilaterally symmetrical elements of *Staufferella* are distinctly depressed basally" and have "basally alate lateral costae." The Hawkesbury specimens have only a slight basal depression, and lack the basally alate lateral costae.

Genus *Triangulodus* van Wamel, 1974

Type species. Scandodus brevibasis (Sergeeva) sensu Lindström, 1971.

Remarks. Bauer (1987, p. 30, 31) as well as Ethington and Clark (1982, p. 109) extensively discussed the definition and naming of this genus. Ethington and Clark (1982) adapted Bradshaw's (1969) *Tripodus* for a very similar apparatus consisting of albid elements. The *Triangulodus* apparatus, as discussed by Bauer (1987), however, contains five coniform and hyaline conodonts. The Hawkesbury specimens are hyaline and consequently placed in *Triangulodus.*

Triangulodus alatus Dzik, 1976

Plate 1.7, figures 6, 7

Triangulodus (?) *alatus* Dzik, 1976, p. 422, Textfig. 20 f-k, Pl. XLI, figs. 2-5.

Multielement Taxonomy

Eoneoprioniodus alatus (Dzik). Dzik, 1983, Fig. 6 (nos. 12, 13).

Triangulodus alatus Dzik. Bauer, 1987, Pl. 5, figs. 3, 4, 6, 9, 10.

Types and occurrence. Hypotypes GSC 98968, scandodiform element, GSC loc. 102971; GSC 98969, acontiodiform element, GSC loc. 102971; unfigured hypotype GSC 98976, paltodiform element, GSC loc. 102971.

Remarks. The Hawkesbury specimens correspond well to Bauer's (1987) illustrations and description of *Triangulodus alatus*. Only three of the five elements are present in the form of the acontiodiform, scandodiform, and paltodiform elements. The broad, basally elongate costae are strongly developed and clearly defined in all three elements.

Indet. trichonodelliform element

Plate 1.7, figure 18

Type and occurrence. Figured specimen GSC 98970, trichonodelliform element, GSC loc. 102957.

Description. A slightly asymmetric trichonodelliform element. The posterior process is broken such that neither the angle of that process with the anterior arch, nor the presence of denticulation can be determined. The cusp has two asymmetric, sharp margins extending tipward from the anterolateral processes. There is also a low carina extending across the posterior face of the cusp, resulting in a twisted appearance. The margins and carina distort the otherwise circular cross-section of the cusp. Two denticles on each process are discrete and oval in cross-section. The basal cavity forms a shallow groove under the lateral processes, which expand as a conical cavity beneath the cusp.

Remarks. This single specimen could probably be assigned to a *Plectodina* apparatus.

Genus indeterminate

Plate 1.7, figure 17

Type and occurrence. Figured specimen GSC 98971, ambalodiform element, GSC loc. 102957.

Remarks. A single, deeply excavated ambalodiform element with a short, stout cusp and four variably developed processes. The posterior, anterior, and outer lateral processes are well developed, whereas the inner lateral one is not. Only the anterior process has a ridge of weak, uneven denticles. There is no evidence of the rest of the apparatus. Such an ambalodiform element suggests an *Amorphognathus* apparatus without other verifying elements.

(?)New genus

Plate 1.7, figures 12, 13

Types and occurrence. Figured specimens GSC 98972, GSC loc. 102971; GSC 98973, GSC loc. 102971; unfigured specimens GSC 98974, GSC loc. 102963; GSC 98975, GSC loc. 102971.

Description. Small angulate, symmetrical to slightly asymmetrical chirognathiform elements. They differ fundamentally from *Chirognathus* in their albid as opposed to hyaline nature. Elements are palmate, with denticles turned slightly inward. Excavation of the base is shallow and expanded beneath the cusp as well as beneath both processes. Cusp and denticles are discrete and oval in cross-section. They are, however, broken in all specimens with the exception of distal denticles on each process, which are reduced, knob-like projections. White matter is well developed in all denticles. The number of denticles on processes vary from three each (including knobs) on symmetrical elements, to three or four on anterior and two or three on the posterior processes, to almost complete reduction of denticles (to knobs) on the posterior process.

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PLATES 1.1 to 1.7

PLATE 1.1

Bryozoa

Figures 1-3, 9, 10. *Batostoma chazyensis* Ross

1, 2. Tangential sections displaying abundant large acanthopores that frequently produce petaloid zooecia, hypotypes GSC 91928, 91926, x40, GSC locs. 103041, 103042, middle (No. 2) and lower (No. 1) biostromes, west face of quarry.

3, 9, 10. Tangential section displaying only a few scattered acanthopores, x20, and longitudinal sections displaying well spaced diaphragms, in zooecia, long acanthopores in both immature (x20) and mature basal (x40) zones, and mesozooecia with abundant diaphragms, hypotype GSC 91924, GSC loc. 102962, middle (No.2) biostrome, north face of quarry.

Brachiopoda

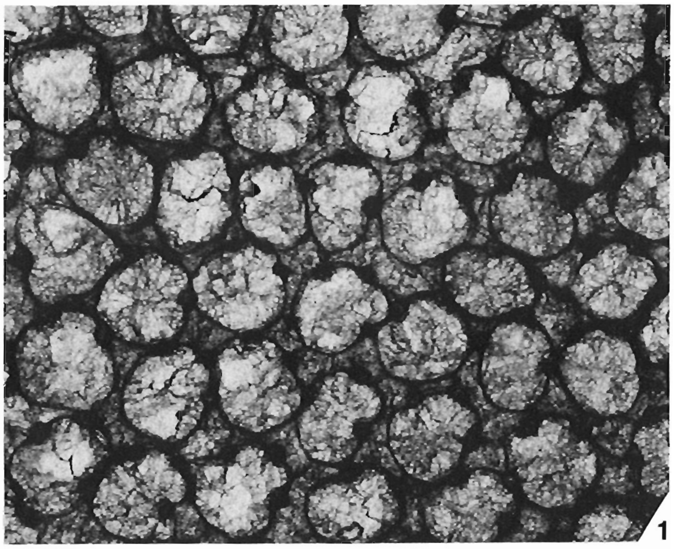
Figures 4, 6. *Mimella imperator* (Billings)

Lateral and posterior views of an articulated specimen, hypotype GSC 91949, x1, GSC loc. 103040, loose, south-central wall of quarry.

Figures 5, 7, 8. *Mimella vulgaris* (Raymond)

Lateral, posterior, and brachial views of a large articulated specimen, hypotype GSC 91950, x2, same locality as figure 4.

PLATE 1.1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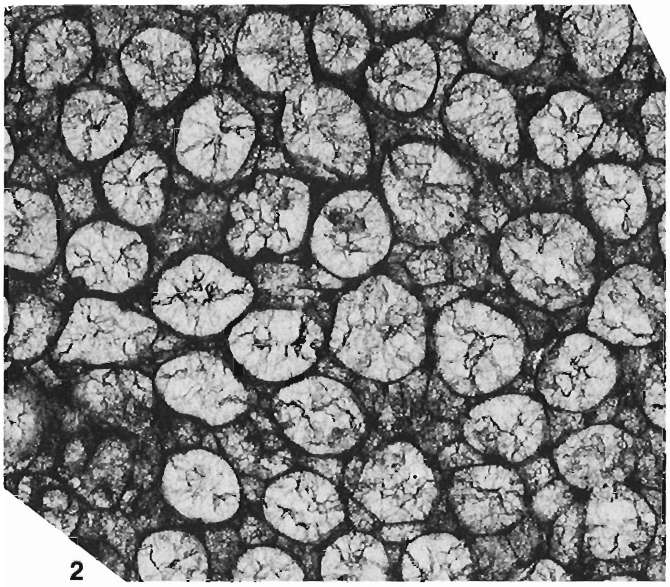
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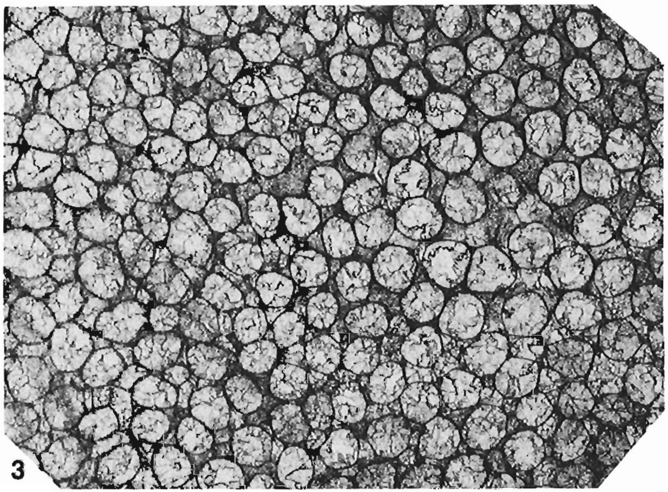
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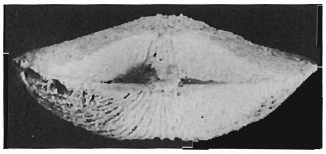
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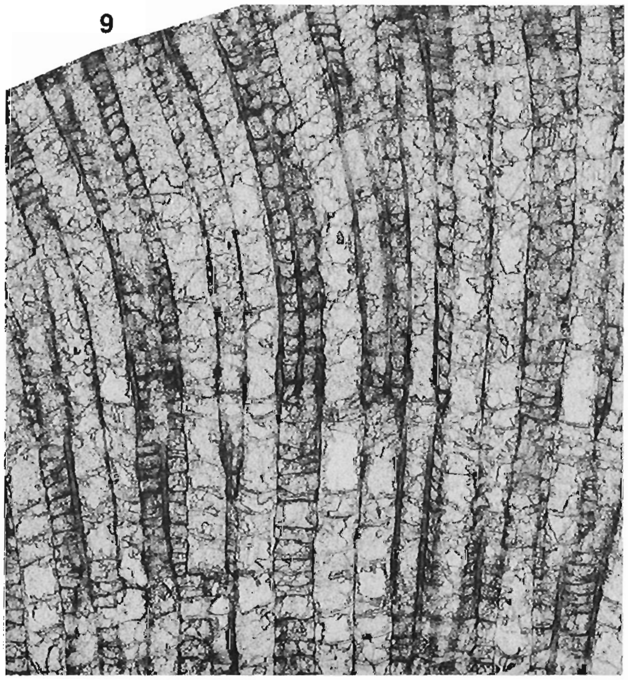
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PLATE 1.2

Bryozoa

Figures 1-3, 10, 11. *Batostoma chazyensis* Ross

1, 2. Tangential section displaying large acanthopores and zooecia, and longitudinal section with long acanthopores and variably spaced zooecial diaphragms, hypotype GSC 91943, x40, GSC loc. 104404, 0.63 m below top of lower (No. 1) biostrome, west face of quarry.

3, 10. Longitudinal section of a multilaminate colony, x5, and tangential section displaying smaller zooecia and acanthopores with solid centres, x40, hypotype GSC 91919, GSC loc. 102959, lower (No. 1) biostrome, west face of quarry.

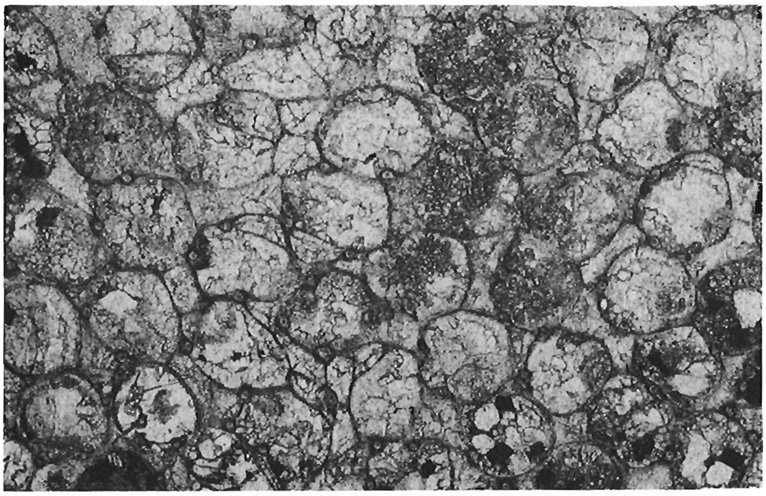
11. Longitudinal section displaying acanthopores of variable length, abundant mesozooecia, and zooecia arising directly from basal attachment, hypotype GSC 91932, x40, GSC loc. 103040, loose, south-central wall of quarry.

Brachiopoda

Figures 4-9. *Rostricellula raymondi* Cooper

4, 5. Brachial and lateral views, hypotype GSC 95613, x2, same locality as figure 11.

6-9. Two anterior and two posterior views, brachial valve uppermost, hypotypes GSC 95614-95617, x2, GSC loc. 104414, loose, south-central face of quarry (figs. 6, 8), and GSC loc. 104409, middle (No. 2) biostrome, west face of quarry (figs. 7, 9).



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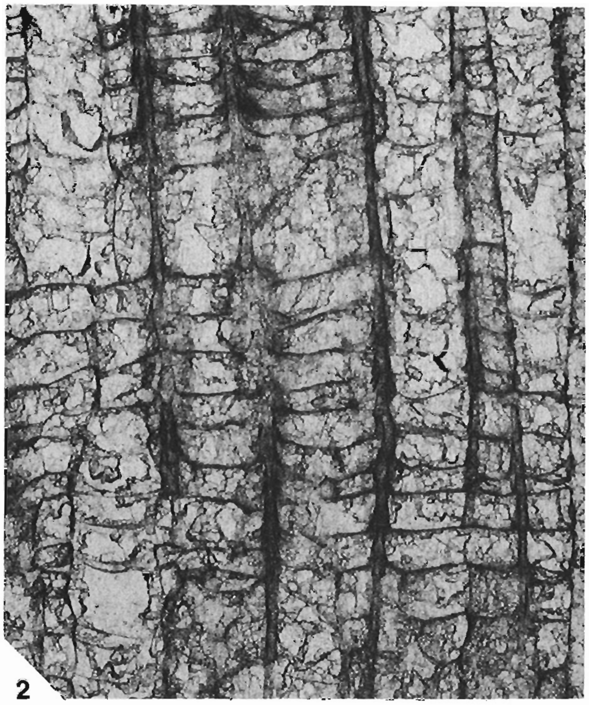

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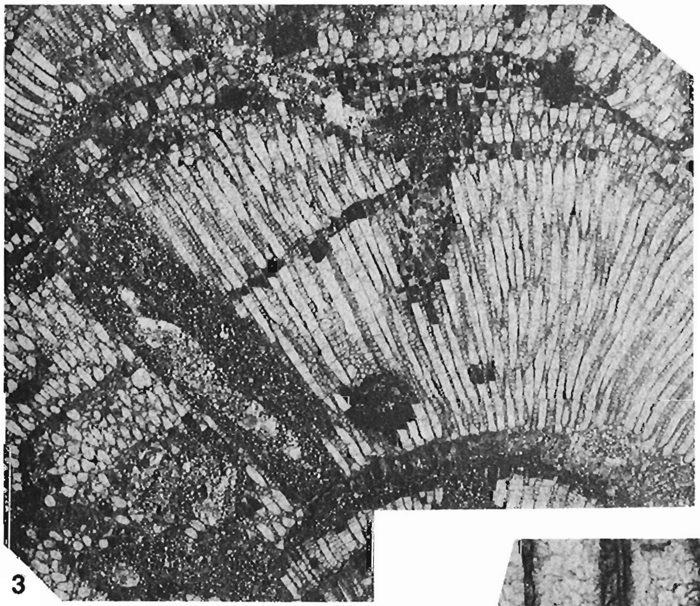

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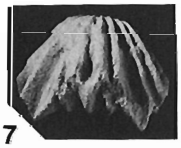

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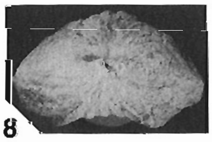

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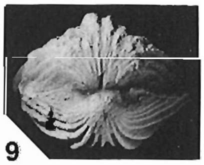

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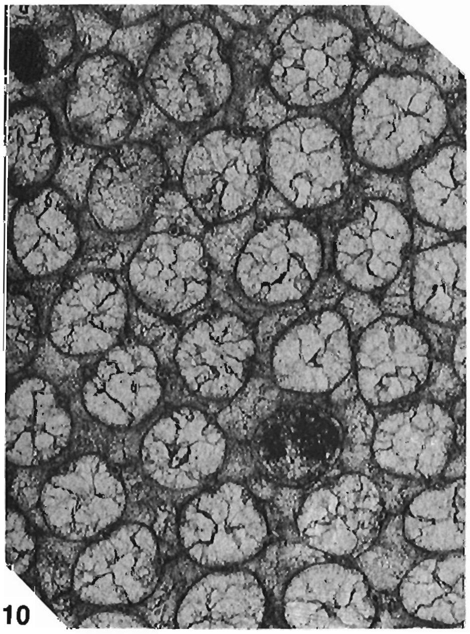

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PLATE 1.3

Bryozoa

Figures 1, 2, 11. *Batostoma chazyensis* Ross

1. Longitudinal and tangential views of a colony entombing a lingulid brachiopod fragment, hypotype GSC 91925, x10, GSC loc. 102962, middle (No. 2) biostrome, north face of quarry.

2, 11. Longitudinal section of a multilayered (8) ramose colony alternating with *Champlainopora chazyensis* (note large boring in upper left corner), x10, and tangential section displaying oval zooecia and abundant mesozooecia and acanthopores, x20, hypotype GSC 91945a, GSC loc. 104404, 0.63 m below top of lower (No. 1) biostrome, west face of quarry.

Figures 3, 10. *Ceramoporella* n. sp.

3. Longitudinal section of a multilayered colony encrusting a shallow bored brachiopod shell (note overgrowth of a *B. chazyensis* colony on the right side), figured specimen GSC 91931a, x5, GSC loc. 103044, loose, south-central wall of quarry.

10. Longitudinal section through at least four layers of *Ceramoporella* n. sp. overgrown by *B. chazyensis*, figured specimens GSC 91948a, x20, GSC loc. 104412, 3.4 m above middle (No. 2) biostrome, west face of quarry.

Brachiopoda

Figures 4, 5-8. *Rostricellula orientalis* (Billings)

Basal Mingan Formation shale, GSC loc. 96701, northeast corner of Eskimo Island or Île du Havre, Mingan Islands, Quebec.

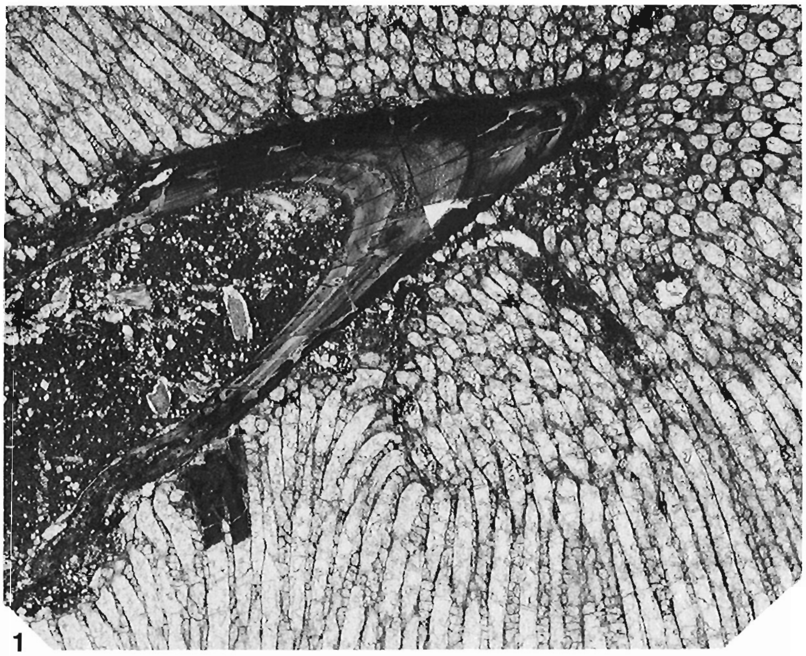
4, 8. Lateral and brachial views of a small, complete specimen, hypotype GSC 95620, x2.

5-7. Anterior, posterior, and pedicle views of small, complete specimens, hypotypes GSC 95621-95623, x2.

Figure 9. *Rostricellula raymondi* Cooper

Brachial view of a narrow, complete specimen, hypotype GSC 95618, x3, GSC loc. 104409, middle (No. 2) biostrome, west face of quarry.

PLATE 1.3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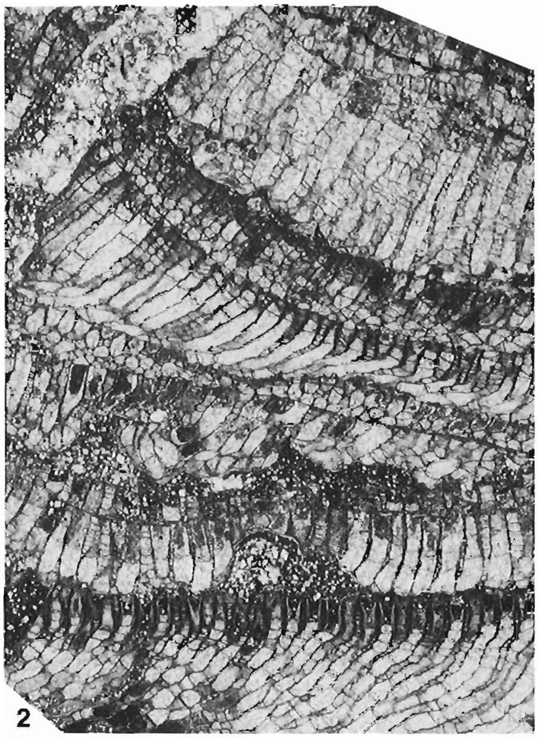
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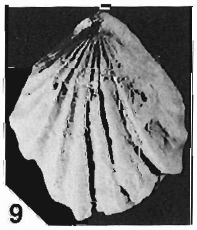
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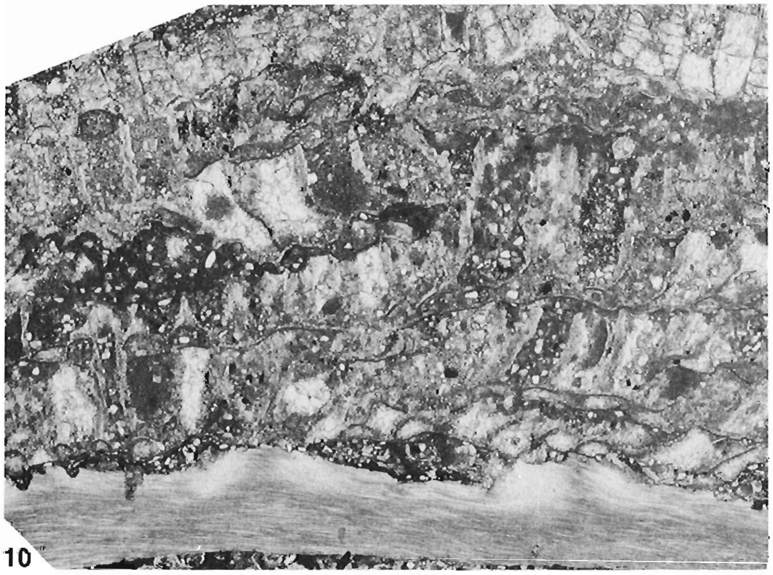
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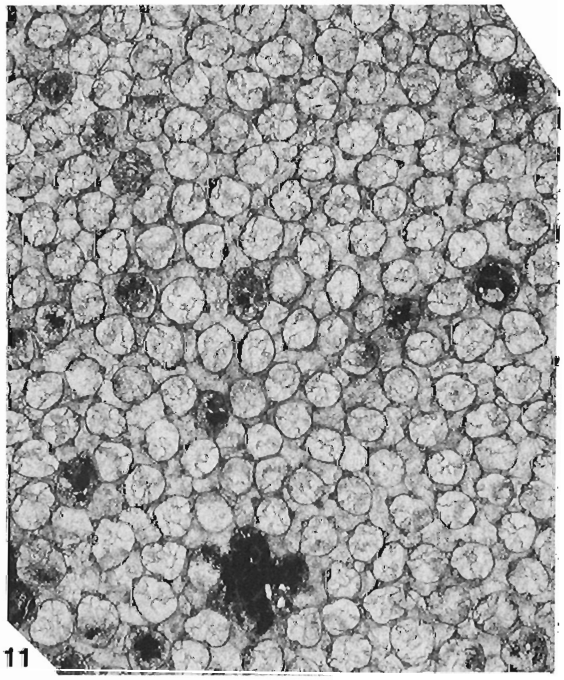
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PLATE 1.4

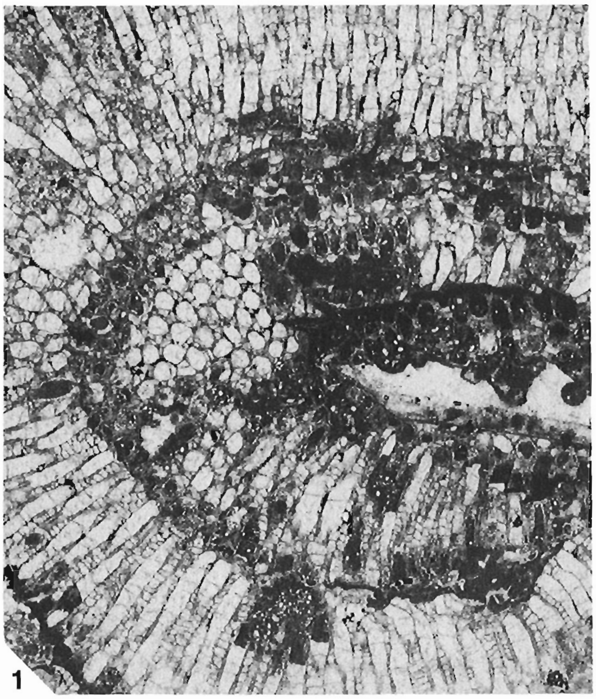
Bryozoa

Figures 1-6. *Batostoma lanensis* Ross

1, 2. Transverse section of a compound colony of *B. lanensis*, *Ceramoporella* n. sp., and *B. chazyensis* with a brachiopod fragment as nucleus, x10, and longitudinal section displaying a growth discontinuity surface, x20, hypotype GSC 91934, GSC loc. 102964, upper (No. 3) biostrome, north face of quarry.

3-5. Tangential sections displaying large zooecia and acanthopores, x20, x40, and transverse section (fig. 4) of a compound colony similar to GSC 91934, x5, hypotype GSC 91937, GSC loc. 102962, middle (No. 2) biostrome, north face of quarry.

6. Tangential section displaying abundant large acanthopores surrounding large zooecia, hypotype GSC 91935, x40, GSC loc. 103040, loose, south-central wall of quarry.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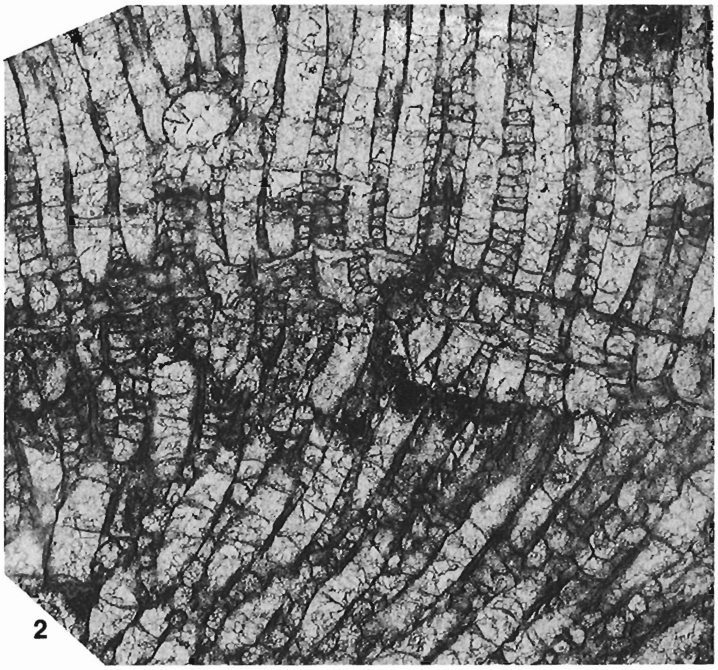
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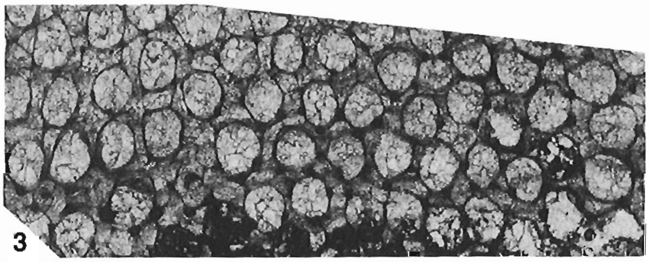
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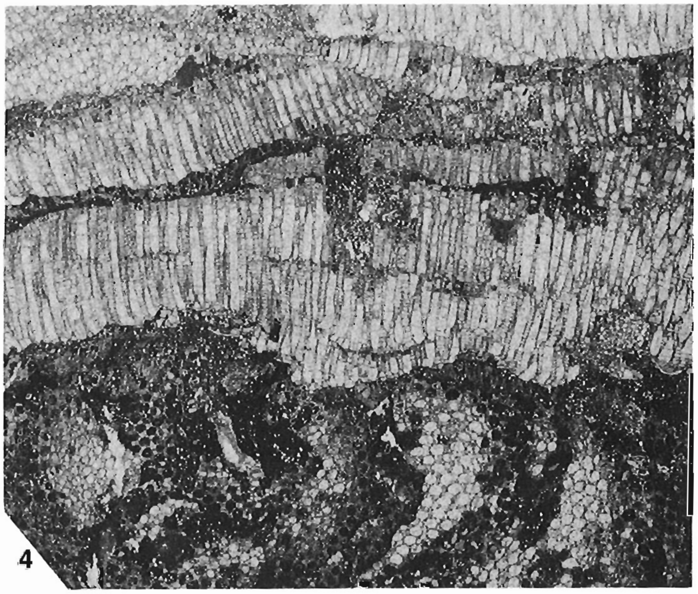
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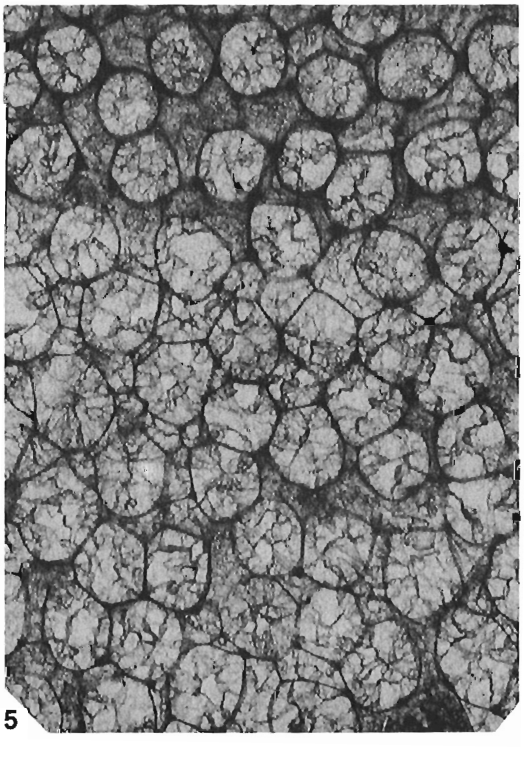
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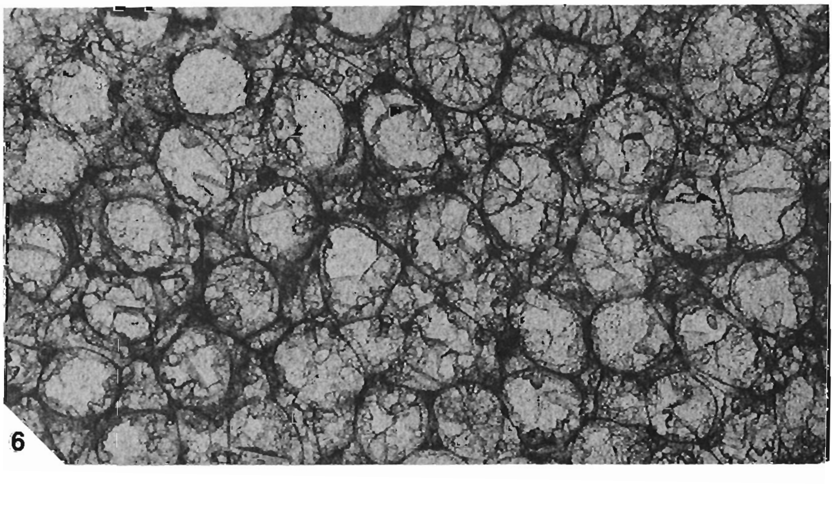
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PLATE 1.5

Bryozoa

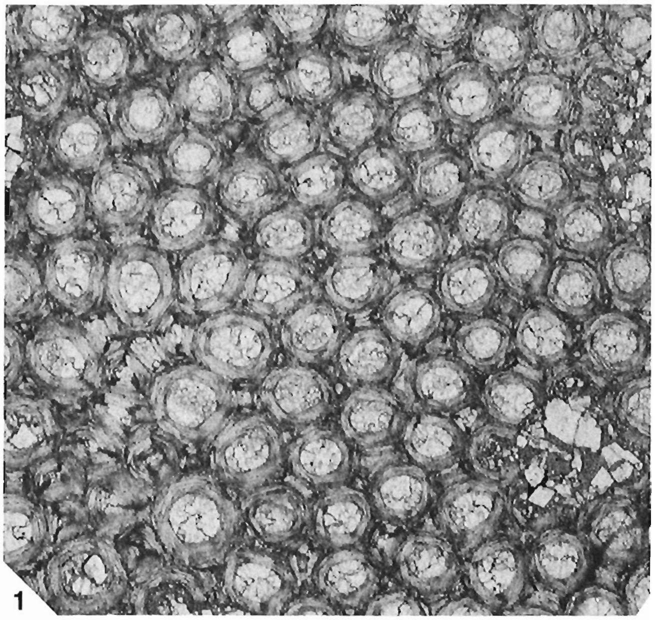
Figures 1-7. *Champlainopora chazyensis* (Ross)

1, 2. Tangential section displaying oval zooecia, thick walls, round clear pores at corners, and longitudinal section displaying abundant diaphragms, hypotype GSC 91940, x40, GSC loc. 102959, lower (No. 1) biostrome, west face of quarry.

3-5. Transverse section displaying polygonal zooecia, x10, deep tangential section displaying oval to polygonal zooecia and angular mesozooecia, x40, and longitudinal section displaying abundant diaphragms throughout and thick walls in exozone, x20, hypotype GSC 91938, same locality as figure 1.

6. Ramose colony, hypotype GSC 91930, x1, GSC loc. 103042, lower (No. 1) biostrome, west face of quarry.

7. Tangential section displaying large acanthopores, oval zooecia, and rare polygonal mesozooecia, hypotype GSC 91942, x40, same locality as figure 6.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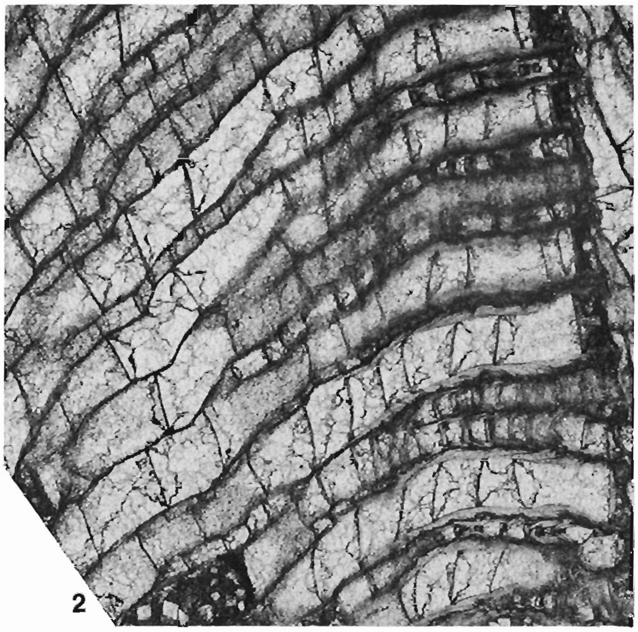
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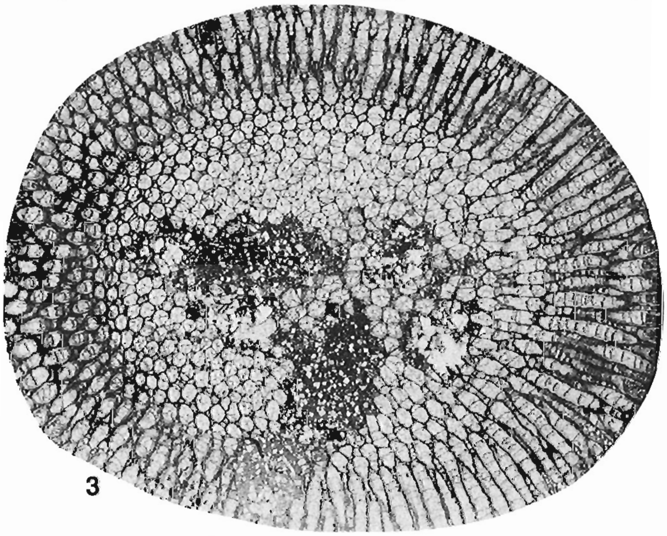
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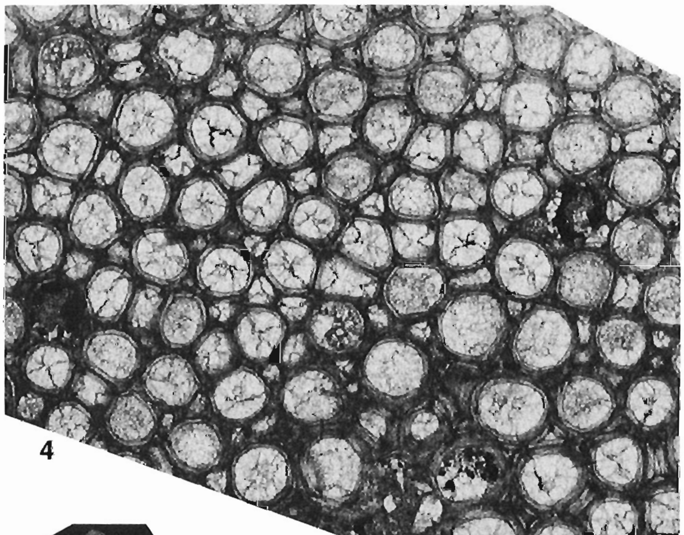
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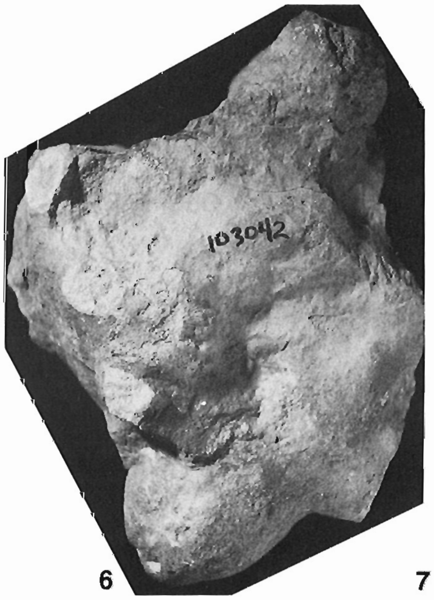

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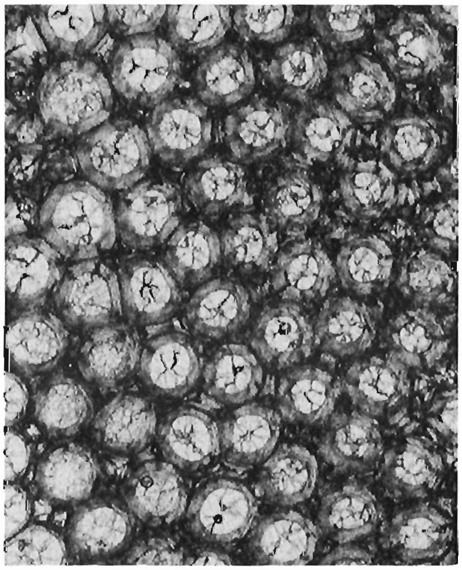
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PLATE 1.6

Bryozoa

Figures 1-4, 8, 9. *Champlainopora chazyensis* (Ross)

1, 4, 8. Tangential section displaying thin to thick walled oval zooecia separated by angular mesozooecia, x20, and longitudinal section displaying abundant diaphragms in both endozone and exozone (fig. 4), x20, contrasting with lateral overgrowth with more widely spaced diaphragms on the opposite side of a ramose colony (fig. 8), x40, hypotype GSC 91946, GSC loc. 104404, 0.63 m below top of lower (No. 1) biostrome, west face of quarry.

2. Tangential section displaying very thick zooecial walls and small clear pores, hypotype GSC 91939, x40, GSC loc. 102959, lower (No. 1) biostrome, west face of quarry.

3, 9. Tangential section displaying closely spaced oval zooecia, thin to thick walls, and a rare clear pore, and longitudinal section with thick walls in exozone and rare mesozooecia, hypotype GSC 91947, x40, same locality as figure 1.

Brachiopoda

Figure 5. *Rostricellula raymondi* Cooper

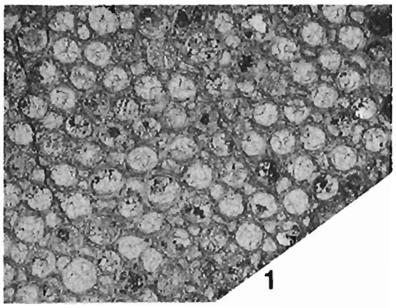
Brachial view of a complete specimen, hypotype GSC 95619, x2, GSC loc. 104409, middle (No. 2) biostrome, west face of quarry.

Cystoidea

Figures 6, 7. *Bolboporites americanus* Billings

6. Oblique view of a globular specimen with low celluliferous cone and long, smooth base, hypotype GSC 95624, x20, Mingan Formation, south end of Sea Cow Island or Grosse Île au Marteau, Mingan Islands, Quebec.

7. Side view of a conical specimen, with high, cone-bearing, irregularly arranged cells and low, smooth base, hypotype GSC 95625, x4, same locality as figure 5.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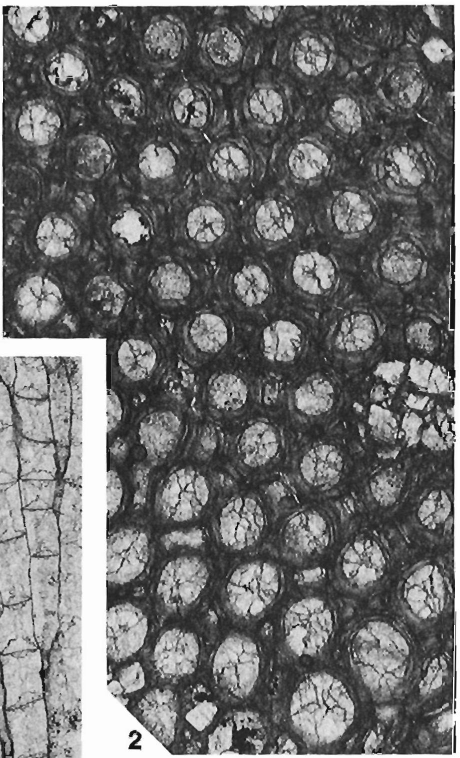
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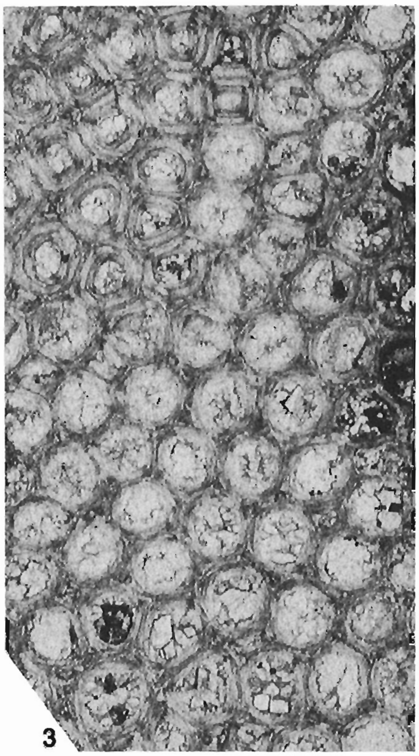
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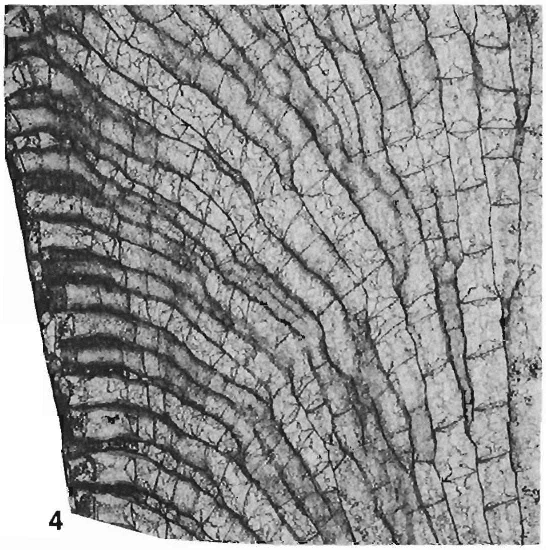
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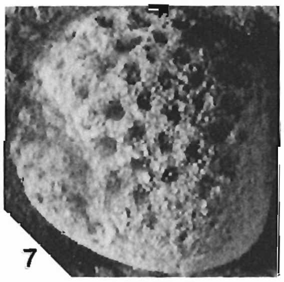
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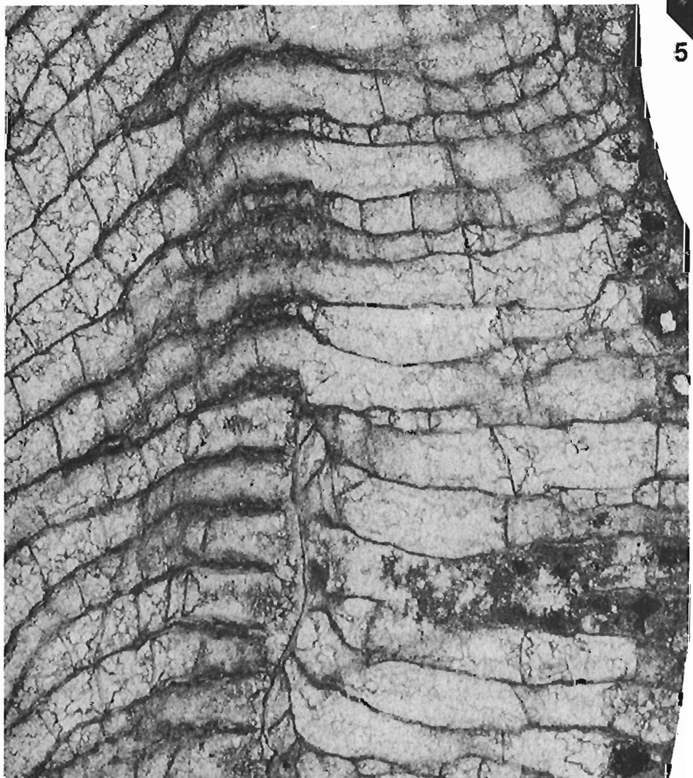
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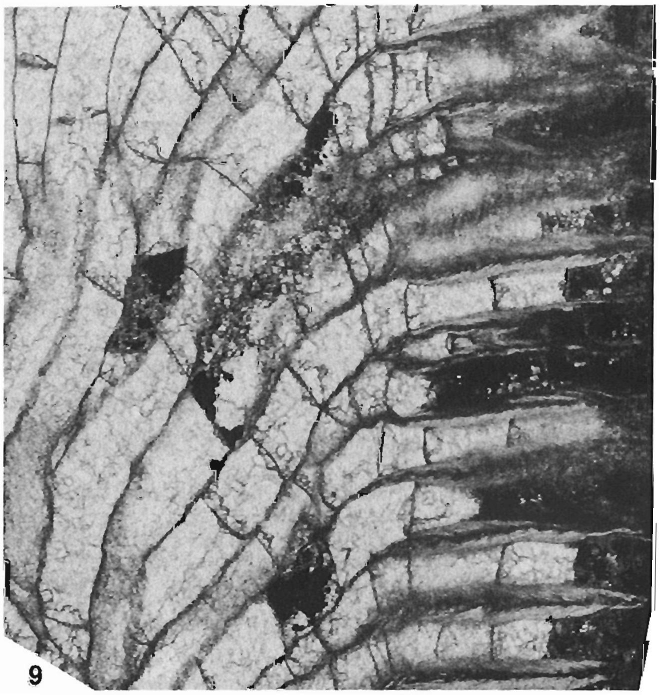
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PLATE 1.7

Conodonta

Figures 1-5. *Phragmodus flexuosus* Moskalenko, 1973

1. Symmetrical phragmodiform element, hypotype GSC 98960, x113, GSC loc. 102961.
2. Cyrtoniodiform element, hypotype GSC 98961, x77, GSC loc. 102972.
3. Dichognathiform element, morphotype A (Pb element), hypotype GSC 98962, x105, GSC loc. 102957.
4. Asymmetrical phragmodiform element, hypotype GSC 98963, x70, GSC loc. 102971.
5. Subcordylodiform element, hypotype GSC 98964, x51, GSC loc. 102958.

Figures 6, 7. *Triangulodus alatus* Dzik, 1976

6. Scandodiform element, hypotype GSC 98968, x79, GSC loc. 102971.
7. Acontiodiform element, hypotype GSC 98969, x96, GSC loc. 102971.

Figure 8. *Multioistodus compressus* Harris and Harris, 1965

Cordylodiform element, hypotype GSC 98957, x86, GSC loc. 102957.

Figure 9. *Cahabagnathus chazyensis* Bergström, 1983

Polyplacognathiform element, hypotype GSC 98951, x53, GSC loc. 102972.

Figures 10, 11. Indet. dichognathiform element

10. Anterior view, figured specimen GSC 98952, x83, GSC loc. 102972.
11. Posterior view, figured specimen GSC 98953, x86, GSC loc. 102972.

Figures 12, 13. (?)New genus

12. Posterior view, figured specimen GSC 98972, x112, GSC loc. 102971.
13. Anterior view, figured specimen GSC 98973, x148, GSC loc. 102971.

Figures 14-16. *Staufferella*? sp.

14. Symmetrical element, figured specimen GSC 98965, x131, GSC loc. 102957.
15. Asymmetrical element, figured specimen GSC 98966, x131, GSC loc. 102957.
16. Asymmetrical element, figured specimen GSC 98967, x131, GSC loc. 102957.

Figure 17. Genus indeterminate

Ambalodiform element, figured specimen GSC 98971, x79, GSC loc. 102957.

Figure 18. Indet. trichonodelliform element

Trichonodelliform element, figured specimen GSC 98970, x132, GSC loc. 102957.

Figures 19, 20. *Panderodus* sp. cf. P. *gracilis* (Branson and Mehl, 1933)

19. Graciliform element, hypotype GSC 98958, x121, GSC loc. 102957.
20. Compressiform element, hypotype GSC 98959, x96, GSC loc. 102972.

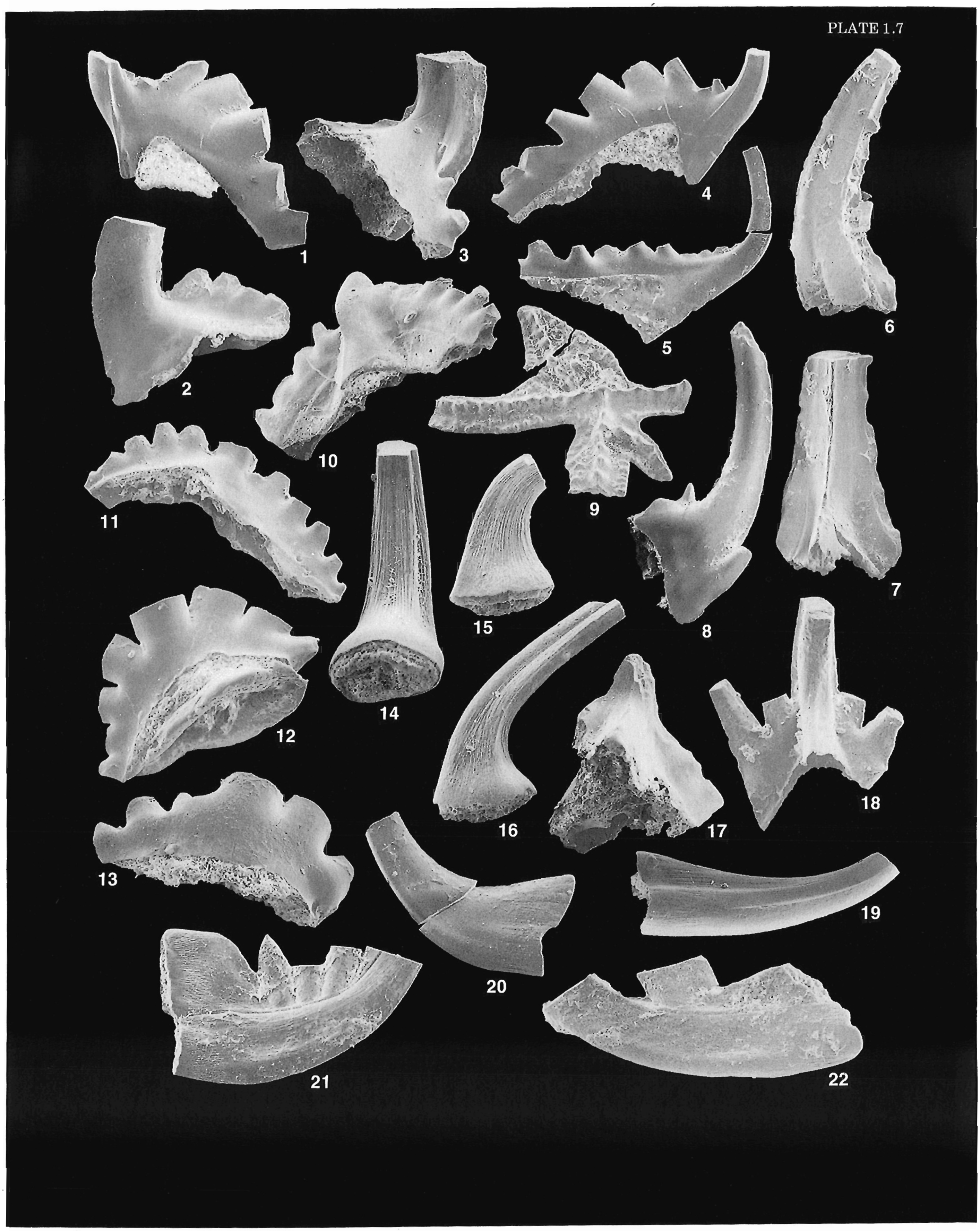
Figure 21. *Belodina monitorensis* Ethington and Schumacher, 1969

Compressiform element, hypotype GSC 98949, x141, GSC loc. 102968.

Figure 22. Indet. grandiform? element

Grandiform element, figured specimen GSC 98950, x105, GSC loc. 102971.

PLATE 1.7



A NEW LOWER SILURIAN CALLOCYSTITID CYSTOID FROM THE LAKE TIMISKAMING REGION, NORTHERN ONTARIO

C.R.C. Paul[1] **and Thomas E. Bolton**[2]

Paul, C.R.C. and Bolton, Thomas E., 1991. A new Lower Silurian callocystitid cystoid from the Lake Timiskaming region, northern Ontario. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 412, p. 35-43.

Abstract

The unique holotype of *Novacystis hawkesi* gen. et sp. nov. is described. *Novacystis* is characterized by a periproct surrounded by plates IL4, L4, L5, and R4. No known callocystitid has a radial, or only one infralateral, contributing to the periproct border. *Novacystis hawkesi* from the Lower Silurian Thornloe Formation, Lake Timiskaming region, Ontario, is the first documented Silurian cystoid from north of the Great Lakes–St. Lawrence Valley region.

Résumé

Les auteurs décrivent l'holotype remarquable de *Novacystis hawkesi* gen et sp. nov. *Novacystis* se caractérise par un périprocte entouré des plaques IL4, L4, L5 et R4. Aucun callocystidé connu ne possède de plaque radiale ou seulement une plaque infralatérale qui constitue la limite du périprocte. *Novacystis hawkesi* découvert dans la Formation de Thornloe du Silurien inférieur, dans la région du lac Témiscamingue en Ontario, est le premier cystoïde silurien provenant du nord de la région des Grands lacs et de la vallée du Saint-Laurent, que l'on ait étudié.

INTRODUCTION

Echinodermata are rare in the Silurian Wabi and Thornloe formations of the Lake Timiskaming region of northern Ontario (Bolton, 1970; Bolton and Copeland, 1972). The upper faunal assemblage of the Wabi Formation on Evanturel Creek includes the edrioasteroid *Hemicystites hawkesi* Bolton. The lower beds of the overlying Thornloe Formation have produced *Caryocrinites*(?) sp., *Protaxocrinus amii* Bolton, *Dimerocrinus* sp., and *Macnamaratylus murrayi* Bolton.

The unique specimen that forms the subject of this paper was originally discovered by G.J. Hawkes in 1970 and donated to the Geological Survey of Canada in 1987.

Articulated cystoids are sufficiently rare fossils to be noteworthy. This one not only possesses a unique plate arrangement, but also greatly extends the known geographic distribution of Lower Silurian cystoids. Representatives of the Callocystitinae have been reported only from North America, and predominantly from the midcontinent area (Broadhead and Strimple, 1978). Hitherto, the northernmost occurrences of North American Silurian cystoids were in the outcrops around the Michigan Basin and along the southern St. Lawrence Valley into New York State.

SYSTEMATIC DESCRIPTIONS

Superfamily GLYPTOCYSTITIDA Bather, 1899

Family CALLOCYSTITIDAE Bernard, 1895

Subfamily CALLOCYSTITINAE Bernard, 1895

Diagnosis. A subfamily of Callocystitidae with five branched or unbranched ambulacra that do not protrude from the thecal surface; usually with small, rounded

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pectinirhombs; with open radial, lateral, and sometimes infralateral circlets.

Remarks. This diagnosis differs very slightly from an earlier version (Paul, 1967c, p. 233). It is now believed that the presence of five ambulacra is significant, even though this is a plesiomorphic character retained from the Upper Ordovician *Lepadocystis*, which does not have interrupted lateral or infralateral circlets.

Genus *Novacystis* gen. nov.

Type species. Novacystis hawkesi gen. et sp. nov.

Diagnosis. A genus of Callocystitinae with unbranched ambulacra, with periproct surrounded by IL4, L4, L5, and R4.

Discussion. No other described callocystitid has plate R4 contributing to the margin of the periproct and thereby interrupting the lateral circlet. (See, for example, the plates in Regnéll, 1945; Paul, 1967a-d; Kesling, 1968; Frest and Paul, 1971; Ausich and Schumacher, 1984.) Only *Lipsanocystis traversensis* Ehlers and Leighley is known to have some specimens in which IL5 does not contribute to the periproct margin, although in that species the periproct border may be formed by the usual four plates (IL4, IL5, L4, L5) or by three, two, or just one (L5) of them. *Lipsanocystis traversensis* is an exception among callocystitids in having so variable an arrangement of plates around the periproct. In most species, the arrangement is fixed and only rare teratological specimens show unusual arrangements. Nevertheless, this raises the possibility that *Novacystis* is based on an aberrant specimen. With only one example available, there is no way to test this. However, nothing else about the specimen suggests that it is at all unusual, nor is there any genus to which the specimen could be attributed without substantial modification of its definition. For the present, the specimen is accepted as a normal cystoid and is attributed to a new genus.

The family Callocystitidae is believed to have evolved from the Cheirocrinidae. All cheirocrinids possess six radial plates, whereas callocystitids have only five. In cheirocrinids, R5 is the smallest radial plate and is situated directly over plate L5. In callocystitids, L5 interrupts the radial circlet and hence it is reasonable to assume that it was plate R5 that was lost in the reduction from six to five radials. Previously, radial plates in callocystitids were numbered from R1 to R5 clockwise around the test as seen in oral view. However, we believe the notation R1-R4 and R6 is a more accurate reflection of the homologies between the radials of the ancestral cheirocrinids and their descendants, and callocystitids.

Novacystis hawkesi gen. et sp. nov.

Plate 2.1, figures 1-6

Holotype. GSC 95812, the only known specimen.

Diagnosis. As for genus, which is monotypic.

Etymology. The species is named in honour of George J. Hawkes, who has contributed much to the knowledge of the echinodermata of the Lake Timiskaming region.

Occurrence. The only known specimen was collected by G.J. Hawkes from an isolated exposure of the Thornloe Formation (Lower Silurian) on Evanturel Creek, 3 miles (5 km) south of the road between Heaslip and Kap-Kig-Iwan Provincial Park, approximately latitude 47°48′N, longitude 79°53′W, south of Englehart, northern Ontario. Its exact stratigraphic position within the Thornloe Formation is uncertain. On projection, the cystid-bearing beds appear to be located in the same lower level as the *Protaxocrinus*-bearing second faunal assemblage beds of Mann Island (Bolton and Copeland, 1972, p. 9, Fig. 2), late Llandovery in age.

Description. Theca: oval to subquadrate in outline, slightly wider above than below, approximately 20 mm high by 15 mm diameter, with five short ambulacra extending down the upper third of the theca and not reaching the level of the midlateral periproct.

Plates: arranged as in Figure 2.1A. Visible plates are B1, B4, and one edge of B2; IL1, IL4, and IL5; L1, L4, and L5; R4, R6, and the edge of R1; O1, O5, O6, and O7. Although the complete arrangement cannot be seen, it is fairly certain the basal and infralateral circlets are closed, whereas the lateral circlet is interrupted by R4 and the radial circlet by L5. Plates are weathered but the surface ornament was probably originally malleated. The weathering reveals thin growth lines at the periphery of some plates.

Rhombs: only L1:R6 is visible. X-rays of the slab failed to reveal other details, including the number of pectinirhombs. L1:R6 has a depressed angular outline (Figure 2.1B), is 9.0 mm wide by 5.0 mm long, and has 30 dichopores. The half-rhomb in L1 has a complete raised vestibule rim, although it is somewhat abraded, with slits reaching only 0.8 mm maximum length centrally. The other half-rhomb has a weakly developed outer rim only, and longer slits that reach up to 1.25 mm

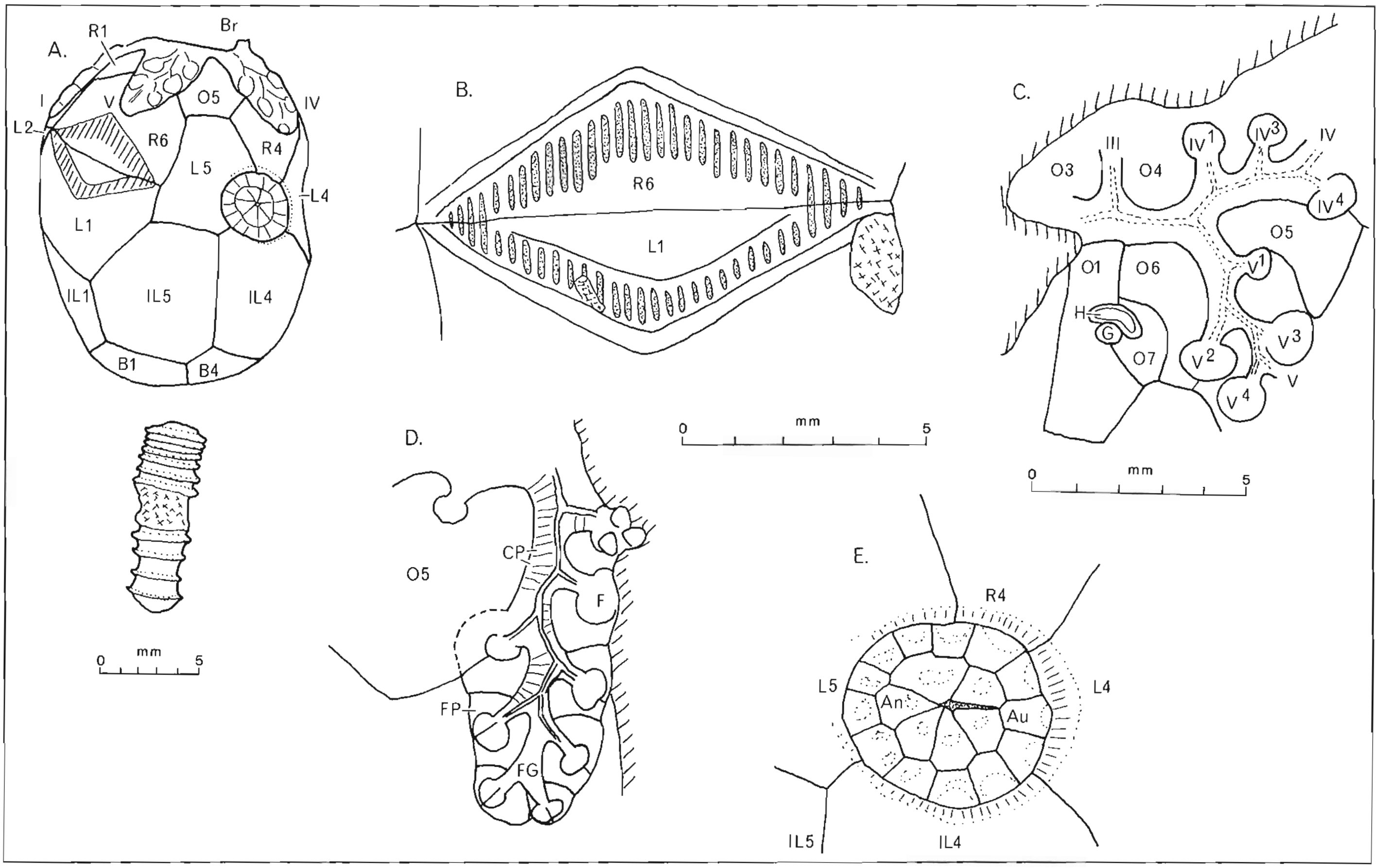

Figure 2.1. Camera lucida drawings of ***Novacystis hawkesi*** *gen. et sp. nov.* ***A****, general view of theca and stem as preserved to show ambulacra, thecal plate arrangement, pectinirhomb and periproct.* ***B****, detail of pectrinirhomb L1:R6. Dichopore slits stippled. Currents entered slits in L1 and exited from those in R6.* ***C****, detail of oral area to show ambulacra III, IV, and V, gonopore and hydropore. Double broken line traces the crest of the ambulacral cover plates.* ***D****, detail of ambulacrum IV. Double line traces crest of ambulacral cover plates.* ***E****, detail of periproct. Dots indicate surface sculpture, lines the periproct rim. Left scale applies to A, middle scale to B, D, and E, right scale to C. In C and D matrix is hatched.*

Symbols: *Roman numerals I, III, IV, and V, ambulacra; IV^1, V^2 etc., brachiole facets (note that IV^2 is not developed). An, anals; Au, auxiliaries; B1, B4, basals; Br, fragment of brachiole; CP, ambulacral cover plate; F, brachiole facet; FG, food groove; FP, ambulacral flooring plate; G, gonopore; H, hydropore; IL1, IL4, IL5, infralaterals; L1, L2, L4, L5, laterals; O1, O3-7, orals; R1, R4, R6, radials.*

centrally. Slit width is apparently constant at 0.10 mm in both half-rhombs. Slit spacing averages one slit per 0.25 mm (measured in R6). The total number of pectinirhombs remains unknown, but all other mid-Silurian or younger callocystitids have three, or rarely two.

Mouth: the oral opening is hidden beneath the cover plates at the confluence of the ambulacra (Figure 2.1C). Parts of three short ambulacra are visible and it is possible to see the food groove leading to a fourth, and the sediment-covered ridge where the fifth lies. Visible ambulacra are I, IV, and V, none of which extends below about two thirds of the thecal height. Ambulacrum I lies on plate R1 and reaches the level of the L1:R6 suture. Only the left side is well exposed and it has five brachiole facets. Ambulacrum IV (Figure 2.1D) reaches halfway down plate R4 and has nine brachiole facets. Facet IV^2 (the first on the right looking down the ambulacrum from the mouth toward the tip) is not developed, suggesting that *N. hawkesi* retains the ancestral arrangement, in which brachiole 2 in ambulacra I and IV are undeveloped. If so, ambulacrum I had eight or nine brachioles. Ambulacrum V reaches to just above the pectinirhomb on R6, and has five or six brachiole facets that alternate regularly. Directly opposite the hydropore and gonopore, a very short section of cover plating for ambulacrum III is visible before it disappears beneath the rock matrix. Adjacent to this is a ridge indicating where ambulacrum II lies. The exposed ambulacra reach 3 mm in width, with a central main food groove, 0.6 mm wide, which is covered with a single series of ornamented cover plates with a sharp-crested central ridge. Lateral branches of the food groove extend to brachiole facets, which are oval and about 0.9 mm across. A few brachiolar plates remain on one or two facets, but the nature of the brachioles is otherwise unknown.

Periproct: this is lateral, almost exactly at mid-height, rounded, and 4.3 mm wide by 4.0 mm high (Figure 2.1E). It is surrounded by IL4, L4, L5, and R4, covered by an anal pyramid and a complete circlet of auxiliaries. There are six geniculate anals forming a pyramid 2.6 mm wide by 2.4 mm high, and 13 ridged auxiliaries. The cover plates are set within a narrow sunken rim on the thecal plates.

Gonopore and hydropore: these lie across suture 01:07 as in all callocystitids (Figure 2.1C). The hydropore is slit-like, adoral to, and wrapped around the circular gonopore.

Stem: only about 10.5 mm of the distal stem remains associated with the theca. It tapers slightly from 3.2 mm maximum diameter proximally to 2.7 mm distally, and is composed of about 25 columnals. Distally, columnals alternate distinctly, with small, thin (0.4 mm high by 2.1 mm diameter) unflanged columnals set between thicker, larger (0.8 mm by 2.7 mm) flanged columnals. The flanges are sharp-edged and at most 0.25 mm thick. Proximally, the alternation of columnals is not obvious and the columnals are thinner. The preserved fragment of stem was approximately at the junction of the proximal and distal portions. Attachment, if any, is unknown.

Discussion. Despite all the thecal plates not being visible (X-rays provided no additional data), *Novacystis* has a thecal plating arrangement unique among callocystitid cystoids. Like *Novacystis*, most callocystitids have four plates around the periproct, but they are IL4, IL5, L4, and L5. No known callocystitid has a radial plate forming part of the periproct border. Equally, we know of only two specimens in which IL5 does not contribute to the periproct border. One is a teratological specimen of the Upper Ordovician apiocystitinid *Lepadocystis moorei*, in which plate IL5 was missing, and the other is the holotype of the Upper Devonian staurocystinid *Lipsanocystis traversensis* (see Paul, 1967b, Textfigs. 2, 5). There is nothing to suggest *N. hawkesi* is based on a teratological specimen, and hence it is attributed to a new genus.

Among Silurian callocystitids, only *Lovenicystis angelini* (Jaekel) from Gotland, Sweden (see Regnéll, 1945, p. 94), *Callocystites brevis* Frest and Paul, 1971 from Sandusky, Indiana, and an undescribed species close to *Tetracystis* from the Appalachians, have short ambulacra restricted to the upper part of the theca. Of these, only *C. brevis* has five ambulacra, but it has a distinctly different plate arrangement.

Ambulacrum III is the one that fails to develop in all callocystitids with only four ambulacra. Thus the clear evidence of the cover plates of ambulacrum III in the present specimen indicates that there are five ambulacra, even if no part of ambulacrum II is actually visible. Callocystitids with five ambulacra include *Lepadocystis* from the Upper Ordovician, *Brockocystis* and *Anartiocystis* from the Lower Silurian, and *Callocystites*, *Coelocystis*, and *Hallicystis* from the Upper Silurian. We suspect that *Coelocystis* should be included within *Callocystites*.

Apart from the plating around the periproct, *Novacystis* differs from all of the above genera in one or more respects. In having fewer pectinirhombs, *Novacystis* differs from *Lepadocystis*, which has five pore rhombs. *Brockocystis* has four pore rhombs, and apparently a closed radial as well as lateral plate circlets, and it has even shorter ambulacra, swollen hollow thecal plates, and a modified stem. *Callocystites* and *Hallicystis* have long ambulacra, which sometimes branch in the former; three smaller rounded pectinirhombs; the lateral plate circlet opens in a different manner; and, in *Callocystites*, an open infralateral circlet. *Anartiocystis* is possibly closest, but has a closed lateral circlet and, in the holotype, three long ambulacra that reach down to the infralateral circlet. They include ambulacra I and V, which are clearly short in *Novacystis*.

We suggest that *Lepadocystis* gave rise to both *Brockocystis* and *Anartiocystis* and that the former was a specialized offshoot. *Anartiocystis* probably gave rise to *Novacystis*, because R4 penetrates quite deeply between L4 and L5 as seen in Ausich and Schumacher (1984, Fig. 2). *Novacystis*, in turn, may have led to *Hallicystis* and *Callocystites*. This suggests that the subfamily Callocystitinae is a monophyletic group with modified thecal plating arrangements producing interrupted plate circlets as a synapomorphy defining it. The angular pectinirhombs suggest *Novacystis* has affinities with *Lepadocystis* and *Anartiocystis*, rather than *Hallicystis* and *Callocystites*. Hence, it may well be the least specialized member of the subfamily, which contains only the three genera *Novacystis*, *Hallicystis*, and *Callocystites* (including *Coelocystis*).

PALEOECOLOGY

The occurrence of the specimen on a slab of rock enables something to be deduced about the environment of deposition. Since the specimen is still largely articulated, it is unlikely that it was transported far before burial and hence inferences about the depositional environment are probably relevant to the living conditions of the cystoid. However, the fossil lacks most of the brachioles and apparently the distal portion of the distal stem. From the position of the remaining fragment of stem, we infer that the proximal stem was originally preserved but has been lost. The uppermost part of the remaining fragment of stem has been glued back onto the slab. Preparation of the oral area also enabled us to confirm that the lack of most of the brachioles is a primary preservational feature and not due to recent erosion. Therefore, we do not think the specimen is preserved exactly where it lived.

The rock slab is of a laminated silt/fine-sand-grade limestone showing evidence of much horizontal burrowing activity. A specimen of *Chondrites*, a trace fossil burrow in hyporelief, shows clearly on the opposite side of the slab to the one on which the cystoid is preserved. This opposite side is presumed to be the underside, and the one with the cystoid the topside, as is evident from the laminae troughing and crossbedding.

Burrows of other morphology are also present and most have obviously been compressed and are filled with a coarser bioclastic sediment. The edges of the slab show the interruption of fine laminations by lenticular structures, many of which are clearly burrow fills, and others undulating over the traces. Burrow fills commonly have a width to height ratio of 2 or 3:1, suggesting that if they were originally circular in cross-section, there has been significant postdepositional compaction. Both surfaces of the slab undulate, but the slab is too small to be certain of the precise morphology of the bedforms. Several eroded laminae on the top surface reveal minute, dark coloured, organic flakes, but their exact nature is uncertain.

We infer that the original sediment was relatively soft, deposited under current activity, and would not have provided a firm surface to which a cystoid could cement its stem. As cementation to hard surfaces was the normal means of attachment for callocystitids, we infer either that *Novacystis* had a detached distal stem, as *Lepocrinites* had, for example, or again that it did not live where it was buried. From the general nature of the slab, we suspect it was deposited rapidly under high energy conditions and that the cystoid was detached from its substrate and smothered. Although alternative interpretations are possible, this one accounts for the slight incompleteness of the specimen as well as the fact that the remains are remarkably well articulated.

ACKNOWLEDGMENTS

We wish to thank George J. Hawkes, the original finder, for allowing us to describe this remarkable specimen, and Mrs. Chappell, Small Animal Hospital, Liverpool, for taking X-rays of the specimen. Critical reviews of the manuscript were provided by T.W. Broadhead (University of Tennessee) and B.S. Norford (Geological Survey of Canada).

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PLATE 2.1

PLATE 2.1

Figures 1-6. *Novacystis hawkesi* gen. et sp. nov.

Holotype GSC 95812, Thornloe Formation, Evanturel Creek, Lake Timiskaming region, Ontario.

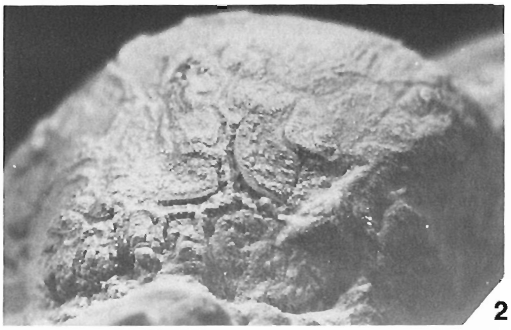
1, 4. Theca turned to display thecal plates, ambulacra I and V, and pectinirhomb, x4, x2.

2, 6. Oral views showing ambulacra, x4.

3. General view of theca and stem showing pectinirhomb and periproct, x2.

5. Side view of theca showing periproct, x4.


1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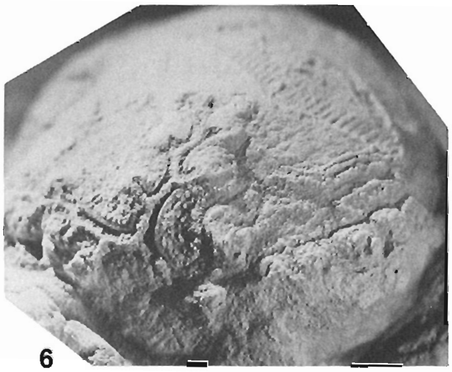
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MIDDLE DEVONIAN GONIATITES FROM THE DUNEDIN AND BESA RIVER FORMATIONS OF NORTHEASTERN BRITISH COLUMBIA

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Abstract

The stratigraphy and faunas of two new occurrences of Middle Devonian goniatites in the Dunedin and Besa River formations of northeastern British Columbia are described. Coeval stratigraphic units and other Devonian goniatite occurrences are reviewed for the belt of rocks extending from Tuchodi Lakes in the Rocky Mountains of northeastern British Columbia to the Anderson River area of the lower Mackenzie Valley, a distance of about 1000 km.

The new goniatite fauna from the upper part of the Dunedin Formation includes *Pinacites jugleri* (Roemer), *Foordites* sp. cf. *F. platypleura* (Frech) and *Foordites* sp. aff. *F. djemeli* (Petter). These are placed in the *Pinacites jugleri* Zone of Eifelian age. This is the second record of the name bearer of this zone in North America. Associated conodonts are placed in the *costatus* Zone.

The new goniatite fauna from the lower part of the Besa River Formation includes *Foordites* sp., *Agoniatites obliquus* (Whidborne), *Maenioceras terebratum* (Sandberger, G. and Sandberger, F.), and subspecies *M. terebratum tenue* (Holzapfel), and *M. t. decheni* (Beyrich). These are part of the *Maenioceras terebratum* Zone of Givetian age. Associated conodonts are assigned to the Middle *varcus* Subzone.

Résumé

Les auteurs décrivent la stratigraphie et les faunes caractérisant deux nouvelles occurrences de goniatites du Dévonien moyen dans les formations de Dunedin et de Besa River, situées dans le nord-est de la Colombie-Britannique. Ils examinent les unités stratigraphiques contemporaines et d'autres occurrences de goniatites du Dévonien, dans la zone lithostratigraphique allant des lacs Tuchodi dans les Rocheuses du nord-est de la Colombie-Britannique, jusqu'à la région de la rivière Anderson dans la basse-vallée du Mackenzie, c'est-à-dire sur une distance d'environ 1000 km.

La nouvelle faune de goniatites provenant de la partie supérieure de la Formation de Dunedin comprend *Pinacites jugleri* (Roemer), *Foordites* sp. cf. *F. platypleura* (Frech) et *Foordites* sp. aff. *F. djemeli* (Petter). Celles-ci sont placées dans la Zone à *Pinacites jugleri* d'âge eifélien. Il s'agit de la seconde fois que l'on note dans la stratigraphie l'espèce qui donne son nom à cette zone en Amérique du Nord. Les conodontes associés sont placés dans la Zone à *costatus*.

La nouvelle faune de goniatites provenant de la partie inférieure de la Formation de Besa River comprend *Foordites* sp., *Agoniatites obliquus* (Whidborne), *Maenioceras terebratum* (Sandberger, G. et Sandberger, F.) et les sous-espèces *M. terebratum tenue* (Holzapfel), et *M. t. decheni* (Beyrich). Elles font partie de la Zone à *Maenioceras terebratum* d'âge givétien. Les conodontes associés sont attribués à la Sous-zone intermédiaire à *varcus*.

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INTRODUCTION

This report describes two new Middle Devonian goniatite faunas from northeastern British Columbia, which were collected from the upper part of the Dunedin Formation and the lower part of the Besa River Formation. The stratigraphy and biostratigraphy of these occurrences are compared to those of other Devonian sequences in the northwestern part of the Western Canada Sedimentary Basin.

The two new faunas, representing the *Pinacites jugleri* and *Maenioceras terebratum* zones, are of interest because of their abundance in Europe and North Africa, but paucity in North America (House, 1979, p. 269-271). Their presence in Western Canada suggests a linkage, by warm equatorial currents, of this area with Europe and North Africa, which formed a part of the Old World Faunal Realm during the Middle Devonian (Heckel and Witzke, 1979, p. 114, 115, Fig. 5).

Location

The goniatite fauna from the Dunedin Formation is located on Mount Halkett at 59°35′N, 126°10′W (NTS 94 M), immediately north of the Alaska Highway and near the northern boundary of British Columbia, about 165 miles (264 km) northwest of Fort Nelson (GSC loc. C-164631). The goniatite fauna from the Besa River Formation is located on the north bank of Chischa River at 58°25′N, 124°27′W, Tuchodi Lakes map-area (NTS 94 K), about 65 miles (104 km) southwest of Fort Nelson and the Alaska Highway in northeastern British Columbia (GSC loc. C-104630). These occurrences are marked by large solid triangles on the index map (Fig. 3.1) and on the cross-sections (Figs. 3.4, 3.5).

Responsibilities

The goniatites and associated faunas were collected by the senior author (U.F.G.W.) in 1961, while he was engaged in geological field work for Union Oil Company of California, the Canadian subsidiary of which is now named Unocal Canada. Preliminary results on the goniatite faunas were presented by Wissner (1987, p. 247) at the Second International Symposium on the Devonian System, in Calgary, Alberta, August 17-20, 1987. The present report is a summary and revision of an internal report on the goniatites prepared by the senior author for the Geological Survey of Canada. The junior author (A.W.N) acted as the Scientific Authority for Energy, Mines and Resources in facilitating the preparation of the original report, and contributed information on stratigraphy and biostratigraphy and coordinated the results of this final report.

STRATIGRAPHY

The goniatite occurrences are spot localities in the Dunedin and Besa River formations that can be easily tied in with the well exposed outcrop sections. The generalized stratigraphy of Devonian strata in northeastern British Columbia, northwestern Alberta, and the Northwest Territories is shown in the regional geological cross-sections of Figures 3.4 and 3.5. These figures illustrate the main rock units, their gross lithology, thickness variations, and approximate correlations.

Dunedin Formation

The name Dunedin Formation was introduced by Taylor and MacKenzie (1970, p. 12-16) to apply to a "uniform sequence of argillaceous and, in places siliceous and dolomitic, dark grey, bedded limestones" that overlies light grey dolomite of the Stone Formation and underlies dark grey shale of the Besa River Formation in northeastern British Columbia. They (Taylor and MacKenzie, 1970, p. 12) designated as type section the exposure in One Ten Creek (58°41′N, 124°48′W), a small stream that flows south from Mount St. Paul and crosses the Alaska Highway a short distance west of Mile 398.

The main outcrops of the Dunedin Formation are within a narrow belt that extends for about 230 miles (370 km) between Halfway River in the south and Caribou Range in the north. The formation is 781 ft. (238 m) thick in the type section and reaches a maximum of 1260 ft. (384 m) in the Sentinel Range to the west. West of the outcrop belt and west and north of Caribou Range, the Dunedin Formation grades within a short distance to shale of the Besa River Formation (Morrow, 1978, Fig. 2, p. 2).

The Dunedin Formation can be divided into two lithofacies: a lower dolomitic wackestone facies, and an upper grainstone–wackestone facies (Morrow, 1978). The dolomitic wackestone facies forms the lower third of the formation and is composed of dolomitic peritidal carbonate deposits. In outcrop sections, this facies is relatively thin bedded, recessive, and light grey in colour. The upper grainstone–wackestone facies forms the upper two thirds throughout most of the Dunedin Formation. It consists of thick bedded to massive, resistant, finely crystalline, dark grey limestone.

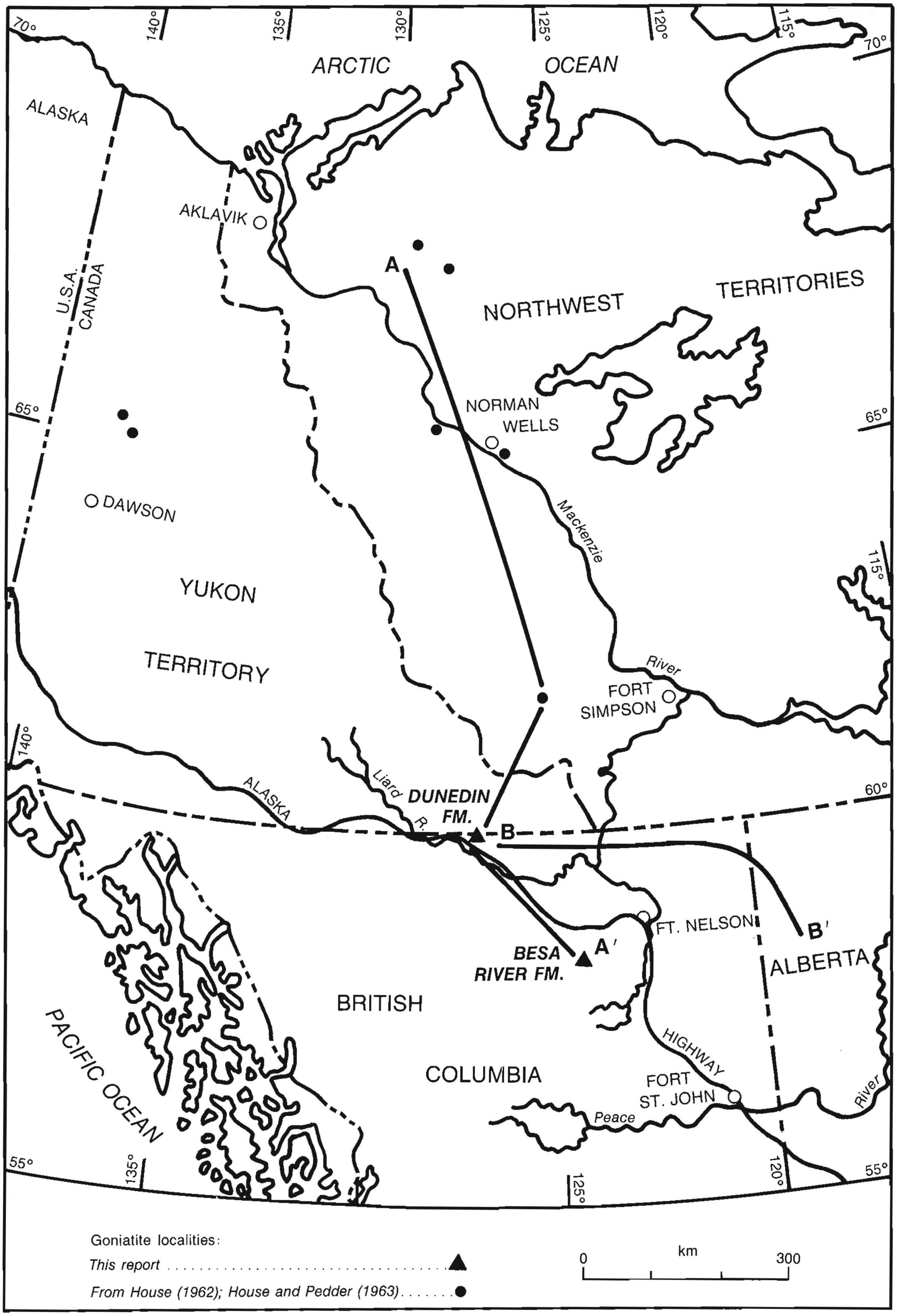
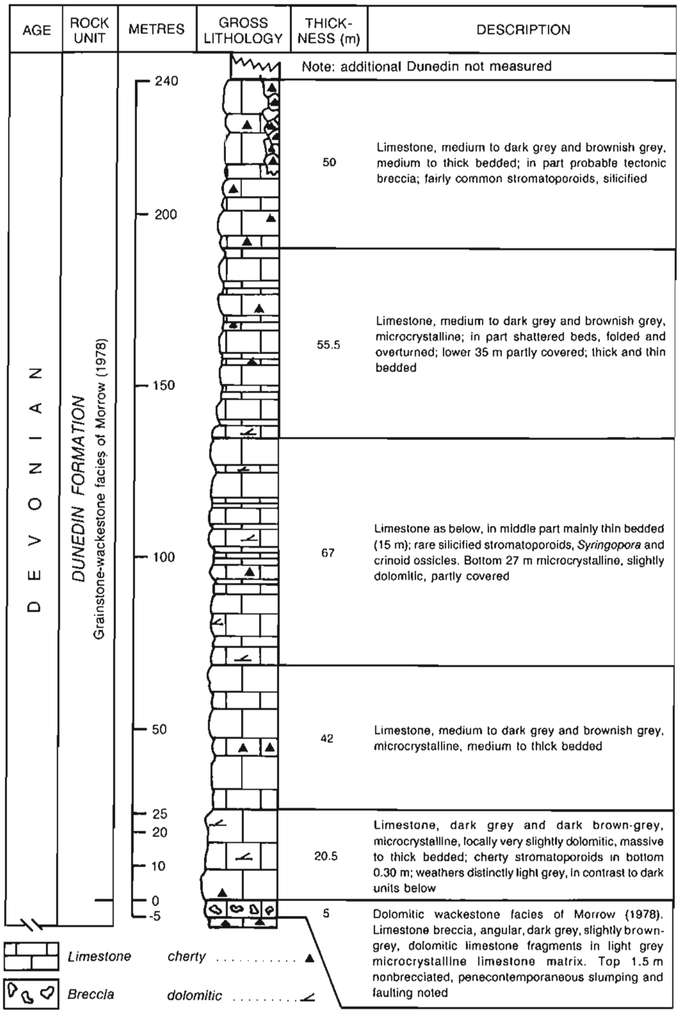


Figure 3.1. Index map of the study area, showing goniatite localities and cross-sections B–B′ (Fig. 3.4) and A–A′ (Fig. 3.5).

The large ostracode, *Moelleritia canadensis* Copeland, occurs in the lower beds of the Dunedin Formation and indicates an Emsian age. The base of the formation is assumed to be about the same age throughout the area. In contrast, the top of the Dunedin Formation is highly diachronous, varying from the *Eoschuchertella adoceta* Zone in the north, to the *Leiorhynchus* sp. cf. *L. castanea* fauna in the south. *Stringocephalus* sp. has been collected from near the top of the formation at a few localities.

The goniatite fauna from the Dunedin Formation was collected from the top of Mount Halkett. The collection was made on a spot check while mapping areally by helicopter. The closest measured section (Fig. 3.2) is located near Mile 474 on the Alaska Highway and shows a measured thickness of 240 m for the Dunedin, but the uppermost part of the formation was not measured. From regional control, about 30 m of additional section are expected at this section. Ferguson and Noble (1968), Taylor and Stott (1973, p. 20), and others have pointed out that tuberous nodules and thin irregular beds of black chert are common in the upper 60 m or so of the Dunedin Formation. On the other hand, the common occurrence of chert has never been observed in the approximately equivalent Nahanni Formation to the north. This, along with other criteria, suggests that the Dunedin Formation is a distinct, mappable unit.



Note: additional Dunedin not measured

THICK-NESS (m)	DESCRIPTION
50	Limestone, medium to dark grey and brownish grey, medium to thick bedded; in part probable tectonic breccia; fairly common stromatoporoids, silicified
55.5	Limestone, medium to dark grey and brownish grey, microcrystalline; in part shattered beds, folded and overturned; lower 35 m partly covered; thick and thin bedded
67	Limestone as below, in middle part mainly thin bedded (15 m); rare silicified stromatoporoids, *Syringopora* and crinoid ossicles. Bottom 27 m microcrystalline, slightly dolomitic, partly covered
42	Limestone, medium to dark grey and brownish grey, microcrystalline, medium to thick bedded
20.5	Limestone, dark grey and dark brown-grey, microcrystalline, locally very slightly dolomitic, massive to thick bedded; cherty stromatoporoids in bottom 0.30 m; weathers distinctly light grey, in contrast to dark units below
5	Dolomitic wackestone facies of Morrow (1978). Limestone breccia, angular, dark grey, slightly brown-grey, dolomitic limestone fragments in light grey microcrystalline limestone matrix. Top 1.5 m nonbrecciated, penecontemporaneous slumping and faulting noted

Figure 3.2. *Surface section of the Dunedin Formation. Location: first ridge, northeast of milepost 474, Alaska Highway, approximately 59°14′N, 125°46′ W, NTS 94 N, British Columbia.*

The fossils came from two types of host rock: 1) dark grey, micro- to very finely crystalline, very homogeneous limestone, probably medium to thickly bedded; and 2) medium grey, microcrystalline, shaly limestone, platy to very thinly bedded.

The goniatites from the shaly limestone are flattened, crushed, and deformed, most probably by compaction. No chert was observed, and not even a trace of silicification is present in any of the fossils. As indicated above, this strongly suggests that the goniatite fauna occurs at least 60 m below the top of the Dunedin Formation.

Besa River Formation

The Besa River Formation was defined by Kidd (1962, 1964) as: "The thick black shale sequence which is present in northeast British Columbia foothills and mountains, lying between Mississippian cherty limestones and Middle Devonian carbonates." The type section proposed by Kidd is located four miles north of Muskwa River at approximately 57°56′30″N, 123°43′00″W, where the formation is estimated to be about 3000 ft. (914.4 m) thick, and where the lower 300 ft. (91.4 m) of the formation is covered. The Besa River Formation (Kidd, 1962, p. 99) consists almost entirely of shale, dark grey to black, thin bedded to fissile, varying from slightly calcareous to noncalcareous. Black chert and pyrite are scattered throughout the section, and siltstone and thin beds of limestone occur in places near the top. In the type area, the lower Besa River Formation is in sharp contact with dark grey carbonate of the Dunedin Formation. These underlying carbonates are exposed on the upper reaches of Besa River and at Kluachesi Mountain (57°59′30″N, 124°06′30″W). In the type area, the top of the Besa River Formation is marked by the base of the first massive limestone of the overlying Prophet Formation. This contact is gradational and assumed to be diachronous from place to place.

Pelzer (1966) in his detailed study of the Besa River Formation showed some of the complexities of facies and thickness changes within the formation. For example, in the Summit Lake area, about 55 miles (88 km) northwest of the type section, the black shale, which is the obvious correlative, is only 1000 ft. (305 m) thick, and is overlain not by Mississippian cherty limestone but by an unnamed silt, shale, and sandstone unit. The Pan American Beaver River A-1 exploratory test well (about 59°58′N, 124°17′W), just south of the Yukon border, encountered a total of 7400 ft. (2256 m) of black shale, overlain by sandstone rather than limestone.

The age range of the Besa River Formation is variable. Where the strata are thickest, in the sections lying farthest west, the formation ranges from basal Givetian of the Devonian to Chesterian of the Mississippian, and thus covers a longer time span than has been indicated for the type section. The base of the formation is marked over most of the area by a carbonate unit named the Dunedin Formation by Taylor and MacKenzie (1970). Younger shelf carbonates including the Pine Point, Sulphur Point, and Slave Point formations appear south and east of the type Besa River area (Morrow, 1978, Fig. 3, p. 3). The top of the Besa River Formation is also variable in stratigraphic position, and may be taken at the base of the Prophet Limestone, or in the absence of that formation, at the base of the Mattson Formation, which marks the onset of coarse clastic deposition at a level within the Chesterian (Pelzer, 1966, p. 317).

Three prominent markers occur within the Besa River Formation. These correspond to the top of the Shunda Formation, the Exshaw Formation, and the Muskwa Member of the Horn River Formation, respectively. These markers serve to divide the Besa River into approximately Upper Mississippian, Lower Mississippian, and Upper Devonian Series plus the Givetian Stage of the Middle Devonian.

Fossils reported by Kidd (1962, p. 101) from the type locality (57°56′30″N, 123°43′00″W) of the Besa River Formation include *Cyrtospirifer thalattodoxa* Crickmay from 2000 ft. (610 m) below the upper contact, indicating a Frasnian (upper Hay River) age; and *Platyrachella rutherfordi* (Warren) from 800 ft. (244 m) below the upper contact, indicating a Kinderhook (lower Banff) age.

From about 1500 ft. (457 m) above the base of a section that outcrops near Nabesche River, north of Peace River, at approximately 56°19′N, 123°25′W and 56°18′N, 123°32′W, Kidd (1962, p. 101) reported *Eleutherokomma* sp. cf. *E. leducensis, Devonoproductus vulgaris,* and *Leiorhynchus* sp. cf. *L. athabaskensis*, which indicate a Frasnian age.

Lower *asymmetrica* Zone conodonts were reported by Taylor and MacKenzie (1970, p. 17) from 17 m above the base of the Besa River Formation from a section 16 km northwest of One Ten Creek. From a section near Robb Lake (56°56′N, 123°46′W), conodonts of the Lowermost or Lower *asymmetrica* Zone have been recovered from 20 m above the base of the formation (Braun et al., 1989). These datings suggest that the beds 17 to 20 m above the base of Besa River at the two localities are equivalent to the Canol Shale of the north, or the Muskwa Shale of the subsurface. These datings also suggest that the Horn River Shale overlying the Dunedin Formation and underlying the Muskwa Shale is, in places, very thin or possibly missing.

The goniatites described in this report from the lower 10 m of the Besa River Formation are Givetian in age. This is one of the very few occurrences where a lower, thin part of the Besa River Formation has been positively dated as Middle Devonian. Pelzer (1966, p. 303, Fig. 12) has suggested that the abrupt thinning of the Givetian part of the Besa River Formation can be explained in terms of the undathem–clinothem–fondothem model of

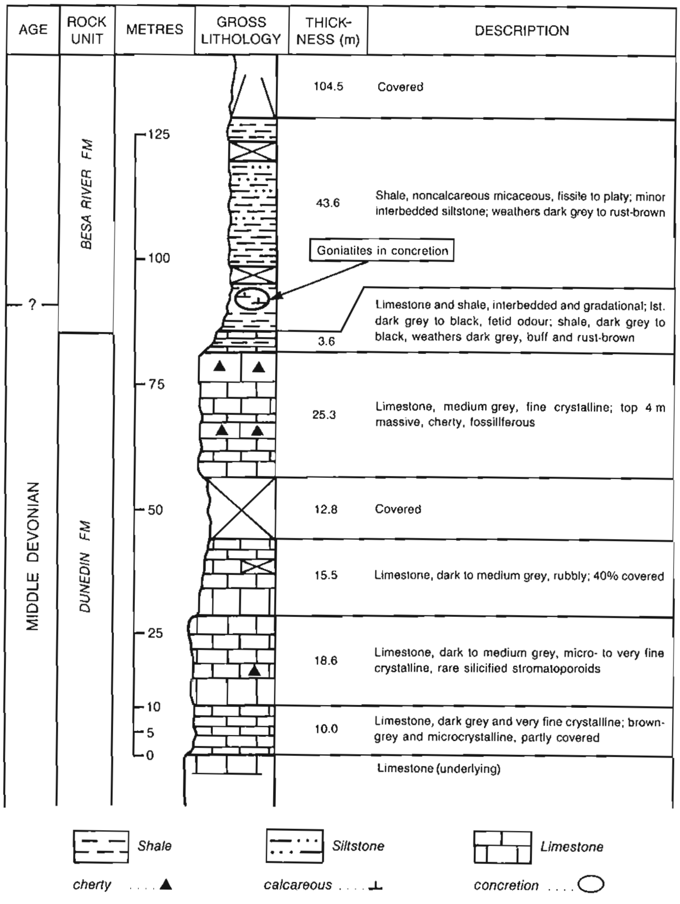


Figure 3.3. *Surface section of the Besa River Formation. Location: north bank of the Chischa River, 58°25′N, 124°20′W, NTS 94 K, Tuchodi Lakes, northeastern British Columbia.*

basin infill described by Rich (1951). The thin Givetian sequence would be represented by the bottom, fondothem deposits.

The Middle Devonian goniatite and other faunas, lithology, and stratigraphic position in the lower 10 m of the Besa River Formation suggest a correlation with the Evie Member of the Horn River Formation of Gray and Kassube (1963), to the east in northeastern British Columbia (Fig. 3.4).

Loose goniatites were originally found in 1961 on the north bank of Chischa River and traced upstream to their origin at 58°25′N, 124°20′W, in a large concretion, about 10 m above the base of the Besa River Formation (Fig. 3.3). A gradational unit of interbedded shale and limestone, about 10 m thick in this area, is included in the Dunedin Formation, as shown in the surface section of Figure 3.3. This contact relationship is somewhat similar to that of the Hume Formation overlain by the Bluefish Member of the Hare Indian Formation in the Mackenzie Plains and Mountains to the north.

Leiorhynchus castanea (Meek) and other fossils were reported by Hughes (1963, p. 4, 5) from the transitional beds at the top of the Dunedin Formation, from a section near the Racing River bridge at approximately 58°44′N, 125°08′W. To the north, *L. castanea* commonly occurs abundantly in transitional beds between the Hume and Hare Indian formations.

Comments on Devonian rocks between northeastern British Columbia and northwestern Alberta

The west to east cross-section B–B′ (Fig. 3.1) of Devonian rocks between northeastern British Columbia and northwestern Alberta is shown in Figure 3.4. The datum for this cross-section is the top of the limestone of the Dunedin Formation in the west, and the top of the

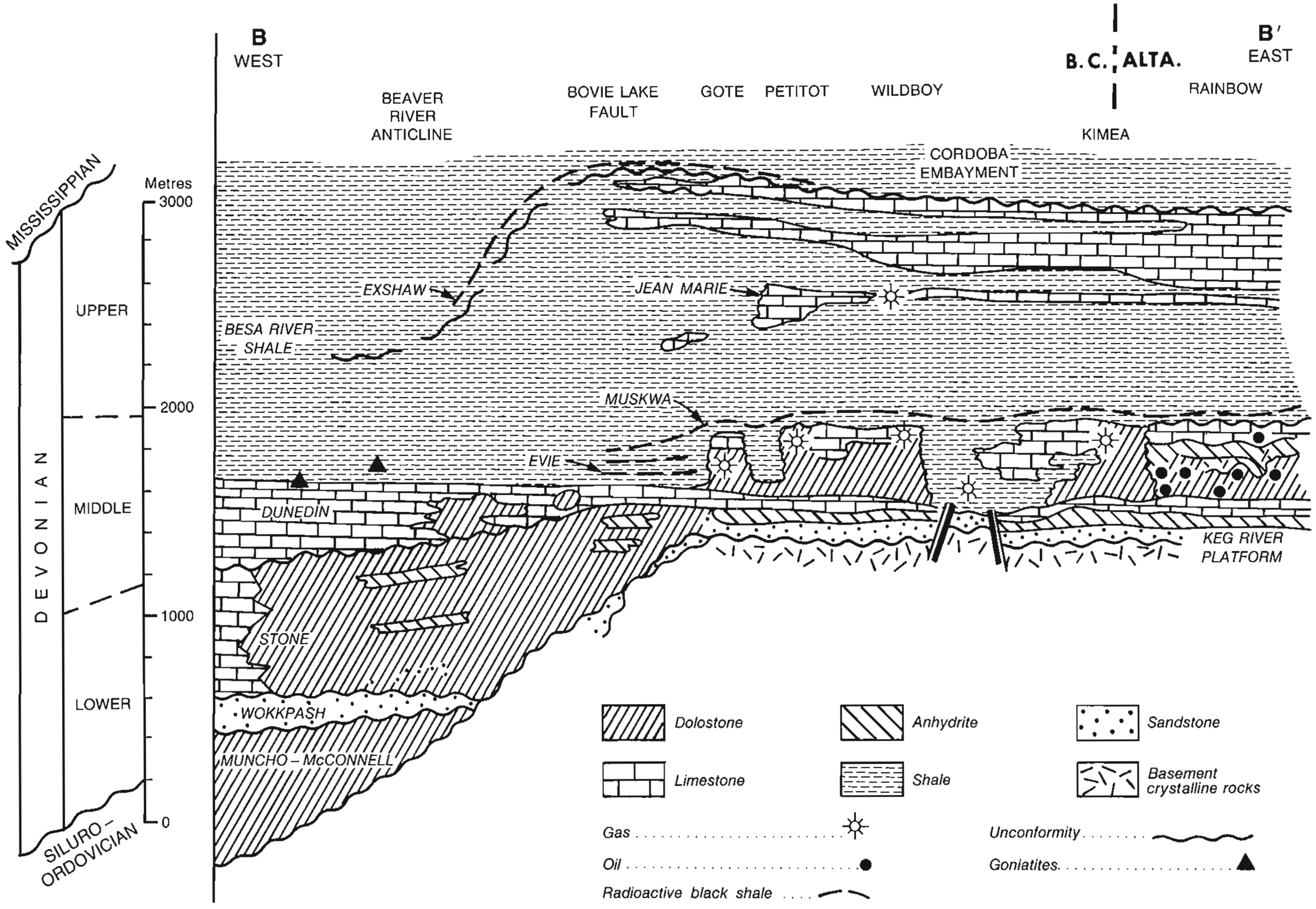


Figure 3.4. Regional west to east (B–B′) cross-section of Devonian rocks between northeastern British Columbia and northwestern Alberta.

limestone of the lower Keg River Formation in the east. The contact between the Dunedin and Besa River formations is highly diachronous. The lower Keg River is a widespread and rather uniform rock unit of bedded limestone. There are very few examples of partial to complete change of this limestone unit to shale, or of dolomitization of local organic reef and/or bank developments.

The tectonic displacement of the horst block in the Cordoba Embayment is definitely post-Chinchaga Formation and most likely post-Lower Keg River Formation. This tectonic activity was probably also responsible for the diachronous contact between the Dunedin and Besa River formations.

The most conspicuous surface and subsurface feature is the Bovie Lake Fault, a wrench fault with up to 1500 m of vertical displacement. It has important tectonostratigraphic implications throughout a large part of the geological history of the area, in addition to its major movement in the Permo-Pennsylvanian. The general north–south trend of this fault coincides with the marked change in thickness of the combined Stone and Dunedin formations from about 1500 m in the west to 500 m in the east. But, in a wider sense, the combined thickness of the Stone and Dunedin formations, which together with Siluro-Ordovician strata is at least 2000 m thick, changes over a distance of about 25 km to about 200 m. This thickness change also marks the trend in the area to reef development in the Givetian. The reefs, which are important reservoirs for gas and oil, are present in the Keg River Formation and its stratigraphic equivalents, up to and including the Slave Point Formation. Organic reefs of various types are present on the east side of this dividing feature, and are absent in the shale basin to the west.

Comments on Devonian rocks between northeastern British Columbia and lower Mackenzie Valley area

The north to south cross-section A–A′ (Fig. 3.1) of Devonian rocks between the Carnwath River area of the lower Mackenzie Valley and northeastern British Columbia is shown in Figure 3.5. The tops of the regionally widespread Middle Devonian carbonates of the Hume Formation, and its approximate equivalents, the

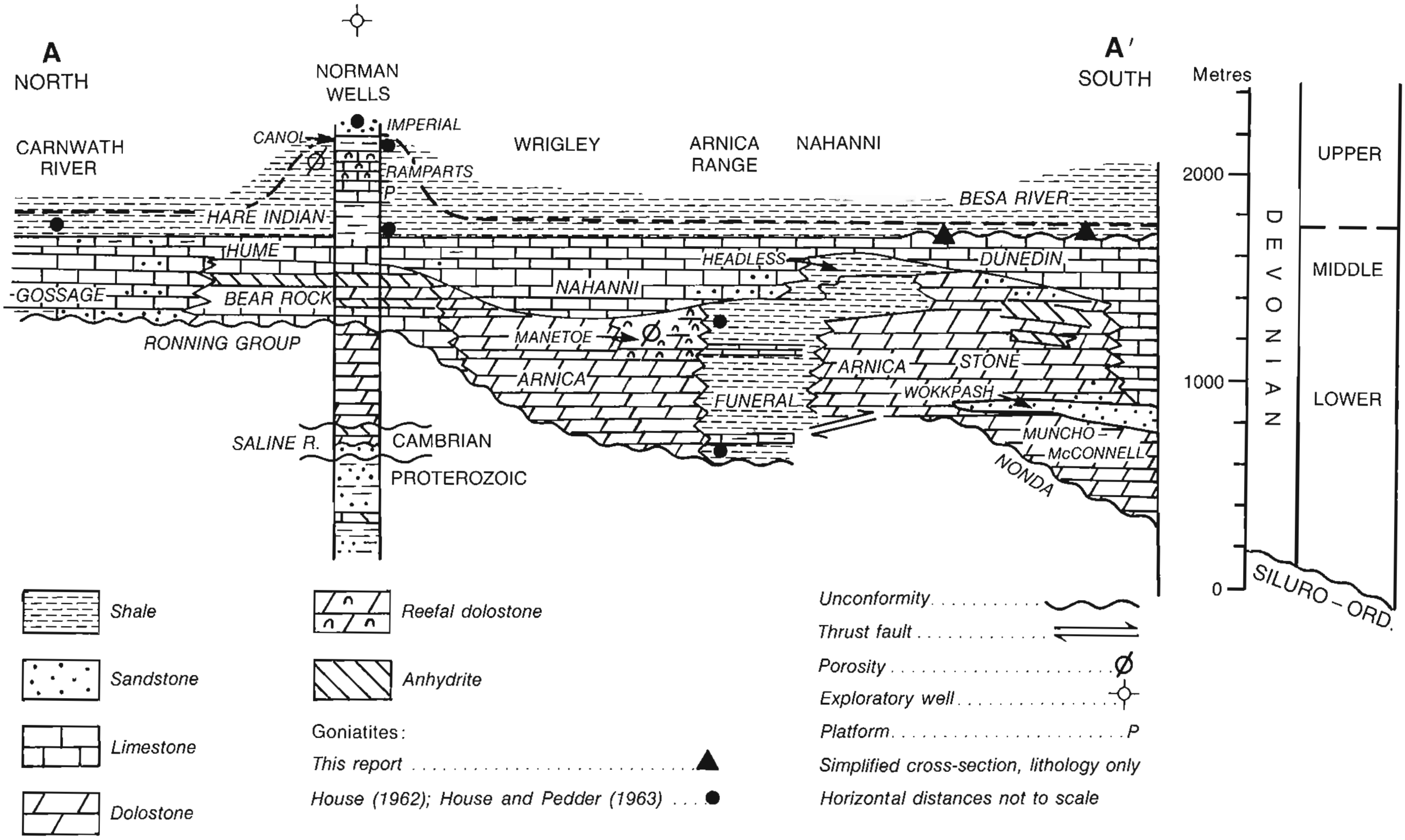


Figure 3.5. Regional north to south (A–A′) cross-section of Devonian rocks between the lower Mackenzie Valley area and northeastern British Columbia.

Nahanni and Dunedin formations, are chosen as key marker levels. With the exception of the Norman Wells area, these units represent the youngest Middle Devonian carbonates. These carbonates are overlain by shale of the Hare Indian, Horn River, and Besa River formations, and equivalent clastic rocks.

The section in the Carnwath River area shows the relatively uniform facies and thickness distribution of a cratonic-type, stable, shallow shelf environment. The section in the Norman Wells area marks the approach to the mobile, unstable shelf to open marine basin transition zone of the inner Mackenzie Mountains. Between the Norman Wells and Wrigley areas there is a marked increase in thickness of sections, and this trend is continued to a lesser degree in the Tuchodi Lakes area of northeastern British Columbia. Between Wrigley and Tuchodi Lakes, the rock units below the Nahanni and Dunedin formations undergo rapid and pronounced facies changes from limestone to shale, dolostone, anhydrite, and evaporitic carbonate, which are more or less perpendicular to the tectonostratigraphic strike of the cross-section. These facies changes are of prime importance and interest for economic geology, especially with respect to reef development and potential reservoirs for hydrocarbons.

The Middle-Upper Devonian boundary in the Norman Wells area is at the base of, or within, the Canol Formation. In the Tuchodi Lakes area of northeastern British Columbia the boundary is at the base of, or within, the Muskwa Member of the Horn River Formation (Braun et al., 1989). In Figure 3.5, this boundary is approximately marked by the dashed line.

BIOSTRATIGRAPHY

In this report, Lower, Middle, and Upper Devonian are used in the sense recommended by the Subcommission on Devonian Stratigraphy (Ziegler and Klapper, 1985). The Subcommission has recommended that the base of the Middle Devonian be defined by the base of the *partitus* conodont Zone. For the base of the Upper Devonian, the lower limit of the Lower *asymmetrica* conodont Zone was chosen. The goniatites *Foordites occultus* and *Pinacites jugleri* are postulated as first appearing in the *partitus* conodont Zone (Ziegler and Klapper, 1985, p. 106). The goniatite genera *Koenenites, Probeloceras*, and *Manticoceras* first appear in the Lower *asymmetrica* conodont Zone (ibid., p. 107).

Dunedin Formation

The absence of chert in the matrix of the goniatite samples from the Dunedin Formation strongly suggests that they were collected from a level at least 60 m below the top of the formation (GSC loc. C-164631). This new goniatite fauna includes *Pinacites jugleri* (Roemer), *Foordites* sp. cf. *F. platypleura* (Frech), and *Foordites* sp. aff. *F. djemeli* (Petter). The presence of the zonal index for the *Pinacites jugleri* Zone (Tables 3.1, 3.2), although based on a fragment, is the first record of this species in Canada, and the second record for North America. The only other record of this species in North America is that by House and Blodgett (1982) from beds of Eifelian age in west-central Alaska where it is associated with *Foordites* sp. cf. *F. platypleura* and ?*Subanarcestes* sp. In western Europe, the *Pinacites jugleri* Zone is marked by the entry of the genera *Pinacites, Sobolewia, Paraphyllites*, and *Foordites* (House, 1962, p. 250). *Pinacites* is known from the Harz Mountains, Rhenisches Schiefergebirge, and Barrandian of Europe; from Morocco and (?)Mauritania of North Africa; and from Turkey and South China (Chlupáč and Turek, 1983, p. 59).

The matrix of the goniatite samples yielded the following conodonts, determined by T.T. Uyeno (GSC Internal Report No. 2-TTU-88):

Belodella sp.
Eognathodus bipennatus (Bischoff and Ziegler)
Icriodus norfordi Chatterton
Neopanderodus sp.
Panderodus sp.
Pelekysgnathus sp.
Polygnathus sp. indet. (small, fragmentary Pa)

These were assigned by Uyeno to the *costatus* Zone of early Eifelian age.

Associated megafossils, determined by A.W. Norris, include the following:

Lingula sp.
Phragmostrophia sp. (fragment)
Productella sp.
Trigonirhynchia sp. aff. *T. occidens* (Walcott) Perry, Klapper, and Lenz, 1974
Gasterocoma? *bicaula* Johnson and Lane, 1969
echinoderm ossicle with single axial canal
Dechenella (*Dechenella*) *maclareni* Ormiston, 1967
Nowakia sp. cf. *N. sulcata* (Roemer)

TABLE 3.1

Middle Devonian goniatite zones with immediately preceding and succeeding Lower and Upper Devonian zones and boundaries of stages (old and new)

SERIES		STAGE	MAJOR ZONES (STUFEN)	COMPILATION OF ZONES	OLD BOUNDARIES			ROCK UNIT; LOCAL OCCURRENCE
					STAGE	SERIES		
DEVONIAN	UPPER	FRASNIAN	*Manticoceras*	*Manticoceras cordatum*	FRASNIAN	UPPER	DEVONIAN	IMPERIAL FORMATION *Manticoceras cordiforme*
	MIDDLE	GIVETIAN	*Pharciceras*	*Pharciceras lunulicosta*				
			Maenioceras	*Maenioceras terebratum* *Maenioceras molarium* *Cabrieroceras crispiforme*	GIVETIAN	MIDDLE		BESA RIVER FORMATION *Maenioceras terebratum*
		EIFELIAN	*Pinacites*	*Pinacites jugleri*	EIFELIAN			DUNEDIN FORMATION *Pinacites jugleri*
	LOWER	EMSIAN	*Anarcestes* *Mimosphinctes*	*Anarcestes lateseptatus*				
					EMSIAN	LOWER		MICHELLE or ROAD RIVER FORMATION *Teicherticeras lenzi*

Several forms in this assemblage point to an early Eifelian age. The echinoderm ossicles with cross-like and dumbbell-shaped axial canals are assigned to *Gasterocoma*? *bicaula*. In northwestern and Arctic Canada, the highest occurrence of these forms is in the *costatus* conodont Zone (Norris, 1985, p. 24, Fig. 3). The presence of a tentaculitid resembling *Nowakia sulcata* suggests an approximate alignment with the *costatus* conodont Zone of Eifelian age (Lütke, 1979, p. 283, 285, Textfig. 1). *Dechenella* (*Dechenella*) *maclareni* is widely distributed in the Canadian Arctic Islands, and in the District of Mackenzie and Yukon Territory where it indicates an Eifelian age (Ormiston, *in* Norris, 1985, p. 26).

Besa River Formation

The goniatites collected from a large concretion about 10 m above the base of the Besa River Formation on the north bank of Chischa River (GSC loc. C-104630) include *Maenioceras terebratum terebratum* (Sandberger and Sandberger), *M. t. tenue* (Holzapfel), *M. t. decheni* (Beyrich), and *Foordites* sp. indet. These are typical forms of the *Maenioceras terebratum* Zone of Givetian age (Tables 3.1, 3.2). According to House (1968, p. 1062) the zone of *Maenioceras terebratum* is marked by *Wedekindella brilonense* and rare *Protornoceras* and *Aulotornoceras*, in addition to the zonal designate. The top of the zone is marked by the extinctions of *Maenioceras, Cabrieroceras, Agoniatites, Foordites, Wedekindella*, and *Sobolewia*.

Associated conodonts, determined by T.T. Uyeno (GSC Internal Report No. 2-TTU-88), from a sample submitted by A. W. Norris, include the following:

Polygnathus linguiformis linguiformis Hinde, gamma morphotype of Bultynck (1970) and zeta morphotype of Ziegler et al. (1976)
Polygnathus timorensis Klapper, Philip, and Jackson

Uyeno dated this fauna as Middle *varcus* Subzone to Lower *hermanni-cristatus* Subzone, Givetian.

Associated conodonts, determined by T.T. Uyeno (GSC Internal Report No. 2-TTU-88), from a sample submitted by W.W. Nassichuk, include the following:

Polygnathus sp. cf. *P. beckmanni* Bischoff and Ziegler
Polygnathus linguiformis linguiformis Hinde, gamma morphotype of Bultynck (1970) and zeta morphotype of Ziegler et al. (1976)
Polygnathus timorensis Klapper, Philip, and Jackson

Uyeno commented that *P. beckmanni* has its upper range in the Middle *varcus* Subzone (Klapper, *in* Klapper and Johnson, 1980). If this fragmentary specimen can be unquestionably assigned to that species, the age is Middle *varcus* Subzone.

Associated megafossils, examined by A.W. Norris, include the following:

cf. *Lingula* sp.
cf. *Buchiola speciosa* (Hall)
indet. spirally coiled gastropod
indet. planispiral gastropod
Metastyliolina sp.
Styliolina sp.
Viriatella sp.
echinoderm ossicle with single axial canal

Buchiola speciosa (Hall) occurs typically in the Tully and Genesee formations and equivalent rocks in North America. It is closely similar to *Buchiola retrostriata* (von Buch) from the Devonian of western Europe. Holzapfel (1895, p. 228, 229, Pl. 11, figs. 15, 15a) illustrates *Cardiola* (*Buchiola*) *retrostriata* von Buch from Devonian goniatite limestones of Martenberg.

TABLE 3.2

Middle Devonian goniatite zones in the Western Canada Sedimentary Basin

SERIES		STAGE	ZONES	REPRESENTATIVE SPECIES
DEVONIAN	UPPER	FRASNIAN	*Manticoceras cordatum*	*Manticoceras cordiforme* Miller; Imperial Formation, Normal Wells area, N.W.T.; House and Pedder (1963)
	MIDDLE	GIVETIAN	*Pharciceras lunulicosta*	*Ponticeras* sp. cf. *P. tschernyschewi* (Holzapfel) and *Probeloceras* sp. in lower 3-12 m of unnamed beds of Braun (1966) at Cacajou Ridge, N.W.T.; House and Pedder (1963)
			Maenioceras terebratum	*Wedekindella brilonense* (Kayser) 40 m above base of Hare Indian Formation at Carnwath River, N.W.T.; House and Pedder (1963) *Maenioceras terebratum terebratum* (Sandberger and Sandberger) *Maenioceras terebratum tenue* (Holzapfel) *Maenioceras terebratum decheni* (Beyrich); 10 m above the base of the Besa River Formation, northeastern B.C. (this report)
			Maenioceras molarium	Not yet reported
			Cabrieroceras crispiforme	Not yet reported
		EIFELIAN	*Pinacites jugleri*	*Pinacites jugleri* (Roemer), *Foordites* sp. cf. *F. platypleura* (Frech); in about the upper third of the Dunedin Formation, northeastern B.C. (this report)
	LOWER	EMSIAN	*Anarcestes lateseptatus*	*Anarcestes* (*Latanarcestes*) sp. cf. *A.* (*L.*) *praecursor* Frech; 143 m below the top of the Funeral Formation, Funeral Range, N.W.T.; House and Pedder (1963)

Review of other Devonian goniatite occurrences from northwestern Canada, *Pinacites jugleri* from Alaska, and *Mimagoniatites nearcticus* from Arctic Canada

Specimens of *Manticoceras cordiforme* Miller are recorded (House and Pedder, 1963, p. 496, 524) from near the eroded top of the Imperial Formation at Norman Wells, about 45 miles (72 km) northwest of Fort Norman. This species is considered to be indicative of either the upper *cordatum* or the *holzapfeli* Zone within the Frasnian Stage.

A goniatite assemblage consisting of *Ponticeras* sp. cf. *P. tschernyschewi* (Holzapfel), *P.* sp., *Probeloceras* sp., and anaptychi has been recorded by House and Pedder (1963, p. 498, 516, 517) from 10 to 40 ft. (3.04-12.2 m) above the base of the Upper Fort Creek Shale (= Unnamed beds of Braun, 1966, p. 253, 254) at Carcajou Ridge at about 65°36′N, 128°30′W. It is now known that the basal parts of the Unnamed beds carry upper *disparilis* Zone conodonts of late Givetian age (Uyeno, *in* Braun et al., 1989), and are within the *Pharciceras lunulicosta* Zone.

Because the *Pharciceras lunulicosta* Zone is now referred to the Middle Devonian, House (1985, p. 18, 19) recommended that the old *Pharciceras* Stufe of Wedekind (1913) be used again between the *Maenioceras* and *Manticoceras* Stufen. The *Pharciceras* Stufe is defined at the base by the entry of *Pharciceras* in New York, and at the top by the entry of *Manticoceras* in the Upper Genundewa.

An ammonoid fauna correlating with the *Maenioceras terebratum* Zone has been collected from a locality 130 ft. (39.6 m) above the base of the Lower Fort Creek Shale (= Hare Indian Formation of Bassett, 1961) on Carnwath River (House, 1962, p. 255; House and Pedder, 1963, Fig. 3). This fauna includes *Wedekindella brilonense* (Kayser) and *Agoniatites* sp.

House and Pedder (1963, p. 498, Textfigs. 1-3) recorded a goniatite and brachiopod fauna from the lower beds of a lower, dark shale unit that outcrops on Bosworth (65°20′N, 126°51′W) and Francis (65°14′N, 126°23′40″W) creeks near Norman Wells. Bassett (1961, p. 490-492) included this rock unit in the Hare Indian Formation. The composite fauna included *Agoniatites* sp. cf. *A. fulgaralis* (Whidborne), *A.* sp. cf. *A. vanuxemi* (Hall), *Cabrieroceras karpinskyi* (Holzapfel), *C.* sp., *Tornoceras* (*T.*) sp. cf. *T.* (*T.*) *westfalicum* (Holzapfel), *Leiorhynchus castanea* (Meek), *Warrenella* sp., *Emanuella* sp., and various tentaculitids. In terms of goniatite zonation this fauna was dated as Givetian. Conodonts associated with *L. castanea* at Powell Creek are assigned to the *ensensis* Zone (Uyeno *in* Norris, 1985, p. 30).

The goniatite *Cabrieroceras* sp. cf. *C. karpinskyi* (Holzapfel) was recorded by Perry et al. (1974, p. 1067, 1093) from between 1765 and 1775 ft. (538 and 541 m) above the base of the Ogilvie Formation at Section S-5 (65°28′N, 138°15′W) in the Yukon Territory where the formation is 1785 ft. (544.1 m) thick. A late Eifelian age was favoured for this form on the basis of comparison with *Cabrieroceras* from Nevada, where it is dated as Eifelian on conodont evidence (Perry et al., 1974, p. 1067).

A goniatite, cf. *Foordites* sp., was recorded by Pedder (*in* Pedder and Klapper, 1977, p. 231) from the upper, recessive, argillaceous member of the Cranswick Formation at Section 6 of Norris (1985) immediately west of the Snake River at 65°26′-29′N, 133°33′-42′W. Associated fossils include numerous dacryoconarid tentaculitids, some inarticulate and articulate brachiopods, trilobite fragments, and a few *Gasterocoma*? *bicaula* Johnson and Lane (Norris, 1985, p. 18). Klapper (*in* Pedder and Klapper, 1977, p. 33) assigned the conodonts from the higher beds of the Upper Member of the Cranswick Formation to the *serotinus* Zone, of Emsian age.

Goniatites of the *Pinacites jugleri* Zone, including the zonal designate, were first recorded from North America by House and Blodgett (1982) from west-central Alaska. They were collected from two levels in the Cheeneetnuk Limestone, approximately 457 m thick, which outcrops in McGrath A-5 quadrangle at 62°04′33″N, 155°09′23″W. Goniatites from a three metre thick bed, 82 m below the top of the formation, include (locality 79RB9): *Pinacites jugleri* (Roemer), *P.* sp. cf. *P. jugleri* (Roemer), and ?*Subanarcestes* sp.; and from a three metre thick bed, 101 m below the top of the formation (locality 79RB8): *Pinacites* sp. juv., and *Foordites* sp. cf. *F. platypleura* (Frech). The conodont *Polygnathus costatus costatus* was found associated with the goniatites at locality 79RB8.

Gyroceratites (*Lamelloceras*) sp. and *Agoniatites* sp. have been found in the lower part of the Funeral Formation at 1446-1476 ft. (440.7-449.9 m) below the top of the formation, in the northern Arnica Range, District of Mackenzie, at 61°55′N, 125°13′W (House and Pedder, 1963, p. 507). In Europe, the genus *Lamelloceras* ranges from the upper Emsian to the middle Eifelian. *Anarcestes* (*Latanarcestes*) sp. cf. *A.* (*L.*) *praecursor* Frech was collected 469 ft. (143 m) below the top of the Funeral Formation in the northern Funeral Range, District of Mackenzie, at about 61°41′30″N, 125°05′W (House and Pedder, 1963, p. 513). The latter species was placed by House (1979, p. 269) in the *Anarcestes lateseptatus* Zone, which is dated by House (1985, Fig. 3a, p. 19) as late Dalejan.

The goniatite, *Teicherticeras lenzi* House (*in* House and Pedder, 1963, p. 508, Pl. 75, figs. 1-3, 10, 11; Textfig. 3), was collected from a locality on Ogilvie River in the Yukon Territory between sections 20 and 21 of Norris (1985). Its horizon and locality were recorded as 296 ft. (90.2 m) below the base of the Hume equivalent (=Ogilvie Formation) at 65°23′N, 138°31′W. Enclosing beds are recorded as "black, styliolinid mudstone". Comparison with the nearest described sections of Norris (1985) suggests that the enclosing beds belong to the lower part of the Michelle Formation or the upper part of the Road River Formation. House (*in* House and Pedder, 1963) dated the goniatite as of probable Emsian age. However, richly fossiliferous sections of the Michelle Formation in the area contain brachiopods of the *Sieberella-Nymphorhynchia pseudolivonica* fauna, dacryoconarids of the *stangulata* Zone, and conodonts of the *dehiscens* Zone (Norris, 1985, p. 15-17, Fig. 3). This *Teicherticerous* record would still be regarded as Emsian in age if the base of the *dehiscens* Zone were taken as the base of the Emsian Stage by the Devonian Subcommission, as seems likely.

A number of other Lower Devonian goniatites have been collected from the Road River Formation of the Yukon Territory, but they remain undescribed. It is suspected that some of these are comparable to the oldest dated ammonoids in the world recorded by Mawson (1987) from the Taravale Formation of Australia, associated with conodonts of the *dehiscens* Zone.

Of unusual interest, although some distance outside the report area, is the first record of a Lower Devonian ammonoid from the Canadian archipelago, *Mimagoniatites nearcticus* Prosh (1987), described from Young Island, in Barrow Strait, at approximately 74°18′00″N, 98°35′00″W, and about 120 km southwest of the settlement of Resolute. It occurs within the Disappointment Bay Formation associated with conodonts of the *inversus* Zone, indicating a late Zlichovian-early Dalejan age.

PALEONTOLOGY

Occurrences

The goniatites were collected from two localities representing different stratigraphic levels and facies. The fauna collected from the upper part of the Dunedin Formation occurs in a medium grey argillaceous limestone. The faunal assemblage is highly diverse, and consists of corals, brachiopods, goniatites, trilobites, and conodonts. The fauna near the base of the Besa River Formation was collected from a large concretion of slightly calcareous to noncalcareous, black, bituminous shale. The faunal assemblage is of low diversity and consists mainly of goniatites, abundant tentaculitids, some bactritids, rare pelecypods, a few gastropods, sparse trilobite fragments, and conodonts.

Preservation

The few goniatite specimens from the Dunedin Formation show fair to poor preservation. Sutures can only be approximated in their general shape from the boundary between the body chamber (sediment filled) and the last chamber of the phragmocone, which is commonly filled with clear, crystalline calcite.

In comparison, most of the goniatite specimens from the Besa River Formation are very well preserved. The finest details of the sculpture of the shell and corresponding details on the moulds are preserved. The smaller specimens are, as a rule, excellently preserved with respect to form, shape, and sculpture of the shell; this also applies to the moulds. The suture lines are visible or could be prepared on many specimens of each species, and reliable measurements could be taken. Medium sized specimens, up to about 40 mm in diameter, are also very well preserved. Most of the larger specimens, exceeding about 45 mm in size, have crushed outermost whorls. The maximum diameter of these specimens could not be measured, and were estimated.

Morphology

Morphological terms for the descriptions of goniatite specimens are adopted from Miller et al. (1957), and the terms applied to the shapes of the growth lines are from Wedekind (1918). Suture lines, shell form, and sculpture, in that order, are the bases for the discrimination, identification, and description of taxa.

Sutures

Wedekind's (1918) fundamental and detailed discussion on sutures and septal areas need not be repeated. The important elements and the applicable terminology are shown by Miller et al. (1957, Fig. 1, p. L13). The illustration of these elements is repeated in this report as Figure 3.6, and that terminology is followed.

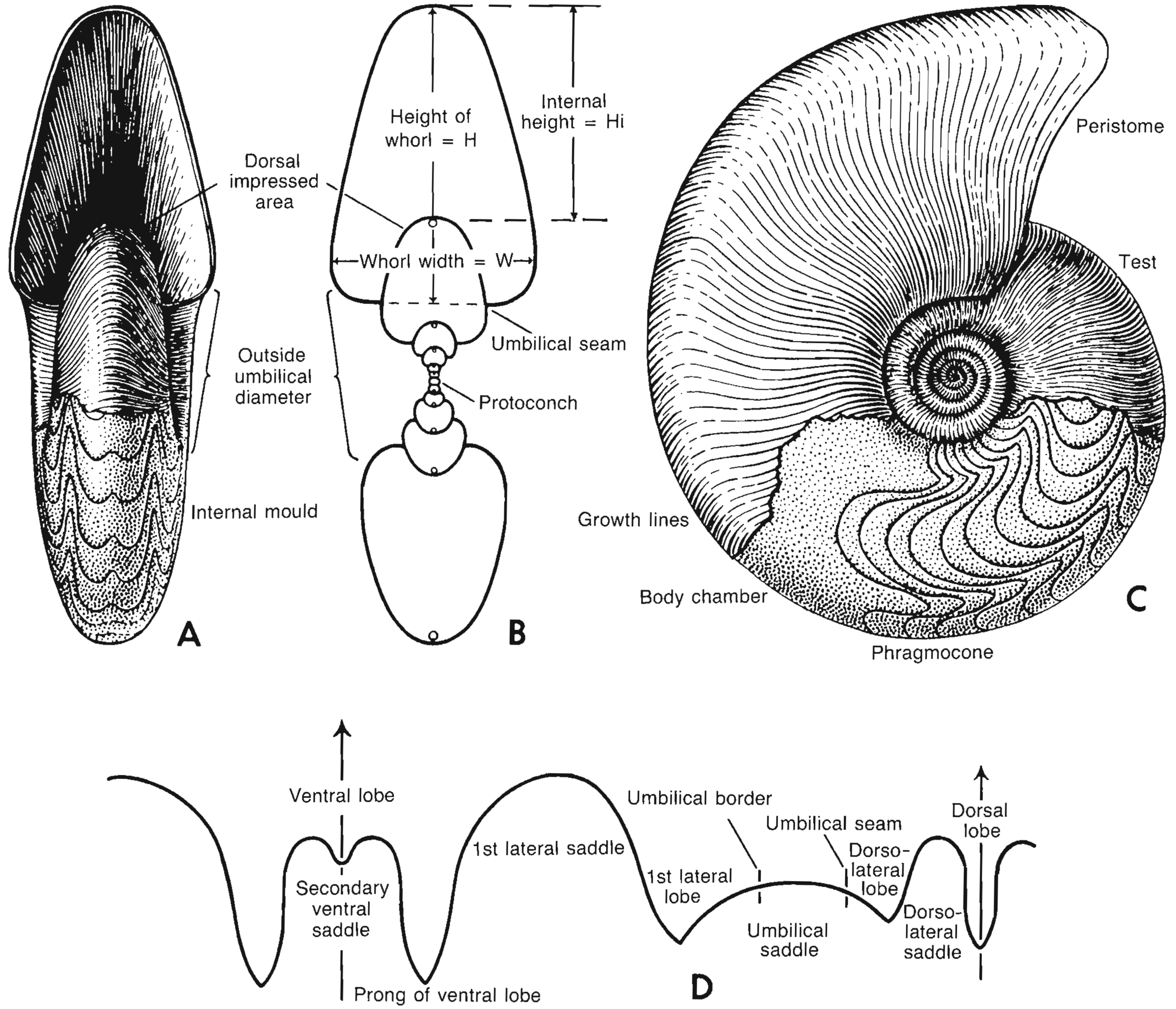


Figure 3.6. *Shell morphology and applied terminology, from Miller et al. (1957). Diagrammatic ventral (A), cross-sectional (B), and lateral (C) views of a typical goniatite,* ***Manticoceras****, about natural size; and (D) enlarged representation of a suture of the same. The upper parts of A and C portray the exterior of the test and show fine growth lines, whereas the lower parts represent the internal mould with the sutures.*

Shell form

Four characters relating to shell form were discussed by Wedekind (1918).

1. The shell either changes uniformly from the very early juvenile to the adult stage, or very different forms follow on the same individual quite abruptly. Wedekind differentiated the following:

    a. Uniform shells: adult shape develops in continuous gradual change.

    b. Biform shells: the juvenile shape is very different from that of the adult, and both are separated by a sudden change.

    c. Tri- or multiform shells: three or more shell types follow each other rather abruptly in the same individual.

2. Different shell forms in lateral view are distinguished by the size of the umbilical area, and the following terms are used (Fig. 3.7).

   a. evolute: whorls overlap very little, producing a wide umbilicus.

   b. involute: whorls overlap greatly, producing a narrow umbilicus.

   Pronounced overlap may cover the inner whorls and produce a very narrow or closed umbilicus, which is termed "occluded".

3. High and low forms are distinguished in ventral view with respect to height and width of shell. A very specialized terminology has been developed, but only the terms discoidal, platycone, and globular are used in this report (Fig. 3.7).

4. According to size, large and small forms are distinguished.

Sculpture

Wedekind (1918) differentiated between primary and secondary elements of sculpture. Primary elements include growth lines, which are a function of growth conditions and are therefore always present. Secondary elements include ribs, nodes, etc., which may or may not be present, and are not necessary elements of sculpture. An example of a secondary element in the material at hand is the development of partial constrictions on typical specimens of *Maenioceras terebratum tenue* (Holzapfel), and occasionally also on *M. terebratum terebratum* (Sandberger and Sandberger) and *M. t. decheni* (Beyrich).

Growth lines

The different forms of growth lines and the terminology applied to them as discussed by Wedekind (1918, p. 100, 101) are outlined in Figure 3.8. Biconvex growth lines have a very prominent convex bow near the external margin of the shell, which is ventrolateral in position, and a minor bow near the umbilical border, which is dorsolateral in position. Wedekind (1918) pointed out that, as a rule, the shape of the growth lines is independent of the shell form. Within narrow limits, however, convex growth lines are nearly straight or linear on the flanks of flat shells, but always have an external sinus.

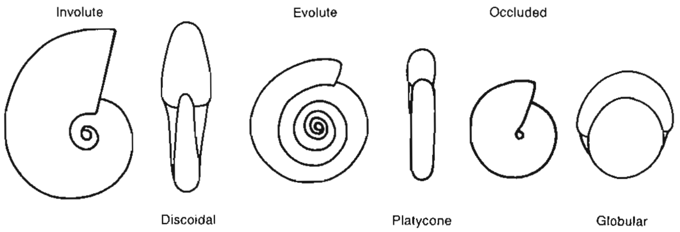


Figure 3.7. Main goniatite shell types and applied terminology.

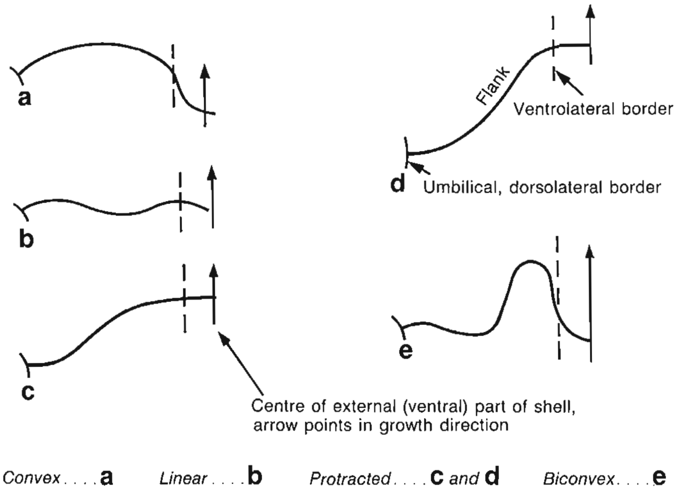


Figure 3.8. Types of growth lines (from Wedekind, 1918).

Wrinkle layer

This sculptural feature, which corresponds to the innermost of the three layers of the shell, the inner prismatic layer, is mentioned and illustrated in many publications on goniatites. For details on this feature the reader is referred to the study by Walliser (1970) who suggested that the combination of different wrinkle layer characteristics is relevant for taxonomic purposes.

Identification

In general, the systematic classification of taxa follows that of Miller and Furnish (*in* Moore, 1957), and later modifications by House (1978). Identification of genera and species in this report is restricted to specimens that can be determined with confidence, even if they are designated "cf." (*confe*r = about equal to) or "aff." (*affinis* = nearest to).

However, additional genera and species in the faunal assemblage from the shales of the Besa River Formation are present. One of these is a form on which suture lines are not evident. The specimens are very small, and exhibit growth lines of 15 in a mm compared to two to four in a mm in specimens of *Maenioceras terebratum* of the same size. Sixteen similar specimens have an involute, discoidal shell, with a lenticular shape and acute venter. The latter feature may be due to compaction, in which case the undeformed venter would be oval shaped (Pl. 3.2, figs. 8, 9). Wedekind (1918) designated similar forms as "*Parodiceras*" *inversum* Wedekind. However, since the genus "*Parodiceras*" is invalid (House, 1978), and no suture is known, the generic affiliation of these specimens must remain open. To establish a new genus without knowledge of the suture is unacceptable because this feature is the most important and fundamental criterion. Furthermore, according to Wedekind (1918), the different species of his genus "*Parodiceras*" are represented by a few specimens only, which is also the case with the assemblage from the Besa River Formation. These undetermined specimens are not of critical importance with respect to biostratigraphic implications, and are, therefore, not formally described.

All of the goniatite material on which this study is based is housed in the collections of the Geological Survey of Canada, 601 Booth Street, Ottawa. All illustrated hypotype specimens are designated by GSC numbers.

SYSTEMATIC DESCRIPTIONS

Family AGONIATITIDAE Holzapfel, 1899

Genus *Agoniatites* Meek, 1877

Type species. By original designation *Goniatites expansus* Vanuxem (1842, p. 146, Textfig. 1) (= *G. vanuxemi* Hall 1879, p. 43).

Agoniatites obliquus (Whidborne, 1889)

Plate 3.1, figures 1-5; Figures 3.9, 3.10

1895 *Agoniatites inconstans* Phillips sp. var. *obliquus* Whidborne, Holzapfel, p. 62, Pl. 5, figs. 1, 5; Pl. 7, fig. 14; Pl. 8, fig. 4.

1918 *Agoniatites oxynotus* Wedekind var. *obliqua* Whidborne, Wedekind, p. 112, Textfig. 21d, Pl. 15, fig. 4.

1959 *Agoniatites obliquus* (Whidborne) 1889, Petter, p. 82, Textfig. 25E, Pl. 1, figs. 1, 3, 7, 8.

Material. Five well preserved specimens of varying size.

Description. Shell form. The shell form is discoidal, involute, with a moderately wide umbilicus on larger specimens. The biform shell changes from moderately evolute in the first two to four volutions, to progressively more involute. The low and rounded cross-section of the early whorls changes to high and discoidal, with relatively flat sides (flanks) and a trapezoidal shape. The umbilical wall changes at the same stages from steeply rounded to a flat shaped wall (inclined at about 120 ± 5 degrees) with a very distinct umbilical border.

Suture line. The suture line is typical for the genus with a very broad lateral lobe and a small, but distinct, external saddle. Furthermore, as pointed out by Wedekind (1918), there is no distinct saddle at the umbilical seam or border. This feature, combined with the sculpture, places the specimens in Wedekind's group of *Agoniatites fulguralis* (Whidborne).

Sculpture. The sculpture consists of well developed ribs in the juvenile stage, about 30 ribs in a volution. The protoconch shows fine striae and the ribs are accompanied by a tight bundling of the growth lines. The ribs have an asymmetric cross-section. They are gently inclined in growth direction, with a comparatively steep wall on the back. The same shape, but weaker, is present on the interior mould, seen where the shell material had broken away. These ribs become progressively weaker with growth, as do the growth lines. Paired, very shallow, longitudinal, ventrolateral furrows or grooves are very well developed on each side of the flat venter.

The close similarity between Holzapfel's "*Agoniatites inconstans* (Phillips) var. *obliquus* Whidborne" and "var. *expansus* Vanuxem" is illustrated in Figure 3.10. The ontogenetic growth pattern of a specimen of each variety is shown from the plots of diameter to width (D/W), diameter to height (D/H), and diameter to umbilical size (D/U). Measurements from Holzapfel's (1895, Pl. 7, figs. 14, 15) two sections show that the rapid increase in height is about the same, but that the ratios of width and size of the umbilicus plotted against diameter are different. These ratios in our specimens are much closer

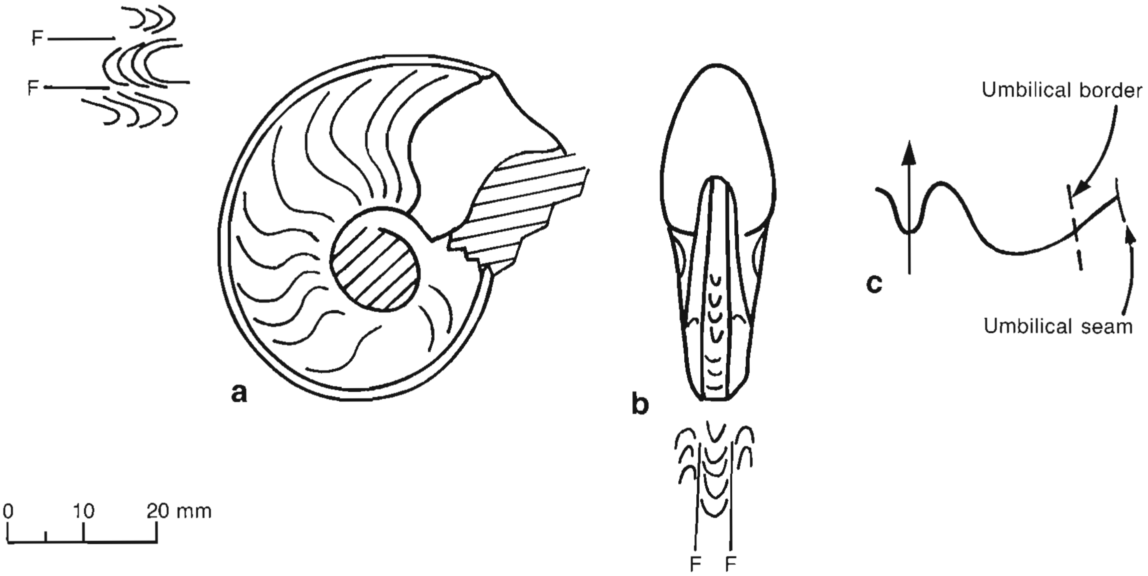


*Figure 3.9. **Agoniatites obliquus** (Whidborne). a. Lateral view of hypotype GSC 92475 showing growth lines, ventrolateral furrows, and growth lines on venter (separate); b. Ventral view of same specimen showing growth lines on venter (separate), section of last fully preserved whorl and one half volution earlier, drawn from closely spaced measurements (Pl. 3.1, figs. 4, 5); c. Suture line of a larger specimen at a whorl height of 22 mm and diameter of 14 mm, hypotype GSC 92057 (Pl. 3.1, figs. 2, 3).*

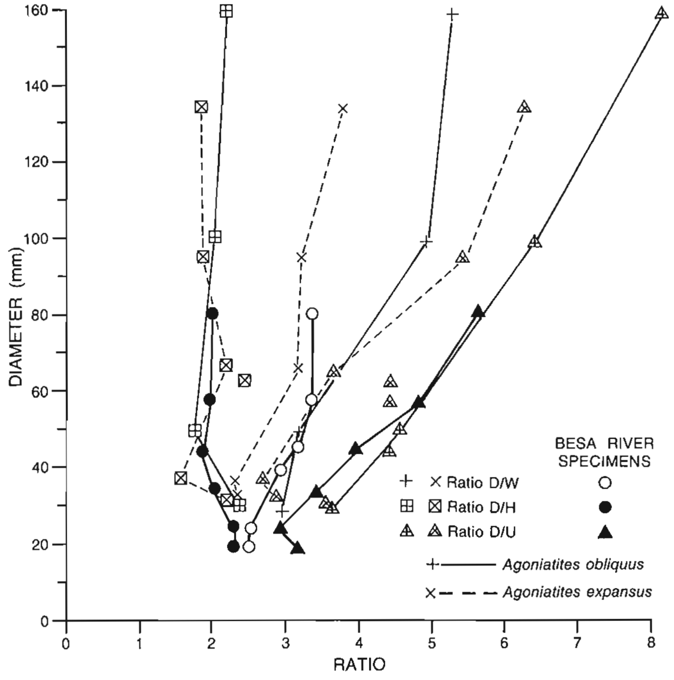


*Figure 3.10. **Agoniatites** spp. Growth pattern in ratios of diameter to width (D/W), to height (D/H), and to size of umbilicus (D/U) (horizontal). All are plotted against diameter (vertical). Measurements were taken from cross-sections of Holzapfel (1895, Pl. 7, figs. 14, 15).*

to those of "var. *obliquus*". The same ratios from the measurements of Petter (1959) for *Agoniatites obliquus* (Whidborne) support the identification, especially since she examined Whidborne's material in the British Museum.

Remarks. Wedekind (1918) concluded that no final assessment of the genus could be given, and that he could not arrive at a sharp discrimination of the species, even with the rich and well preserved material from Martenberg. Holzapfel (1895, p. 66) came to the same conclusion, stating "As mentioned before, all possible gradations exist between these forms, and I am unable to decide for many of these specimens, whether they belong to one or to another" (of these varieties).

House (1978) pointed out the need for a modern, population-statistical study of suitable material. Without this, the identification of our specimens appears as the best choice at the present stage of knowledge. Furthermore, comparison with Wedekind's material in Göttingen supported the identifications.

Horizon. Besa River Formation.

Family ANARCESTIDAE Steinmann, 1890

Subfamily PINACITINAE Schindewolf, 1933

Genus *Pinacites* Mojsisovics, 1882

Type species. Goniatites emaciatus Barrande, 1865 (original designation); evidently conspecific with *Pinacites jugleri* (Roemer, 1843).

Pinacites jugleri (Roemer, 1843)

Plate 3.2, figures 10, 11

1918 *Pinacites jugleri* (A. Roemer) Kayser, 1883, Wedekind, p. 116, Textfig. 25a.

1959 *Pinacites jugleri* (Roemer, 1843), Petter, p. 121, Pl. 6, figs. 16, 19.

1983 *Pinacites jugleri* (Roemer, 1843), Chlupáč and Turek, p. 60, Pl. 16, figs. 1-9, Textfigs. 12a, b (contains a detailed synonymy).

Material. One moderately well preserved fragment of a medium sized specimen. The fragment is very slightly crushed on one side of the flank, close to the venter, but there can be no doubt that the venter is very sharply acute, a feature typical for the species. The fragment is a mould on which biconvex growth lines are faintly visible.

A more detailed description cannot be given, and measurements are in this case meaningless.

Genus *Foordites* Wedekind, 1918

Figure 3.11

Type species. Aphyllites occultus platypleura Frech, 1889.

Wedekind (1918) characterized the genus as follows:

Suture: E (external); L (lateral); J (dorsal lobe).

"Thin, discoidal, involute and large-size goniatites with evenly slow growth in height. Paired external grooves always present, but small. Suture trilobate, pseudomagnosellar. Always without a seam-lobe. The seam-saddle is sometimes small."

For an understanding of the writers' open taxonomic approach, considering the widely different views regarding the genus, and the "rather miscellaneous group of primitive goniatites" within the family Pinacitidae, the discussion by House (1978, p. 36-38) provides the necessary background information. House calls for restraint in designating new species, but suggests paying close attention to distinct morphological differences in specimens with "primitive sutures", especially in the cases of supported different ages.

The type species, *Foordites platypleura* (Frech), is reillustrated by House (1978, Textfig. 8), and he states: "Species included with *Foordites* are typically laterally compressed, flat-sided, with a narrowly rounded or tabular venter and, in the type species, with ventrolateral furrows."

Figure 3.11 of this report shows several cross-sections and sutures, obtained from Wedekind (1918), Petter (1959), and House (1978) to provide some background for the following discrimination and identification of the specimens from the Dunedin Formation and one from the Besa River Formation.

Foordites sp. cf. *F. platypleura* (Frech, 1889)

Plate 3.2, figure 12; Plate 3.3, figure 7;
Figure 3.11, g

1918 *Foordites platypleura* (Frech, 1889), Wedekind, p. 114, Textfig. 22b.

1959 *Foordites platypleura* (Frech, 1889), Petter, p. 112, Textfig. 30F, Pl. 5, fig. 14.

1978 *Foordites platypleura* (Frech), House, p. 38, Textfig. 8.

Material. One partly broken and damaged specimen, three fragments, in part slightly deformed (tectonic), sculpture in part obliterated by recrystallization.

Description. The shell form is involute, flat-sided, and in one deformed fragment, most likely trapezoidal, with a broad, slightly rounded venter. Paired, and weakly developed ventrolateral furrows are present on the mould and on the shell where preserved. The sculpture consists of coarse, wide, double-lirate, biconvex growth lines. Very weak ribs are present on the mould only. They are parallel to the growth lines and of the same shape. The fragment of the best preserved specimen (Fig. 3.11, g), has the following approximate dimensions (by restoration): a diameter of 31 mm; and a width of 6.6 mm; or a D/W ratio of 4.7, which is the same as the ratio of *Foordites platypleura* (Frech) measured on the ventral view of Figure 8B of House (1978). The partial suture of Fig. 11, g is from another specimen.

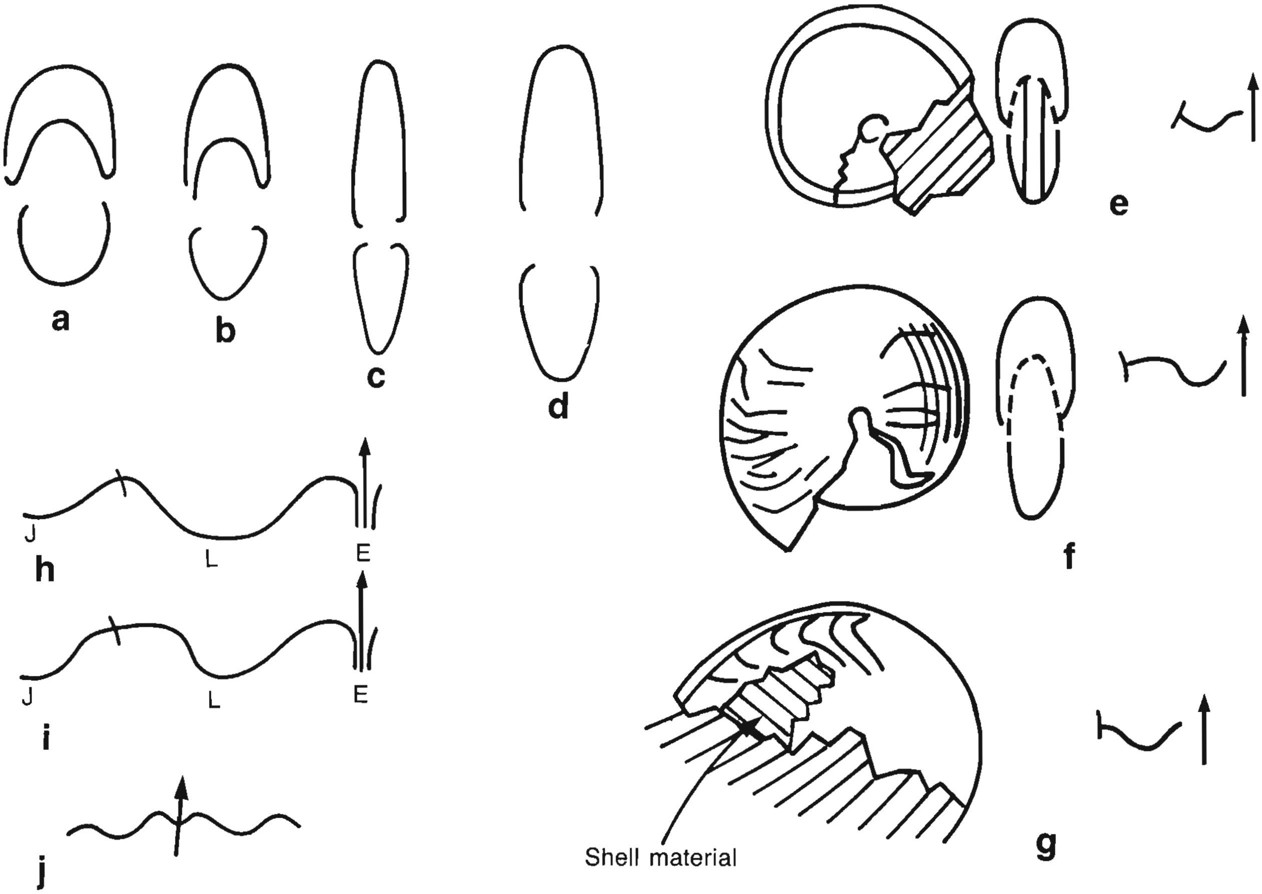


Figure 3.11. Genus ***Foordites*** *Wedekind, 1918. Cross-section from Petter (1959), based on Algerian material. Type sutures from Wedekind (1918, Pl. 14, figs. 5a, b); a.* ***Foordites psittacinum*** *(Whidborne); b.* ***Foordites djemeli*** *(Petter, 1955); c.* ***Foordites numismalis*** *(Petter, 1955); d.* ***Foordites platypleura*** *(Frech); e.* ***Foordites*** *sp. aff.* ***F. djemeli*** *(Petter, 1955), hypotype GSC 92476, figure drawn from closely spaced measurements, Dunedin Formation, GSC locality C-164631; f.* ***Foordites*** *sp. indet., hypotype GSC 92006, figure drawn from closely spaced measurements, Besa River Formation, GSC locality C-164630; g.* ***Foordites*** *sp. cf.* ***P. platypleura*** *(Frech), hypotype GSC 92068, Dunedin Formation, GSC locality C-164631; h. Type suture of* ***Anarcestes****, from Wedekind (1918); i. Type suture of* ***Foordites****, from Wedekind (1918); j. Suture of* ***Foordites platypleura*** *(Frech), from House (1978, Textfig. 8B. p. 38).*

The sutures of the specimens from the Dunedin Formation are closer to Wedekind's (1918) ***Anarcestes****-type suture. The lateral lobe is very broad and occupies the major part of the flank. The suture of* ***Foordites*** *sp. indet., from the younger Besa River Formation, is much closer to Wedekind's (1918)* ***Foordites****-type suture. The lateral lobe occupies the outer half of the flank toward the venter, it is visible only on the other flank of the shell and was transferred accordingly.*

The fragment shown in Plate 3.2, figure 12, is a mould of the body chamber, which is slightly deformed and broken. The last septum is well exposed in its lateral portion along the boundary between the sediment-filled body chamber and the clear crystalline calcite of the phragmocone. The external (ventral) part is broken and the ventral lobe is not preserved. The lateral lobe is asymmetric, slightly steeper on the umbilical portion, and spans the major part of the flank or lateral part of the shell.

Remarks. The suture is very close to that reillustrated by House (1978, Fig. 8b). This "primitive" type of suture is closer to the "type-suture" of *Anarcestes* than *Foordites* as illustrated by Wedekind (1918, Pl. 14, figs. 5a, b). This situation indicates that the older species of the "primitive" genus *Foordites* may have an *Anarcestes*-type suture (Eifelian), which in time develops into the typical *Foordites* suture. In combination with shell form and sculpture, distinct species with stratigraphic significance could emerge. The suggestion by House (1978) "to continue to recognize the distinction" (between the genera *Foordites* and *Holzapfeloceras*) "since it may have stratigraphical value" appears valid indeed and should be adhered to, until proven otherwise with sufficient, well preserved material collected in place and in sequence.

Horizon. Dunedin Formation.

Foordites sp. aff. *F. djemeli* (Petter, 1955)

Plate 3.3, figs. 5, 6; Figure 3.11, e

1959 *Foordites djemeli* (Petter, 1955); Petter, p. 112, Figs. 12, 30B; Pl. 5, figs. 16, 17.

Material. Three internal undeformed moulds, preserved in medium grey limestone, medium to very coarsely crystalline calcite in the body chamber; clear, crystalline calcite in the phragmocone portion. Some shell material is still preserved in one specimen.

Dimensions (mm).

	Depth	Width	Ratio (D/W)
Hypotype GSC 92476	21.3	9.6	2.2
Hypotype GSC 92473	16.2	8.7	1.9
Hypotype GSC 99804	15.0	7.4	2.0
From Petter (1959)	40.0	12.0	3.3
for comparison.	31.0	10.0	3.1
	29.0	9.0	3.2
	20.0	9.0	2.2

Description. The shell form of these specimens is discoidal with rounded sides and rounded venters. Shell is involute with a relatively narrow umbilicus. Paired, shallow, ventrolateral furrows are present. The sculpture consists of poorly preserved, coarse, relatively thick and evenly spaced, biconvex growth lines. The suture, which can be approximated from the boundary between the body chamber (sediment filled) and the last chamber of the phragmocone (clear, crystalline calcite), points to a broad and rounded lateral lobe, which occupies the major part of the flank.

Remarks. From a comparison of the cross-sections and other features, the specimens from northeastern British Columbia most closely resemble *Foordites djemeli*. Furthermore, the tendency toward flattening of the shell with growth is suggested by comparison of the ratios D/W with increasing size. This, however, is merely a suggestion based on the small number of available specimens.

Horizon. Dunedin Formation.

Foordites sp. indet.

Plate 3.2, figures 6, 7; Figure 3.11, f

Material. One well preserved specimen, slightly crushed on the venter of the last quarter whorl (body chamber).

Dimensions. (where undeformed) D = 26 mm; W = 9.8 mm; H = 13.7 mm.

Description. Involute, discoidal shell with a narrow umbilicus, well rounded venter, and gently rounded sides. Greatest width at the border of the 4 mm wide umbilicus; gently inclined umbilical border.

The sculpture consists of very fine, biconvex growth lines, two in a mm at their greatest distance on the narrow, ventrolateral convex bow that turns into a distinct sinus over the round venter. Fine, longitudinal striations are weakly developed on the outer third of the side.

Remarks. The shell form (Figure 3.11, f) is between that of *Foordites djemeli* (Petter) and *F. numismalis* (Petter), which are of Eifelian age. It has very little similarity with *Foordites psittacinum* (Whidborne) of Givetian age. The designation of a new species is unwarranted because of the limited material.

Horizon. Besa River Formation.

Genus *Maenioceras* Schindewolf, 1933

Type species. *Goniatites terebratus* Sandberger and Sandberger, 1851. [=*Maeneceras auct*. (non Hyatt, 1884)].

Figures 3.12, 3.15

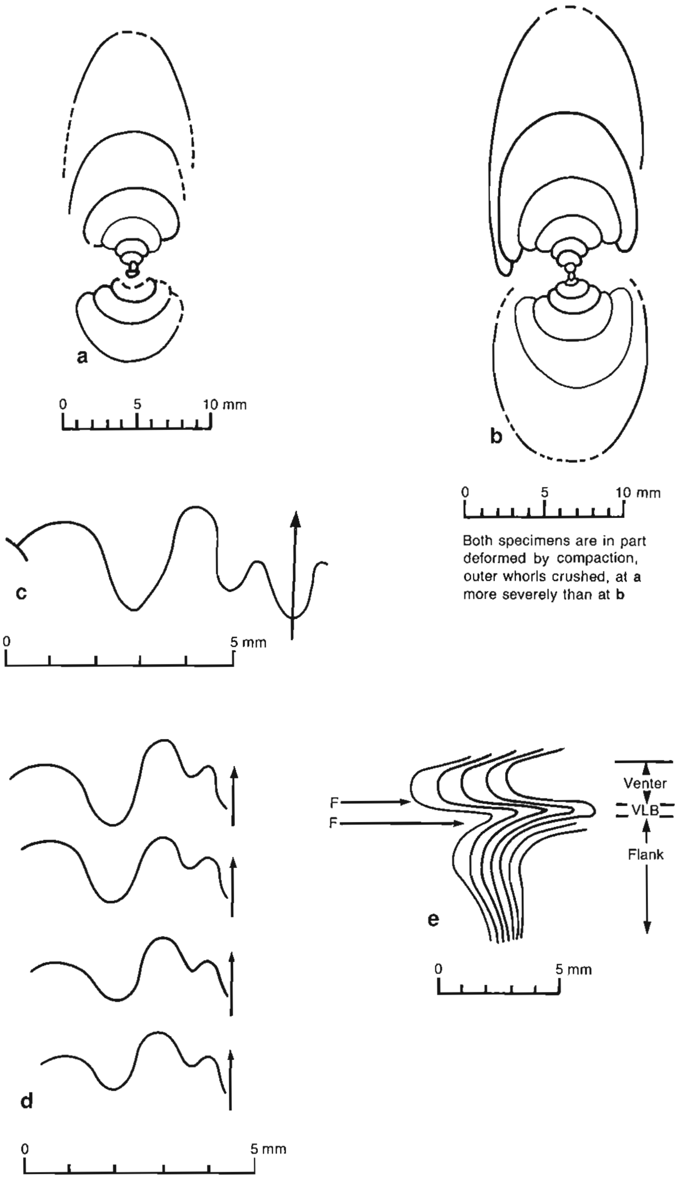
Description. The suture of six lobes is typical for the genus, with a deep and pointed lateral lobe, a pointed ventrolateral (adventive) lobe and rounded saddles.

The biform shell is, in the juvenile stage, evolute to the fourth volution, with an open umbilicus. The whorls are ventrally compressed, wider than high, with well rounded flanks. The shell changes over the next volution to become progressively more and more involute. The whorls become higher than wide and the umbilical portion overlaps increasingly the previous whorl or whorls, leading to a very narrow and eventually closed umbilicus. The flanks of the medium to larger sized, discoidal shells, are very gently arched to flat and parallel sided, with a rounded or flat and finally concave venter.

The sculpture consists of very distinct biconvex growth lines with a prominent, wide, deep, and rounded sinus on the venter. There are about three lines in a mm, where they are widest apart on the flanks, and about six to eight in a mm near the umbilical border. This indicates a strong rate of growth on small sized shells with the potential to develop medium to large sized shells.

Strong ribs of biconvex shape may be developed, especially in the early whorls, but only on the inner side of the shell, and are therefore preserved only on the internal mould. They number about 20 ribs in a volution at a diameter of 11 mm, and about 25 in a volution at 15 mm diameter (Pl. 3.1, figs. 9, 10), and gradually become weaker with increasing growth. These ribs result from a periodic thinning and thickening of the shell, on the inner side only, which corresponds generally with stronger growth lines on the outer part of the shell. Their cross-sectional shape is gently inclined in growth direction with a steep wall on the back.

Single (ventral) or paired (ventrolateral) grooves or furrows may be present. These lead, where present, to a distinct, wide and flat carina on the venter.



Both specimens are in part deformed by compaction, outer whorls crushed, at **a** more severely than at **b**

Figure 3.12. *Genus* ***Maenioceras*** *Schindewolf, 1933. Typical features of form, suture and sculpture. a. cross-section of hypotype GSC 92477 showing compaction of outer whorls by crushing; b. cross-section of hypotype GSC 92478 showing less severe compaction of outer whorls; c. and d. typical features and variability of suture lines at various growth stages; e. typical shape of growth lines on the flank, ventrolateral furrow and venter.*

In the abundant and well preserved material at hand, there is a continuous, gradual change in the overall shape of the biform shell. This appears to be typical for the genus, as are the suture and its pointed lobes, and the very prominent lappets, immediately adjacent to the venter. Their size and form varies with the shape of the growth lines and the depth of their external sinus. These typical features of the suture, the ontogenetic development of the shell, and the growth lines are illustrated in Figure 3.12.

Figure 3.13 shows the ontogenetic growth pattern of the shell. Ratios of diameter to width (D/W) and diameter to internal height (D/Hi) are plotted (horizontal axis) against the diameter (vertical axis); measured on cross-sections of peels (Figs. 3.12a, b). The tendency of the growth pattern, using the conventional measurements at full volutions, is shown by the lines connecting every second measurement. The neglible departure of the D/W ratio confirms the importance of the shell form as a specific taxonomic criterion, in agreement with Wedekind (1918). The departure of the ratio D/Hi indicates a considerable range of variation in the early growth stages, up to a diameter of about 10 mm. This variability is intimately associated with the biform shell, but the tendencies of the growth pattern remain the same. This, however, is only an indication and has to be substantiated by additional sectioned material.

Discrimination of species and/or subspecies, especially in the small size classes, hinges on the combination of the ratios of D/W and D/Hi with distinct shapes, like flat or arched flanks, flat or round venter, and sculptural elements.

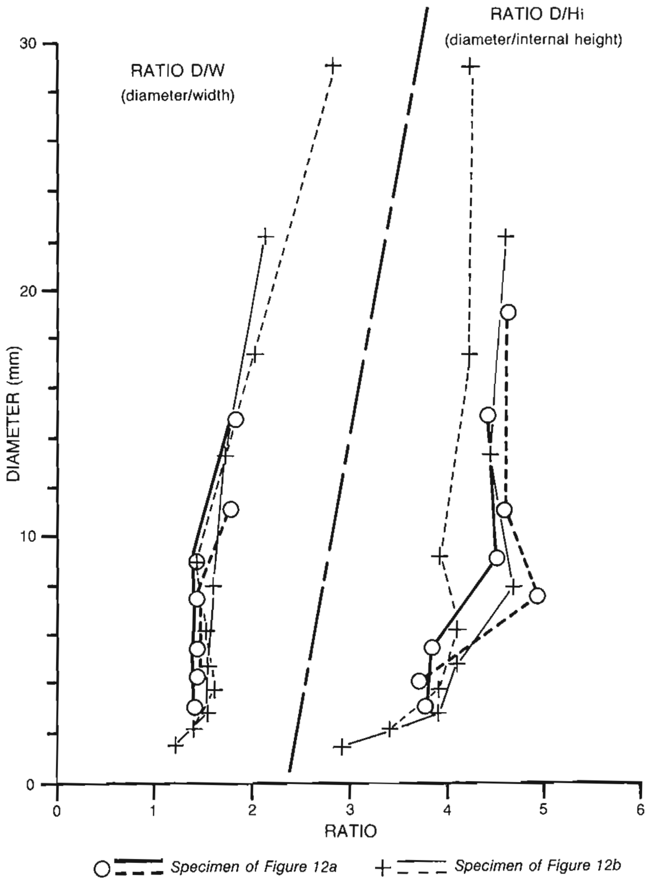


Figure 3.13. Maenioceras terebratum tenue (Holzapfel, 1895). Ontogenetic development and growth pattern in ratios of diameter/width (D/W) and diameter/internal height (D/Hi) horizontal), plotted against diameter (vertical). Measurements taken from peels of cross-sections (Fig. 3.12).

Figure 3.14 shows the diameter and width of 120 specimens of *Maenioceras terebratum* and subspecies. Random checks were done for the typical suture and widely spaced growth lines to confirm the placement of small specimens, up to about 10 mm diameter, in the genus. The position of various types and identified specimens of several authors are included and marked on the graph. The width and diameter were used by Wedekind (1918) to discriminate between his variants within the group of *Maenioceras terebratum*, in combination with other criteria.

The relative frequency distribution of specimens of the *M. terebratum* group from our assemblage is shown in Figure 3.15. This figure is interpreted as representing a live population, with the largest part of about 65 per cent (18 ± 6 mm) most likely representing specimens in the adolescent to mature stages.

From the work of Holzapfel (1895) and especially Wedekind (1918), the morphological variations within *Maenioceras terebratum* are subdivided into three varieties between which there is more or less continuous gradation. These three end members are here treated as subspecies, along the line of Wedekind's (1918) “variations”. They fall within a group recognized by Wedekind that is characterized by a narrow or closed umbilicus, with a maximum width of five mm. The three variants or subspecies are distinguished as follows (modified from Wedekind, 1918):

Maenioceras terebratum (Sandberger, G. and Sandberger, F., 1850-56).

Moderately thick shell, 9 mm wide at 22 mm diameter, the average ratio of diameter to width (D/W) is 2.4; flanks flat or gently arched; venter flat to slightly rounded, normally with ventrolateral furrows. Very distinct ribs on the mould of small specimens diminish and finally disappear with increasing size; partial constrictions may be present on medium to large sized specimens.

Maenioceras terebratum tenue (Holzapfel, 1895).

Very thin shell, 6.5 mm wide at 23 mm diameter, the average ratio of diameter to width (D/W) is 3.2; flanks flat and parallel-sided; distinctly flat venter with ventrolateral furrows. Strong ribs are present on the mould of small specimens, which are similar in all aspects to those of *Maenioceras terebratum*.

Maenioceras terebratum decheni (Beyrich).

Thick shell, 12 mm wide at 25 mm diameter, the average ratio of diameter to width (D/W) is 1.8; small, subglobular specimens are very smooth, and the absence of ribs on the mould is typical for the subspecies; the venter is distinctly rounded on small to medium sized specimens, but ventrolateral furrows are developed on mature specimens; indications of partial constrictions have been observed on one specimen.

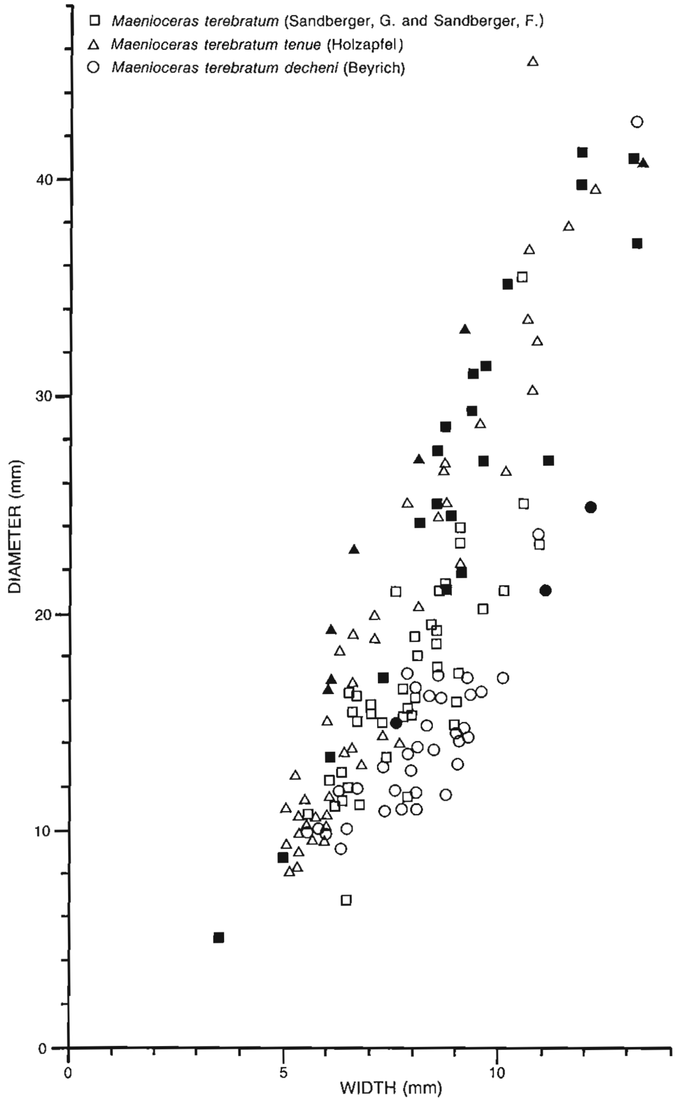


***Figure 3.14. Maenioceras terebratum** (Sandberger, G. and Sandberger, F.) and subspecies. Graph of width plotted against diameter. Data are from a faunal assemblage of 120 specimens, collected from the Besa River Formation, Chischa River, northeastern British Columbia, GSC locality C-169630. Thirty-one measurements were taken from the literature (Holzapfel, 1895; Wedekind, 1918; Petter, 1959; Bensaïd, 1974; and Göddertz, 1987) and are marked by similar solid symbols.*

Maenioceras terebratum terebratum (Sandberger, G. and Sandberger, F., 1850-56)

Plate 3.1, figures 6-8; Plate 3.2, figures 1-5, 13, 14; Figure 3.16

1895 *Maeneceras terebratum* Sandberger sp.; Holzapfel, p. 107; Pl. 4, figs. 14, 18; Pl. 6, figs. 6, 7, 9.

1918 *Maeneceras terebratum* Sandberger; Wedekind, p. 114; Pl. 16, fig. 7.

1959 *Maenioceras terebratum* (Sandberger, 1850); Petter, p. 122; Fig. 31A; Pl. 6, figs. 18, 22.

Material. Eighty-one specimens of varying size.

Dimensions. The diameter varies from 4 to 40 mm. Specimens of 25 ± 10 mm diameter have an average ratio of diameter to width (D/W) of 2.4, varying from 1.7 to 2.8.

Description. Involute, discoidal shell of medium thickness, with a narrow to closed umbilicus. The flanks are parallel-sided, flat to gently arched with a flat to slightly rounded venter. Shallow, ventrolateral furrows are well developed.

The suture with six lobes has rounded saddles and a distinctly pointed lateral lobe.

The sculpture consists of prominent biconvex growth lines with a minor convex bow on the dorsolateral part of the flank, a wide sinus over the main part of the flank and a very distinct, long and narrow convex curvature close to the venter. This curvature is indicative of the long and very delicate lappets, which are open on the venter, conforming in their opening with the depth of the broad and deep sinus of the growth lines over the venter. Ribs of the same general shape as the growth lines are present on the mould only. They were observed on juvenile to medium sized specimens, and result from a periodic thinning and thickening on the inner part of the shell. The width of these ribs corresponds with the spacing of stronger growth lines on the outside. Both suture and sculpture are typical for the genus.

Remarks. These specimens are identified with confidence as *Maenioceras terebratum terebratum*, based on the combination of the ratio D/W, shape, and sculpture. Within the subspecies, the flat and/or rounded shapes occur in all combinations with the sculptural features, which are observed on these and on additional specimens, but were not measured (deformed and/or fragments). Additional well preserved specimens show continuous gradations in all aspects of form, dimensions, and sculpture between the type and the other two extreme end members, *Maenioceras terebratum tenue* (Holzapfel) and *Maenioceras terebratum decheni* (Beyrich).

Horizon. Besa River Formation.

Maenioceras terebratum tenue (Holzapfel, 1895)

Plate 3.1, figures 9-11; Figures 3.14-3.17

1895 *Maeneceras tenue* Holzapfel, p. 111; Pl. 6, fig. 8.

1918 *Maeneceras terebratum* var. *tenuis* Holzapfel; Wedekind, p. 115; Fig. 23d.

1959 *Maenioceras terebratum* var. *tenue* Holzapfel; Petter, p. 124; Fig. 31B; Pl. 6, figs. 15, 20, 21.

Material. Ninety specimens of varying size from 5 to 40 mm diameter.

Dimensions. Medium sized specimens of 30 ± 5 mm diameter have an average ratio D/W of 3.2, ranging from 3.0 to 3.6.

Description. Thin, involute, discoidal shell with a very narrow to closed umbilicus. The flanks are parallel-sided, flat to very gently arched. The venter is flat to concave, with well developed ventrolateral furrows, which produce on larger specimens a distinct carina on the venter. On specimens of 30 to 40 mm diameter, the carina is about 2 mm high and 3 mm smaller than the width of the ventrolateral flank, as illustrated in Figure 3.17, d.

The sculpture of most specimens shows very distinct, deep partial constrictions, about 2 mm wide, on the dorsolateral half of the flank, about 8 to 10 in a volution. These constrictions appear to start at about 20 mm diameter. Their general shape follows the growth lines, with slightly less pronounced curvature. Their deepest impression lies on the middle of the flank with a uniform slope on each side. This symmetric cross-section is in contrast to the ribs—termed grooves ("sillons") by Bensaïd (1974) and Göddertz (1987)—which are gently inclined in growth direction with a sharp and steep backward edge. These ribs result from the corrugated shape of the inner, prismatic layer of the shell; they are present on the mould only, and coincide on adequately

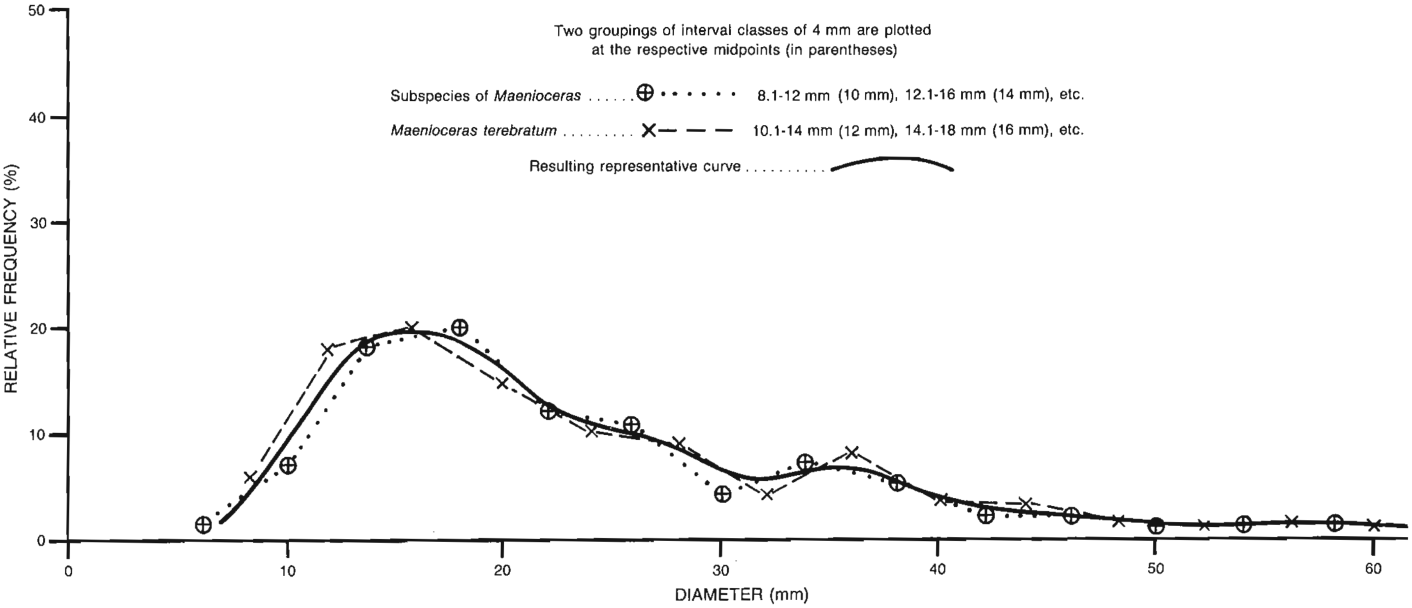


***Figure 3.15. Maenioceras terebratum** (Sandberger, G. and Sandberger, F.) and subspecies. Relative frequency distribution of size classes in per cent of maximum size. Data are from a faunal assemblage of 160 specimens, collected from the Besa River Formation, Chischa River, northeastern British Columbia, GSC locality C-169630. Fifty specimens were flattened and crushed by compaction. Their original diameters were estimated to be about 15 per cent smaller than measured.*

preserved specimens with stronger, narrowly paired growth lines on the sculpture of the outside shell. These ribs are much more frequent than the constrictions; five occur in the interval between constrictions at a diameter of 34 mm (Pl. 3.1, fig. 10). They are strong and very distinct on small to medium sized specimens, become gradually weaker with increasing size, and finally disappear completely. Other sculptural features, as well as the suture, are typical for the genus as described previously.

Remarks. Typical representatives of this subspecies are easy to recognize in the medium to large size classes, even as fragments and when not too severely deformed. Specimens larger than about 10 mm in diameter are, as a rule, quite thin with a flat venter and at least slight indications of ventrolateral furrows. However, all gradations exist in all sizes between the subspecies and the type.

The very distinct partial constrictions were not described by Holzapfel (1895). However, a few specimens from the type material at the University of Göttingen clearly had these constrictions on the mould and one on the outer shell material, where this was preserved. Therefore, and in view of their presence, even if very rare, on the other subspecies, designation of a new species on the basis of these constrictions is not acceptable.

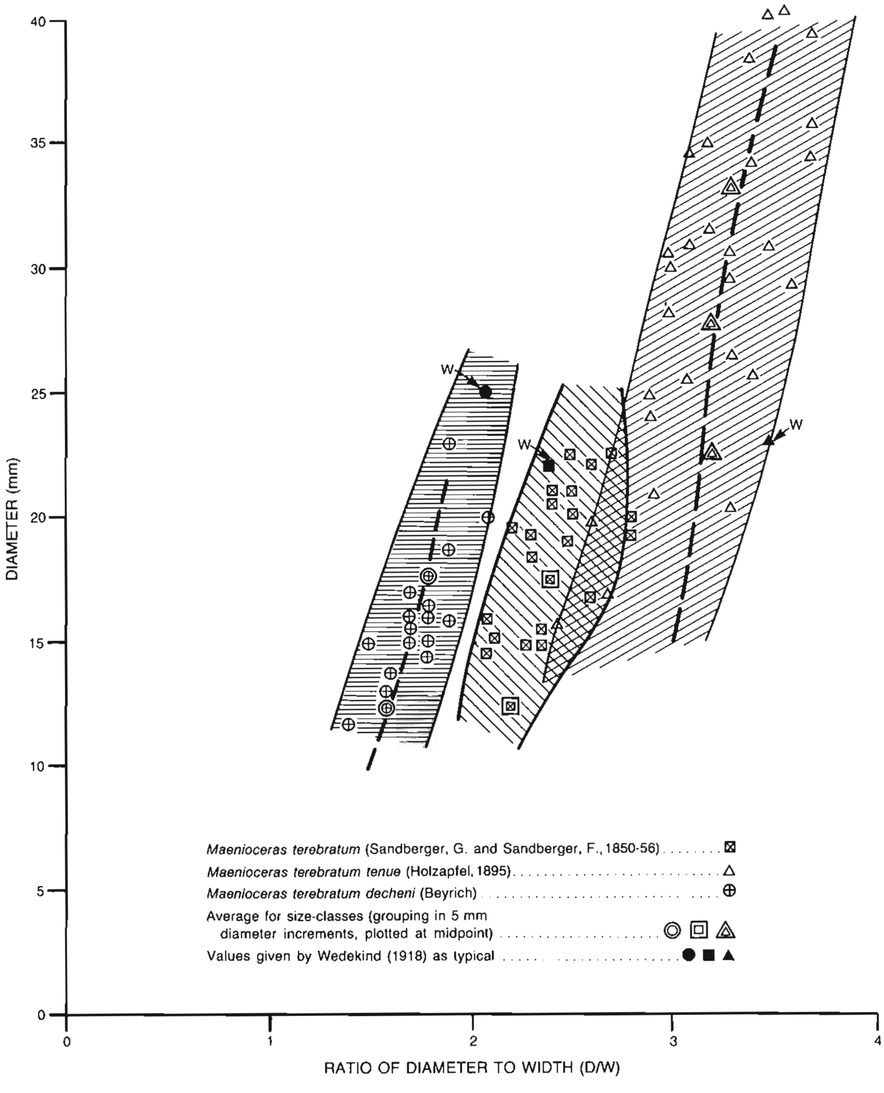


Figure 3.16. Ratio of diameter to width (horizontal) plotted against diameter in mm (vertical) of identified specimens of ***Maenioceras terebratum*** *(Sandberger, G. and Sandberger, F.),* ***M. terebratum tenue*** *(Holzapfel), and* ***M. terebratum decheni*** *(Beyrich).*

The same constrictions are illustrated by Bensaïd (1974, p. 104, Pl. 2, fig. 4; Pl. 6, fig. 2) on specimens of *Maenioceras terebratum* (Sandberger, G. and Sandberger, F.) and are described as grooves ("sillons falciformes").

However, specimens of *Maenioceras crassum* Bensaïd (1974, p. 105, Pl. 1, fig. 10), and *Maenioceras sulcatostriatum* Bensaïd (1974, p. 105, Pl. 2, figs. 2, 3, 6, 8, 9) described from the Devonian of Morocco, show grooves on the early whorls of the shell. These grooves are already very strong at a diameter of 10 mm (Bensaïd, 1974, Pl. 2, figs. 2, 9a), and are well developed over the entire flank; the apex of their curvature lies on the ventrolateral third of the flank in contrast to the middle flank position of the constrictions. Their form shows a cross-section similar to the ribs on the mould of our specimens, gently inclined in growth direction with a sharp and steep backward edge. The two types of grooves ("sillons") are completely different sculptural features, different in their origin, shape, number, and ontogenetic development. Therefore, the writers prefer the term"constrictions" for the depressions of the shell that are absent in the juvenile stage, and appear at a diameter of about 20 mm, and are of the same shape on the outside shell and on the mould. To avoid possible confusion and misinterpretation, the term "ribs" is applied to the more numerous sculptural features that result from the corrugated shape of the inner prismatic layer, and are developed on the mould only. The same sculptural feature, also termed "grooves", was noted by Göddertz (1987, p. 178, 179) on specimens of *Maenioceras crassum* Bensaïd and *Maenioceras sulcatostriatum* Bensaïd from the Devonian of southwest Algeria. This feature, in association with other characters, was considered by Göddertz to be of sufficient importance for the erection of a new subgenus, *Maenioceras* (*Afromaenioceras*). It should be pointed out that both Bensaïd (1974) and Göddertz (1987) noted that these grooves on the early whorls of *Maenioceras sulcatostriatum* Bensaïd and *Maenioceras crassum* Bensaïd are not a constant feature of these species, and that they disappear completely in the adult stage. This observation supports the conclusion of this study, that the sculptural feature of the numerous ribs on the mould of the early whorls of *Maenioceras terebratum* and *M. terebratum tenue* is only a second order taxonomic criterion.

Horizon. Besa River Formation.

Maenioceras terebratum decheni (Beyrich)

Plate 3.3, figures 1-4; Figures 3.14, 3.16, 3.17

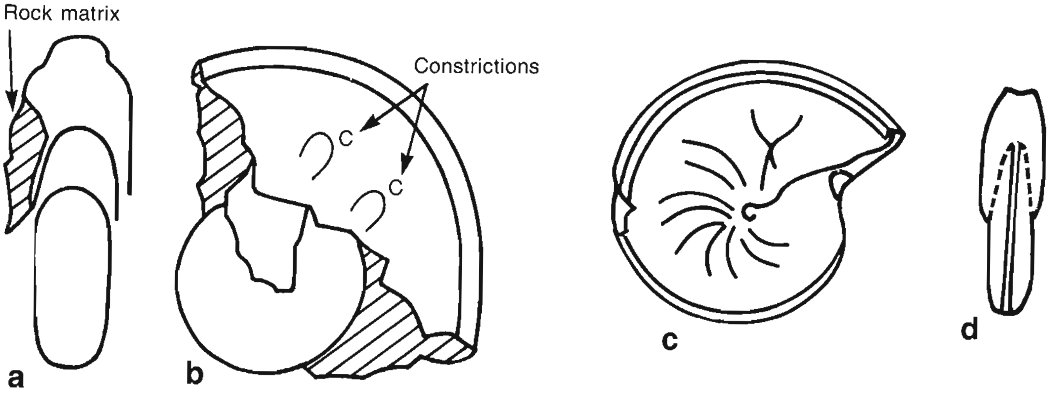
1895 *Maeneceras decheni* (Beyrich) Kayser, Holzapfel, p. 114, Pl. 4, figs. 15, 16.

1918 *Maeneceras terebratum* var. *decheni* Beyrich, Wedekind, p. 114, Figs. c/1-3.

Material. Sixty-three specimens of varying size.

Dimensions. The average ratio of diameter to width, D/W, is 1.8 with a range from 1.4 to 2.2, for specimens ranging in diameter from 12 to 23 mm.

Description. Thick, involute, discoidal shell with a small to closed umbilicus. Where present, the small umbilicus is



Note: Ventral views drawn from closely spaced measurements.

***Figure 3.17.** a, b. **Maenioceras terebratum decheni** (Beyrich), hypotype GSC 92472, Besa River Formation. c, d. **Maenioceras terebratum tenue** (Holzapfel), hypotype GSC 92479, Besa River Formation.*

well defined with a steeply rounded umbilical wall. The flanks are rounded to progressively more parallel-sided with increasing size. The subglobular shell of small specimens is smooth and no internal ribs are present, in contrast with the other subspecies. The venter is very well rounded, nearly half circular on smaller specimens, and very smooth up to a size of at least 25 mm in diameter. No ventrolateral grooves or furrows were observed up to this size. However, large specimens have very well developed ventrolateral furrows (Pl. 3.3, figs. 1-4; Fig. 3.17). The same was observed by Holzapfel (1895, p. 114). Very small specimens with shell material show very faint traces of "apparent" grooves along the straight and parallel sides of the closely spaced growth lines of the ventral sinus. How real these apparent grooves are is very difficult to determine. The same feature can be observed on very small specimens of *M. terebratum* and *M. terebratum tenue*. These faint traces certainly indicate at least the potential for the development of ventrolateral furrows. Furthermore, on the remaining part of the fragmentary outer whorl of the large illustrated specimen (Fig. 3.17), are the remnants of depressions, which resemble the partial constrictions described previously.

Remarks. Typical members of the subspecies, in the small to medium size range of about 10 to 20 mm diameter, can be identified with confidence, on the basis of form, shape, and sculpture. As shown in Figures 3.14 and 3.15, the field of overlap with the other subspecies is relatively small, and combined with sculptural features, *Maenioceras terebratum decheni* shows less gradation to the other subspecies. It appears that mature specimens, larger than 30 mm in diameter, approach the form of the relatively thin discoidal shell of all three subspecies with a ratio D/W of 3.3 ± 0.5. However, the well rounded venter with prominent ventral furrows differentiates large specimens from the other two subspecies with their flat to even concave venter. *Maenioceras terebratum decheni* could very well represent a distinct species, on the basis of the combination of form, shape, and sculpture.

However, only two large specimens are available in our collection, and these only in fragmentary preservation of the outer whorls. No mature, completely preserved, larger sized specimens are described in the literature; the largest specimen (Wedekind, 1918, p. 114) has a diameter of 25 mm. Until sufficient, well preserved large specimens support the designation of a distinct species, the writers prefer to follow Wedekind (1918), who considered *Maenioceras terebratum decheni* as a variety of the *Maenioceras terebratum* group.

Horizon. Besa River Formation.

CONCLUSIONS

The goniatites from the upper Dunedin Formation at Mount Halkett represent the *Pinacites jugleri* Zone of Eifelian age. This is the first record of the zonal goniatite from Canada, and the second record from North America. Even if represented by a fragment, the thin, discoidal form of the relatively large shell with its very distinctive, acute venter, leaves no doubt regarding the identification. The biostratigraphic placement is strongly supported by the presence of *Foordites* sp. cf. *F. platypleura* (Frech), and associated megafossils and conodonts. The associated conodonts are indicative of the *costatus* Zone.

The goniatites from the lowermost part of the dark, bituminous shale of the Besa River Formation at Chischa River represent the *Maenioceras terebratum* Zone of the Givetian Stage. Specimens of the genus *Maenioceras* Schindewolf dominate the fauna. Minor elements of "primitive", small sized goniatites, which remain open in their generic affiliation, are not of critical biostratigraphic importance. Associated conodonts are placed in the Middle *varcus* Subzone.

The designation of *Maenioceras terebratum tenue* (Holzapfel) as a subspecies of *Maenioceras terebratum* (Sandberger and Sandberger) appears to be sufficiently supported. For the present, *Maenioceras terebratum decheni* (Beyrich) is also designated as a subspecies. However, a more detailed investigation of additional material from Europe and North Africa, especially of well preserved, mature specimens, might establish *Maenioceras decheni* as a species in its own right. The very rare occurrence of *Maenioceras terebratum decheni* in the *Stringocephalus* beds in Germany (Holzapfel, 1895), and the comparable relative abundance in the Besa River assemblage, along with the absence of *Wedekindella brilonense* (Kayser) may point to an older and stratigraphically lower species zone within the major *Maenioceras* Zone of the Givetian.

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Photographs of the goniatites are by B.C. Rutley, and prints are by W.B. Sharman and C. Riley.

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PLATE 3.1

All illustrated specimens are from the lowermost part of the Besa River Formation; GSC locality C-039521 (=C-169630).

Figures 1-5. *Agoniatites obliquus* (Whidborne, 1889)

1. Side view of a juvenile specimen showing sculpture on the exterior of the first chamber (protoconch), x10; hypotype GSC 92056.

2, 3. Front and side views of a specimen with flat venter, weak ventrolateral furrows and suture line, x1; hypotype GSC 92057.

4, 5. Front view of a small specimen showing flat venter and distinct furrows; side view showing bundling of fine growth lines forming ribs on inner whorls, x2; hypotype GSC 92058.

Figures 6-8. *Maenioceras terebratum terebratum* (Sandberger, G. and Sandberger, F., 1850)

6. Side view of an incomplete specimen showing delicate lappets, x1; hypotype GSC 92059.

7. Side view showing strong ribs on the mould and very strong growth lines on the exterior, which coincide in shape and position with the ribs on the mould; suture line is well preserved, x4; hypotype GSC 92060.

8. Front view of the same specimen showing thick shell, low internal whorl height over flat venter and faint furrows, x4; hypotype GSC 92060.

Figures 9-11. *Maenioceras terebratum tenue* (Holzapfel, 1895)

9, 10. Front and side views of a specimen showing ribs on the mould, fine growth lines on the exterior, deep partial constrictions, relatively flat flanks, and thin shell form (width), x1; hypotype GSC 92061.

11. Side view of a specimen showing very fine growth lines, deep impressions of partial constrictions and pronounced ventrolateral furrows, x1; hypotype GSC 92062.

PLATE 3.1

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PLATE 3.2

All illustrated specimens are from the lowermost part of the Besa River Formation, GSC locality C-039521 (=C-169630), unless otherwise indicated.

Figures 1-5; 13, 14. *Maenioceras terebratum terebratum* (Sandberger, G. and Sandberger, F., 1850)

1. Side view of a specimen showing very fine sculpture on the exterior, and ribs on mould, x4; hypotype GSC 92063.

2, 3. Side and front views of a specimen showing suture line marked in white, x1; hypotype GSC 92064.

4, 5. Side and front views of a relatively thick specimen with flat venter and distinct furrows, x2; hypotype GSC 92065.

13, 14. Side and front views of a partially crushed specimen (outer whorl), with a moderately thin shell with slightly rounded venter and distinct furrows, x1; hypotype GSC 92070.

Figures 6, 7. *Foordites* sp. indet.

Side and front views of a relatively thin specimen with a rounded venter, x1; hypotype GSC 92066.

Figures 8, 9. "*Parodiceras*" sp. cf. "*P.*" *inversum* Wedekind, 1918

Side and front views of an average sized specimen, x2; hypotype GSC 92067.

Figures 10, 11. *Pinacites jugleri* (Roemer, 1843)

10. Oblique frontal view of a fragment of a specimen, which shows a sharply wedge-shaped cross-section, x1.

11. Side view of the same fragment, showing faint sculpture, x1; hypotype GSC 92068; GSC locality C-164131, from the upper part of the Dunedin Formation.

Figure 12. *Foordites* sp. cf. *F. platypleura* (Frech, 1889)

Side view of a fragment of a specimen showing ventrolateral furrow and sculpture on the flank, x1; hypotype GSC 92069; GSC locality C-164131, from the upper part of the Dunedin Formation.

Figure 15. Fragment of calcareous shale concretion from the lower part of the Besa River Formation.

Hand specimen showing the variety of fossils embedded in matrix of the concretion, x0.5; hypotype GSC 92071; GSC locality C-039521 (=C-163630).

PLATE 3.2


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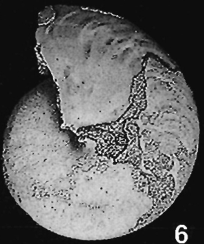
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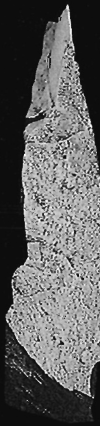
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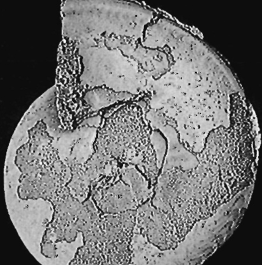
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PLATE 3.3

Figures 1-4. *Maenioceras terebratum decheni* (Beyrich)

1. Side view of an incomplete specimen showing a very narrow umbilicus and parts of constrictions, x1; hypotype GSC 92472, GSC locality C-039521, from the lower part of the Besa River Formation.
2. Front view of the same specimen, showing rounded venter with distinct carina and ventral furrows, x1.
3. Side view of inner, complete part of the same specimen, showing the smooth and rounded venter of the thick shell, x1.
4. Front view of inner, complete part of the same specimen, showing the smooth and rounded venter of the thick shell, x1.

Figures 5, 6. *Foordites* sp. aff. *F. djemeli* (Petter, 1955)

5. Side view of a specimen showing faint ventrolateral furrows, x2; hypotype GSC 92473; GSC locality C-164131, from the upper part of the Dunedin Formation.
6. Front view of the same specimen, showing arched flanks and relatively flat venter with furrows, x2.

Figure 7. *Foordites* sp. cf. *F. platypleura* (Frech, 1889)

Side view of a fragment, showing faint growth lines on mould of body chamber and partly exposed septum in contact with phragmocone, x2; hypotype GSC 92474; GSC locality C-164131, from the upper part of the Dunedin Formation.

PLATE 3.3


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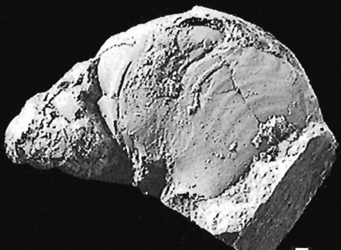
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LOWER CARBONIFEROUS MIOSPORE ASSEMBLAGES FROM THE HART RIVER FORMATION, NORTHERN YUKON TERRITORY

J. Utting[1]

Utting, J., 1991. Lower Carboniferous miospore assemblages from the Hart River Formation, northern Yukon Territory. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 412, p. 81-99.

Abstract

Palynological assemblages from the type section of the Lower Carboniferous Hart River Formation of the northern Yukon (Eagle Plain area) contain trilete and monolete spores; monosaccate pollen occur in the uppermost part. Two assemblage zones, the *Murospora aurita-Rotaspora fracta* Assemblage Zone of late Viséan, V_3 age, and the *Potonieisporites elegans* Assemblage Zone of early Serpukhovian age, have been established. The palynofloras are similar to Viséan and Serpukhovian (where known) assemblages elsewhere in Western Canada, the Canadian Arctic Archipelago, and Spitsbergen, but different from those of Atlantic Canada, which was situated in a different floral province, although some taxa occur in both localities.

The environment of deposition suggested by study of the palynomorphs was probably nearshore marine, although anoxic conditions may have occurred at times. The climate was probably humid to dry.

The thermal maturity is within the "oil window" and the abundance of alginite suggests a good source rock potential.

Résumé

Des assemblages palynologiques provenant du stratotype de la Formation de Hart River (Carbonifère inférieur), située dans le nord du Yukon (région de la plaine d'Eagle) contiennent des spores trilètes et monolètes; il existe des pollens monosaccates dans la partie sommitale de la formation. Deux zones caractérisées par un assemblage, la Zone à *Murospora aurita-Rotaspora fracta* datant du Viséen tardif, c'est-à-dire V_3, et la Zone de l'assemblage à *Potonieisporites elegans* datant du début du Serpukhovien, ont été définies. Les palynoflores ressemblent aux assemblages du Viséen et du Serpukhovien présents ailleurs dans l'ouest du Canada, dans l'archipel arctique canadien et au Spitsberg, mais diffèrent généralement de ceux de la région atlantique du Canada qui se trouvaient dans une province floristique différente, même si certains taxons se retrouvent dans les deux localités.

Le milieu sédimentaire indiqué par l'étude des palynomorphes était probablement de type marin infralittoral, mais un milieu anoxique a pu exister à certaines époques. Le climat était probablement variable, passant d'humide à sec.

La maturité thermique se situe au niveau de la "fenêtre d'hydrocarbures", et l'abondance d'alginite semble indiquer que la roche-mère a un bon potentiel.

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INTRODUCTION

Carboniferous and Permian rocks consisting of marine carbonates and siliciclastics associated with minor nonmarine deposits are widely distributed in surface and subsurface sections of the northern Yukon Territory (Bamber and Waterhouse, 1971; Graham, 1973; Pugh, 1983). Regional and international biostratigraphic correlations for this succession are based on a variety of fossil groups including brachiopods, foraminifers, corals, ammonoids (goniatites), conodonts, and miospores (e.g., Nelson, 1961, 1962; Nelson and Johnson, 1968; Ross, 1967; Bamber and Waterhouse, 1971; Nassichuk, 1971; Nassichuk and Bamber, 1978; Mamet and Bamber, 1979; Waterhouse and Waddington, 1982; Bamber et al., 1989). The succession is summarized by Bamber et al. (1989), and by Richards et al. (in press). Carboniferous rocks deposited in the northern Richardson and British mountains are separated from older strata by a regional unconformity, a reflection of the uplift and erosion that occurred during the Ellesmerian Orogeny. The presence of a disconformity in the southern Eagle Plain area has not been established, but detailed biostratigraphic work has yet to be carried out (Bamber et al., 1989). During the Carboniferous, deposition of shallow water siliciclastics and carbonates, and deeper water siliciclastics, took place in marine environments.

The Lower Carboniferous includes the upper Ford Lake Formation (Brabb, 1969; Pugh, 1983) of Viséan age (Richards et al., in press) in Alaska and the Yukon, the Hart River Formation (Bamber and Waterhouse, 1971) of late Viséan (V_3) to early Serpukhovian age (Richards et al., in press), and the Blackie Formation (Pugh, 1983) of early Serpukhovian to Kasimovian(?) age (Richards et al., in press). The Ford Lake Formation consists of predominantly dark grey, silty, pyritic shale and siltstone with subordinate sandstone, conglomerate, and silty limestone; the unit was probably deposited in a moderately deep water, basinal environment (Richards et al., in press). The Hart River Formation is a sequence of thinly laminated, cherty spiculite and spicule lime packstone with subordinate sandstone, siltstone, and calcareous shale. Lime grainstone occurs locally in eastern outcrops. The unit was deposited in shelf, slope, and basin environments (Richards et al., in press). The Blackie Formation, which overlies and grades northwestward into shelf carbonates, consists of a lower black, bituminous shale, in part silty or sandy, with rare argillaceous limestone, and an upper, dark brown-grey, argillaceous, slightly calcareous or dolomitic siltstone, very dark brown-grey, partly silty shale and some thin beds of argillaceous limestone (Pugh, 1983). Most of the unit was deposited in shallowing-upward conditions in basin to slope environments. Shale and spiculitic carbonates of the lower Blackie onlap eastward and northward over the slope and shelf deposits of the Hart River Formation (Richards et al., in press). Some conglomerate and sandstone units are probably channel-fill deposits that had a northeastern provenance (Pugh, 1983).

This study concerns the type section (116H-1B) of the Hart River Formation, located on the north bank of the Peel River (Fig. 4.1) in the southern Eagle Plain. It was first described by Bamber and Waterhouse (1971), who sampled the marine fauna and collected material for preliminary palynological study. The uppermost beds assigned to the formation by Bamber and Waterhouse (1971) consist of poorly exposed shale. These beds are more appropriately included in the Blackie Formation introduced later by Pugh (1983) and in this paper they are assigned to that formation (Fig. 4.2). Resampling of the type section by E.W. Bamber and J. Utting in the summer of 1986 for palynomorphs, conodonts, ammonoids, and foraminifers, yielded abundant, well preserved palynomorphs and an associated marine fauna (Bamber et al., 1989).

The aim of the palynological study is to determine the age of the palynomorph assemblages, the probable environment of deposition, and the thermal maturity (Utting, 1989). The vertical distribution of palynomorphs is described and assemblage zones are proposed (Fig. 4.3). Palynological comparisons are made with other Lower Carboniferous localities in Canada and with spore zones of Western Europe (Fig. 4.4). The ages thus obtained are compared with those determined from the marine fauna of the Hart River type section (Fig. 4.5).

PREVIOUS PALYNOLOGICAL WORK

Palynological data from Carboniferous and Permian rocks of the northern Yukon have been published by Barss (1967, 1972, 1980), Bamber and Barss (1969), Barss *in* Bamber and Waterhouse (1971), Norford et al. (1971), Barss *in* Martin (1972), Barss *in* Pugh (1983), Walton *in* Graham (1973), and Bamber et al. (1989). There have been no detailed earlier studies of the type section of the Hart River Formation, although Barss (1972) commented on the similarity of the taxa in two samples with those of the "Aurita Assemblage" of Spitsbergen (Playford, 1962, 1963), Axel Heiberg Island (Playford and Barss, 1963), and the Nahanni River, Northwest Territories (Hacquebard and Barss, 1957). Barss *in* Norford et al. (1971) gave assemblage lists for subsurface core samples attributed to the Hart River Formation (Socony Mobil-W.M. Birch YT B-34 and Socony Mobil-W.M. Blackie No. 1 YT M-59). Those assigned to the middle member of the Hart River Formation of Birch YT B-34 were dated as "probably middle Namurian" (lower Bashkirian) and those from the upper member as "probably Permian". The upper member, and possibly the middle member, were incorrectly assigned to the Hart River Formation; these samples are actually from a younger unit. The same applies to samples from the middle member and upper member of the "Hart River Formation" in Blackie No. 1 YT M-59 that were dated as "probably Permian" by Barss *in* Norford et al. (1971). In Blackie No. 1 YT M-59, Graham (1973, Fig. 3) correctly assigned the "middle" and "upper" members to an "unnamed Pennsylvanian shale and siltstone" (i.e., the Blackie Formation of Pugh, 1983) and to the Jungle Creek Formation, respectively.

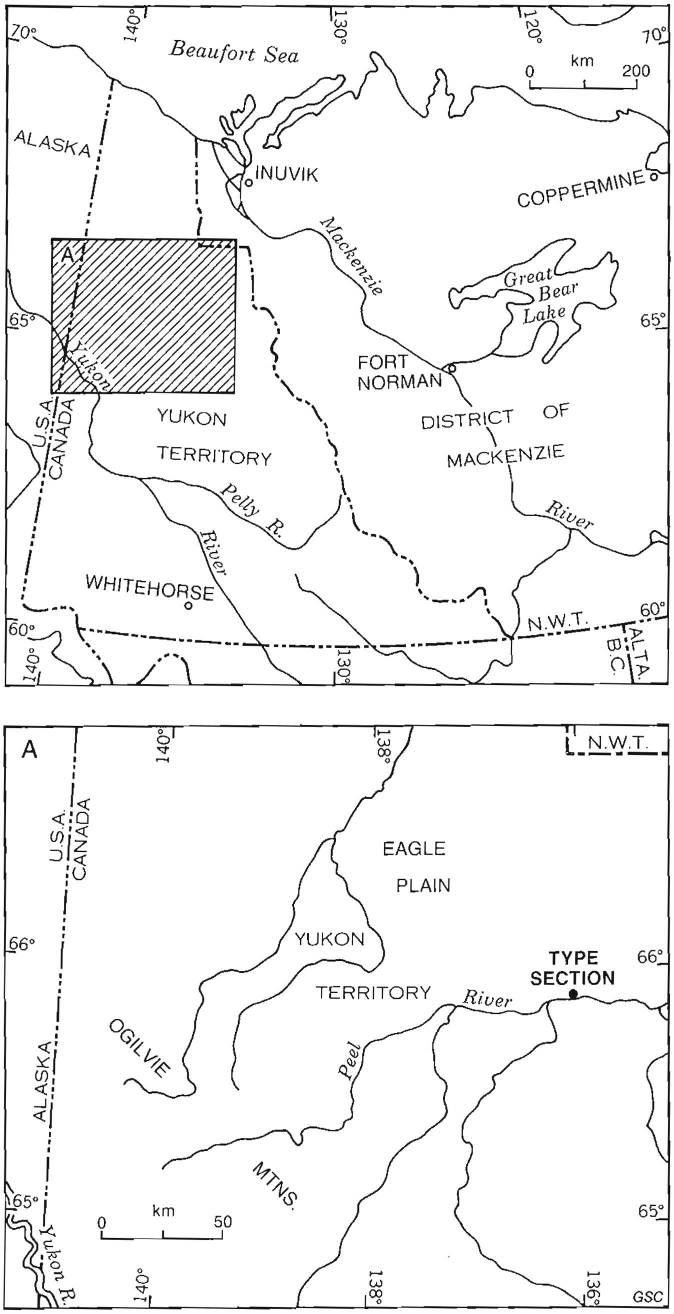

Figure 4.1. Location of the type section of the Hart River Formation, Peel River section (116H-1B), northern Yukon Territory.

STRATIGRAPHIC PALYNOLOGY

A total of 21 samples of dark grey shale and siltstone were processed using standard preparation techniques; 10 samples contained palynomorphs.

The quality of palynomorph preservation varies from very good to very poor; for example, in the middle part of the Hart River Formation, spore exines have been severely damaged by the growth of pyrite crystals, but in the upper part of the formation, pyrite is less common and the preservation of the palynomorphs is good. The assemblages, which include 32 genera and 44 species (Fig. 4.3), contain trilete and monolete spores, with monosaccate pollen occurring in the upper part of the formation. A representative selection of miospore taxa is illustrated in Plates 4.1 and 4.2. Qualitative and relative abundance data are shown in Figure 4.3. Two informal zones, *Murospora aurita–Rotaspora fracta* Assemblage Zone of late Viséan (V_3) age and *Potonieisporites elegans* Assemblage Zone of early Serpukhovian age have been established.

The zones are informal as they are based on only one section. The method used to establish the zones is modified from that of Richardson and McGregor (1986), who used "a combination of the co-occurrence of whole assemblages comprising several characteristic taxa, and the first appearance of selected species and form features. The earliest records of one or two selected species, observed in a variety of facies and irrespective of relative abundance (which may, however, be significant for local correlations), are used to define the base of each zone in a reference section". In the present study, the lower boundary of the lower zone is undefined, as the underlying Ford Lake Formation has yet to be studied in detail. The upper limit of the upper zone has also not yet been established; the lower part of the Blackie Formation at this locality is poorly exposed and not yet studied.

Description of palynological assemblages, and age determinations from palynomorphs

The probable ages given in the following section are based on comparisons with assemblages of approximately

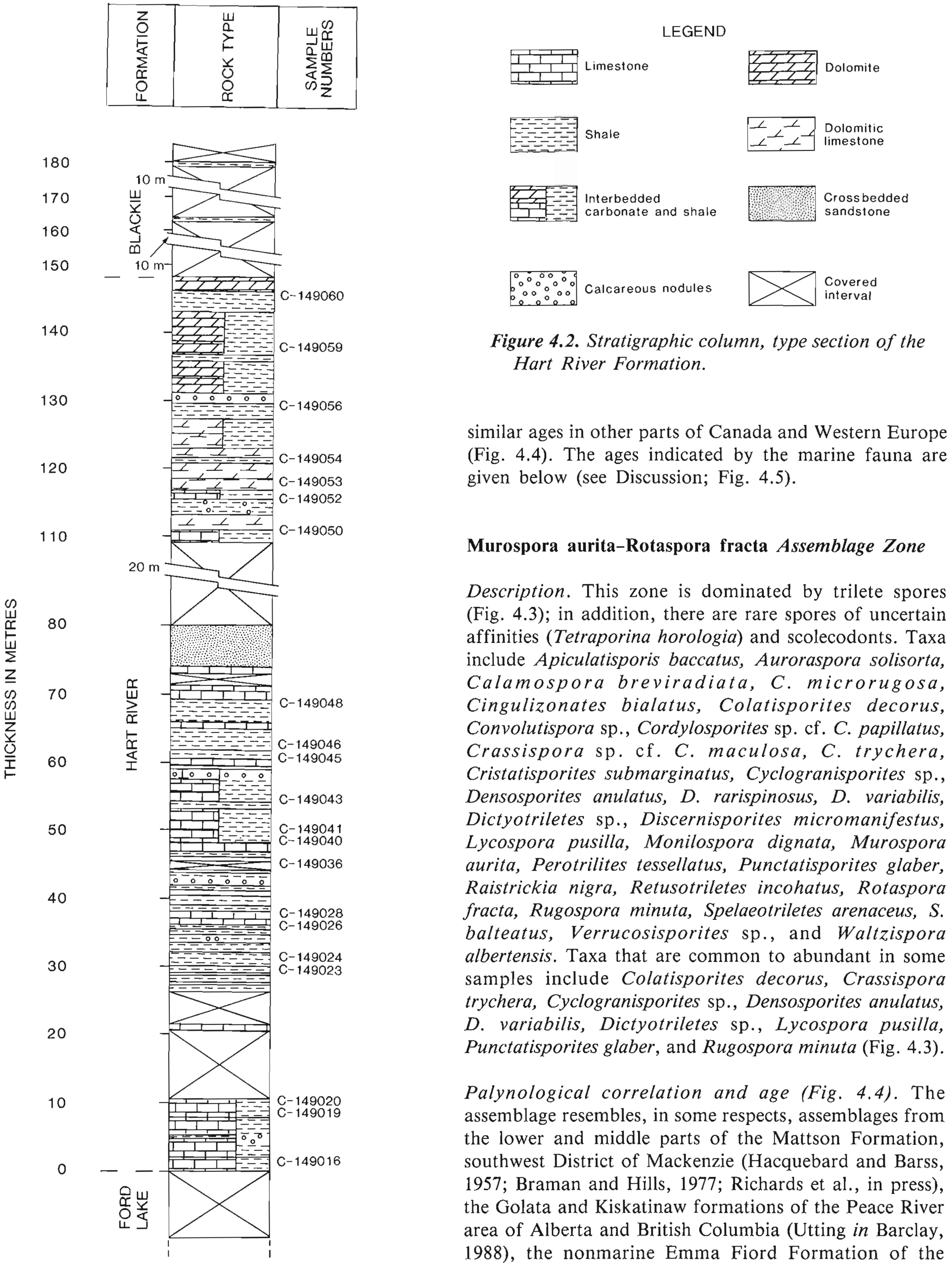

Figure 4.2. Stratigraphic column, type section of the Hart River Formation.

similar ages in other parts of Canada and Western Europe (Fig. 4.4). The ages indicated by the marine fauna are given below (see Discussion; Fig. 4.5).

Murospora aurita-Rotaspora fracta *Assemblage Zone*

Description. This zone is dominated by trilete spores (Fig. 4.3); in addition, there are rare spores of uncertain affinities (*Tetraporina horologia*) and scolecodonts. Taxa include *Apiculatisporis baccatus, Auroraspora solisorta, Calamospora breviradiata, C. microrugosa, Cingulizonates bialatus, Colatisporites decorus, Convolutispora* sp., *Cordylosporites* sp. cf. *C. papillatus, Crassispora* sp. cf. *C. maculosa, C. trychera, Cristatisporites submarginatus, Cyclogranisporites* sp., *Densosporites anulatus, D. rarispinosus, D. variabilis, Dictyotriletes* sp., *Discernisporites micromanifestus, Lycospora pusilla, Monilospora dignata, Murospora aurita, Perotrilites tessellatus, Punctatisporites glaber, Raistrickia nigra, Retusotriletes incohatus, Rotaspora fracta, Rugospora minuta, Spelaeotriletes arenaceus, S. balteatus, Verrucosisporites* sp., and *Waltzispora albertensis.* Taxa that are common to abundant in some samples include *Colatisporites decorus, Crassispora trychera, Cyclogranisporites* sp., *Densosporites anulatus, D. variabilis, Dictyotriletes* sp., *Lycospora pusilla, Punctatisporites glaber*, and *Rugospora minuta* (Fig. 4.3).

Palynological correlation and age (Fig. 4.4). The assemblage resembles, in some respects, assemblages from the lower and middle parts of the Mattson Formation, southwest District of Mackenzie (Hacquebard and Barss, 1957; Braman and Hills, 1977; Richards et al., in press), the Golata and Kiskatinaw formations of the Peace River area of Alberta and British Columbia (Utting *in* Barclay, 1988), the nonmarine Emma Fiord Formation of the

Sverdrup Basin, Canadian Arctic Archipelago (Utting et al., 1989b), and the "Aurita" Assemblage of Spitsbergen (Playford, 1962, 1963). The assemblage is younger than those from the Kekiktuk and lowermost Kayak formations (upper Tournaisian, Tn_3 to lower Viséan V_1) of the British Mountains of northern Yukon, which contain *Tripartites incisotrilobus* (Naumova) Karczewska and Turnau, 1974, and *Tumulispora rarituberculata* (Luber) Potonié, 1956 (pers. obs.).

There are some similarities between the Hart River assemblages and those of late Viséan (V_3) age from the Upper Windsor Group of Atlantic Canada (Utting, 1987). Species common to both localities are *Auroraspora solisorta, Colatisporites decorus, Crassispora trychera, Cristatisporites submarginatus, Discernisporites micromanifestus, Lycospora pusilla, Punctatisporites glaber, Raistrickia nigra, Retusotriletes incohatus*, and *Rugospora minuta*. Absent in Atlantic Canada is the cingulate genus *Murospora*, and *Densosporites* is rare.

Comparison of material from Western Europe, especially the British Isles, suggests that, based on the presence of *Raistrickia nigra*, the Yukon material is no older than the *Raistrickia nigra–Triquitrites marginatus* (NM) Zone of late Viséan (V_3) age. Many species typical of the zone are lacking, and it is not possible to assign the material to subzones DP or ME of the NM Zone (Fig. 4.4). The presence of rare specimens of *Rotaspora fracta* indicates a possible age equivalence with the overlying lowermost *Tripartites vetustus-Rotaspora fracta* (VF) Zone of Clayton et al. (1977), also of late Viséan (V_3) age. The main cause for the differences between the Yukon assemblage, and the Western Europe and Atlantic Canada assemblages, is that the Yukon was in a different floral province in the Viséan (Clayton, 1985).

Occurrence. Lower part of the upper Hart River Formation type section (115 to 130 m above the base of the formation; Figs. 4.2, 4.3). No palynomorphs were found in samples from the middle part (35 to 115 m

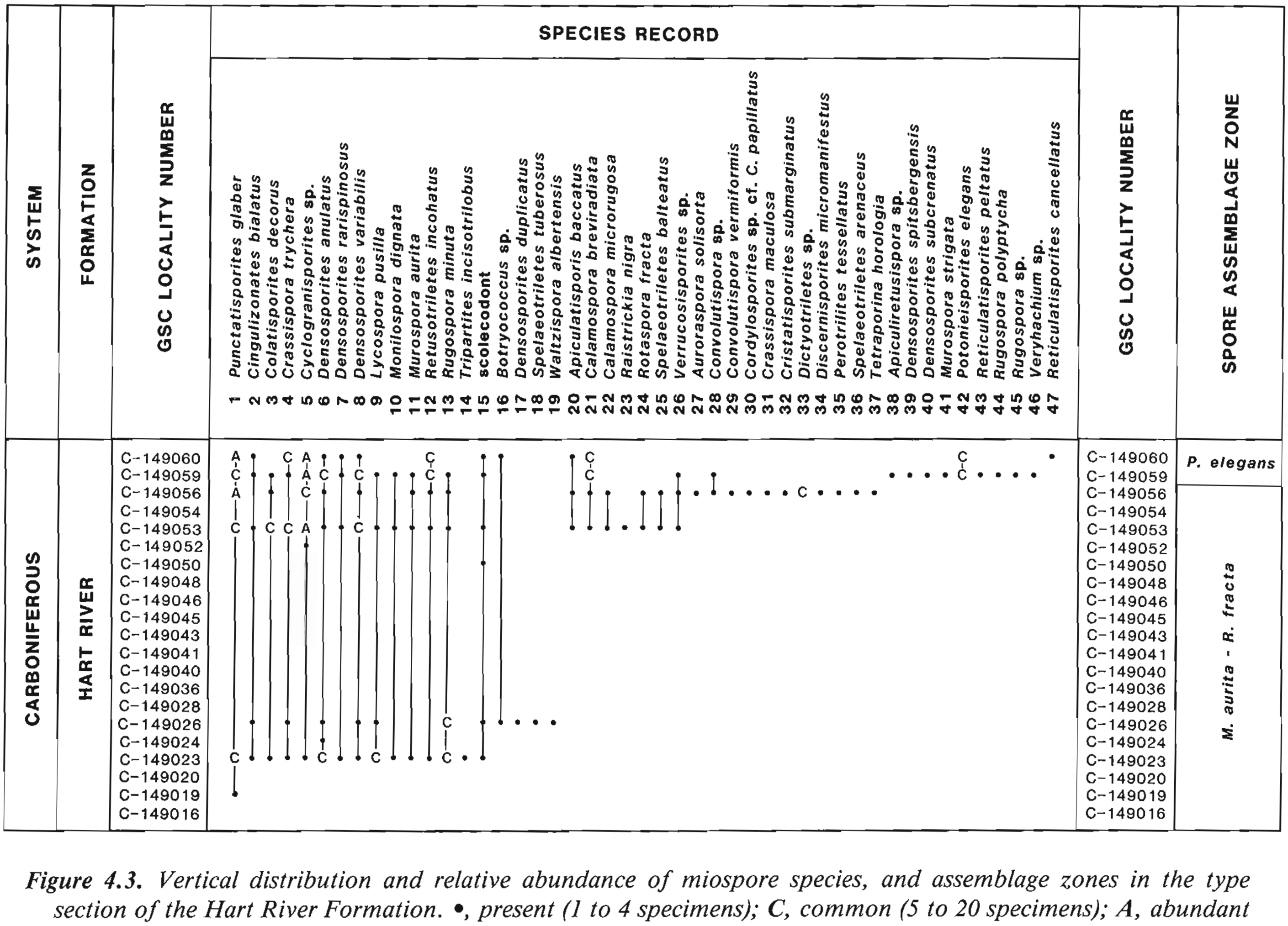

Figure 4.3. Vertical distribution and relative abundance of miospore species, and assemblage zones in the type section of the Hart River Formation. •, present (1 to 4 specimens); C, common (5 to 20 specimens); A, abundant (21 or more specimens).

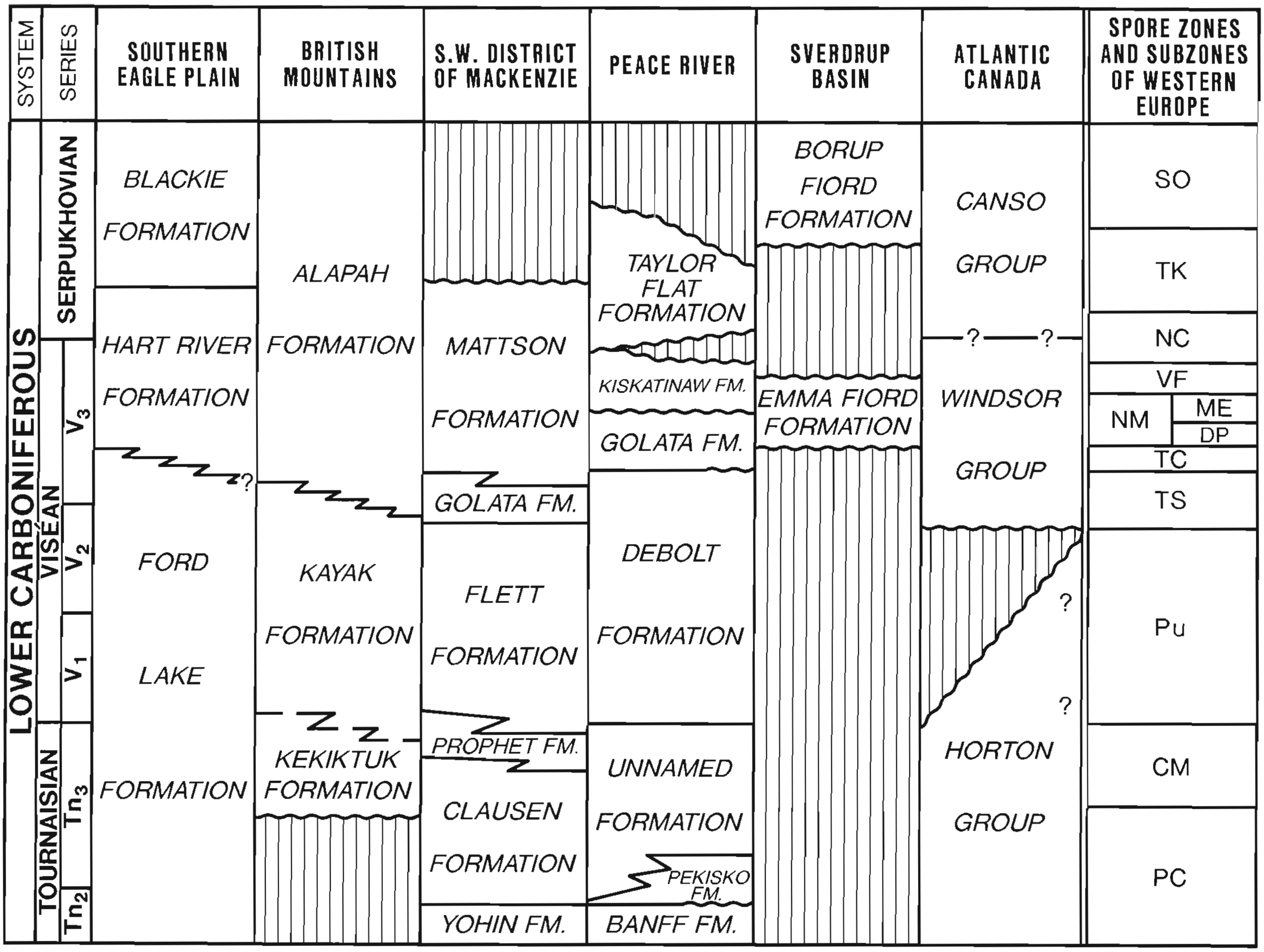

Figure 4.4. Correlation with rock units in other parts of Canada and tentative correlation with the spore zones of the British Isles and elsewhere in Western Europe.

*Column 1, Southern Eagle Plain. Bamber and Waterhouse, 1971; Waterhouse and Waddington, 1982; Pugh, 1983; Bamber et al., 1989. Column 2, British Mountains. Bamber and Waterhouse, 1971; Utting (pers. obs). Column 3, Southwestern District of Mackenzie. Hacquebard and Barss, 1957; Braman and Hills, 1977; Richards et al. (in press). Column 4, Peace River, Alberta and British Columbia. Halbertsma, 1959; Staplin, 1960; Bamber and Mamet, 1978; Utting in Barclay, 1988. Column 5, Sverdrup Basin, Mamet **in** Thorsteinsson, 1974; Utting et al., 1989b. Column 6, Atlantic Canada, Neves and Belt (1971); Utting, 1987. Column 7, Clayton et al. (1977); Clayton (1985).*

*PC Zone, **Spelaeotriletes pretiosus-Raistrickia clavata** Zone; CM Zone, **Schopfites claviger-Auroraspora macra** Zone; Pu Zone, **Lycospora pusilla** Zone; TS Zone, **Knoxisporites triradiatus-K. stephanephorus** Zone; TC Zone, **Perotrilites tessellatus-Schulzospora campyloptera** Zone; NM Zone, **Raistrickia nigra-Triquitrites marginatus** Zone; DP Subzone, **Tripartites distinctus-Murospora parthenopia** Subzone; ME Subzone, **Murospora margodentata-Rotaspora ergonauli** Subzone; VF Zone, **Tripartites vetustus-Rotaspora fracta** Zone; NC Zone, **Bellispores nitidus-Reticulatisporites carnosus** Zone; TK Zone, **Stenozonotriletes triangulus-Rotaspora knoxi** Zone; SO Zone, **Lycospora subtriquetra-Kraeuselisporites ornatus** Zone.*

above the base of the formation), although alginite fragments are abundant. In the lower part (30 to 35 m above the base of the formation), spores are poorly preserved and severely damaged by the growth of pyrite on the exines. Nevertheless, sufficient taxa can be identified for tentative assignment to the *Murospora aurita-Rotaspora fracta* Assemblage Zone. In addition, the beds contain *Waltzispora albertensis, Tripartites incisotrilobus, Densosporites duplicatus*, and *Spelaeotriletes tuberosus.*

Potonieisporites elegans *Assemblage Zone*

Description. The assemblage is similar to the *Murospora aurita-Rotaspora fracta* Assemblage Zone, but in addition contains *Densosporites spitsbergensis, D. subcrenatus, Murospora strigata, Potonieisporites elegans, Reticulatisporites cancellatus, Rugospora polyptycha*, and rare acanthomorph acritarchs (e.g., *Veryhachium* sp.) and scolecodonts. Taxa that are common to abundant in some samples include *Calamospora breviradiata, Crassispora trychera, Cyclogranisporites* sp., *Densosporites anulatus, D. variabilis, Potonieisporites elegans*, and *Punctatisporites glaber* (Fig. 4.3).

The most important characteristic of this zone is the first appearance of monosaccate pollen. Specimens have been identified as *Potonieisporites elegans*; many of these are fragmented and incomplete, and in others the central body is corroded. When the central body is severely corroded, it is difficult to differentiate the specimens from the closely related monosaccate genus *Florinites.*

Palynological correlation and age. Records of Serpukhovian (lower Namurian) assemblages in Western Canada are sparse. Barss (*in* Norford et al., 1971, p. 8) recorded younger, probable "middle Namurian" (lower Bashkirian), assemblages from the middle member of the Hart River Formation in borehole Socony Mobil-W.M. Birch YT B-34. The assemblages include monsaccate taxa *Florinites visendus, F. guttatus, F.* sp., and *Potonieisporites elegans.* Assemblages of Serpukhovian age have been recorded in the upper part of the Mattson Formation of northeastern British Columbia and southwest District of Mackenzie (Utting *in* Richards, 1983; Richards et al., in press); they contain *Florinites* sp. and *Costatascyclus crenatus.* The Taylor Flat Formation of the Peace River area of western Alberta and eastern British Columbia contains *Florinites* sp. and was assigned an early Late Carboniferous age by Staplin (*in* Halbertsma, 1959).

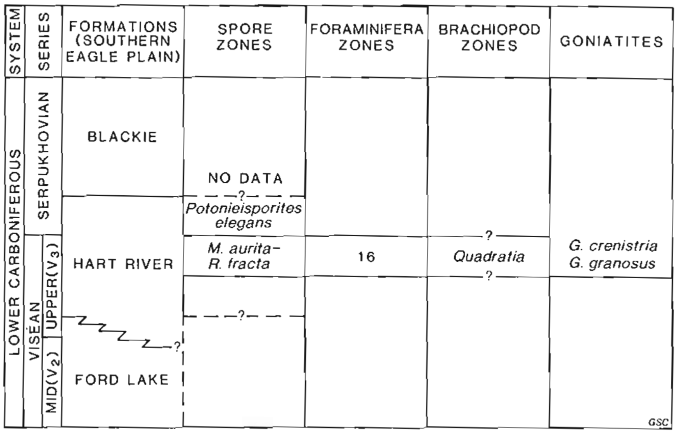

Figure 4.5. Summary of biostratigraphic data available from the type section of the Hart River Formation.

Column 1, Southern Eagle Plain. Bamber and Waterhouse, 1971; Waterhouse and Waddington, 1982; Pugh, 1983; Bamber et al., 1989. Column 2, Spore zones (this paper). Column 3, Foraminifera zones. Mamet (1984). Column 4, Brachiopod zones. Bamber and Waterhouse, 1971; Waterhouse and Waddington, 1982; Bamber et al., 1989. Column 5, Goniatites. Sellers and Furnish (1960); Bamber and Waterhouse (1971); Mamet and Bamber (1979).

In Atlantic Canada, *Potonieisporites elegans* appears in rocks of Namurian A (Serpukhovian) age of the Canso Group of Nova Scotia (Neves and Belt, 1971) and in the Searston Formation of southwest Newfoundland (Utting, 1987). There are a few other species common to both Yukon and Atlantic Canada (e.g., *Crassispora trychera, Lycospora pusilla, Rugospora minuta*, and *R. polyptycha*).

In terms of the zonation of Western Europe of Clayton et al. (1977) and Clayton (1985), and based largely on the first appearance of *Potonieisporites elegans*, the assemblage correlates with the upper part of the *Bellispores nitidus-Reticulatisporites carnosus* (NC) Zone, which is of Serpukhovian age (Fig. 4.4). However, many species characteristic of the NC Zone are lacking.

Occurrence. Uppermost part (130 to 138 m above base) of the Hart River Formation type section (Figs. 4.2, 4.3). As outlined above, the uppermost beds of the type section of the Hart River Formation of Bamber and Waterhouse (1971) include poorly exposed shale beds. These beds (Fig. 4.2) are more appropriately assigned to the Blackie Formation introduced by Pugh (1983).

THERMAL MATURITY AND ORGANIC MATTER

Spores in samples from the type section of the Hart River Formation are medium orange to light brown, indicating a Thermal Alteration Index of 2 to 2+ (Utting, 1989). This is equivalent to a vitrinite reflectance value of R_o 0.6 to 0.9, following the scale proposed by Utting et al. (1989a). Most samples contain abundant alginite, identified by its fluorescence, which suggests good source rock potential. The proportion of woody and coaly material is generally low. Similar results were obtained in Hart River samples some 35 km to the northeast, at Palmer Lake (Utting, 1989, station 10).

DISCUSSION

Age determinations from palynological data are supported by those from the marine fauna of the Hart River Formation (Fig. 4.5). The *Murospora aurita–Rotaspora fracta* Assemblage Zone from the lower and upper parts of the formation and the *Potonieisporites elegans* Assemblage Zone from the top 10 m were dated from palynological criteria as late Viséan (V_3) and Serpukhovian, respectively. The marine fauna from the middle part of the formation contains brachiopods of the *Quadratia* Zone of late Viséan to Serpukhovian age (Bamber and Waterhouse, 1971). Foraminifera from the middle part of the formation belong to zone 16 of late Viséan age (Mamet, 1984). *Goniatites crenistria* Phillips was identified by Sellers and Furnish (1960) from a bed 103.5 m above the base. This and *G. granosus* Portlock from approximately the same horizon indicate a late Viséan age (Sellers and Furnish, 1960; Bamber and Waterhouse, 1971; Mamet and Bamber, 1979). In the northern Ogilvie Mountains, the lower part of the Blackie Formation contains conodonts of late Viséan to Serpukhovian age (Bamber et al., 1989).

ENVIRONMENT OF DEPOSITION

Graham (1973) suggested that the carbonates and siliciclastics of the Hart River Formation prograded southwestward, and that deposition occurred in shelf, slope, and basin environments. The presence of abundant trilete spores, occasional scolecodonts, and rare acritarchs in the productive samples from the Hart River Formation suggests a marine nearshore environment of deposition. Severe damage by the growth of pyrite crystals on the spore exines suggests the possibility of anoxic conditions at the water/sediment interface, at times during deposition.

The climate was probably moderately humid to dry, according to the scheme proposed by van der Zwan et al. (1985). These authors expressed climate in relative terms of dry, moderately humid, and humid; actual amounts of precipitation are uncertain. The V_3 assemblages contain moderately humid floral elements such as *Perotrilites tessellatus* (rare), *Rotaspora* (rare), and *Densosporites* (common); present are humid elements such as *Murospora aurita*. Common are specimens of dry floral elements such as *Colatisporites, Rugospora*, and *Crassispora trychera*. This contrasts with other material approximately 800 km to the southeast, from the Mattson Formation, which van der Zwan et al. (1985) suggested was deposited in a humid climate. However, it should be pointed out that coals in the Mattson Formation have a low proportion of vitrinite and a high proportion of inertinite macerals (semifusinite, fusinite, micrinite, etc.). This suggests deposition under conditions unusually conducive to the degradation and oxidation of plant material, such as might occur in an environment with a fluctuating water cover along with extended periods of relative dryness (A.R. Cameron and K. Pratt, pers. comm.). Prior to deposition of the Mattson Formation, the climate was probably arid. Thin anhydrite beds were deposited in the underlying Debolt Formation (Meijer Drees, 1986).

CONCLUSIONS

1. Two informal palynological assemblage zones, the *Murospora aurita–Rotaspora fracta* Assemblage Zone of late Viséan, V_3 age, and the *Potonieisporites elegans* Assemblage Zone of early Serpukhovian age, are present in the type section of the Hart River Formation. Correlation of the zones with standard European chronostratigraphic units, established from independent palynological evidence, is supported by data from several marine faunal groups.

2. The Viséan and Serpukhovian palynoflora from the northern Yukon show similarities with those of a similar age from other localities in Western Canada, the Sverdrup Basin of the Canadian Arctic Archipelago, and Spitsbergen. Assemblages from Atlantic Canada are different, but contain some species in common with the Yukon assemblages.

3. Deposition probably took place in nearshore marine environments, although there may have been anoxic conditions at times. The climate was probably moderately humid to dry.

4. The thermal maturity is within the lower range of the "oil window" and the abundant alginite fragments suggest a good source rock potential.

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APPENDIX

SYSTEMATIC CLASSIFICATION

Systematic classification of miospore species recorded from northern Yukon Territory and listed in this paper

Anteturma PROXIMEGERMINANTES Potonié, 1970

Turma TRILETES-AZONALES (Reinsch) Potonié,1970

Suprasubturma ACAMERATITRILETES Neves and Owens, 1966

Subturma AZONOTRILETES (Luber) Dettmann, 1963

Infraturma LAEVIGATI (Bennie and Kidston) Potonié, 1956

Subinfraturma CONCAVATI Dybová and Jachowicz, 1957

Genus *Calamospora* Schopf, Wilson, and Bentall, 1944

C. breviradiata Kosanke, 1950
C. microrugosa (Ibrahim) Schopf, Wilson, and Bentall,

Genus *Punctatisporites* (Ibrahim) Potonié and Kremp, 1954

P. glaber (Naumova) Playford, 1962

Genus *Retusotriletes* (Naumova) Streel, 1964

R. incohatus Sullivan, 1964

Genus *Waltzispora* Staplin, 1960

W. albertensis Staplin, 1960

Infraturma APICULATI (Bennie and Kidston) Potonié, 1956

Subinfraturma GRANULATI Dybová and Jachowicz, 1957

Genus *Cyclogranisporites* Potonié and Kremp, 1956

Cyclogranisporites sp.

Subinfraturma NODATI Dybová and Jachowicz, 1957

Genus *Apiculatisporis* Potonié and Kremp, 1956

A. baccatus (Hoffmeister, Staplin, and Malloy) Staplin, 1960

Subinfraturma BACULATI Dybová and Jachowicz, 1957

Genus *Raistrickia* (Schopf, Wilson, and Bentall) Potonié and Kremp, 1955

R. nigra Love, 1960

Infraturma MURORNATI (Potonié and Kremp) Dybová and Jachowicz, 1957

Subinfraturma VERRUCATI Dybová and Jachowicz, 1957

Genus *Verrucosisporites* (Ibrahim) Smith, 1971

Verrucosisporites sp.

Genus *Convolutispora* Hoffmeister, Staplin, and Malloy, 1955

Convolutispora sp.

Genus *Dictyotriletes* (Naumova) Smith and Butterworth, 1967

Dictyotriletes sp.

Genus *Cordylosporites* Playford and Satterthwait, 1985

C. sp. cf. *C. papillatus* Playford and Satterthwait, 1985

Subturma AURITOTRILETES Potonié and Kremp, 1956

Infraturma AURICULATI (Schopf) Dettmann, 1963

Genus *Tripartites* Schemel emend. Potonié and Kremp, 1954

T. incisotrilobus (Naumova) Karczewska and Turnau, 1974

Infraturma CINGULATI (Potonié and Kremp) Dettmann, 1963

Genus *Knoxisporites* Potonié and Kremp, 1954

K. stephanephorus Love, 1960
Knoxisporites sp.

Genus *Rotaspora* Schemel, 1950

R. fracta (Schemel) Smith and Butterworth, 1967

Genus *Murospora* Somers, 1952

M. aurita (Waltz) Playford, 1962

Genus *Monilospora* Hacquebard and Barss emend. Staplin, 1960

M. dignata Playford, 1963

Suprasubturma LAMINATITRILETES Smith and Butterworth, 1967

Subturma ZONOLAMINATITRILETES Smith and Butterworth, 1967

Infraturma CRASSITI (Bharadwaj and Venkatachala) Smith and Butterworth, 1967

Genus *Crassispora* Bharadwaj emend. Sullivan, 1964

C. trychera Neves and Ioannides, 1974
C. sp. cf. *C. maculosa* Sullivan and Marshall, 1966

Infraturma CINGULICAVATI Smith and Butterworth, 1967

Genus *Cingulizonates* Dybová and Jachowicz emend. Butterworth, Jansonius, Smith, and Staplin, 1964

C. bialatus (Waltz) Butterworth and Smith, 1967

Genus *Cristatisporites* Potonié and Kremp emend. Butterworth, Jansonius, Smith, and Staplin, 1964

C. submarginatus (Playford) Utting, 1987

Genus *Densosporites* (Berry) Butterworth, Jansonius, Smith, and Staplin, 1964

D. anulatus (Loose) Smith and Butterworth, 1967
D. rarispinosus Playford, 1963
D. sphaerotriangularis Kosanke, 1950
D. spitsbergensis Playford, 1963
D. subcrenatus (Waltz) Potonié and Kremp, 1956

Genus *Lycospora* (Schopf, Wilson, and Bentall) Potonié and Kremp, 1954

L. pusilla (Ibrahim) Schopf, Wilson, and Bentall, 1944

Suprasubturma CAMERATITRILETES Neves and Owens, 1966

Subturma SOLUTITRILETES Neves and Owens, 1966

Infraturma DECORATI Neves and Owens, 1966

Genus *Spelaeotriletes* Neves and Owens, 1966

S. balteatus (Playford) Higgs, 1975
S. tuberosus Utting, 1987

Genus *Perotrilites* Couper, 1953

P. tessellatus (Staplin) Neville, 1973

Subturma MEMBRANATITRILETES Neves and Owens, 1966

Infraturma CONTINUATI Neves and Owens, 1966

Genus *Discernisporites* Neves emend. Neves and Owens, 1966

D. micromanifestus (Hacquebard) Sabry and Neves, 1967

Genus *Grandispora* Hoffmeister, Staplin, and Malloy, 1955

Grandispora sp.

Genus *Rugospora* Neves and Owens, 1966

R. minuta Neves and Ioannides, 1974
R. polyptycha Neves and Ioannides, 1974

Suprasubturma PSEUDOSACCITRILETES Richardson, 1965

Infraturma TRILETISACCITI Leschik, 1955

Genus *Auroraspora* Hoffmeister, Staplin, and Malloy, 1955

A. solisorta Hoffmeister, Staplin, and Malloy, 1955

Genus *Colatisporites* Williams, 1973

Colatisporites decorus (Bharadwaj and Venkatachala) emend. Williams, 1973

Anteturma VARIEGERMINANTES Potonié, 1970

Turma SACCITES Erdtman, 1947

Subturma MONOSACCITES (Chitaley) Potonié and Kremp, 1954

Infraturma TRILETESACCITI, Potonié, 1970

Genus *Costatascyclus* (Felix and Burbridge) Urban, 1971

C. crenulatus (Felix and Burbridge) Urban, 1971

Infraturma VESICULOMONORADITI Potonié, 1970

Genus *Potonieisporites* Bharadwaj, 1954

P. elegans (Wilson and Kosanke) Wilson and Venkatachala, 1964 emend. Habib, 1968

GROUP ACRITARCHA Evitt, 1963

Veryhachium sp.

INCERTAE SEDIS

Genus *Tetraporina* Naumova, 1939 ex Naumova, 1930

T. horologia (Staplin) Playford, 1963

PLATES 4.1 to 4.2

In the explanation of figures, the species name is followed by the GSC locality number, the slide number, stage co-ordinates and GSC type number. All figures are approximately x500, unless otherwise stated. All specimens are housed in the type collection of the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario.

All photomicrographs were taken under bright field illumination, except where indicated by the letter IC (= interference contrast illumination). Stage co-ordinates given in the explanation of plates and in the systematic palynology section are those of Leitz Orthoplan microscope no. 9856599 of the Institute of Sedimentary and Petroleum Geology, Calgary, Alberta.

PLATE 4.1

Murospora aurita–Rotaspora fracta Assemblage Zone

Figure 1. *Rotaspora fracta* (Schemel) Smith and Butterworth, 1967

GSC loc. C-149056, P-2914-66-3, 37.5 x 109.8, GSC 94458.

Figure 2. *Punctatisporites glaber* (Naumova) Playford, 1962

GSC loc. C-149056, P-2914-66-3, 14.8 x 104.2, GSC 94459.

Figure 3. *Waltzispora albertensis* Staplin, 1960

GSC loc. C-149026, P2914-53-3, 31.1 x 106.4, GSC 94460.

Figure 4. *Retusotriletes incohatus* Sullivan, 1964

GSC loc. C-149056, P-2914-66-3, 12.2 x 107.7, GSC 94461.

Figure 5. *Verrucosisporites* sp.

GSC loc. C-149056, P-2914-66-3, 34.6 x 98.6, GSC 94462.

Figure 6. *Murospora aurita* (Waltz) Playford, 1962

GSC loc. C-149053, P-2914-64-3, 18.8 x 106.4, GSC 94463.

Figure 7. *Calamospora breviradiata* Kosanke, 1950

GSC loc. C-149053, P-2914-64-4, 40.0 x 106.0, GSC 94464.

Figure 8. *Calamospora microrugosa* (Ibrahim) Schopf, Wilson, and Bentall, 1944

GSC loc. C-149053, P-2914-64-4, 13.3 x 100.2, GSC 94465.

Figure 9. *Raistrickia nigra* Love, 1960

GSC loc. C-149053, P-2914-64-4, 17.1 x 100.4, GSC 94466.

Figure 10. *Dictyotriletes* sp.

GSC loc. C-149056, P-2914-66-3, 23.8 x 97.1, GSC 94467.

Figure 11. *Convolutispora vermiformis* Hughes and Playford, 1961

GSC loc. C-149056, P-2914-66-3, 36.5 x 106.0, GSC 94468.

Figure 12. *Tripartites incisotrilobus* (Naumova) Karczewska and Turnau, 1974

GSC loc. C-149023, P-2914-51-3, 38.2 x 110.0, GSC 94469.

Figure 13. *Densosporites anulatus* (Loose) Smith and Butterworth, 1967

GSC loc. C-149023, P-2914-51-3, 13.7 x 100.6, GSC 94470.

Figure 14. *Densosporites duplicatus* (Naumova) Potonié and Kremp, 1956

GSC loc. C-149026, P-2914-53-3, 38.8 x 109.1, GSC 94471.

Figure 15. *Spelaeotriletes balteatus* Playford, 1963

GSC loc. C-149056, P-2914-66-3, 15.5 x 103.6, GSC 94472.

Figure 16. *Rugospora minuta* Neves and Ioannides, 1974

GSC loc. C-149023, P-2914-51-3, 25.6 x 96.2, GSC 94473.

Figure 17. *Crassispora trychera* Neves and Ioannides, 1974

GSC loc. C-149023, P-2914-51-3, 7.2 x 108.7, GSC 94474.

Figure 18. *Densosporites variabilis* (Waltz) Potonié and Kremp, 1956

GSC loc. C-149053, P-2914-64-3, 34.2 x 105.6, GSC 94475.

Figure 19. *Crassispora* sp. cf. *C. maculosa* Sullivan and Marshall, 1966

GSC loc. C-149056, P-2914-66-3, 39.0 x 109.7, GSC 94476.

Figure 20. *Spelaeotriletes tuberosus* Utting, 1987

GSC loc. C-149026, P-2914-53-3, 11.2 x 97.7, GSC 94477.

Figure 21. *Murospora* sp.

GSC loc. C-149056, P-2914-66-3, 35.7 x 107.6, GSC 94478.

Figure 22. *Discernisporites micromanifestus* (Hacquebard) Sabry and Neves, 1971

GSC loc. C-149056, P-2914-66-3, 24.2 x 101.1, GSC 94479.

Figure 23. *Colatisporites decorus* (Bharadwaj and Venkatachala) emend. Williams, 1973

GSC loc. C-149056, P-2914-66-3, 42.4 x 105.1, GSC 94480.

Figure 24. *Perotrilites tessellatus* (Staplin) Neville, 1973

GSC loc. C-149056, P-2914-66-3, 11.2 x 107.3, GSC 94481.

Figure 25. *Tetraporina* sp.

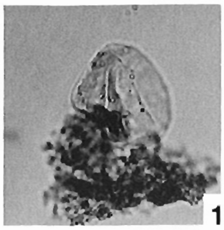
GSC loc. C-149056, P-2914-66-3, 8.2 x 95.0, GSC 94482.

Figure 26. *Grandispora* sp.

GSC loc. C-149056, P-2914-66-4, 31.4 x 98.2, GSC 94483.

Figure 27. (IC) *Auroraspora solisorta* Hoffmeister, Staplin, and Malloy, 1955

GSC loc. C-149056, P-2914-66-3, 37.1 x 108.7, GSC 94484.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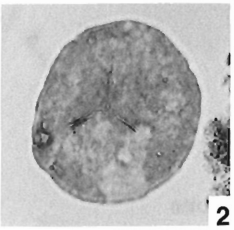
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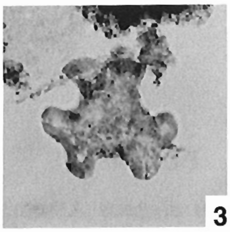
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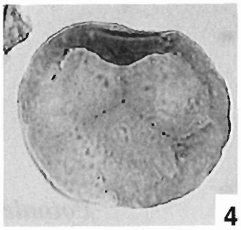
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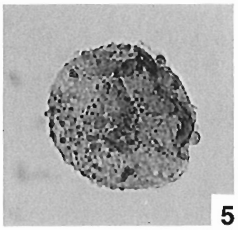
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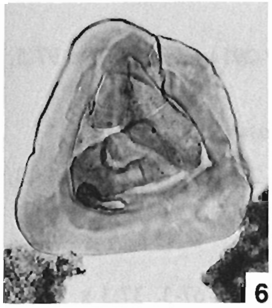
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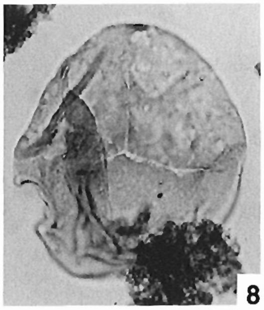
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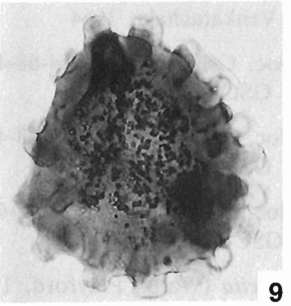
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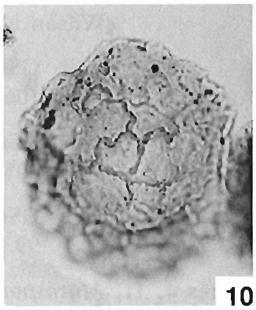
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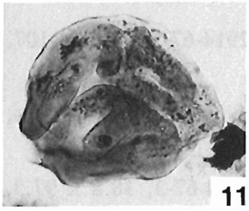
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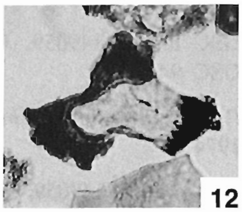
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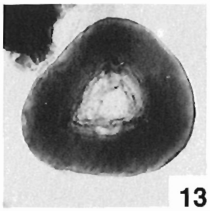
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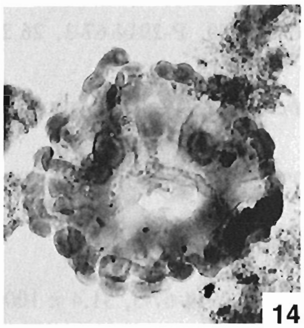
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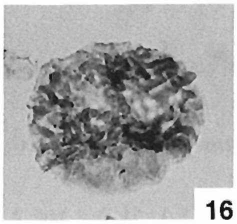
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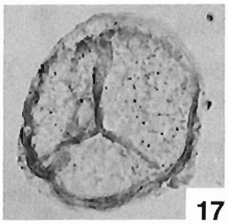
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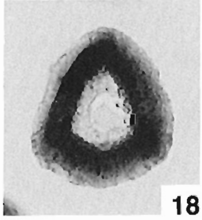
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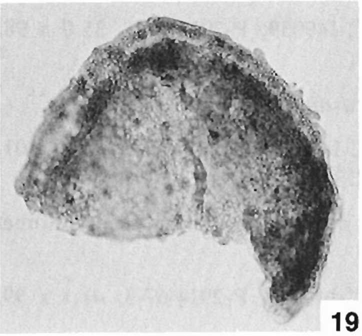
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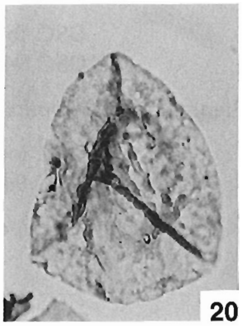
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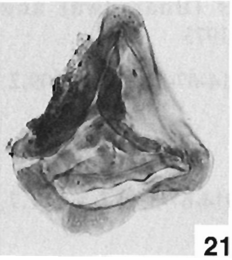
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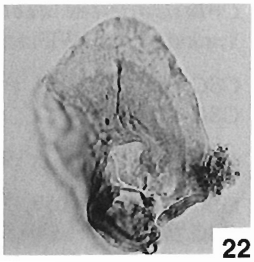
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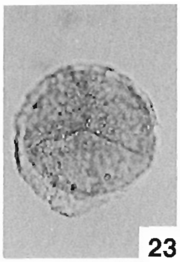
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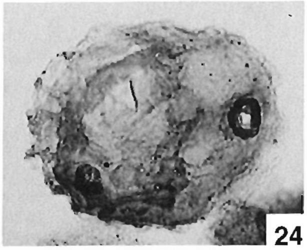
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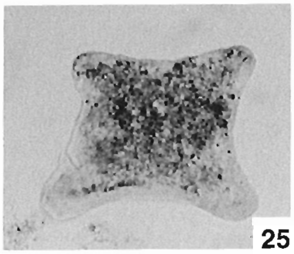
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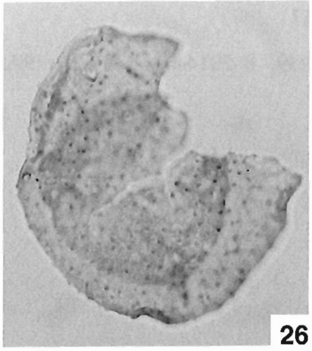
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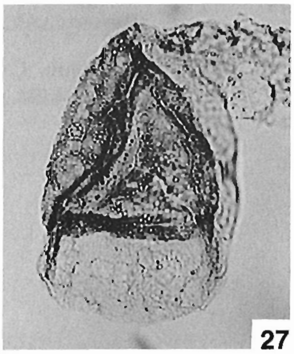
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PLATE 4.2

Potonieisporites elegans Assemblage Zone

Figures 1-3. *Potonieisporites elegans* (Wilson and Kosanke) Wilson and Venkatachala, 1964

1. GSC loc. C-149060, P-2914-68-4, 30.6 x 106.3, GSC 94485.
2. GSC loc. C-149060, P-2914-68-4, 40.2 x 103.3, GSC 94486.
3. GSC loc. C-149060, P-2914-68-6, 20.0 x 99.1, GSC 94487.

Figures 4, 11. *Murospora aurita* (Waltz) Playford, 1962

4. GSC loc. C-149059, P-2914-67-3, 38.9 x 97.5, GSC 94488.

11. GSC loc. C-149059, P-2914-67-3, 26.2 x 99.8, GSC 94495.

Figure 5. *Densosporites subcrenatus* (Waltz) Potonié and Kremp, 1956

GSC loc. C-149059, P-2914-67-3, 34.0 x 99.4, GSC 94489.

Figure 6. *Convolutispora* sp.

GSC loc. C-149059, P-2914-67-3, 31.4 x 100.8, GSC 94490.

Figure 7. *Murospora strigata* (Waltz) Playford, 1962

GSC loc. C-149059, P-2914-67-3, 35.0 x 98.6, GSC 94491.

Figure 8. *Monilospora dignata* Playford, 1963

GSC loc. C-149059, P-2914-67-3, 24.4 x 101.0, GSC 94492.

Figure 9. *Lycospora pusilla* (Ibrahim) emend. Somers, 1972

GSC loc. C-149059, P-2914-67-3, 41.1 x 99.6, GSC 94493.

Figure 10. *Cingulizonates bialatus* (Waltz) Smith and Butterworth, 1967

GSC loc. C-149059, P-2914-67-3, 34.2 x 99.5, GSC 94494.

Figure 12. *Cordylosporites* sp. cf. *C. papillatus* Playford and Satterthwait, 1985

GSC loc. C-149059, P-2914-67-3, 30.6 x 97.5, GSC 94496.

Figure 13. *Densosporites rarispinosus* Playford, 1963

GSC loc. C-149060, P-2914-68-3, 23.2 x 103.2, GSC 94497.

Figure 14. *Rugospora* sp.

GSC loc. C-149059, P-2914-67-3, 37.3 x 100.6, GSC 94498.

Figure 15. *Densosporites spitsbergensis* Playford, 1963

GSC loc. C-149059, P-2914-67-3, 21.2 x 107, GSC 94499.

Figure 16. *Rugospora polyptycha* Neves and Ioannides, 1974

GSC loc. C-149059, P-2914-67-3, 38.8 x 97.3, GSC 94500.

Figure 17. *Cristatisporites submarginatus* (Playford) Utting, 1987

GSC loc. C-149059, P-2914-67-3, 19.8 x 95.1, GSC 94501.

Figure 18. *Reticulatisporites cancellatus* (Waltz) Playford, 1962

GSC loc. C-149059, P-2914-67-3, 38.2 x 106.2, GSC 94502.

Figure 19. *Colatisporites decorus* (Bharadwaj and Venkatachala) Williams, 1973

GSC loc. C-149059, P-2914-67-3, 32.4 x 109.2, GSC 94503.

Figure 20. (IC) *Veryhachium* sp. (x750)

GSC loc. C-149059, P-2914-67-3, 9.7 x 101.7, GSC 94504.


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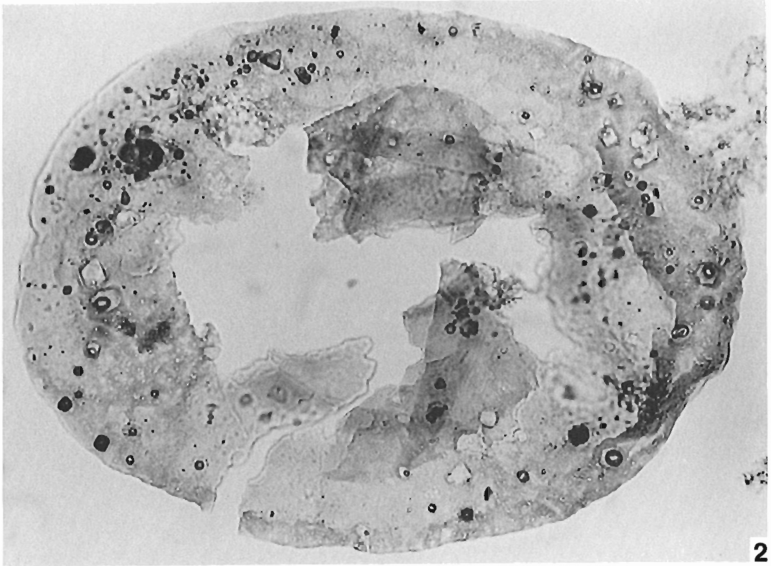
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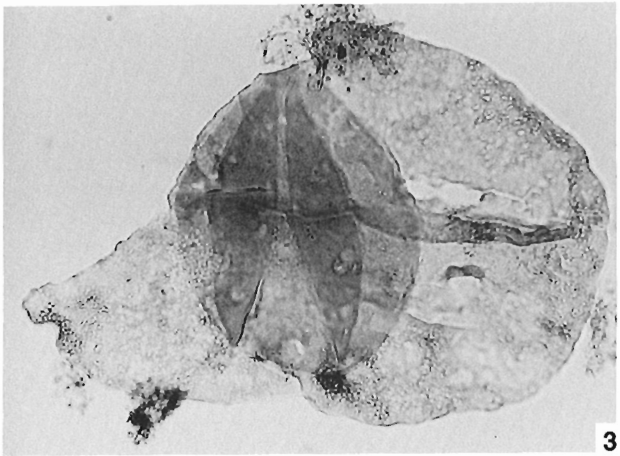
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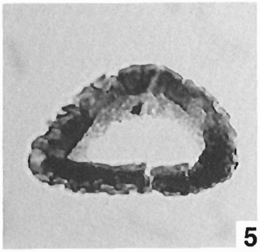
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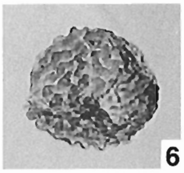
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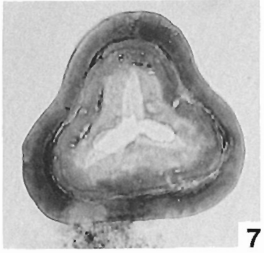
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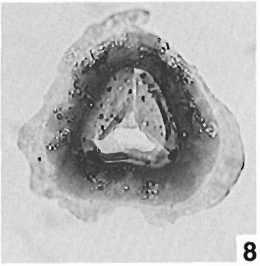
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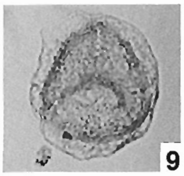
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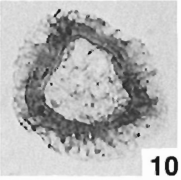
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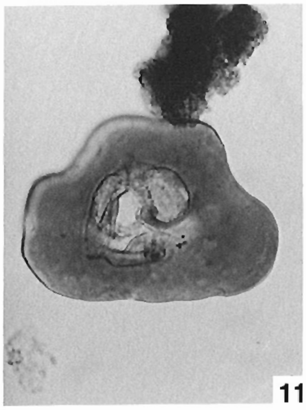
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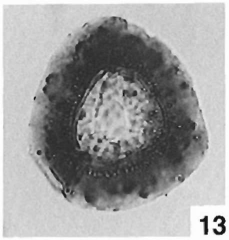
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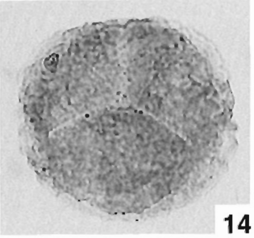
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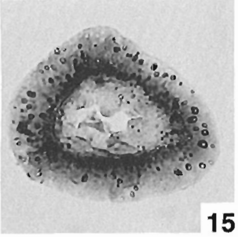
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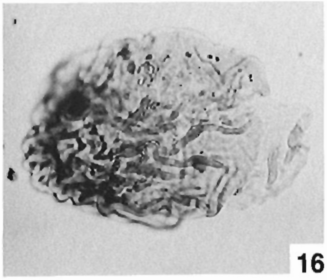
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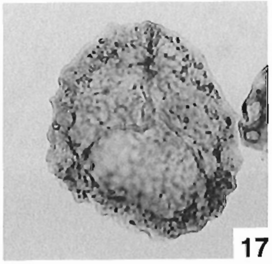
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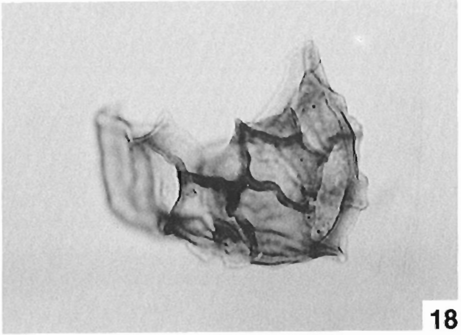
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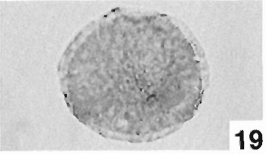
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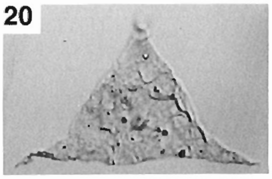

A HIGH LATITUDE UPPER TRIASSIC FLORA FROM THE HEIBERG FORMATION, SVERDRUP BASIN, ARCTIC ARCHIPELAGO

Sidney R. Ash[1] and James F. Basinger[2]

Ash, S.R. and Basinger, J.F., 1991. A high latitude Upper Triassic flora from the Heiberg Formation, Sverdrup Basin, Arctic Archipelago. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 412, p. 101-131.

Abstract

The Heiberg Formation of Late Triassic-Early Jurassic age contains abundant plant megafossils at many localities in the eastern part of the Sverdrup Basin, Canadian Arctic Archipelago. This flora, described here for the first time, flourished on deltas that formed along the southerly margins of the Sverdrup Basin at nearly 60°N paleolatitude. Fossils from eleven localities in the Fosheim Member of the Heiberg Formation have been studied and are assigned to the horsetails (two species), ferns (six species), cycadophytes (three species), ginkgophytes (two species), czekanowskias (one species), and conifers (eight species). Three unassigned forms are also present. Elements of both Upper Triassic and Lower Jurassic floras of the northern hemisphere are present. However, several of the forms found in the Heiberg (e.g., *Camptopteris* and *Anthrophyopsis*) are restricted to the Upper Triassic, and the flora as a whole compares most closely with the high latitude Upper Triassic (Upper Norian) *Lepidopteris* floras in east Greenland, Sweden, and Siberia. The Heiberg flora lived near the borderline between the Upper Triassic European-Sinian and Siberian floral areas, as it contains species characteristic of both areas. The composition of the flora, together with the associated coal beds, indicates that the plants grew in a relatively warm climate that had an abundance of rainfall and well developed seasons.

Résumé

La Formation d'Heiberg, qui s'échelonne du Trias tardif au Jurassique précoce, contient d'abondants mégafossiles végétaux, dans de nombreuses localités de la partie est du bassin de Sverdrup, situé dans l'archipel arctique canadien. Cette flore, décrite pour la première fois dans cet ouvrage, prospérait dans des deltas formés sur les marges sud du bassin de Sverdrup à une paléolatitude de presque 60°N. Les fossiles provenant de 11 localités, et situés dans le Membre de Fosheim de la Formation d'Heiberg, ont été étudiés et ont été placés dans les Équisétales (deux espèces), les Filicales (six espèces), les Cycadophytes (trois espèces), les Ginkgophytes (deux espèces), les Czekanowskias (une espèce), et les Conifères (huit espèces). Il existe aussi trois formes non classées. On y trouve des éléments des flores de l'hémisphère nord appartenant au Trias supérieur et au Jurassique inférieur. Cependant, plusieurs des formes rencontrées dans la Formation d'Heiberg (par exemple *Camptopteris* et *Anthrophyopsis*) sont limitées au Trias supérieur, et la flore dans son ensemble ressemble très fortement aux flores des hautes latitudes situées dans le Trias supérieur (Norien supérieur), c'est-à-dire aux flores à *Lepidopteris* du Groenland oriental, de la Suède et de la Sibérie. La flore de la Formation d'Heiberg vivait près de la limite entre les aires floristiques européenne-sinienne et sibérienne du Trias supérieur, puisqu'elle contient des espèces caractéristiques des deux aires. La composition de la flore, en même temps que les couches de houille associées, indique que ces végétaux se sont développés dans un climat relativement chaud, à précipitations abondantes et saisons bien définies.

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INTRODUCTION

Identifiable plant megafossils occur at many places in the Heiberg Formation of Late Triassic–Early Jurassic age in the eastern part of the Canadian Arctic Archipelago, particularly on Ellesmere Island (Fig. 5.1). The flora, which has not been previously described, is of particular interest because it is one of only ten high-paleolatitude Upper Triassic–Lower Jurassic floras known in the northern hemisphere (Fig. 5.2) and is the most northerly of such floras in the western hemisphere. The fossils are mainly impressions of leaves, stems, and reproductive structures, and a small amount of permineralized wood. Although some of the fossils have been identified in previous reports, none has ever been described or used to correlate the enclosing strata with other units, except very superficially.

In this report we discuss 25 genera of plant megafossils collected since 1955 from 11 localities in the Heiberg Formation on Ellesmere, Axel Heiberg, Cornwall, and Cameron islands in the eastern part of the Arctic Archipelago (Table 5.1, Appendix). The diversity of flora at most of these localities is small, often consisting of only one or two species. However, at localities 2 (Fig. 5.3) and 3 on Ellesmere Island, where samples were systematically collected, the floral diversity is much greater (see Appendix). Also noteworthy is locality 6, where a small collection includes at least four species, including a cone and reproductive structure (Pl. 5.3, figs. 5, 10).

The Heiberg flora contains elements of both the Upper Triassic (Upper Norian[1]) *Lepidopteris* flora and the Lower Jurassic (Hettangian) *Thaumatopteris* flora recognized in east Greenland, Sweden, and Siberia (see Vakhrameev, 1964 and Vakhrameev et al., 1970 for summaries). However, it seems most closely related to the Upper Triassic *Lepidopteris* flora, particularly that described from east Greenland by Harris (1926, 1931, 1932a, b, 1935, 1937), the only other high paleolatitude flora known in the northern part of the western hemisphere.

The fossils described and illustrated here have been deposited in the collections of the Geological Survey of Canada (GSC) in Calgary and the National Museum of Natural Science, Paleobiology Division (PB) in Ottawa. Most of the duplicate specimens from localities 1-3 are stored in the University of Saskatchewan collections. A few selected duplicates from these localities have been deposited in the U.S. National Museum of Natural History (Smithsonian Institution), Washington, D.C.

PREVIOUS INVESTIGATIONS

Plant fossils apparently were discovered in the Heiberg Formation in 1853 by members of one of several parties sent in search of the Franklin Expedition (Tozer, 1963b). Petrified wood was found on Cameron Island (loc. 11, Fig. 5.1, the Appendix) by members of the search party led by Lt. Sherard Osborn (1855). No additional plant fossils were identified from the formation until over a century later when petrified wood and leaf impressions collected in 1955 during Operation Franklin were listed in the expedition report (Fortier et al., 1963). The impressions were found in the upper part of the unit at several scattered localities (locs. 4, 5, 7-9) on Axel Heiberg Island (Glenister, 1963; Souther, 1963) and identified by Wayne L. Fry. In the expedition report, Tozer (1963b) confirmed that petrified wood occurs in the Heiberg Formation on Cameron Island (loc. 11) and McLaren (1963) noted that it also occurs in the formation on Cornwall Island (loc. 10). In 1981, Suneby obtained a few plant megafossils from the Heiberg (loc. 6) on Axel Heiberg Island while collecting samples for palynological analysis. The following year J.F. Basinger and D.L. Dilcher collected a few impressions from the Heiberg at locality 2 on Ellesmere Island (Basinger, 1983, pers. comm.). The present authors made a systematic search in 1985 for plant megafossils in the Heiberg Formation, resulting in the discovery of two new localities (locs. 1, 3) on Ellesmere Island. A preliminary list of plant fossils collected at that time was published in Ash (1986).

Palynomorphs were first described from the Heiberg Formation by McGregor (1965). Since then they have been described from the formation at a number of localities in the Canadian Arctic Archipelago by several authors including Fisher and Bujak (1975), Bujak and Fisher (1976), Felix (1975), Felix and Burbridge (1977), and Fisher (1979). More recently, Suneby (1984) and Suneby and Hills (1988) studied the palynology of the Heiberg Formation in detail and recognized four biozones and two subzones in the unit.

STRATIGRAPHIC FRAMEWORK

The Heiberg Formation was originally defined by Souther in 1963, although it had been discussed in general

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[1] In this report we follow the recommendation of Tozer (1979) that the Rhaetian Stage be combined with the Norian Stage. Thus, the Rhaetian of previous reports (e.g., Harris, 1937) is deemed to be equivalent to the Late Norian, and the Norian–Hettangian boundary corresponds to the Triassic-Jurassic boundary.

terms by Tozer (1961). The distribution and general characteristics of the unit were summarized later by Thorsteinsson and Tozer (1970). Recently the formation was redefined and described in considerable detail by Embry (1982, 1983a, b). According to these authors the Heiberg Formation conformably overlies the Barrow Formation of Late Triassic age (Norian stage) and is conformably overlain by the Jameson Formation of Early Jurassic age (Pliensbachian and early Toarcian stages). The Heiberg consists predominantly of sandstone, siltstone, shale, and thin coal seams; it ranges in thickness from only a few metres along the margins of the basin to about 2000 m in the central part of the basin, immediately west of Axel Heiberg Island.

The Heiberg Formation in the eastern part of the basin, where the plant fossils described here occur, was divided by Embry (1983a) into three conformable members. In ascending order, they are the Romulus (50-400 m thick), Fosheim (up to 800 m thick), and Remus (up to 220 m thick) members.

The Heiberg Formation was deposited by northward-flowing streams in two large deltas that prograded into the Sverdrup Basin (Embry, 1982). Embry believes that the Romulus Member was deposited in a delta front environment whereas the Fosheim Member, which contains most of the plant fossils in this study, was deposited in a delta plain environment. The Remus

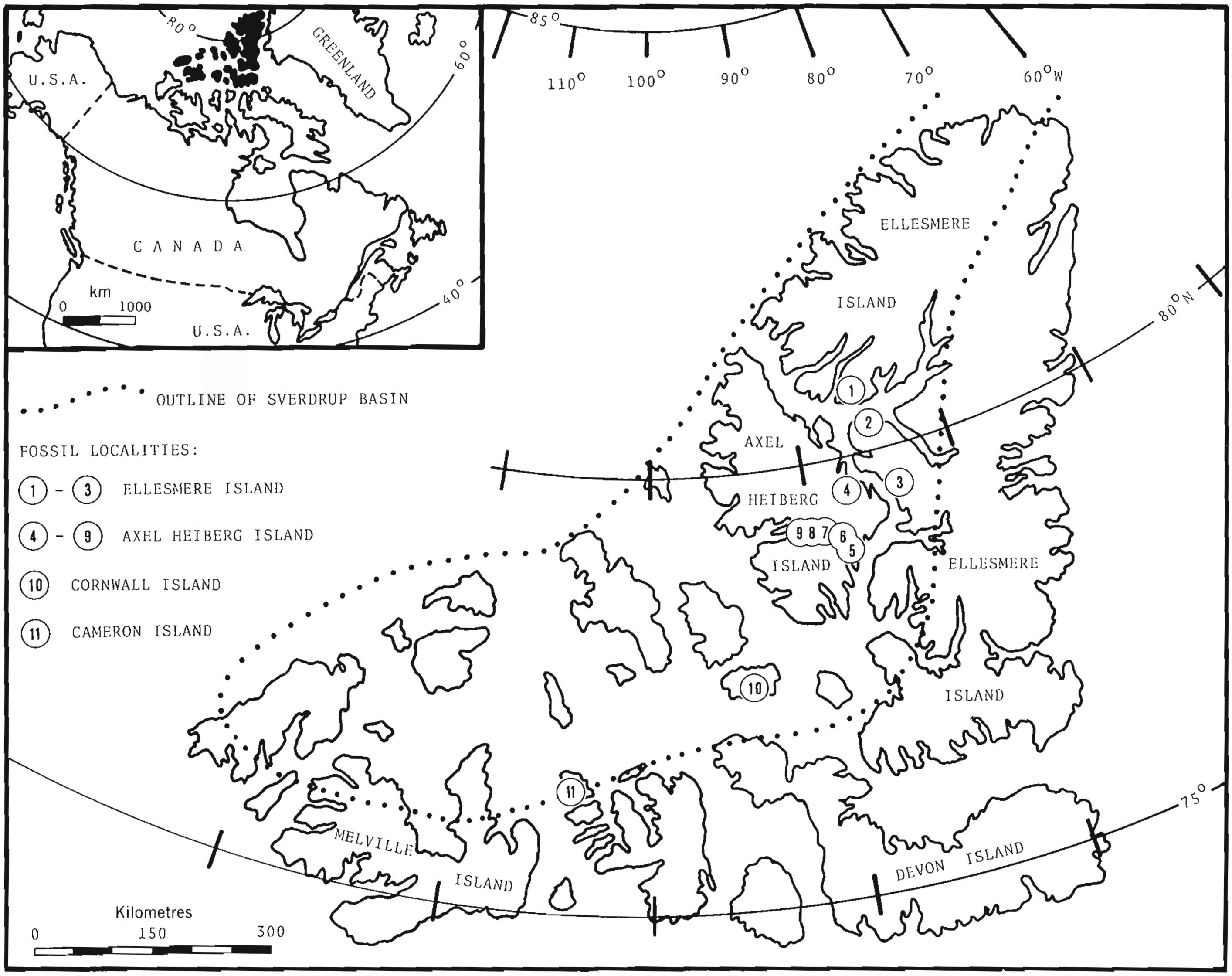

Figure 5.1. *Map of the northern Arctic Archipelago of Canada showing the outline of the Sverdrup Basin and plant megafossil localities in the Heiberg Formation. The index map shows the location of the Arctic Archipelago relative to the rest of Canada. The outline of the Sverdrup Basin was adapted from Embry (1983, Fig. 1).*

Member is thought to have been deposited in a beach and nearshore marine environment.

Embry (1983a), in redefining the Heiberg Formation, attempted to establish its age on the basis of invertebrates and palynomorphs found both in the formation and in the conformable underlying and overlying units. He inferred a Norian age for the Romulus Member, a Late Norian through Early Pliensbachian age for the Fosheim Member, and a Pliensbachian to Early Toarcian age for the Remus Member. Suneby (1984) and Suneby and Hills (1988) found that the members defined by Embry did not coincide exactly with their three biostratigraphic zones. They agree with Embry that the Romulus Member is Norian in age and that the base of the Fosheim Member is of Late Norian age. They also concurred with Embry that the Fosheim Member contains the Triassic–Jurassic boundary. However, they found that the upper limit of the Fosheim Member is not the same age over the entire region. It appears to vary considerably in age, particularly in the sections examined by Suneby (1984), possibly terminating in the Hettangian or extending into the Pliensbachian. Therefore the time represented by the Fosheim Member is much more restricted in many places than realized by Embry (1983a).

The base of the Remus Member, which conformably overlies the Fosheim Member, therefore must vary in age areally, from Hettangian to Pliensbachian. Suneby (1984) and Suneby and Hills (1988) generally agree that the top of the Remus Member is Pliensbachian–Early Toarcian in age.

In summary, the Heiberg Formation ranges from the Early Norian Stage of the Late Triassic to the Early Toarcian Stage of the Early Jurassic according to Embry, 1983 or into the Early Pliensbachian to Early Toarcian of the Early Jurassic according to Suneby, 1984 and Suneby and Hills, 1988.

CORRELATION AND AGE OF THE HEIBERG FLORA

W.L. Fry, who (*in* Tozer, 1963a) identified the plant fossils collected during Operation Franklin, considered the flora insufficiently varied to permit a precise age determination. However, he suggested that the flora was Late Triassic to Early Jurassic in age because it resembled the flora of that age described from east Greenland by Harris (1937).

Many of the plant megafossils known from the Heiberg Formation occur in both Upper Triassic (Late Norian) and Lower Jurassic (Liassic) floras at many localities in the northern hemisphere, particularly in east Greenland, Sweden, and Siberia. Conspicuous by their absence in the Heiberg flora are two key forms: *Lepidopteris*, the index fossil for the Upper Triassic *Lepidopteris* floral zone, and *Thaumatopteris*, the index fossil for the Lower Jurassic *Thaumatopteris* floral zone as established by Harris (1937). Some of the plant megafossils, such as *Phlebopteris* sp. cf. *P. angustiloba, Camptopteris spiralis*, and *Anthrophyopsis crassinervis*, are short-ranging forms that occur elsewhere only in Upper Triassic strata. Only one of the fossils discussed here (*Podozamites* sp.) seems to occur exclusively in Lower Jurassic (Hettangian) strata.

The discrepancy in the ages of the fossils studied here may be due partly to the fact that the older collections were made without good stratigraphic control, prior to the subdivision of the formation into members, so that some of the fossils are from horizons of significantly different ages. Further work on the stratigraphy and flora of the Heiberg may show that some of the localities discussed here occur below the Triassic–Jurassic boundary and that others occur above it. For example, the flora from localities 3 and 8 most probably occurs in the Upper Triassic portion of the Heiberg whereas the flora from locality 2 could be from the Lower Jurassic part of the formation. Currently it appears that the bulk of the known Heiberg flora is Late Triassic in age.

UPPER TRIASSIC AND LOWER JURASSIC FLORAL PROVINCES AND THE HEIBERG FLORA

Two Upper Triassic floral areas have been recognized in the northern hemisphere by Dobruskina (1982): a Siberian area (Siberian-Canadian area of Meyen, 1987) to the north (see Fig. 5.2) and a more southerly European-Sinian area (Equatorial area of Meyen, 1987). The boundary between the two areas was near or slightly north of 60°N paleolatitude, although it dipped south and approached 55°N paleolatitude in European Russia, as shown in Figure 5.2.

The flora of the Siberian area seems to be somewhat impoverished. It is dominated by horsetails (*Neocalamites, Equisetites*), ferns (especially *Cladophlebis, Todites*), peltasperms, and ginkgoes, such as *Sphenobaiera*. Dipterid ferns (such as *Clathropteris*) and cycadophytes rarely occur. This flora has been recognized in the U.S.S.R. at localities 7, 11, 16-18 (Fig. 5.2).

The flora in the more southerly Late Triassic European–Sinian area is much richer. It includes abundant ferns (e.g., *Marattiopsis, Todites, Dictyophyllum, Clathropteris, Camptoperis,* and *Phlebopteris*), many cycadophytes (*Pterophyllum,* *Anomozamites, Nilssonia*) and conifers (*Podozamites, Swedenborgia, Voltzia*), several ginkgoes such as *Ginkgo, Ginkgoites, Baiera,* and *Sphenobaiera*, and czekanowskias (*Czekanowskia*). This flora occurs at localities 1-6, 13-15, 19-22, 25, 26 (Fig. 5.2).

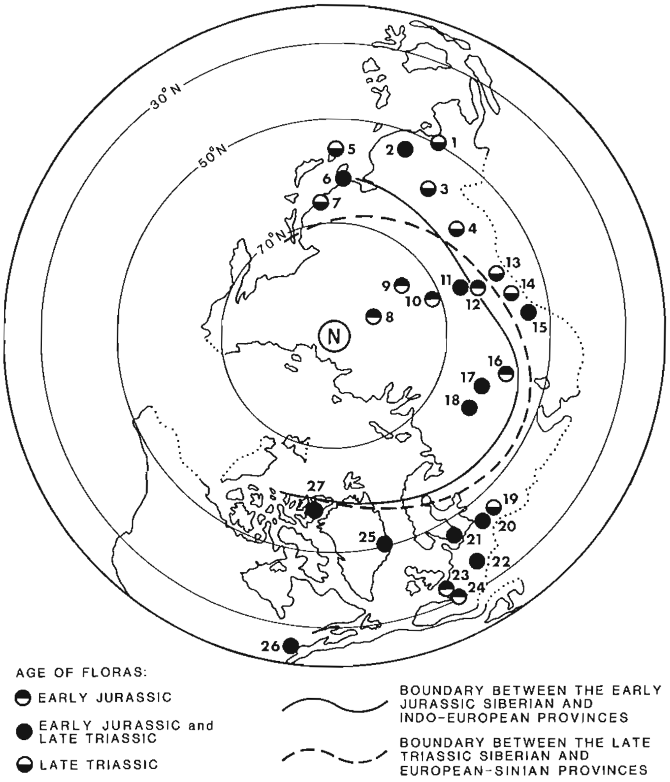

Figure 5.2. *Predrift map, 200 million years ago, of the northern hemisphere showing significant Upper Triassic and Lower Jurassic plant megafossil localities and the principal localities in the Heiberg Formation. The boundaries between the Siberian and European-Sinian floral areas are indicated for the Upper Triassic by a dashed line (after Dobruskina, 1982) and for the Lower Jurassic by a solid line (after Vakhrameev, 1964). In both cases, the Siberian area is to the north and the European-Sinian area to the south of the line. The base map was adapted from Smith et al., 1981, Ziegler et al., 1982, Irving, 1983, and Scotese and Denham, 1988. Locality data are from Vakhrameev, 1964, Barnard, 1973, and Dobruskina, 1982. The localities are as follows: 1, Tonkin; 2, Hunan; 3, Szechuan; 4, Xizang; 5, Yamagushi; 6, Korea; 7, south Primoria; 8, Vilyuy depression; 9, Kansk; 10, Chlym/Yenise; 11, Kenderlyk; 12, Alakol; 13, Issyk Kul; 14, Sonkul; 15, Fergana; 16, Turgay; 17, Chelyabinsk; 18, Bogoslvsk; 19, Hungary; 20, Poland; 21. Scania; 22, Franconia and adjacent areas in France; 23, Normandy; 24, Vendee et Serres; 25, Greenland; 26, Hartford Basin; 27, Ellesmere Island.*

Two floral areas also have been recognized in the Early Jurassic in the northern hemisphere by Vakhrameev (1964): a Siberian area (Siberian-Canadian area of Meyen, 1987) to the north and a more southerly European-Sinian area (Equatorial area of Meyen, 1987). The boundary between these two areas was generally a few degrees south of the boundary between the Triassic areas described above. However, weak evidence suggests that they may have coincided in Scandinavia and Greenland.

The Lower Jurassic floras of the Siberian area are generally small. Typically they are dominated by the fern *Cladophlebis*, the conifer *Podozamites*, and the ginkgophytes (*Ginkgoites, Sphenobaiera*), they lack dipterid ferns, and contain few cycadophytes. These floras occur at localities 8-12, 16-18 (Fig. 5.2).

The Lower Jurassic floras of the European-Sinian area contain an abundance of large horsetails (*Neocalamites*), dipterid ferns (*Clathropteris, Thaumatopteris*), cycadophytes (e.g., *Zamites, Otozamites, Anomozamites*), conifers (*Podozamites, Pagiophyllum, Brachyphyllum*), and ginkgophytes (*Ginkgo, Ginkgoites, Baiera, Sphenobaiera*), together with a few species of *Phlebopteris, Cladophlebis,* and *Todites*. Lower Jurassic European-Sinian floras occur at localities 2, 6, 12-15, 20-26 (Fig. 5.2).

It appears that the Heiberg flora (see Table 5.1), with its abundance of large horsetails (*Neocalamites*), dipterid ferns (*Camptopteris spiralis* and *Clathropteris meniscoides*), ginkgophytes (*Ginkgo siberica, Sphenobaiera spectabilis*), and conifers, together with the paucity of *Cladophlebis*, probably belongs to the Upper Triassic European-Sinian area of Dobruskina (1982). However, it also has some characteristics of the floras of the Upper Triassic Siberian Province of Vakhrameev (1964) because it contains an abundance of ginkgophytes and only a few cycadophytes. As the flora contains some of the elements found characteristically in both floral provinces, it is possible that the Heiberg flora grew near the border between the two provinces, as shown in Figure 5.2, or that there was no such division in the western hemisphere.

PALEOCLIMATIC IMPLICATIONS

The composition of the Heiberg flora, as well as certain features of the individual plants, are helpful in interpreting the climate under which the plants grew. The large horsetails (*Neocalamites*), with stems up to 12 cm in diameter, and large fern leaves, such as *Camptopteris* and *Clathropteris*, indicate a warm moist climate, as modern horsetails and ferns grow largest in such climates. The nearest living relatives of both these ferns now inhabit areas in Malaysia where the climate is warm to hot and very moist, because cycadophytes generally are thought to have lived in slightly drier areas. The rarity of cycadophytes (e.g., *Ptilophyllum, Anomozamites,* and *Pterophyllum*) in the Heiberg flora probably implies that the climate was very moist. These forms were restricted to local areas of well drained soils away from water courses, similar to conditions where modern cycads grow. The presence of ginkgophytes also suggests a warm moist climate; fossil ginkgophytes (e.g., *Ginkgo* and *Sphenobaiera*) found in Eurasia are generally considered

TABLE 5.1

Systematic list of plant megafossils found in the Heiberg Formation, Arctic Islands

Taxa	Localities[1]										
	1	2	3	4	5	6	7	8	9	10	11
Class Sphenopsida											
Equisetites grosphodon					•						
Neocalamites hoerensis		•	•								
Class Filicopsida											
Order Marattiales											
Marattiopsis sp. cf. *M. asiatica*	•										
Order Filicales											
Todites recurvatus		•			?						
Phlebopteris angustiloba								•			
Camptopteris spiralis								•			
Clathropteris meniscoides			•		•						
Cladophlebis sp.			•								
Class Gymnospermopsida											
Order Cycadeoidales											
Ptilophyllum sp.							•		?		
Anomozamites sp.									•		
Pterophyllum subaequale				•							
Order Ginkgoales											
Ginkgo siberica		•	•								
Sphenobaiera spectabilis		•	•								
Order Czekanowskiales											
Czekanowskia sp.		•									
Order Voltziales											
Swedenborgia major		•									
Order Coniferales											
Stachyotaxus elegans						•					
Podozamites sp.		•	•			•					
Pelourdea sp.			•								
Araucarioxylon sp.											•
Mesembrioxylon sp. A										•	
Cone A			•								
Cone B						•					
Order uncertain											
Taeniopteris tenuinervis		•	•								
Reproductive structure A						•					
Anthrophyopsis sp. cf. *A. crassinervis*			•								

[1] Localities are shown on the index map (Fig. 5.1) and described in the appendix.

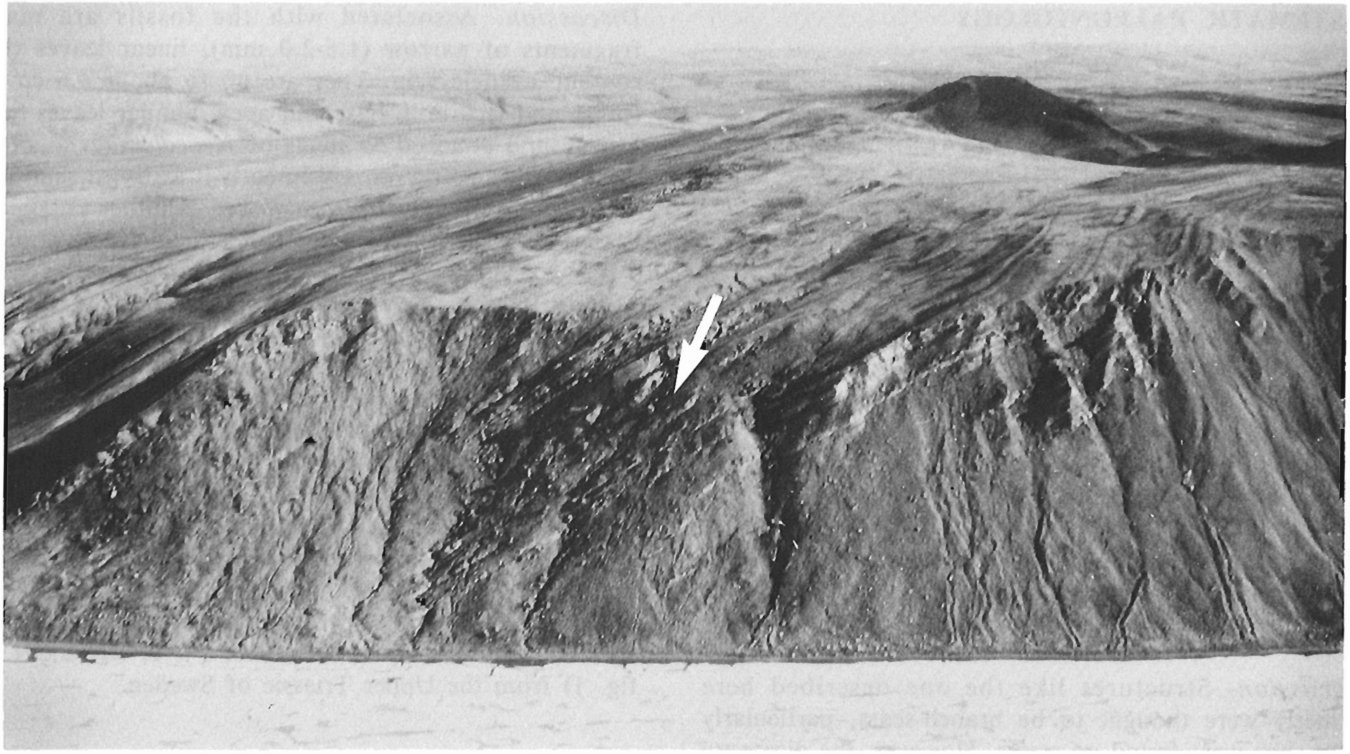

Figure 5.3. A view of the Heiberg Formation on the south side of Greely Fiord. Locality 2, (indicated by arrow), is in the upper part of the Fosheim Member of the Heiberg Formation near the top of the sea cliffs. Photograph by SRA.

to have lived in warm moist conditions. Their northward displacement during Middle and Late Jurassic time is attributed to growing aridity in southern Eurasia (Vakhrameev, 19 64). Extant conifers are adapted to a wide variety of climatic regimes but are commonly found under somewhat dry conditions. The few conifers known in the Heiberg flora probably lived on higher and better drained areas than the bulk of the flora.

The presence of broad growth rings in conifer wood (*Mesembrioxylon*) supports the theory that rainfall was sufficient during most of the growing season. The growth rings also imply that seasonality was moderately well developed; because the late wood is narrow, it would appear that dormancy was brought on very rapidly, possibly in response to shorter days at high paleolatitudes. According to Parrish and Spicer (1988), such changes are characteristic of high-latitude areas lacking extremes of temperatures. Thus it appears that most of the Heiberg flora grew under moist, warm conditions, and that seasonal changes did occur.

MATERIALS AND METHODS

The plant fossils described here vary considerably in preservation. Most are represented by impressions on bedding planes of brown-weathering, hard grey sandstone, as at localities 1-3 (see Appendix). Many of the ferns are preserved in this manner, as are the cycadophytes and some specimens of the conifer *Podozamites*. A few ferns and cycadophytes have been found as carbonized impressions within grey sandstone (locs. 5, 7, 8). Ginkgophytes are usually represented by carbonaceous compressions, as at localities 2 and 3, although they are also found in brown-weathering, hard, grey sandstone. Most coniferous fossils occur in black carbonaceous shale, as at locality 6, and are represented by shiny impressions. Wood is permineralized by quartz.

The natural system of plant classification proposed by Stewart (1983) has been adopted for the systematic treatment of the Heiberg flora.

SYSTEMATIC PALEONTOLOGY

Class SPHENOPSIDA

Order EQUISETALES

Genus *Equisetites* Sternberg

Equisetites grosphodon Harris

Plate 5.1, figure 5

Occurrence. Fosheim Member of the Heiberg Formation, Axel Heiberg Island. Figured specimen GSC 90705 from locality 5. Previously known only from the Upper Triassic of east Greenland (Harris, 1931).

Description. The species is represented by a single nodal diaphragm that shows a central granular area bordered by a ring of spokes and a smooth narrow rim.

Discussion. Structures like the one described here formerly were thought to be branch-scars, particularly when they were found on stems. However, the discovery of some isolated structures with attached leaves showed that they were actually nodal diaphragms (Seward, 1898). Nodal diaphragms commonly occur in lower Mesozoic floras, such as the Upper Triassic and Lower Jurassic east Greenland flora described by Harris (1926, 1931). The Heiberg specimen compares most closely in size and general features to the diaphragms attributed to *Equisetites grosphodon* by Harris (1931).

Genus *Neocalamites* Halle

Neocalamites hoerensis (Schimper) Halle

Plate 5.1, figures 1-3

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimens GSC 96630, 96632 from locality 3, and GSC 96631 from locality 2. *Neocalamites hoerensis* occurs at many Upper Triassic localities in Greenland, Europe, and Asia (Boureau, 1964; Duan, 1987) and at Lower Jurassic localities in Japan (Kimura, 1959b).

Description. The fossils assigned to this species are incomplete impressions and pith casts of aerial stems. The impressions are up to 16.0 cm in width and 65 cm in length; the pith casts are about 3.5 cm in diameter and up to 6.3 cm in length. Typically, the surface of both types of fossils shows longitudinal ridges and nodes. Small, round leaf scars about 1 mm in diameter are present at the nodes in four specimens.

Discussion. Associated with the fossils are many fragments of narrow (1.5-2.0 mm), linear leaves that contain a single vein. They are up to about 4.6 cm in length and lack both base and apex. Similar leaves have been found attached to stems of *Neocalamites* at other localities (e.g., Kon'no, 1962), so it is assumed that here they also are leaves of *Neocalamites*. Another possibility is that they are fragments of the leaf *Czekanowskia*.

Most species of *Neocalamites* are rather imperfectly differentiated from each other, so comparisons are difficult. However, the fossils described here compare most closely with those attributed to *N. hoerensis* (e.g., Halle, 1908; Harris, 1931; Boureau, 1964). Particularly important is the size of the specimen and the fact that it does not show lateral branches. This indicates that lateral branches were not usually borne in regular whorls, which is also the case in other specimens assigned to *N. hoerensis* (Harris, 1931, p. 29). GSC specimen 96630 (Pl. 5.1, fig. 1) closely compares with specimens of the species illustrated by Halle (1908, Pl. 1, fig. 3, Pl. 2, fig. 1) from the Upper Triassic of Sweden.

Class FILICOPSIDA

Order MARATTIALES

Family MARATTIACEAE

Genus *Marattiopsis* Schimper

Marattiopsis sp. cf. *M. asiatica* Kawasaki

Plate 5.1, figure 4

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96633 from locality 1. *Marattiopsis* and the fossil species of *Marattia* occur most commonly in the Lower Jurassic, such as in Sweden (Antevs, 1919; Lundblad, 1950), Greenland (Harris, 1931), Iran (Kilpper, 1964), Israel (Lorch, 1961), and China (Zhiyan, 1983), and in younger strata (e.g., the Middle Jurassic of England—see Harris, 1961), as well as in the Upper Triassic of Vietnam (Zeiller, 1903), Korea (Kawasaki, 1939), China (Hsu et al., 1979), and Japan (Kimura and Tsujii, 1980). *Marattiopsis asiatica* occurs principally in the Upper Triassic and Lower Jurassic of Asia.

Description. This specimen is an imprint of a pinna that lacks a base. Its margin is entire and the apex tapers abruptly to an acuminate tip. Most of the veins are unbranched, although a few branch once either close to the midrib or near the margin.

Discussion. It is uncertain whether this fossil represents a sterile pinna or is merely the sterile apical portion of a much longer fertile pinna, such as the specimen of *Marattiopsis horensis* illustrated by Antevs (1919, Pl. 2, fig. 6) from the Lias of Sweden. Although the fossil examined here is incomplete, enough material is present to demonstrate that it has the characteristics of both the fossil genus *Marattiopsis* and the living genus *Marattia.* Harris (1961) attributed fossils like this to *Marattia,* but we prefer to assign it to the fossil genus because nothing is known about its reproductive organs. If these are subsequently described and prove similar to those of the living taxon, we would recommend assigning the fossil to *Marattia.*

The pinna base, required for certain specific identification, is unfortunately lacking. Otherwise, the fossil compares very closely in outline, width, and vein density with specimens attributed to *Marattiopsis asiatica* Kawasaki (1939) from many localities in the Upper Triassic and Lower Jurassic of Asia (Kimura and Tsujii, 1980). The fossil is very similar to the specimens described by Hsu et al. (1979) from the Upper Triassic of Sichuan, China, and by Caifan (1982) and Zhyan (1983) from the Liassic of Hunan, China. The specimen can be distinguished from *M. horensis* (Schimper) Thomas from the Lower Jurassic of Sweden (Antevs, 1919, Pl. 2, figs. 6-8) because it has less dense venation (10 per cm versus 20 per cm in the present fossil) and significantly wider pinnae. The venation is also less dense (10 per cm at the margin) in the more widely distributed species *M. muensteri,* although the Heiberg specimen is within the size range of that species (see Harris, 1931).

Order FILICALES

Family OSMUNDACEAE

Genus *Todites* Seward

Todites recurvatus Harris

Plate 5.1, figures 13, 14

1963a, b *Asplenium* (*Cladophlebis*) *argutulum* Geyler. Fry, *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island and Axel Heiberg Island. Figured specimens GSC 96634 and 96635 from locality 2. GSC specimen 90711 from GSC locality 4 (identification questionable). *Todites recurvatus* was previously known only from the Liassic of Greenland (Harris, 1931) and the Carnian of Japan (Takahashi, 1950; Kimura, 1980).

Description. The pinnules of this fossil are slightly falcate in outline and are so closely set that they overlap slightly. Lateral veins arise from the pinnule midrib at a low angle and most fork once near the margins; those near the base of the pinnule fork twice. Margins of the pinnules are entire in the lower part but bear slightly recurved minute teeth in the upper part. The teeth are equal in number to the veins reaching the margin of the pinnule.

Discussion. The fossil (GSC 90711) from locality 4, attributed to *Asplenium* (*Cladophlebis*) *argutulum* by Fry (*in* Souther, 1963, p. 434), may actually be a poorly preserved specimen of *Todites recurvatus.* The pinnules are the typical size for *T. recurvatus* and the gross morphology is similar. However, no apical teeth are visible on the pinnules, so the fossil can only be tentatively referred to *T. recurvatus.*

The other fossils (GSC 96634, 96635) compare very closely in both morphology and size with the type material of *T. recurvatus* described from the Liassic of east Greenland by Harris (1931). The fine, recurved marginal teeth of the Heiberg specimens are particularly similar to those found in the specimens from Greenland. This species can be distinguished from *Todites denticulata,* a more widely distributed lower Mesozoic species that also has a denticulate margin, because *T. recurvatus* does not show specialized basiscopic pinnules on each pinna (see Harris, 1961). Furthermore, the pinnules of the present species are slightly shorter than the sterile pinnules of *T. denticulata.*

Family MATONIACEAE

Genus *Phlebopteris*

Phlebopteris angustiloba

Plate 5.1, figure 7

1963a, b *Laccopteris* sp. indet. Fry *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Probably the Fosheim Member of the Heiberg Formation but possibly the upper part of the underlying Romulus Member, Axel Heiberg Island. Figured specimen GSC 90707 from locality 8. *Phlebopteris* is widely distributed in Upper Triassic and Jurassic floras of the northern hemisphere (Andrews, 1970). *Phlebopteris angustiloba* is relatively common in the Lower Jurassic of east Greenland (Harris, 1931), Sweden (Nathorst, 1878; Antevs, 1919), Germany (Gothan, 1914), and Poland, and also occurs in the Upper Triassic of Poland (Raciborski, 1891).

Description. The pinnules in this fossil are linear and arise at right angles from the pinna rachis. The pinnule midrib is narrow. Although the lateral venation is not clearly visible, the pinnules do show rectangular fields.

Discussion. Phlebopteris has priority over the name *Laccopteris* and the latter name should be ignored (Arnold, 1947). Although this fossil is incomplete, it clearly shows several of the characteristic features of the genus *Phlebopteris*. The specific assignment is somewhat uncertain, but the fossil does compare fairly closely with some of the specimens attributed to *Phlebopteris angustiloba* by Hirmer and Hoerhammer (1936, Pl. 6, figs. 4, 4a) and others (e.g., Harris, 1931; Tralau, 1965).

Family DIPTERIDACEAE

Genus *Camptopteris* Presl (Nathorst)

Camptopteris spiralis Nathorst

Plate 5.1, figure 6

1963a, b *Dictyophyllum* sp. Fry *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Probably the Fosheim Member of the Heiberg Formation or possibly the upper part of the Romulus Member, Axel Heiberg Island. Figured specimen GSC 90706a from locality 8. *Camptopteris* seems to be an exclusively Upper Triassic taxon. The species *C. spiralis* was known previously only from the uppermost Triassic of Sweden. *C. lunzensis* occurs in the Carnian of Austria, and *C. japonica* occurs in the Carnian of Japan.

Description. The several slender pinnae fragments contain straight slender midribs, and show reticulate venation and low, marginal teeth pointing forward. The vein meshes formed by the secondary veins in the lamina are about 1 mm in diameter.

Discussion. Because no carbonaceous residue is present on these specimens, they are difficult to illustrate. However, all specimens show the typical venation of the species and a small portion of the toothed margin. All of the fragments examined are isolated, but three lie parallel to each other on the bedding plane of one rock sample and may be the remains of adjacent pinnae of the same leaf.

Although the specimens are fragmentary, they show some of the characteristic features of the genus *Camptopteris*, such as slender pinnae with low teeth and reticulate venation. The present fossils compare most closely with the genotype, *C. spiralis* (cf. Pl. 5.1, fig. 6 with Nathorst, 1878, Pl. 4, figs. 4, 5 and Nathorst, 1906, Pl. 7, fig. 12) of the three species attributed to *Camptopteris*. They can be distinguished from *C. japonica* (Yokoyama) Kon'no (1968) by the narrower pinna with shallower toothed margins and from *C. lunzensis* Stur (1883) by the toothed rather than smooth margin.

Genus *Clathropteris* Brongniart

Clathropteris meniscoides Brongniart

Plate 5.1, figures 8-12

1963a, b *Clathropteris meniscoides* Brongniart. Fry, *in* Tozer, p. 81 and *in* Glenister, p. 477.

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island and Axel Heiberg Island. Figured specimens GSC 96636, 96637a, b, 96638 from GSC locality 3, GSC 90708 from GSC locality 5, and GSC 90709 from GSC locality 5. *Clathropteris meniscoides* is widely distributed in the uppermost Triassic and the Lower Jurassic throughout the world, including east Greenland (Harris, 1931), Japan (Kimura, 1980), China (Hsu et al., 1979; Zhiyan, 1983), and in eastern United States (Cornet et al., 1973).

Description. These specimens are mostly fragments of broad pinnae that show large forward curving marginal teeth. Primary branch veins come off the pinna rachis at a high angle and then bend forward at a lower angle where each enters a marginal tooth. Secondary branch veins form large prominent meniscus-shaped meshes. Tertiary branch veins form small square to polygonal meshes, which occasionally contain blind-ending branches.

Discussion. The abundance of specimens of this species is probably a reflection of both its large size as well as its frequency in the flora. Although most of the fragments are rather small, they show some features characteristic of the taxon. The meniscus-shaped vein meshes, typical of the species, are especially important.

Family uncertain

Genus *Cladophlebis* Brongniart

Cladophlebis sp.

Plate 5.1, figure 15

1963a, b *Cladophlebis* sp. indet. Fry, *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96639a, and other specimens from GSC locality 3. *Cladophlebis* occurs widely in Triassic-Lower Cretaceous rocks and is of little biostratigraphic value.

Description. The pinnules are slightly oblong and falcate and are connected by a narrow strip of undivided lamina. The pinnule margins are typically entire. The midribs are slender, usually slightly undulate, and run nearly to the apex. Lateral veins arise at a low angle from the midrib and fork two or three times with their branches forking once or, imperfectly, twice.

Discussion. *Cladophlebis* is widely distributed in lower Mesozoic strata throughout the world. Most of the species attributed to this genus have been distinguished on the basis of minor differences. Harris (1931) reported the occurrence of four species of *Cladophlebis* in the Upper Triassic-Lower Jurassic of east Greenland. Because the present material is so limited and the morphology is not particularly distinctive, it seems fruitless to compare it to any of the presently known species.

Class GYMNOSPERMOPSIDA

Order CYCADEOIDALES

Genus *Ptilophyllum* Morris

Ptilophyllum sp.

Plate 5.2, figure 9

1963a *Ptilophyllum* sp. Fry, *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Possibly the Fosheim Member of the Heiberg Formation but more likely the underlying Romulus Member, Axel Heiberg Island. Figured specimen GSC 90712 from GSC locality 7. *Ptilophyllum* ranges from the Upper Triassic into the Lower Cretaceous (Meyen, 1987).

Description. The leaf is once pinnate. The pinnae attached to the top of the rachis are straight to slightly falcate in outline with rounded apices directed forward and with asymmetrical bases. The basiscopic margin of each pinna is generally concealed by the next pinna below but apparently is decurrent, whereas the acroscopic margin is contracted and forms a rounded angle.

Discussion. Specimen GSC 90712 from locality 7 forms the basis for the above description as it was the only specimen assigned by Fry to this taxon that could be located. Although the specimen from locality 9 was not examined by us, it is tentatively assigned to *Ptilophyllum* sp. This specimen compares fairly closely with some of the fossils from the Lower Jurassic of Japan that were assigned to *Ptilophyllum nipponicum* by Kimura and Tsujii (1982, Pl. 42, figs. 4, 8). They are about the same size as the Heiberg specimen and also have decurrent basal margins and rounded acroscopic margins. The fossil described here also resembles those from the Jurassic of India attributed to *Ptilophyllum distans* (Feistmantl) Jacob and Jacob (1954) by Bose and Kasat (1972, Pl. 6, fig. 52), although the Heiberg specimen is somewhat larger. The specimen compares less closely with *Ptilophyllum cutchesne* described from the Jurassic of central Asia by Iminov (1976, Pl. 18, fig. 1).

Genus *Anomozamites* Schimper

Anomozamites sp.

Plate 5.2, figure 10

1963a *Anomozamites* sp. Fry, *in* Tozer, p. 31 and *in* Souther, p. 434.

Occurrence. Fosheim Member of the Heiberg Formation, Axel Heiberg Island. Figured specimen GSC 90713 from GSC locality 9. *Anomozamites* ranges from the Upper Triassic to the Lower Cretaceous (Harris, 1969).

Description. The leaf is once pinnate. The rachis bears oppositely arranged pinnae attached to the top of the rachis. They are falcate in outline with rounded apices directed forward, and nonconstricted bases. The outline and proportions of the pinnae indicate that this specimen is assigned to the correct genus. However lack of preservation of its cuticle makes specific identification uncertain. The fossil does resemble several Upper Triassic-Lower Jurassic species of *Anomozamites* (e.g., *A. minor* and *A. nitida*) in general appearance and size (cf. Harris, 1932a, figs. 10A, 11E; Iminov, 1976, Pl. 2). However, these and most other species of the genus can be separated only on the basis of their cuticles.

Genus *Pterophyllum* Brongniart

Pterophyllum subaequale Hartz

Plate 5.2, figures 6, 7

1963a *Pterophyllum subaequale* Hartz. Fry, *in* Tozer, p. 81 and *in* Souther, p. 434.

Occurrence. Fosheim Member of the Heiberg Formation, Axel Heiberg Island. Figured specimens GSC 90714 and 90715 from GSC locality 4. *Pterophyllum subaequale* is known primarily from the Upper Triassic of Sweden (Johansson, 1922) and the Lower Jurassic of east Greenland (Harris, 1932a).

Description. The two poorly preserved fossils indicate that the leaf is once pinnate. The pinnae are attached laterally and are linear with parallel sides, almost symmetrically expanded bases, and blunt apices.

Discussion. The fragmentary nature of the specimens makes it impossible to determine the length of the leaves. The specimens consist of just a portion of the rachis and bases of the pinnae. Only one specimen shows entire pinnae.

These fossils compare fairly closely in general morphology and size with *Pterophyllum subaequale* from the Lower Jurassic (*Thaumatopteris* Zone) in Greenland (Harris, 1932a, fig. 41A) and from the Upper Triassic of Sweden (Johansson, 1922). The rachis in the Heiberg fossils also has a wrinkled surface, which is characteristic of that species, although the pinnae venation is slightly denser (4 per mm versus 3 per mm in the specimens from Greenland). The present fossil is also close to *Pterophyllum astartense* from the Upper Triassic (*Lepidopteris* Zone) of Greenland (cf. Harris, 1932b, figs. 19A, 20A) but that species typically has a smooth rachis and much shorter pinnae.

Order GINKGOALES

Family GINKGOACEAE

Genus *Ginkgo* Linnaeus

Ginkgo siberica (Heer) Seward

Plate 5.2, figures 1, 4

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimens GSC 96640 and 96641 from localities 2 and 3, respectively. *Ginkgo siberica* has been described by many authors from numerous Upper Triassic to Lower Cretaceous localities worldwide.

Description. This leaf has a distinct petiole and a wedge-shaped lamina, which is deeply divided into several segments. These are typically divided once again, resulting in 8-10 ultimate lobes with rounded apices. The divisions of the leaf are usually regular and the notch separating the ultimate lobes on each segment is relatively shallow compared with the divisions between the segments.

Discussion. These specimens vary from leaves that have long narrow segments and lobes to leaves with rather broad segments and lobes. Such variation is common within many species of *Ginkgo* and *Ginkgoites* (Seward, 1919; Harris, 1935; Harris and Millington, 1974).

The leaves described here are within the morphological range of several early Mesozoic species of *Ginkgo* and *Ginkgoites*. However, since the cuticle is commonly used to separate and define those species, it is difficult to fully compare the Heiberg leaves with them. The Heiberg leaves are especially similar to the cosmopolitan species *Ginkgo siberica* (Heer) Seward and to *G.* sp. cf. *G. siberica* Heer described from the Middle Jurassic of Yorkshire by Harris and Millington (1974). The Heiberg leaves have therefore been assigned to the species *G. siberica*. Another comparable species is *G. longifolius* (Phillips) Harris from the Middle Jurassic of Yorkshire. However, it commonly has five veins per segment whereas the Heiberg specimens usually have more than five. The latter specimens also resemble *Ginkgo taeniata* (Braun) Harris from the Lower Jurassic (*Thaumatopteris* Zone) in Greenland. However, the ultimate lobes in the Heiberg fossils are more regularly notched than in the Greenland specimens (cf. Harris, 1935, figs. 9, 10).

Genus *Sphenobaiera* Florin

Sphenobaiera spectabilis (Nathorst) Florin

Plate 5.2, figures 2, 3, 5, 8, 11

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimens GSC 96642a, b, 96643, 96644, 96645 from locality 2. In the northern hemisphere the genus *Sphenobaiera* ranges from the Upper Triassic to the Lower Cretaceous and is most common in the Lower and Middle Jurassic. Its range in the southern hemisphere seems to be more restricted. *Sphenobaiera spectabilis* is known from the Upper Triassic of Sweden (Lundblad, 1959) and Siberia (Dobruskina, 1982).

Description. The specimens are wedge-shaped leaves which lack distinct petioles. The lamina is usually divided into four broad ultimate segments by two successive dichotomies. The margins of the ultimate segments are nearly parallel except near the apices where they converge abruptly to form an acute apex.

Discussion. This taxon is one of the most abundant seed plants in the Heiberg flora. One of the complete leaves forks once, five others fork three times, and the remainder fork twice. Many of the leaves have rather broad (1.0-1.5 cm) segments and a few have very narrow (1.5-2.5 mm) whip-like segments. Harris (1926, 1935) reported that this species in the Upper Triassic–Lower Jurassic of east Greenland showed the same range in width of segments and that there were forms of intermediate width. The cuticles were also similar in all forms, so he assigned them to the same species. As no intermediate forms are present in our collection, it is possible that two different species are represented. However, because their cuticles have not been studied they all have been assigned to *Sphenobaiera spectabilis*.

The fossils described here compare most closely with *Sphenobaiera spectabilis* described from the Lias of Greenland by Harris (1926, 1935) and Sweden by Nathorst (1906), Johansson (1922), Florin (1936). In fact, they compare unusually closely with the type specimens described from Sweden by Nathorst (1906). Another similar species is *Sphenobaiera ophioglossum* from the Middle Jurassic of Yorkshire (Harris and Millington, 1974). However, in the Heiberg fossils, the segments diverge at a larger angle (75°-80° in *S. spectabilis* versus 8°-30° in *S. ophioglossum*) and the leaves have a shorter base. The Heiberg leaves resemble *S. stormbergensis* from the Upper Triassic Molteno Formation in South Africa, but the segment margins in the Heiberg specimens are parallel and taper to an apex over a shorter distance than in *S. stormbergensis* (cf. Pl. 5.2, fig. 4 with Anderson and Anderson, 1985, Pl. 199, fig. 4). They can be distinguished from most other species of *Sphenobaiera* on the basis of overall size of the leaf and width of the segments. For example, in many Triassic and Jurassic taxa (e.g., *S. paucipartia, S. pecten,* and *S. tenuifolia*) the segments are about one quarter the width of the segments of typical examples of *S. spectabilis* and they usually dichotomize three times or more.

Order CZEKANOWSKIALES

Genus *Czekanowskia* Heer

Czekanowskia sp.

Plate 5.2, figure 12

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96646 from locality 2. *Czekanowskia* ranges from the uppermost Triassic to the Lower Cretaceous (Harris and Miller, 1974). According to Vakhrameev et al. (1970) *Czekanowskia* was at its maximum distribution during the Middle Jurassic.

Description. The taxon is represented by single-veined leaves up to 8 cm long and about 1 mm wide. The leaf margins are parallel.

Discussion. Several bedding planes at locality 2 are covered with these fossils. It is almost certain that these fossils belong to *Czekanowskia*, although the base and apex of the leaves and the cuticle necessary for positive identification have not been observed. *Czekanowskia* often occurs with *Sphenobaiera* at other localities in the lower Mesozoic of the northern hemisphere in Siberia, Greenland, and Sweden.

These leaf fragments are within the size range of several species of *Czekanowskia* and also of *Solenites*. However, *Solenites* is known with assurance from only the Middle Jurassic and Upper Deltaic of Yorkshire (see Harris and Millington, 1974) and for that reason it is unlikely that the Heiberg fossils represent that genus.

Order VOLTZIALES

Family VOLTZIACEAE

Genus *Swedenborgia* Nathorst

Swedenborgia major Harris

Plate 5.3, figure 1

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96647 from locality 2. The genus seems to be restricted to the Upper Triassic and Lower Jurassic of Greenland (Harris, 1935), Korea (Kon'no, 1944), Russia (Stanislavsky, 1976), China (Duan, 1987), and Japan (Kimura, 1959a). The species *S. major* is otherwise known only from the Lower Jurassic (*Thaumatopteris* Zone) of Greenland.

Description. The cone scale consists of the upper part of a slender stalk and the remains of four of five sharply pointed lobes. It appears that the basal attachment of a seed is present near the base of the lobe (farthest right, Pl. 5.3, fig. 1).

Discussion. In his discussion of this genus, Harris (1935) noted that it occurred in Greenland in association with narrow-leafed species of *Podozamites*. It is interesting to note that a narrow-leafed *Podozamites* also occurs in the Heiberg flora most abundantly at the same locality as this specimen of *Swedenborgia*.

Although the Heiberg fossil is fragmentary, it almost certainly represents *Swedenborgia major* Harris (1935) as it compares closely with the type specimens described from the Lower Jurassic (*Thaumatopteris* Zone) of east Greenland. All other well known species of *Swedenborgia* are much smaller than the Heiberg specimen. In other respects it compares fairly closely with *S. attenuata* described form the uppermost Triassic of Korea by Kon'no (1944, Pl. 1, figs. 4, 10, 11). The Heiberg fossil is about the same size as *S. longiloba* Stanislavsky, but the individual lobes are much wider (cf. Stanislavsky, 1971, figs. 59a-m).

Order CONIFERALES

Family CEPHALOTAXACEAE

Genus *Stachyotaxus* Nathorst

Stachyotaxus elegans Nathorst

Plate 5.3, figure 2

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen PB 02985 from locality 6. *Stachyotaxus* occurs in the Upper Triassic and Lower Jurassic at several localities in Asia and western Europe.

Description. This species is represented by a single leafy shoot. The stem is slender and straight and bears linear-lanceolate leaves in two ranks that arise oppositely from the stem at a high angle.

Discussion. Specific classification of this specimen is uncertain without knowledge of its cuticular features. However it compares fairly closely with *Stachyotaxus elegans* from the Upper Triassic of Sweden (Nathorst, 1908) and Greenland (Harris, 1935). The fossil is similar to some of the specimens of *Stachyotaxus septentrionalis* described by Möller (1903) from the Lower Jurassic (Liassic) of Sweden.

Family uncertain

Genus *Podozamites* Braun

Podozamites sp.

Plate 5.3, figures 3, 8

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island and Axel Heiberg Island. Figured specimens GSC 96648 and 96649 from localities 2 and 3, respectively; other specimen from locality 6. The "type 1" *Podozamites* leaf of Harris occurs in the Lower Jurassic of east Greenland (Harris, 1935).

Description. The stem of the leafy shoot is slender, somewhat lax and bears spirally arranged linear lanceolate leaves. The leaf bases are twisted where they join the stem so that the leaves lay in a plane during life. The leaves have parallel margins and evenly contracted bases and apices.

Discussion. The leafy shoot must have been rather large, because the longest specimen, lacking both base and apex, measures about 17 cm. Complete leaves up to 5 cm in length are present. However, one leaf fragment is 7 cm long and, judging by the taper of the apical portion, this leaf could have been as long as 10 cm. These fossils conform with the group Harris (1935) called "narrow leafed *Podozamites*" which, as noted above, occur with the cone scale *Swedenborgia* in the Lower Jurassic of Greenland as it does in the Heiberg flora.

Some of the fossils described here resemble the isolated leaves from the Lower Jurassic of Sweden that Möller (1903, Pl. 1, fig. 1) attributed to *Podozamites lanceolatus*. They compare more closely with the fossils from the Lower Jurassic that Harris (1926) assigned to *Podozamites agardhianus*. Later, Harris (1935) placed these fossils in what he termed the "type 1" *Podozamites* leaf in the *schenki–agardhianus* group, one of four types he established to contain forms he felt could not be realistically assigned to a species without more data.

Genus *Pelourdea* Seward

Pelourdea sp.

Plate 5.3, figure 9

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96650 from locality 3. Ribbon-like leaves similar to those described here are so widespread in the Paleozoic and Mesozoic that they are of little biostratigraphic value.

Description. The specimen is a linear-lanceolate leaf that tapers gradually from the basal region to the apex. Although not completely preserved, the base of the leaf appears to be somewhat rounded. The margins of the leaf are entire and slightly enrolled.

Discussion. Ribbon-like leaves resembling these specimens occur at many localities in the Paleozoic and Mesozoic, which due to unknown affinities, have been referred to several different genera. Paleozoic forms are often referred to *Cordaites* Unger (1850), whereas Mesozoic forms have been assigned to *Pelourdea* Seward (1917), *Desmiophyllum* Lesquereux (1878), and others. Until more is known about the fossils described here it seems best to assign them to *Pelourdea.*

The only species in the Heiberg flora with which this fossil might be confused is an isolated leaf of *Podozamites* as both are narrow, long, and have parallel venation. However, *Podozamites* has parallel sides with flat margins whereas *Pelourdea* is linear-lanceolate and has enrolled margins. Also, this leaf is slightly more than twice as broad as the leaves of *Podozamites.*

The specimen is similar to the fossils Harris (1935) referred to *Desmiophyllum* type 3. There is also some resemblance to one of the specimens of *Desmiophyllum* type A described form the Upper Triassic of Russia by Stanislavsky (1976, Pl. 48, fig. 6).

Genus *Araucarioxylon* Kraus

Araucarioxylon sp.

Occurrence. Near the top of the Heiberg Formation, Cameron Island, locality 11. *Araucarioxylon* is widely distributed in both the Upper Paleozoic and Mesozoic, so it has little stratigraphic significance.

Discussion. Fry (*in* Souther, 1963) identified some petrified wood collected from the upper part of the Heiberg Formation on Cameron Island during Operation Franklin in 1955 as *Araucarioxylon* sp.. Apparently this wood came from the wood locality of Osborn (1855). Unfortunately, it has not been possible to locate the fossil wood collected in either 1853 or 1955.

Genus *Mesembrioxylon* Seward

Mesembrioxylon sp. A

Plate 5.3, figures 11-16

1963 *Protocedroxylon* sp. Bannan, *in* Souther, p. 530.

Occurrence. Fosheim Member of the Heiberg Formation, Cornwall Island. Figured specimens GSC 90716a, b, c from locality 10. *Mesembrioxylon* has a long stratigraphic range extending from the Permian into the late Tertiary (Thayn and Tidwell, 1984).

Description. The largest fragment has a diameter of about 18 cm. Typically the growth rings are faint and are usually about 50 to 70 tracheids wide. The late wood is only 2 to 6 tracheids wide. The transition from early to late wood is abrupt. The early tracheids are rectangular to square in cross-section and range from 12-24 μm x 24-38 μm with walls 18-22 μm thick. The lumens are generally elliptical to circular in cross-section. Late wood tracheids are small (typically 6-10 μm x 8-14 μm) and radially flattened with narrow oval lumens and walls that are 20-28 μm thick. Most tracheids are more than 1.2 mm long with wedge-shaped ends. Intercellular spaces and axial parenchyma are uncommon. Radial tracheary pitting is mostly uniseriate, rarely biseriate. The pits are bordered, generally separate and rarely contiguous. Typically pits are circular (7-10 μm in diameter) with small circular apertures about 2 μm in diameter. The borders are about 1 to 2 μm broad. No tangential pitting has been observed. Rays are abundant, about 6 to 10 a mm measure tangentially, and dominantly uniseriate, 1 to 26 cells high (typically 5 to 8 cells high) with 1 to 3 rows of tracheids present between each ray. The ray cells are rectangular in radial view and round in tangential view. They are about 21 to 28 μm in diameter and usually more than 420 μm in length. Crossfield pitting is the podocarpoid type with 2 to 4 bordered pits in each crossfield. The crossfield pits are up to 8 μm in diameter and have almost elliptical, obliquely inclined apertures up to 6 μm in diameter. The pit borders are about 1 μm broad.

Discussion. The narrow late wood in this fossil suggests that there was very rapid cessation of growth of the parent plant. This could have been brought about by either normal seasonal change or the onset of unfavourable growth conditions such as low light levels, lower temperatures, and drought (Creber, 1977). The narrow late wood probably resulted from sudden dormancy triggered by low light levels as is characteristic of conifers at high paleolatitudes. About 200 million years ago, when the Fosheim Member of the Heiberg Formation was being deposited, the Sverdrup Basin was situated about 60°N (Smith et al., 1981; Scotese and Denham, 1988). Narrow late wood in mid-Cretaceous wood from Alaska has similarly been attributed to low light levels because of the high paleolatitude of the localities (Parrish and Spicer, 1988).

The podocarpoid pitting of this specimen distinguishes it from *Protocedroxylon*, which has *Araucarioxylon*-type pitting (tracheids with uniseriate, flattened bordered pits or multiseriate polygonal pits).

Cone A

Plate 5.3, figure 4

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96651 from locality 3.

Description. This cone is cylindrical with a rounded apex. Its base is unknown. It is about 5.5 mm in diameter and about 28 mm long. The cone consists of an axis bearing scales, which are about 2 mm broad.

Discussion. The specimen is tentatively assumed to be a male cone because of its size and morphology.

Cone B

Plate 5.3, figure 10

Occurrence. Fosheim Member of the Heiberg Formation, Axel Heiberg Island. Figure specimen PB 02987 from locality 6.

Description. These cones are probably incomplete because the apices seem to terminate rather abruptly, resulting in a rather globular outline. They are about 1-1.2 cm wide and about 2 cm long. The cones consist of an axis bearing spirally arranged thin "cone scales". The scales comprise a basal part about 2 mm wide and 9 mm long that bears the seed and a part about 2 mm long that extends beyond the seed and tapers to an acute apex. The seeds are oval, 2 mm wide and 5 mm long. The two cones appear to be attached to a leafy shoot that bears small linear-lanceolate leaves, each containing a single vein.

Order uncertain

Genus *Taeniopteris* Brongniart

Taeniopteris tenuinervis Braun

Plate 5.3, figures 6, 7

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimens GSC 96652 and 96653 from localities 2 and 3, respectively. *Taeniopteris tenuinervis* is known from the Upper Triassic of Sweden (Johansson, 1922) and Greenland (Harris, 1932b). However, other *Taeniopteris* and *Taeniopteris*-like leaves similar to the fossils described here occur in the lower Mesozoic in many parts of the world. Thus the occurrence of *Taeniopteris* in the Heiberg Formation is of little biostratigraphic significance.

Description. The leaf is narrow and linear, tapering gradually toward the apex from a broad base. The longest fragment is 8.5 cm long with a maximum width of 1.3 cm. Margins of the leaf are straight to slightly wavy.

Discussion. Harris (1932a) assigned similar specimens to the non-committal genus *Taeniopteris* because their cuticles are unknown. This makes it impossible to assign them. We follow Harris in this policy.

The leaves described here appear to belong to a single species. In general appearance and size they compare fairly closely with the fossils described as *Taeniopteris tenuinervis* by Johansson (1922, Pl. 1, figs. 6, 16, 22). However, they are not as similar to the specimens attributed to *T. tenuinervis* from the Upper Triassic of Greenland by Harris (1932a, Textfig. 20). They also compare fairly closely with the specimens from the Upper Triassic of Russia identified as *T.* sp. cf. *T. ferganensis* by Genkina (1966) and to the specimens described as *Taeniopteris* sp. by Stanislavsky (1976, Pl. 74, figs. 3, 5, 7).

Reproductive structure A

Plate 5.3, figure 5

Occurrence. Fosheim Member of the Heiberg Formation, Axel Heiberg Island. Figured specimen PB 02986 from locality 6.

Description. The specimen consists of a stalk bearing lateral appendages. The base and apex of the stalk are missing. The fossil is about 4.6 cm long and has a maximum width of about 2.4 cm. The stalk is about 3 mm wide and bears appendages alternately at the lateral margins in intervals of about 5 mm. Each appendage consists of a narrow, outward- and forward-directed arm that terminates in a thick oval body. The straight to slightly curving arms, which are about 1 mm wide and 4-6 mm long, are arranged at an angle of about 45°-65° to the stalk. The oval bodies are about 4-5 mm wide and 5-6 mm long. They are attached at their base to the arm and their long axis generally lies parallel to the long axis of the stalk. The outer margins of the oval bodies are typically smooth and entire, but a short angular beak about 1 mm wide and 1 mm long occurs on the forward-directed end of a few of the bodies, opposite the attachment area.

Discussion. The fossil appears to be a pinnate organ as the lateral appendages arise in two ranks along the margins of the stalk and not in a helix as they would in a cone. If the fossil is indeed a pinnate organ, then the stalk should be termed the rachis and the appendages should be termed pinnae. The oval bodies appear to be seeds because they are comparatively thick and are about the same size as some isolated Mesozoic seeds (e.g., Harris, 1935, Pl. 18, fig. 3; Johansson, 1922, Pl. 5, figs. 25, 26; Xu Ren et al., 1979, Pl. 72, fig. 7). Furthermore, maceration of the carbonaceous matter from one of the oval bodies yielded only small scraps of cuticle. There is no indication that the seeds were enclosed in any type of structure but rather that they were borne upright on the ends of the arms.

Although several pinnate upper Paleozoic and lower Mesozoic reproductive structures compare at least superficially with the distinctive fossil described here, they vary in detail and most are pollen bearing. Examples of such superficially similar pollen-bearing organs are *Feraxotheca* Millay and Taylor (1977) from the Pennsylvanian of North America, *Pteruchis* Thomas (1933) from the Upper Triassic of southern Africa (see Townrow, 1962), *Pramelreuthia* Krasser from the Upper Triassic of Austria (see Krausel, 1949), and *Pteroma* Harris (1964) from the Middle Jurassic of Yorkshire. Seed-bearing structures with which the Heiberg fossil compares in general include *Peltaspermum* Harris (1932a) from the Upper Triassic of Greenland and *Stenorhachis* Saporta (1875) from the Lower Jurassic of Sweden and Spitsbergen (Nathorst, 1902). In all of these, each sporophyll consists of a complex of two or more parts, in contrast to the present specimen where each sporophyll seems to consist of a single seed-like body resting on the end of an arm. One fossil that has a single seed-like body at the end of lateral appendages is *Trichopitys* Saporta (1875) from the Lower Permian of France. The seed-bearing appendages in that fossil appear to be arranged in a helix on a thick axis borne in the axil of some ginkgophytic leaves (Florin, 1949). Its seeds are inverted, in contrast to the oval bodies in the Heiberg fossil, which seem to be forward-directed. Another fossil with a single seed-like body at the end of each lateral appendage is *Beania* Carruthers (1869) from the Middle Jurassic of Yorkshire. However, as Harris (1964) has shown, the lateral appendages of *Beania* are arranged in a helix around the axis and the seeds are borne in pairs below the peltate apex of the appendages.

Genus *Anthrophyopsis* Nathorst

Anthrophyopsis sp. cf. *A. crassinervis*

Figure 5.4

Occurrence. Fosheim Member of the Heiberg Formation, Ellesmere Island. Figured specimen GSC 96654 from locality 3. The genus *Anthrophyopsis* is known elsewhere from only the latest Triassic of Sweden (Nathorst, 1878-86), Greenland (Harris, 1926, 1932a, 1937), and Australia (Flint and Gould, 1975).

Description. The shape and size of the leaf are uncertain as the margins are visible in only a few places. However, it appears that the fossil represents the apical region of a linear leaf that had a rounded apex and entire but possibly slightly wavy margins. The base is unknown. The leaf fragment has a maximum width of about 4.8 cm and a length of about 10 cm. The midrib is slender (about 0.3 mm wide) and inconspicuous, as are the lateral veins, which are about 0.1 mm wide. The lateral veins arise at an acute (usually 30°-45°) angle and at irregular intervals, forking at once into forward and backward branches that join those of adjacent veins to form primary arches. The primary arches are greater in width (about 7-10 mm) than height (usually 1.5-2.0 mm), triangular, and bear two to five outer veins that usually anastomose several times with adjacent veins to form angular polygonal meshes. The vein meshes nearest the midrib are about 7-10 mm long and 1 mm wide and become progressively smaller toward the leaf margins, where they are only 2-4 mm long. In most of the leaf beyond the row of primary arches the vein meshes lie approximately at right angles to the margin. The leaf substance appears to have been rather thin.

Discussion. Although the fossil described here is an indistinct impression, when immersed in kerosene it shows many of the typical features of the specimens from Greenland and Sweden assigned to the genus *Anthrophyopsis*. Unfortunately, this interesting leaf has so little contrast that the photograph shows few of its features. A sketch of the venation of the fossil is given in Figure 5.4.

Little is known about the morphology of *Anthrophyopsis* and its relationships. Consequently, its name and classification have been changed several times, as summarized by Harris (1937). More recently the Chinese specimens that Florin (1933) had included in *Anthrophyopsis* have been reassigned by Xu Ren et al. (1979) to *Ctenis*.

The Heiberg *Anthrophyopsis* is much narrower (4.8 cm wide) than the leaf (20 cm wide) assigned to the genus by

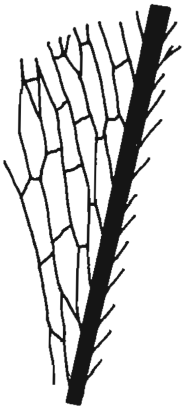

Figure 5.4. *Sketch of the venation along the midrib of* ***Anthrophyopsis*** *sp. cf.* ***A. crassinervis****; x2; GSC specimen 96654; locality 3.*

Harris (1932a) and its vein meshes are correspondingly smaller. However it is about twice as wide as the specimen (2.1 cm wide) described from the Upper Triassic of Australia by Flint and Gould (1975). The undivided Heiberg leaf apparently is unrelated to the Chinese specimens attributed to *Anthrophyopsis* by Florin (1933), as they are the remains of a pinnate leaf and are more like *Ctenis* (see Xu Ren et al., 1979).

In gross morphology, *Anthrophyopsis* does resemble some of the glossopterid leaves described from the southern continents, as noted by others (e.g., Harris, 1935). The Heiberg specimen seems very similar to the leaf assigned to *Scutum rubidgeum* from the Permian of southern Africa (cf. Anderson and Anderson, 1985, p. 115). Similar comparisons could also be made between glossopterid foliage and the specimens described from Greenland and Sweden, but cuticles are different enough to distinguish them. The fossil is somewhat similar in morphology to *Sagenopteris* but it is much larger than typical specimens of that taxon.

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APPENDIX

Locality Data

Many of the collections were made before the Heiberg Formation was subdivided by Embry (1982, 1983a). Therefore, it has been necessary to estimate their stratigraphic positions in terms of those divisions. The names of collectors and dates on which collections were made are also given, with the appropriate references. Localities are listed in order from north to south, and shown on the index map in Figure 5.1.

ELLESMERE ISLAND

Locality 1

Southeast of the Blue Mountains on the south side of a major easterly flowing stream at about lat. 80°39′N, long. 85°37′W. Near the base of the Fosheim Member. Leaf impressions preserved in hard, brown-weathering, grey sandstone. Locality USPC68. Collected by S.R. Ash and H.O. Ash, 1985.

Locality 2

About 19 km east of Mt. Lockwood in the sea cliffs on the south side of Greely Fiord at about lat. 80°16′N, long. 84°52′W. A view of the locality is given in Figure 5.3. Upper part of the Fosheim Member. Leaf impressions and compressions preserved in hard, brown-weathering, grey sandstone. Locality USPC69. Collected by J.F. Basinger and D.L. Dilcher, 1982, and by S.R. Ash and H.O. Ash, 1985.

Locality 3

On the west limb of the Fosheim Anticline on the south side of a major westwardly flowing stream at about lat. 79°37′N, long. 84°50′W. About 76 m below the top of the Fosheim Member. Leaf impressions preserved in hard, brown-weathering, greyish sandstone. Locality USPC70. Collected by S.R. Ash and H.O. Ash, 1985.

AXEL HEIBERG ISLAND

Locality 4

On the east side of Buchanan Lake near Savik Creek. About 223 m below the top of the formation, within the Fosheim Member. Leaf impressions preserved in interbedded grey sandstone and highly carbonaceous black shale. GSC 4667. Collected in 1955 (Souther, 1963, p. 434).

Locality 5

In the vicinity of Wolf Fiord. About 165 m below the top of the formation probably within the Fosheim Member. Leaf impressions preserved in yellowish, light grey sandstone with flecks of carbon. GSC 4731. Collected in 1955 (Glenister, 1963, p. 477).

Locality 6

West limb of the Wolf Fiord Anticline at about lat. 78°45′N, long. 88°43′W. About 90 m below the top of the formation, within the Fosheim Member. Leaf impressions preserved in hard, dark grey, fissile shale. Locality USPC71. Collected in 1981 (Suneby, 1984).

Locality 7

Fifteen miles (24.1 km) east of the head of Strand Fiord. About 233 m above the base of an incomplete, isolated 693 m thick section with neither base nor top apparent, within either the Fosheim or the Romulus member. Leaf impressions in hard, massive, grey sandstone. GSC 4648. Collected in 1955 (Souther, 1963, p. 434).

Locality 8

Same locality as 7 but 433 m above the base of the incomplete section of the formation, possibly within the Fosheim Member but more likely in the Romulus Member as it contains typical Upper Triassic plant fossils. Leaf impressions in grey, silty sandstone and hard, quartzose sandstone. GSC 4647. Collected in 1955 (Souther, 1963, p. 434).

Locality 9

Nine miles (14.5 km) east of the head of Strand Fiord. About 663 m below the top of the formation, possibly within the Fosheim Member. Leaf impressions preserved in light grey, silty sandstone. GSC 2665 (not seen), 4700, and 4701. Collected in 1955 (Souther, 1963, p. 434).

CORNWALL ISLAND

Locality 10

South and southeast of Mount Nicolay. Near the top of the Fosheim member. Petrified wood and unidentified plant fragments (not seen). GSC plant locality 4639. Collected in 1955 (McLaren, 1963, p. 530).

CAMERON ISLAND

Locality 11

Half a mile (0.8 km) north of Rendezvous Hill. Near the top of the Heiberg Formation. Petrified wood (not seen) and unidentifiable plant remains preserved in hard, platy sandstone. Collected in 1853 (Osborn, 1855) and in 1955 (Tozer, 1963b, p. 643).

PLATE 5.1

Figures 1-3. *Neocalamites hoerensis*

1. Stem showing two nodes bearing small leaf scars, GSC 96630, x½, locality 3.
2. Pithcast showing longitudinal ridges characteristic of the species, GSC 96631, x1, locality 2.
3. Node and portion of adjacent internodes, GSC 96632, x1, locality 3.

Figure 4. *Marattiopsis* sp. cf. *M. asiatica* Kawasaki

Apical portion of a sterile pinna showing characteristic venation, GSC 96633, x1, locality 1.

Figure 5. *Equisetites grosphodon*

Remains of a nodal diaphragm, GSC 90705, x2, locality 5.

Figure 6. *Camptopteris spiralis*

Fragment of a pinna showing the low forward-directed teeth and reticulate venation characteristic of the taxon. The margins of the fossil have been outlined with white paint to define the morphology more clearly, GSC 90706a, x2, locality 8.

Figure 7. *Phlebopteris angustiloba*

Fragment of a pinna showing the fields formed by secondary veins typical of the species, GSC 90707, x1, locality 8.

Figures 8-12. *Clathropteris meniscoides*

8. Fragment of a pinna showing secondary and tertiary venation. The meniscoid pattern, characteristic of the taxon, is not as strongly developed in this specimen as in the specimen shown in figure 9, GSC 96636, x1, locality 3.
9. Fragment of lamina showing strong meniscoid patterns formed by the secondary venation, GSC 90708, x2, locality 5.

10, 11. Part and counterpart of the petiole and remains of the two basal arms, one of which shows a small fragment of lamina, GSC 96637a, b, x½, locality 3.

12. Fragment of the lamina showing details of venation including blind vein endings in some vein meshes, GSC 96638, x2, locality 3.

Figures 13, 14. *Todites recurvatus*

13. Remains of two pinnae showing the venation and the characteristic form of the pinnules, GSC 96634, x1, locality 3.
14. Central part of a leaf showing the bases of several pinnae and the main rachis of the leaf, GSC 96635, x½, locality 3.

Figure 15. *Cladophlebis* sp.

Central part of a leaf showing a portion of the main rachis and several incomplete pinnae, GSC 96639a, x1, locality 3.


1


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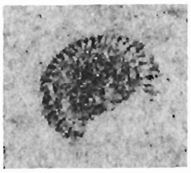
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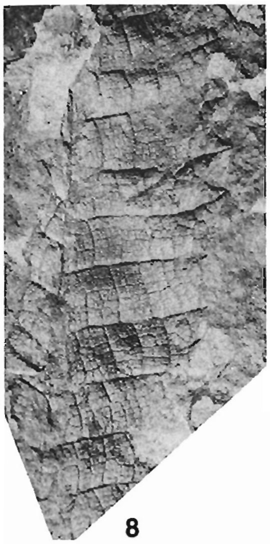
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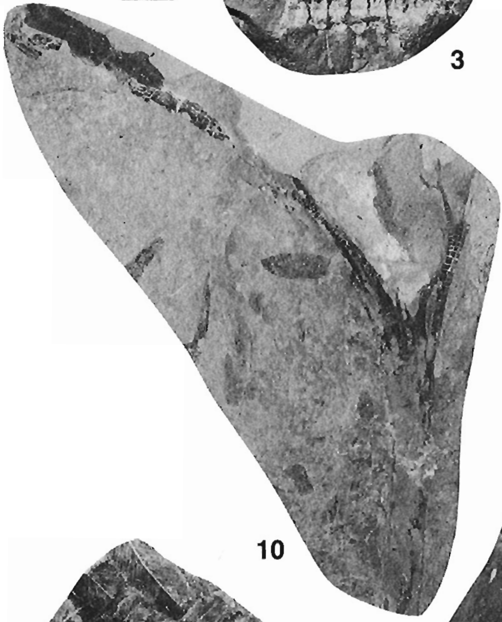
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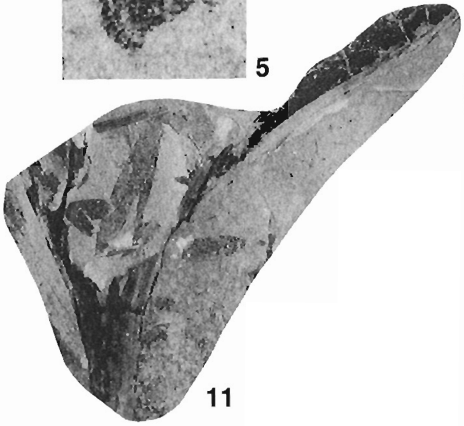
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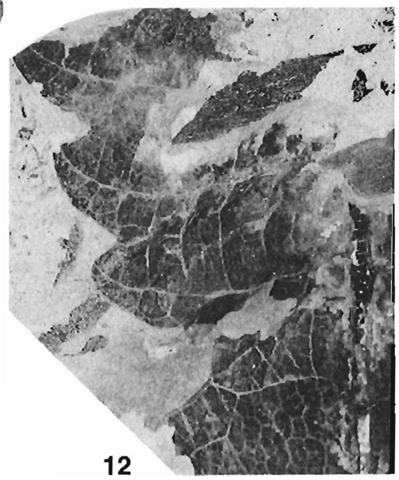
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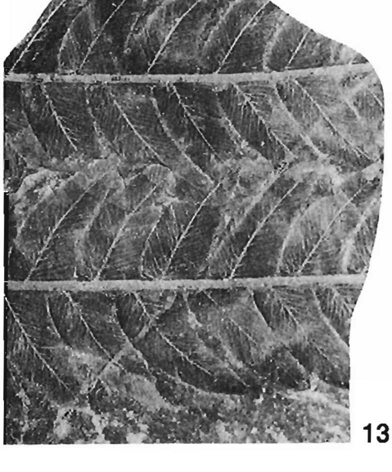
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PLATE 5.2

Figures 1, 4. *Ginkgo siberica*

1. Remains of a large leaf with broad segments, GSC 96640, x1, locality 2.

4. Leaf with short, narrow segments with parallel sides, GSC 96641, x1, locality 3.

Figures 2, 3, 5, 8, 11. *Sphenobaiera spectabilis*

2, 3. Two leaves consisting of four segments, GSC 96643, 96644, x½; locality 2.

5. A leaf in which the segments are greatly reduced in width, GSC 96642a, x½, locality 2.

8. A leaf in which each of the two main segments is subdivided near the apex, GSC 96642b, x1, locality 2.

11. A leaf composed of eight narrow, whip-like ultimate segments superimposed on the remains of a second leaf also composed of eight narrow, whip-like segments, GSC 96645, x½, locality 2.

Figures 6, 7. *Pterophyllum subaequale*

Midrib area of two leaves, GSC 90714, 90715, x1, locality 4.

Figure 9. *Ptilophyllum* sp.

Fragment of a leaf showing the characteristic linear, forward-directed pinnae, GSC 90712, x1, locality 7.

Figure 10. *Anomozamites* sp.

Fragment of the central part of a leaf showing the short, forward-directed falcate pinnae characteristic of the genus, GSC 90713, x1, locality 9.

Figure 12. *Czekanowskia* sp.

A small slab of rock showing fragments of the narrow linear leaves, GSC 96646, x½, locality 2.


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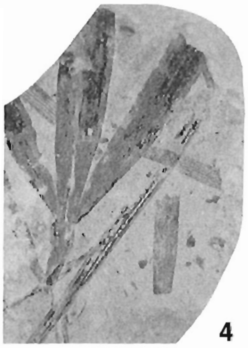
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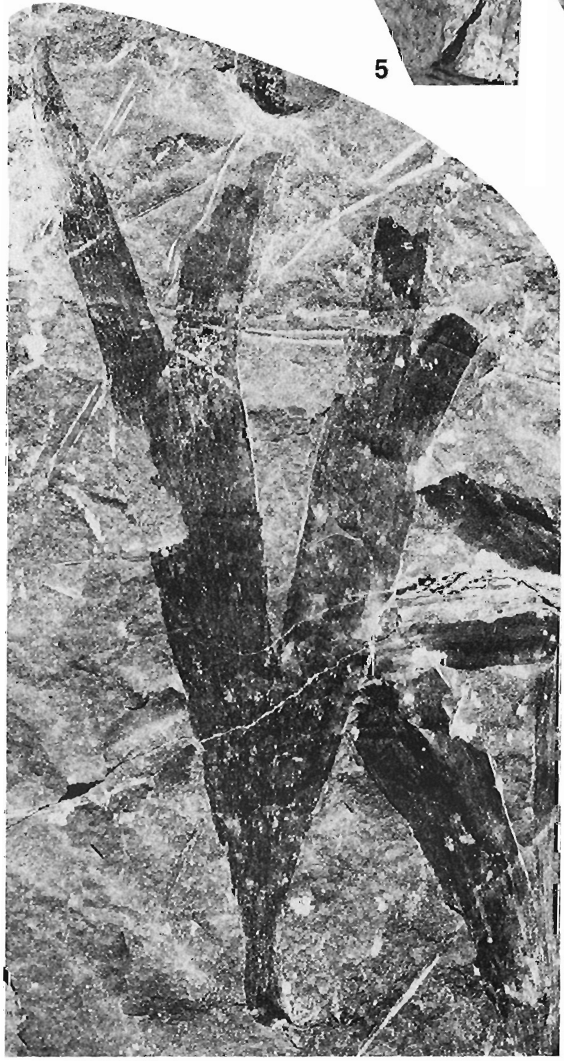
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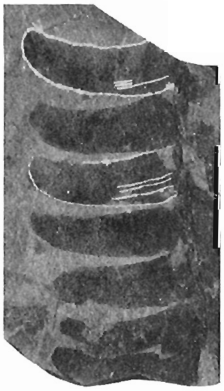
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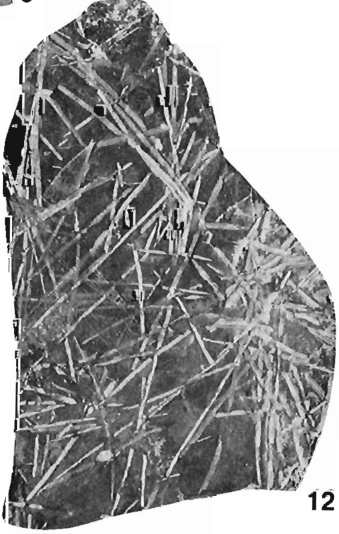
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PLATE 5.3

Figure 1. *Swedenborgia major*

Fragment of a single cone scale, GSC 96647, x2, locality 2.

Figure 2. *Stachyotaxus elegans*

Fragment of the leafy shoot, PB 02985, x1, locality 6.

Figures 3, 8. *Podozamites* sp.

Leafy shoots showing the form and venation of the leaves and their mode of attachment to the stem, GSC 96648, x½, locality 2; GSC 96649, x1, locality 3.

Figure 4. Cone A

The specimen appears to be virtually complete, GSC 96651, x1, locality 3.

Figure 5. Reproductive structure A

The forward-directed appendages of this pinnate organ are clearly visible, PB 02986, x1, locality 6.

Figures 6, 7. *Taeniopteris tenuinervis*

Fragments showing the strong midrib and, in the left hand specimen, the transverse venation and parallel margins, GSC 96652, x1, locality 2; GSC 96653, x1, locality 3.

Figure 9. *Pelourdea* sp.

A fragment showing the tapering apex and rounded base, GSC 96650, x1, locality 3.

Figure 10. Cone B

The two short globose cones appear to be attached to a stem that also bears a leafy shoot resembling *Stachyotaxus* on the lower left, PB 02987, x1, locality 6.

Figures 11-16. *Mesembrioxylon* sp. A

11. Transverse section showing large rectangular to square tracheids with rounded lumens in the early wood. The end of a growth ring extends upward and to the left in the right hand portion of the figure. See figure 12 for an enlargement of the growth ring, GSC 90716a, x200, locality 10.
12. Transverse section showing the end of a growth ring extending upward and to the left in the centre of the figure. Compare the large tracheids of the early wood with the small, thicker walled tracheids of the late wood, GSC 90716a, x500, locality 10.
13. Tangential section showing general uniseriate vascular rays, GSC 90716b, x500, locality 10.
14. Radial section showing typical uniseriate tracheary pitting. Although the pits are contiguous they are not flattened, GSC 90716c, x1000, locality 10.
15. Radial section showing rare biseriate tracheary pitting, GSC 90716c, x500, locality 10.
16. Radial section showing crossfield pitting, GSC 90716c, x1000, locality 10.


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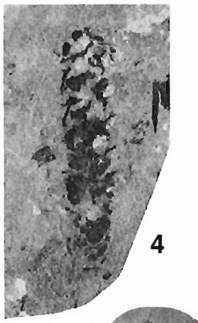
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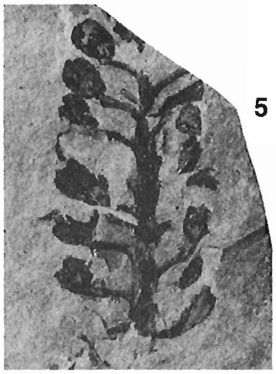
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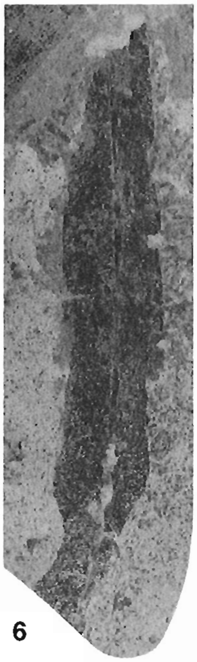
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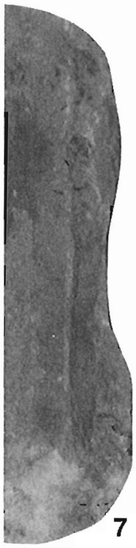
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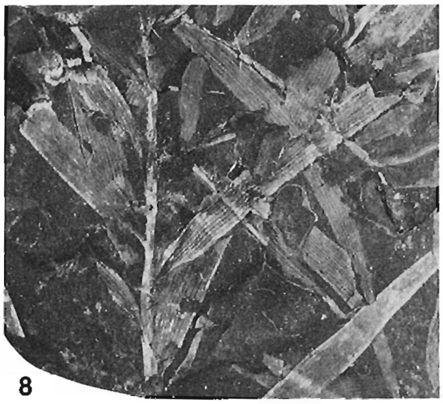
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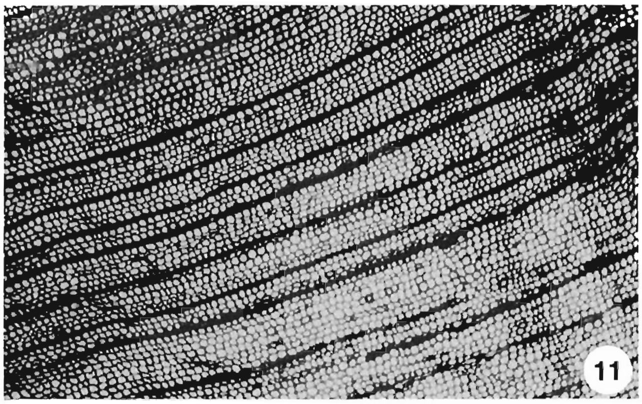
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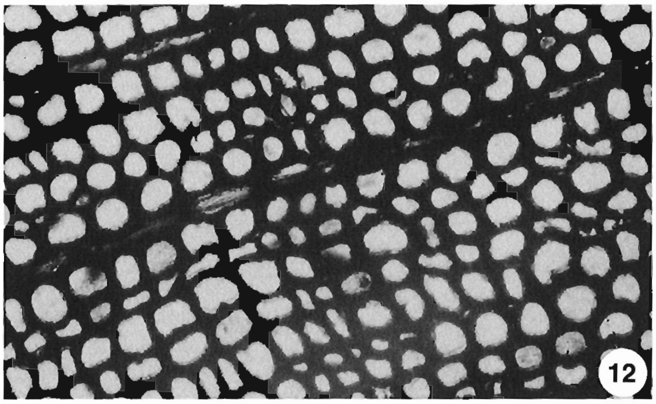
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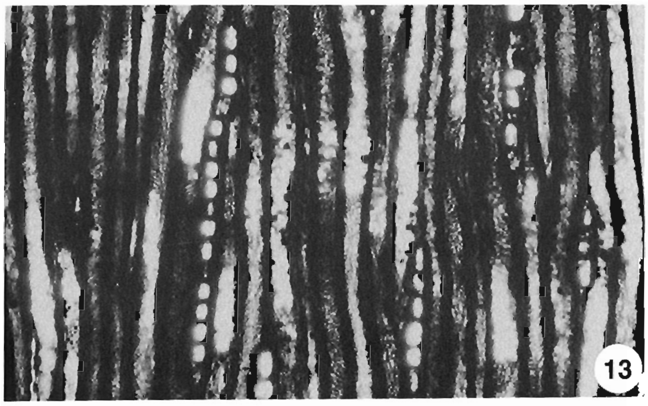
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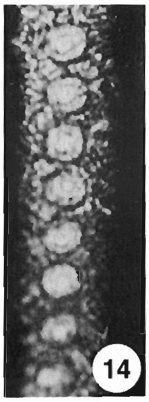
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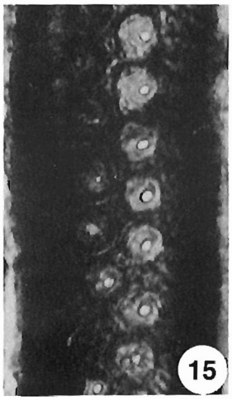
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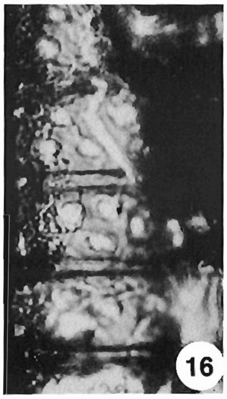
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LOWER BAJOCIAN (MIDDLE JURASSIC) AMMONITES AND BIVALVES FROM THE WHITESAIL LAKE AREA, WEST-CENTRAL BRITISH COLUMBIA

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Hall, R.L., Poulton, T.P., and Diakow, L., 1991. Lower Bajocian (Middle Jurassic) ammonites and bivalves from the Whitesail Lake area, west-central British Columbia. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 412, p. 133-167.

Abstract

The Smithers Formation of the Hazelton Group in west-central British Columbia contains an abundant and varied marine fauna of Middle Jurassic age. This report provides the first description of the Lower Bajocian faunas from the Whitesail Lake area. The ammonites and bivalves can be assigned to four zones of the Lower Bajocian and provide the means for correlation with coeval faunas elsewhere in Canada and the United States, as well as with the standard zones of northwestern Europe.

The oldest zone contains *Sonninia* (*Euhoploceras*) *dominans* Buckman and *Sonninia tenuicostata* n. sp. (microconch) and is correlated with the lowest Bajocian Discites Standard Zone. A younger fauna, containing *Sonninia* (*Sonninia*) sp. cf. *S.* (*S*) *tuxedniensis* Imlay and *S.* (*S.*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt), is correlated with the Sauzei or lower Humphriesianum Standard Zones; several other associations of identifiable sonniniid and stephanoceratid ammonites also belong to this interval. *Zemistephanus* in association with *Chondroceras* may represent the middle part of the Humphriesianum Standard Zone, and *Stephanoceras itinsae* (McLearn) together with *Chondroceras oblatum* (Whiteaves) are correlated with the middle and upper parts of the Humphriesianum Standard Zone.

The range of *Zemistephanus* is extended upward, from that previously reported, into the middle part of the Humphriesianum Standard Zone.

Bivalves occur locally in rich and varied assemblages that are characteristic of the Lower Bajocian regionally in west-central British Columbia in that they are dominated by characteristic species of the trigoniid genus *Myophorella*, including *M. dawsoni* (Whiteaves).

Most of the ammonites are cosmopolitan, but *Zemistephanus* is restricted to Western Canada and southern Alaska. These data may indicate little post-Bajocian northerly movement of the allochthonous terranes on which *Zemistephanus* is found, including Stikinia, on which the present report is based.

Résumé

La Formation de Smithers, appartenant au Groupe de Hazelton, dans le centre ouest de la Colombie-Britannique, contient une faune marine abondante et variée datant du Jurassique moyen. Le présent rapport fournit la première description des faunes du Bajocien inférieur provenant de la

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région du lac Whitesail. Il est possible de classer les ammonites et les bivalves dans quatre zones du Bajocien inférieur, et d'établir ainsi une corrélation avec des faunes contemporaines d'autres régions du Canada et des États-Unis, ainsi qu'avec les zones standard du nord-ouest de l'Europe.

La zone la plus ancienne contient *Sonninia (Euhoploceras) dominans* Buckman et *Sonninia tenuicostata* n. sp. (microconque); elle est corrélée avec la Zone standard à Discites du tout début du Bajocien. Une faune plus récente, contenant *Sonninia (Sonninia)* sp. cf. *S.* (*S.*) *tuxedniensis* Imlay et *S.* (*S.*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt) est corrélée avec la Zone standard à Sauzei ou avec la partie inférieure de la Zone standard à Humphriesianum; plusieurs autres associations d'ammonites identifiables du groupe de sonniniidés et stéphanocératidés appartiennent aussi à cet intervalle. L'intervalle de *Zemistephanus*, en association avec *Chondroceras*, représente peut-être la partie moyenne de la Zone standard à Humphriesianum, et l'intervalle de *Stephanoceras itinsae* (McLearn), en même temps que celui de *Chondroceras oblatum* (Whiteaves), est corrélé avec les parties moyenne et supérieure de la Zone standard à Humphriesianum.

L'intervalle de *Zemistephanus* a été prolongé vers le haut, comparativement au niveau anciennement indiqué, jusque dans la partie moyenne de la Zone standard à Humphriesianum.

On rencontre par endroits des bivalves dans des assemblages riches et variés qui sont caractéristiques du Bajocien inférieur, à l'échelle régionale, dans le centre ouest de la Colombie-Britannique, puisqu'ils sont dominés par des espèces caractéristiques appartenant au genre (trigoniidés) représenté par *Myophorella*, notamment par *M. dawsoni* (Whiteaves).

La plupart des ammonites sont cosmopolites, mais *Zemistephanus* est limité à l'ouest du Canada et au sud de l'Alaska. Ces données pourraient indiquer qu'il n'y a eu qu'un faible déplacement post-bajocien, vers le nord, des terranes allochtones où l'on rencontre *Zemistephanus*, en particulier le terrane de Stikinia, sur l'étude duquel se base le présent rapport.

INTRODUCTION

The thick succession of Jurassic sedimentary and volcanic strata in west-central British Columbia includes fossiliferous beds whose fossils permit subdivision and correlation of the units in which they are found. This report describes, for the first time, the ammonites and bivalves from rocks of Early Bajocian age from the Whitesail Lake map area. They are all from the Smithers Formation of the Hazelton Group (Tipper and Richards, 1976).

The first comprehensive description of the regional geology of the Whitesail Lake map area was by Duffell (1959). He described the geological framework of the area, including the many important mineral showings and prospects, as well as the stratigraphy of the Jurassic rocks and their associated fossils. More recent contributions concerning the Middle Jurassic rocks are from Woodsworth (1979, 1980), Diakow and Mihalynuk (1987), and Diakow and Koyanagi (1988). The area has long been of interest because of its mineral potential and continues to be the subject of many government and industry studies.

PREVIOUS AND PRESENT PALEONTOLOGICAL WORK

Aalenian ammonites from the Smithers Formation of Whitesail Lake area have been described by Frebold (1951) and Poulton and Tipper (in press). The younger Middle Jurassic ammonites have not been described previously although preliminary identifications, mainly by H. Frebold, have appeared in reports by Duffell (1959), Tipper and Richards (1976), Poulton (1979), and others. A few Middle Jurassic trigoniid bivalves from the area, most of which are very useful for biostratigraphic subdivision and correlation, were described by Poulton (1979).

The material studied includes all collections from the National Type Collection of the Geological Survey of Canada, collected by geologists of the Geological Survey, the British Columbia Ministry of Energy, Mines and Petroleum Resources, and private exploration companies over many years. Collections resulting from fieldwork by Diakow in 1986 through 1988 and major collections by Poulton and Hall in 1987 and 1988 are the most recent additions. Only the most significant ammonoids and associated bivalves are illustrated and described. Other fossils, including some from other localities where the stratigraphic context is not clear, serve to document the distribution of Bajocian rocks for regional geological purposes.

STRATIGRAPHY

The Jurassic strata of Whitesail Lake and adjacent areas (Fig. 6.1) are assigned to the Hazelton and Bowser Lake groups, which are separated by a diachronous transition ranging in age from Late Bajocian to Bathonian (Tipper and Richards, 1976). The Lower Bajocian strata, which yielded the fossils described in this report, are part of the Smithers Formation (Hazelton Group), a unit of marine feldspathic greywacke, siltstone, and shale with minor interbeds of pebble conglomerate, limestone, chert, and fine tuff. Strata of demonstrably Aalenian and Early Bajocian age are somewhat sporadically distributed in the Whitesail Lake map area. Diakow and Koyanagi (1988) suggested that such sporadic occurrences resulted from local disconformities within the Smithers Formation. In particular, the extensive Aalenian beds of Troitsa Peak and Michel Lake areas (Poulton and Tipper, in press) are apparently absent below the Lower Bajocian strata in nearby sections at Cummins Creek and Chikamin Mountain.

Lower Bajocian fossils occur in four areas. A well exposed section of fossiliferous rocks, apparently including the entire Bajocian section of the area, is exposed in the upper part of Cummins Creek on the north side of Whitesail Lake. A similar section is exposed on the northwest side of Chikamin Mountain between Whitesail and Eutsuk lakes. Isolated outcrops along logging roads north of Tahtsa Reach also contain many fossils, as do those in the area of Nadina Fire Lookout. The fossils from the Nadina Lookout area do not contribute new information, however, and are not described in this report.

Cummins Creek

Fine to medium grained green and grey volcaniclastic sedimentary rocks of the Smithers Formation are exposed in a small fault-bounded block in the upper part of Cummins Creek (Fig. 6.1A), about 4 km southeast of Troitsa Peak. They are about 100 m thick and are faulted against flows and tuffs of the Lower Jurassic Telkwa Formation. The Smithers Formation is overlain, apparently conformably, by laminated tuffaceous shale and siltstone of the Ashman Formation, the basal unit of the Bowser Lake Group. The first Bajocian fossils in this section were recovered by Diakow in 1986.

A thick, resistant, massive to thick bedded, dark green, feldspathic greywacke occurs low in the Smithers Formation. *Sonninia* sp. cf. *S. furticarinata* (Quenstedt), *S.* sp. cf. *S. tuxedniensis* Imlay, and other indeterminate sonniniids and stephanoceratids occur about 30 m below the top of this sandstone (GSC loc. C-146156; Fig. 6.1A, loc. 1). *Sonninia* sp. and *Stephanoceras* sp. (unfigured) occur together in the upper 15 m of this unit (GSC locs. C-146157,C-146158; Fig. 6.1A, locs. 2, 3). Overlying, variably resistant beds of sandstone and siltstone contain *Stephanoceras itinsae* (McLearn), *Chondroceras oblatum* (Whiteaves), and *Oxycerites* sp. (GSC locs. C-146160, C-146161; Fig. 6.1A, loc. 5), with *Stephanoceras* sp. (unfigured) about 30 m above them (GSC loc. C-146162; Fig. 6.1A, loc. 6).

Bivalves occur throughout this interval but are common only in a few beds where ostreiids predominate.

Chikamin Mountain

Fossiliferous feldspathic greywacke with minor accretionary lapilli tuff interbeds occur 2.5 km northwest of the peak of Chikamin Mountain (Fig. 6.1B). This succession, about 150 m thick (Diakow and Koyanagi, 1988), overlies with apparent conformity tuffs and flows that may represent the Lower Jurassic Telkwa Formation.

Fossils have been collected from this locality by many geologists since they were reported by Duffell (1959). The lowest Middle Jurassic fossils include poorly preserved *Emileia* and *Zemistephanus* (both unfigured) (GSC loc. C-146168). *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves), *Zemistephanus*, and *Chondroceras oblatum* (Whiteaves) occur about 50 m higher (GSC locs. C-53525, C-146165, C-146166, C-146167; Fig. 6.1B, loc. 1), whereas *Zemistephanus*, *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves), *Phylloceras*, and *Chondroceras oblatum* (Whiteaves) occur about 60 to 100 m above material at GSC locality C-146167 (GSC locs. C-146163, C-146164; Fig. 6.1B, loc. 2).

North of Tahtsa Reach

Several localities yield a variety of faunas in feldspathic greywacke and siltstone (Figs. 6.1C, D). Poor exposure due to low topographic relief and extensive forest and soil cover prevents recognition of a stratigraphic succession. Bajocian fossils were first reported by Duffell (1959) and have been collected from many localities since then.

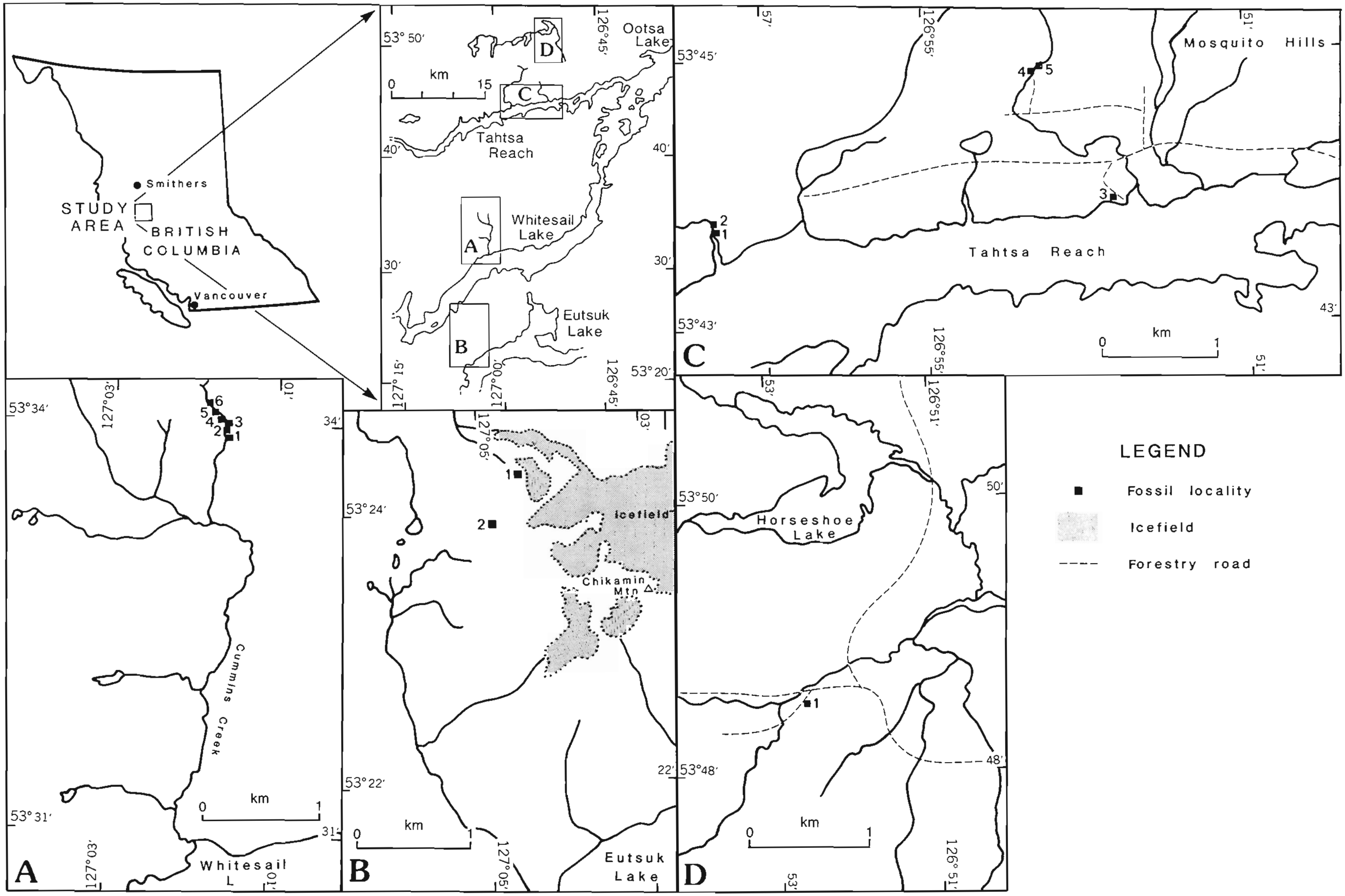

Figure 6.1. Location of study area, Whitesail Lake, British Columbia and details of fossil localities.

The oldest Bajocian fossils in the area, including *Sonninia* (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman and *Sonninia tenuicostata* n. sp., come from a quarry along a logging road south of Horseshoe Lake (GSC loc. C-168517; Fig. 6.1D, loc. 1). Bivalves are also abundant there.

"Fossil Canyon" has yielded Bajocian ammonites to several collectors, since the locality was first mentioned by Duffell (1959). This locality, originally on the north side of Tahtsa River, is now largely flooded by Tahtsa Reach, which is an arm of Whitesail Lake (Nechako Reservoir) produced by the Kemano Dam near Kitimat. Fossiliferous Bajocian beds are still exposed (GSC locs. C-53554, C-168520; Fig. 6.1C, locs. 1, 2). They yield *Stephanoceras variabilis* (Imlay), large *Phylloceras* sp., belemnites, and a variety of bivalves.

Stephanoceras sp. cf. *S. skidegatense* (Whiteaves) occurs east of "Fossil Canyon", on the north side of Tahtsa Reach (GSC loc. C-168521; Fig. 6.1C, loc. 3), whereas *Zemistephanus richardsoni* (Whiteaves) has been collected farther upstream (GSC locs. C-168518, C-168519; Fig. 6.1C, locs. 4, 5; M. Mihalynuk was the first to collect in the area, in 1986).

JURASSIC PALEOGEOGRAPHIC AND TECTONIC SETTING

The Jurassic stratigraphy in the Whitesail Lake map area (NTS 93 E) is similar to that in the Smithers map area to the north (Tipper and Richards, 1976), where the rocks are more fossiliferous and the succession more complete and better understood. The similarity of the Jurassic strata between the two areas indicates that they were deposited within a single basin (the Hazelton Trough) in the Early Jurassic and part of the Middle Jurassic. Volcanic and sedimentary fill of the Hazelton Trough is preserved in a northwest-trending belt that occupies much of western British Columbia between the Coast Crystalline Belt to the west and the Omineca Crystalline Belt and Quesnellia Terrane to the east.

The complex history of the allochthonous terranes in the Western Canadian Cordillera, which remains controversial and is undergoing constant re-evaluation, is not discussed in detail here. The area occupied by the Hazelton Trough coincides approximately with Stikinia, the largest allochthonous terrane in British Columbia. Similarities in the character of certain Jurassic units were considered by Tipper (1984) to indicate a common "shale episode" that united all the major western terranes (including Wrangellia, Stikinia, and Quesnellia) by Middle Jurassic time, about the time they were thought to have accreted to the western margin of North America.

The Hazelton Trough was bounded on the north, at about latitude 57°N, by the southwest-trending Stikine Arch, and was bisected at about latitude 54°N by the southwest-trending Skeena Arch, a dominant feature of the Whitesail Lake map area. The Skeena Arch was a tectonic uplift characterized by a particularly thick accumulation of Lower Jurassic volcanics. The arch acted as a barrier between the smaller Middle and Upper Jurassic basins — the Bowser and Nechako basins, respectively (Tipper, 1984) — developed to its north and south (Tipper and Richards, 1976). They are best developed in later Middle Jurassic time.

Paleobiogeographic analysis of ammonites is one tool that has proved useful in determining possible terrane displacements through time (Taylor et al., 1984; Smith and Tipper, 1986). The Lower Bajocian ammonites described in this report contain a mixture of species, some cosmopolitan (but not boreal), and some endemic to western North America. The latter include *Zemistephanus*, which characterizes the Athabascan Province of the East Pacific Realm (Taylor et al., 1984). On the North American craton, *Zemistephanus* is not known to occur farther south than southern Alberta, where it appears in the Fernie Formation (Hall and Westermann, 1980). This suggests that Stikinia was located no farther south during the Early Bajocian than about the present latitude of southern Alberta. Such a location is consistent with the evidence mentioned above for the timing of accretion to the craton of the amalgamated terrane that includes Stikinia.

AGE AND CORRELATION OF THE FAUNAS

The Lower Bajocian (=Middle Bajocian prior to common acceptance of the Aalenian stage in recent years) faunas from the Whitesail Lake area can be assigned to assemblage zones proposed by Hall and Westermann (1980) and Taylor (1988) for western North America; these zones, in turn, can be correlated fairly confidently with European Standard Zones because of the presence of cosmopolitan forms (Table 6.1).

The oldest Bajocian fauna represented in the Whitesail Lake area consists of *Sonninia* (*Euhoploceras*) *dominans* Buckman and *Sonninia tenuicostata* n. sp., which occur together in the small roadside quarry at locality 1 in Figure 6.1D. The Tuberculatum Zone, erected by Taylor (1988, p. 124) for an ammonite fauna from basal Bajocian strata in eastern Oregon and correlative with the European Discites and superjacent Ovalis zones, is characterized by numerous species of *Euhoploceras* with *Docidoceras, Asthenoceras, Latiwitchellia, Witchellia*, and *Sonninia*. Although none of the species of *Euhoploceras* recorded from that zone is identical to *S.*

(*E.*) sp. cf. *S.* (*E.*) *dominans* from Whitesail Lake, the faunas are approximately coeval. In western Europe, *S.* (*E.*) *dominans* is known in southern England and the Isle of Skye in Scotland, occurring mainly in the Discites Zone (Westermann, 1966; Imlay, 1973); it may also occur at the top of the subjacent Concavum Zone of the Aalenian (Morton, 1975).

On Cummins Creek (Fig. 6.1A, loc. 1), the lowest fossiliferous strata have yielded external moulds of *Sonninia* (*Sonninia*) sp. cf. *S.* (*S.*) *tuxedniensis* Imlay, *S.* (*S.*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt), and smaller, unidentifiable sonniniids. *Sonninia furticarinata* occurs in Skye with *Dorsetensia* spp., an association that Morton (1975) allocated to the uppermost Sauzei Zone (Hebridica Subzone) or lowermost Humphriesianum Zone (Cycloides = Romani Subzone).

TABLE 6.1

Correlation of the Bajocian faunas from Whitesail Lake with those of North American assemblage zones previously erected in Western Canada and United States, and with northwestern European Standard Zones

	EUROPEAN STANDARD ZONES AND SUBZONES		ASSEMBLAGE ZONES CONTERMINOUS UNITED STATES (Taylor, 1988)		ASSEMBLAGE ZONES SOUTHERN ALASKA AND WESTERN CANADA (Hall and Westermann, 1980)		WHITESAIL LAKE FAUNAS (this paper)			
BAJOCIAN	HUMPHRIESIANUM	BLAGDENI			OBLATUM		*Stephanoceras itinsae* *Chondroceras oblatum* *Oxycerites* sp. *Myophorella dawsoni* *Plagiostoma hazeltonense* ? *Pholadomya* sp. ? *Vaugonia* sp. *Pinna* sp.			
		HUMPHRIESIANUM						*Zemistephanus richardsoni*	*Stephanoceras skidegatense* *Myophorella argo*	*Stephanoceras variabilis* *Phylloceras* sp.
		ROMANI	KIRSCHNERI	RICHARDSONI	KIRSCHNERI	RICHARDSONI	*Chondroceras* sp. *Zemistephanus* sp. stephanoceratids			
	SAUZEI	HEBRIDICA		OREGONENSIS		?	*Sonninia (Sonninia)* sp. cf. *S. (S.) tuxedniensis*		*Stephanoceras* sp.	
		SAUZEI	CRASSICOSTATUS		CRASSICOSTATUS		*Sonninia (Sonninia)* sp. cf. *S. (S.) furticarinata*		*Sonninia* sp.	
	LAEVIUSCULA	LAEVIUSCULA		BURKEI	WIDEBAYENSE	SUTNEROIDES				
		OVALIS	TUBERCULATUM	OCHOCOENSE						
	DISCITES			WESTI		CAMACHOI	*Sonninia (Euhoploceras)* sp. cf. *S. (E.) dominans* *Sonninia (?Euhoploceras) tenuicostatum* *Camptonectes* sp.			
AALEN.	CONCAVUM		PACKARDI		AMPLECTENS					

Sonninia tuxedniensis is associated in the upper parts of the Red Glacier Formation of southern Alaska with *Parabigotites crassicostatus* (macro- and microconchs) and therefore is allocated to the *Parabigotites crassicostatus* Zone of Hall and Westermann (1980, p. 19). That zone is correlative with the European Sauzei Zone. The *P. crassicostatus* Zone has also been recognized in eastern Oregon, where the nominate species is associated with *Sonninia, Lissoceras, Emileia*, and early stephanoceratids (Taylor, 1988, p. 124).

Mixed faunas of stephanoceratids and sonniniids occur in the middle parts of the section on Cummins Creek (Fig. 6.1A, locs. 2, 3) and probably represent the upper part of the Sauzei Zone or lower part of the Humphriesianum Zone. Unfortunately these specimens occur as weathered moulds, mostly exposed in sagittal cross-sections, and could not be collected or further identified.

A single, partial external mould at locality 3 in Figure 6.1C, identified as *Stephanoceras* sp. cf. *S. skidegatense* may indicate correlation with the lower or middle part of the Humphriesianum Standard Zone. The type locality for this species is at Richardson Bay on southern Maude Island (Queen Charlotte Islands), where it occurs in the Richardson Bay Formation with *Chondroceras defontii*. This fauna is probably of similar age to the *Stephanoceras itinsae-Chondroceras oblatum* fauna from nearby South Balch Island, but the two have never been found in stratigraphic succession.

The *Z. richardsoni* Subzone makes up the upper part of the *Stephanoceras kirschneri* Assemblage Zone (Hall and Westermann, 1980, p. 20) and is correlative with the Romani Subzone, the lowest subzone in the Humphriesianum Standard Zone. Based on ammonite ranges from southern Alaska, the *Zemistephanus richardsoni* fauna was assumed by Hall and Westermann (1980) to be older than both the above-mentioned faunas containing *Stephanoceras*. The faunas described herein shed new light on the age of *Zemistephanus*. The association of several specimens of undoubted *Zemistephanus* with numerous small stephanoceratids and several fragments of *Chondroceras* at locality 1 in Figure 6.1B, indicates that *Zemistephanus* may range higher than realized by Hall and Westermann (1980). Numerous moulds of juvenile stephanoceratids occurring with *Zemistephanus* at Chikamin Mountain could be inner whorls from *Stemmatoceras* (broad forms) and *Skirroceras* (compressed forms), which could belong to the *Zemistephanus richardsoni* Assemblage Zone. On the other hand, if they represent stephanoceratids from the *Chondroceras oblatum* Assemblage Zone, then the stratigraphic range of the genus *Zemistephanus* is extended upward into at least the middle parts of the Humphriesianum Zone.

The highest ammonite-bearing beds on Cummins Creek (Fig. 6.1A, loc. 5), yield an association of *Stephanoceras itinsae* (macroconch) and *Chondroceras oblatum* (micro- and macroconchs), which clearly represent the *Chondroceras oblatum* Assemblage Zone. That zone has been correlated with the middle and upper parts of the Humphriesianum Zone (Hall and Westermann, 1980).

SYSTEMATIC PALEONTOLOGY

Class CEPHALOPODA

Order AMMONOIDEA Hyatt, 1889

Suborder AMMONITINA Hyatt, 1889

Superfamily HILDOCERATACEAE Hyatt, 1867

Family SONNINIIDAE Buckman, 1892

Genus *Sonninia* Bayle, 1879

Sonninia (*Sonninia*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt, 1858)

Plate 6.1, figure 1

See Morton, 1975, p. 78, for synonymy of *S.* (*S.*) *furticarinata*.

Material. An incomplete lateral mould (GSC 89749) with many attached oysters from locality 1 (Fig. 6.1A), where it is associated with *S. tuxedniensis* Imlay; UTM grid reference 307367, Troitsa Lake 1:50,000 topographic sheet, NTS 93 E/11 (GSC loc. C-146156).

Description. Specimen reached diameter of at least 90 mm; probably entirely septate. On inner whorls, visible lower parts of flanks are flat, with a sharply rounded umbilical shoulder and vertical umbilical wall. Umbilicus represents approximately 33 per cent of shell diameter. Ribs on lower flanks rectiradiate, broad but faint, and evenly spaced.

On last preserved half-whorl, flanks become slightly inflated and converge gradually to acutely fastigate venter but the whorl remains strongly compressed; keel not well preserved. Umbilical shoulder remains sharply rounded and umbilical wall vertical. Ribs at this stage very faint, simple, widely spaced, and gently concave forward.

Short segment of suture line visible on mid- to upper flank near end of specimen is complex and deeply dissected.

Discussion. The flat flanks, very faint to obsolete ribbing and vertical umbilical wall all closely resemble specimens illustrated by Morton (1975) from the uppermost Sauzei Zone (Hebridica Subzone) and lower Humphriesianum Zone (Cycloides Subzone) of Skye. Those specimens are larger and more complete, and have a more obtusely fastigate venter and somewhat finer ribbing on the phragmocone whorls. The species occurs at comparable stratigraphic levels in several parts of southern Germany (Dorn, 1935; Oechsle, 1958).

Sonninia (Sonninia) sp. cf. *S.* (*S.*) *tuxedniensis* Imlay, 1964

Plate 6.2, figure 4

cf. *Sonninia tuxedniensis* Imlay, 1964.

Material. One incomplete lateral mould (GSC 92839) from locality 1 (Fig. 6.1A); Smithers Formation, east bank of Cummins Creek, UTM grid reference 307367, Troitsa Lake 1:50 000 topographic sheet, NTS 93 E/11 (GSC loc. C-146156).

Description. Moderately large *Sonninia* that reached a diameter of at least 110 mm, with umbilical diameter about 40 per cent of shell diameter. Inner whorls with moderately rounded flanks and curved umbilical wall; last preserved half-whorl shows evidence of flattening of flanks due to crushing. Slight egression of whorl evident near end of specimen.

Ornamentation on inner whorls consists of blunt, thick, and rounded simple ribs, of irregular spacing and height, radial, or commonly with variable backward inclination on lower flanks; no sign of tubercles at any stage. On the last preserved half-whorl, ribs are broad and rounded, simple, evenly spaced; they curve slightly backward from umbilical seam, then flex gently forward in midflank, and begin to curve backward again but become faint on upper flank. Conspicuous growth striations also present on this half-whorl.

The faint trace of part of a septal suture indicates it was complex and moderately dissected.

Discussion. The backward inclination, irregular strength and spacing of ribs on the inner whorls and the rounded flanks with single, heavy, flexuous ribs on the last half-whorl all compare closely to specimens of *S. tuxedniensis* Imlay from the upper parts of the Red Glacier Formation in southern Alaska (Imlay, 1964). The Alaskan specimens, however, have more widely spaced ribs on the outer whorls (8 versus 12 on our specimen at similar diameters). The species occurs in place in the upper 500 feet (152.4 m) of the Red Glacier Formation of southern Alaska and only questionably in the overlying Fitz Creek Siltstone (Imlay, 1964, p. 33). That part of the Red Glacier Formation belongs to the lower *Stephanoceras kirschneri* Assemblage Zone.

Sonninia (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman, 1892

Plate 6.1, figures 4, 5; Plate 6.2, figures 1-3;
Plate 6.4, figure 11; Figure 6.2

cf. *Sonninia dominans* Buckman, 1892.

Material. Four partial external moulds and four slightly crushed whorl fragments (GSC 92835-92838; GSC 94430) from a small quarry on the south side of the road at grid reference 398641, Nadina River 1:50 000 topographic sheet, NTS 93 E/15; (Fig. 6.1D, loc. 1) (GSC loc. C-168517).

Description. Moderately evolute, large sonniniid that reached at least 150 mm in diameter. Body chamber fragments attached to two of the three-dimensional specimens have gently convex flanks, which round evenly onto narrow venter with keel (apparent height partly due to lateral crushing) but no ventral furrows. Flanks generally smooth but one specimen still bears very broad, gentle radial swellings. Whorls on last part of

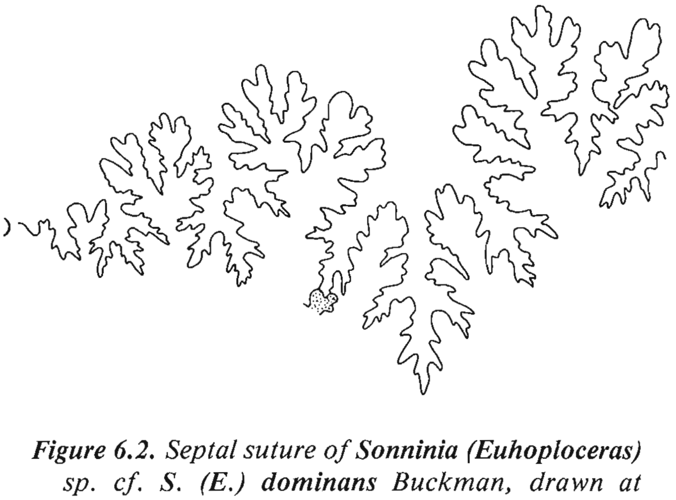

Figure 6.2. Septal suture of ***Sonninia (Euhoploceras)*** *sp. cf.* ***S. (E.) dominans*** *Buckman, drawn at whorl height of 4.2 mm and whorl width of 27.6 mm, x1.5. Figured specimen GSC 92838, from GSC loc. C-168517.*

phragmocone also compressed (H/W = 1.7), with gently convex flanks, narrow venter with high keel, and strongly rounded umbilical margin leading to low, steep umbilical wall. Ribs begin at umbilical margin, always simple, broad, rounded and strong, rectiradiate to very slightly rursiradiate in midflank, then curving forward on the upper flank. On inner whorls, where only lower part of flank visible, ribs strong, rounded and increase in strength toward midflank; 14 in half a whorl. No tubercles visible at any stage.

Septal suture complex, with deeply dissected elements; L broad, deep and trifid, umbilical elements straight, not suspended (Fig. 6.2).

Discussion. The oval whorls bearing unbranched, strong ribs that become stronger ventrally and persist onto the body chamber are all features of *Sonninia (Euhoploceras) dominans* described by Imlay (1973) from eastern Oregon. Weak tuberculation was said to be restricted to the smallest whorls of Imlay's specimens (Imlay, 1973, p. 63) but is not visible in our material. Ribbing style and density on inner whorls match those on Imlay's material very closely, but our specimens have smoother body chambers on which ribbing becomes obsolete. In this last feature, they resemble Oregon specimens placed in *E. modesta* Buckman by Imlay (1973); however, this latter species has a more distinct umbilical edge and more evolute inner whorls than both the Oregon material ascribed to *S.* (*E.*) *dominans* and our specimens.

Imlay compared his material with numerous Buckman "species", which he drew into synonymy with *S. dominans*. These were some of the many Buckman "species" Westermann (1966) concluded were members of a highly variable, single population, on the basis of intergrading and covarying morphologies and the fact that they all came from a single bed in the Discites Zone (Lower Bajocian) of Bradford Abbas, Dorset. Most workers agree with the extreme "splitting" represented by Buckman's treatment, but not all have accepted Westermann's recognition of a single biospecies—*Sonninia* (*E.*) *adicra* (Waagen)—because the specimens may come from a highly condensed bed (Imlay, 1973; Morton, 1975). Our specimens would fall into Westermann and Riccardi's (1972, p. 52) category having compressed, involute shells with obsolete ornament; both the values for whorl compression (H/W = 1.7) and relative umbilical diameter (U = 0.3) fall within the ranges established by Westermann (1966) for *Euhoploceras*. Our form is somewhat more compressed and more evolute than most species recently placed in this subgenus from eastern Oregon by Taylor (1988).

In Europe, the species occurs most commonly in the Discites Zone and possibly also in the upper part of the subjacent Concavum Zone (Morton, 1975). The eastern Oregon occurrences in the middle and upper parts of the Weberg Member were correlated with the Discites Zone (Imlay, 1973).

Sonninia tenuicostata n. sp. (microconch)

Plate 6.1, figures 2, 3, 6-13;
Figures 6.3A-C, 6.4A-D

Etymology. Latin, *tenuis* and *costatus*; referring to the slender, single ribs on the phragmocone whorls.

Holotype. Holotype, GSC 92829, from GSC locality C-168517 (Pl. 6.1, figs. 6, 7; Fig. 6.4C), from the Smithers Formation (Hazelton Group), (Fig. 6.1D, loc. 1); UTM grid reference 398641, Nadina River 1:50 000 topographic sheet, NTS 93 E/15. Lower Bajocian, Discites Standard Zone.

Material. Numerous external moulds (GSC 92827-92834) occurring in fine, greenish grey siltstone interbedded with red tuff; collected from many large blocks covering the floor of a small quarry on the south side of the road at UTM grid reference 398641, Nadina River 1:50 000 topographic sheet, NTS 93 E/15; (Fig. 6.1D, loc. 1) (GSC loc. C-168517). One specimen (Pl. 6.1, fig. 9) preserved mostly as an external mould but with the ultimate quarter-whorl of the body chamber preserved in three dimensions with the base of a lateral lappet.

Diagnosis. Compressed, moderately evolute microconch bearing short, lateral lappets, with the last part of the body chamber smooth. Phragmocone has gently convex flanks, lacks distinct umbilical shoulder, has narrow

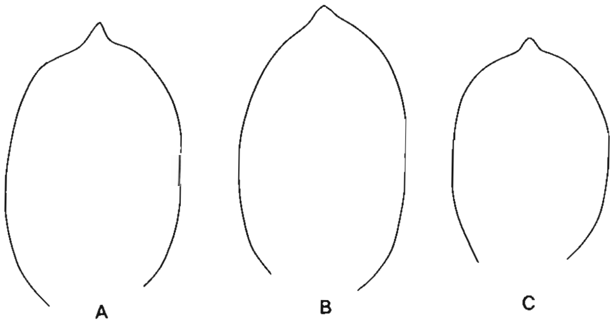

Figure 6.3. *Whorl cross-sections of* ***Sonninia tenuicostata*** *n. sp., all x2.5.* ***A.*** *GSC 94457,* ***B.*** *GSC 94456,* ***C.*** *GSC 94455, all from GSC loc. C-168517.*

venter with keel but no furrows, and generally fine, densely spaced, gently falcoid, simple ribs.

Description. Shell planulate and moderately evolute, with very shallow umbilicus representing about one third of shell diameter; no obvious egression of body chamber. The shell attained a diameter of at least 75 mm.

Whorls strongly compressed throughout, much higher than wide, H/W = 1.51-2.30, with later whorls slightly more compressed than earlier whorls. Flanks almost flat to very gently rounded, sloping gradually toward umbilical seam with very narrow, steeper umbilical wall developed on only a few specimens. Upper flanks round gradually onto narrow, smooth venter with high and sharp keel, but lacking associated furrows (Fig. 6.3).

Ribs always simple, of moderate strength, and gently falcoid throughout; appearing almost on the umbilical seam, nearly rectiradiate to gently prorsiradiate in midflank where maximum strength is attained, then curving forward at ventral extremities and disappearing before reaching keel. Rib spacing and strength both irregular on some specimens; nodes never present. The one certain body chamber fragment (Pl. 6.1, fig. 9) is smooth in the vicinity of the aperture.

Septal sutures relatively complex and elements deeply dissected; L large, trifid and straight. Umbilical elements not suspended; I very long and narrow (Fig. 6.4).

Discussion. These specimens bear numerous resemblances to several smaller species of *Dorsetensia* (suspected microconchs) described by Morton (1972) from Skye, but each of his species was said to be characterized by a sharp to rounded umbilical angle and steep to vertical umbilical walls. The present specimens have very gently sloping lower flanks and lack a distinct umbilical angle or wall. Most of the forms from Skye have more inflated and somewhat quadrate whorls, with the venter clearly separated from the flanks, sometimes tabulate bisulcate. Unfortunately, no cross-sections or septal sutures were illustrated.

The present specimens are distinguished from *Witchellia* in being more evolute, lacking a tabulate venter, and in having more complex septal sutures (see Morton, 1975, p. 42, 43 for a review of sonniniid genera) and from most *Sonninia* in lacking tubercles at any growth stage.

Sonniniidae gen. et sp. indet.

Plate 6.3, figures 7-9

Material. Two small external moulds (GSC 83530, 94420), each only a half-whorl, from locality 1 (Fig. 6.1A); UTM grid reference 307367, Troitsa Lake 1:50 000 topographic sheet, NTS 93 E/11 (GSC locs. C-146156, C-146157).

Description. Specimens small, 20-25 mm shell diameter. Whorls compressed, with flat flanks rounding gently toward umbilical seam; venter rounded, with low keel. Ribs simple, flexuous, and somewhat uneven in both spacing and strength.

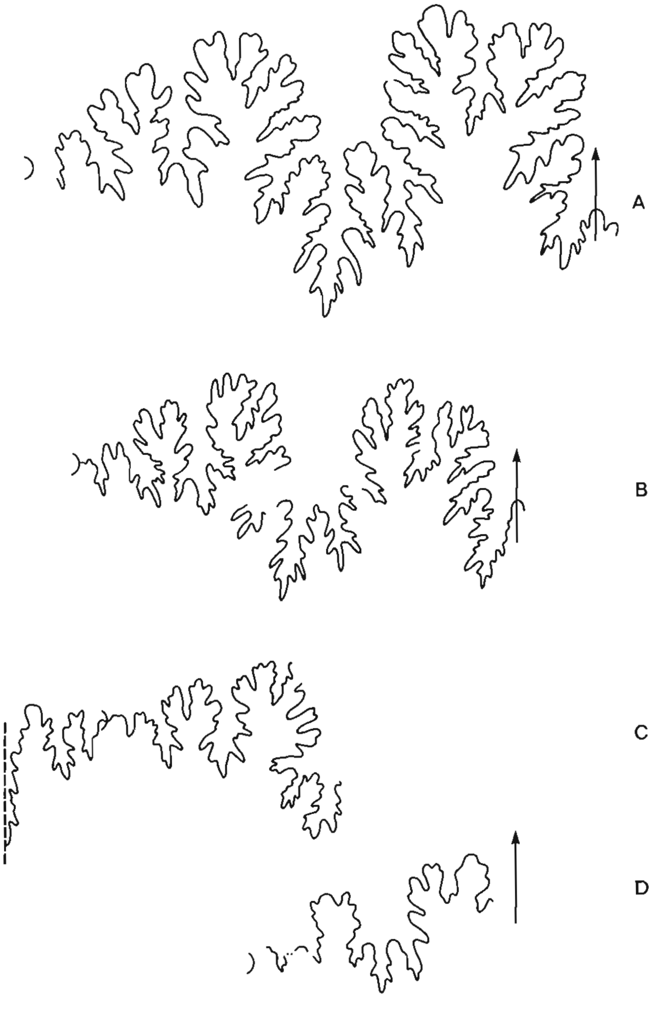

Figure 6.4. *Septal sutures of **Sonninia tenuicostata** n. sp., all x2.5. **A**. whorl width of 11.3 mm, figured specimen GSC 92832; **B**. whorl width of approximately 11 mm, figured specimen GSC 94368; **C**. whorl width of 10.9 mm, holotype, GSC 92829; **D**. whorl width of 7.0 mm, figured specimen GSC 94455. All specimens from GSC loc. C-168517.*

Discussion. These specimens may represent microconch sonniniids such as *Pelekodites* or inner whorls of the associated *Sonninia*, but are too small and incomplete for identification.

Superfamily HAPLOCERATACEAE Zittel, 1884

Family OPPELIIDAE Bonarelli, 1894

Subfamily OPPELIINAE Bonarelli, 1894

Genus *Oxycerites* Rollier, 1909

Oxycerites sp. indet.

Plate 6.4, figure 12

Material. A single lateral impression (GSC 94431) from Smithers Formation, west bank of Cummins Creek, (Fig. 6.1A, loc. 5); UTM grid reference 305371, Troitsa Lake 1:50 000 topographic sheet, NTS 93 E/11 (GSC loc. C-146160).

Description. Maximum diameter of 29.3 mm, involute, with umbilicus representing only 15 per cent of shell diameter, keeled, and apparently smooth.

Discussion. The genus is a rare but widespread component of Middle and Upper Bajocian faunas. A finely ribbed species, *O. stantoni*, occurs in the *Stephanoceras kirschneri* Zone in southern Alaska (Imlay, 1964, p. 28).

Superfamily STEPHANOCERATACEAE Neumayr, 1875

Family SPHAEROCERATIDAE Buckman, 1920

Genus *Chondroceras* Mascke, 1907

Chondroceras oblatum (Whiteaves, 1876) (macroconch, microconch)

Plate 6.4, figures 1-3

See Hall and Westermann, 1980, p. 52, for synonymy of *C. oblatum.*

Material. Lateral impression of one complete microconch (GSC 94421) and several distorted and fragmental macroconch specimens from Smithers Formation, Cummins Creek (GSC loc. C-146160); another impression of entire macroconch (GSC 94422) from bed 0.6 m above (GSC loc. C-146161). Both from grid reference 305371, Troitsa Lake 1:50 000 topographic sheet, NTS 93 E/11 (Fig. 6.1A, loc. 5). Partial mould (GSC 94423) from Chikamin Mountain (GSC loc. C-146165), grid reference 279189, Chikamin Mountain 1:50 000 topographic sheet, NTS 93 E/6 (Fig. 6.1B, loc. 2).

Description. Complete macroconch with body chamber that consists of about three quarters of last whorl, showing strong egression, ending with broad constriction followed by smooth collar, which is widest at venter and narrows toward umbilical margin. Seven primary ribs on last half-whorl, concave and prorsiradiate; below midflank each primary bifurcates without development of nodes or swellings, and other ribs arise at this level by intercalation; secondary ribs outnumber primaries 3:1. Secondaries curve backward slightly over the upper flanks.

Microconch (25.5 mm) reaches half the mature diameter of macroconch (47.3 mm), with terminal constriction and smooth collar similar to that of macroconch. The collar, however, is widest on its lateral part, producing a short, broad lappet. Last half-whorl also exhibits uncoiling, with seven curved primary ribs that branch below midflank without tubercles and with approximately three secondaries per primary.

Discussion. The specimens under discussion have primary ribs that are slightly more curved and secondary ribbing that is finer than in specimens from the Queen Charlotte Islands (Hall and Westermann, 1980, Pl. 14); the microconch has a more open umbilicus than in the allotype.

The species was discussed and its dimorphism first demonstrated by Hall and Westermann (1980); it was used by them as the index species for the *Chondroceras oblatum* Zone, and is a common species throughout western North America.

Family STEPHANOCERATIDAE Neumayr, 1875

Subfamily STEPHANOCERATINAE Neumayr, 1875

Genus *Stephanoceras* Waagen, 1869

Stephanoceras itinsae (McLearn, 1927) (macroconch)

Plate 6.5, figures 1-4

See Hall and Westermann, 1980, p. 37, for synonymy of *S. itinsae.*

Material. One large, incomplete lateral impression and two small, incomplete lateral impressions (GSC 94432-94434) from Smithers Formation, west bank of Cummins Creek, UTM grid reference 305371, Troitsa Lake 1:50 000 topographic sheet, NTS 93 E/11 (Fig. 6.1A, loc. 5) (GSC loc. C-146160). Another specimen (GSC 94435) from "Fossil Canyon", north side of Tahtsa Reach, UTM grid reference 345552 (GSC loc. C-168520).

Description. The larger specimen (Pl. 6.5, fig. 1) exceeds 180 mm in diameter and is slightly distorted, giving a false impression of egression and hence growth direction.

Coiling is moderately evolute, with the umbilical seam running just above the line of tubercles throughout the phragmocone. Lower flanks are gently convex, sloping gradually to the umbilical seam. Primary ribs long, slender, and sharp, of moderate relief, concave, prorsiradiate, and closely spaced; density increases gradually from 12 to 20 in a half-whorl on phragmocone whorls, and there are 23 on the last preserved half-whorl (presumably the body chamber).

Throughout the phragmocone, primary ribs terminate with a small, round tubercle but on final half-whorl become broader, with lower relief, and lack tubercles or swellings at the point of bifurcation. Secondary ribs are fine and dense, where visible on phragmocone whorls, outnumbering primaries by 4:1, but on last half-whorl become fainter, and the secondary/primary ratio decreases to 2.5:1.

The small whorl fragment (Pl. 6.5, figs. 2, 3) has similar fine, sharp and concave primary ribs ending in small, round tubercles from which arise three secondaries that are sharp and continue forward on the upper flank.

Discussion. Stephanoceras itinsae was revised and its sexual dimorphism discussed by Hall and Westermann (1980). It is a common species in western North America in the *Chondroceras oblatum* Zone. The small fragment (Pl. 6.5, fig. 3) has similar ribbing to that on the microconch of the species (Hall and Westermann, 1980, Pl. 8, figs. 2-7).

Stephanoceras sp. cf. *S. skidegatense* (Whiteaves, 1876) macroconch

Plate 6.5, figure 8

See Hall and Westermann, 1980, p. 43, for synonymy of *S. skidegatense.*

Material. One partial external mould (GSC 94438), showing flanks of half a whorl, with smaller fragments of inner whorl and what is probably part of mature body chamber. From UTM grid reference 402556, Whitesail Reach 1:50 000 topographic sheet, NTS 93 E/10, on road leading down to north shore of Tahtsa Reach of Whitesail Lake (Fig. 6.1C, loc. 3) (GSC loc. C-168521).

Discussion. There are 18 strong, slightly concave-forward, primary ribs in a half-whorl and most bifurcate into equally strong and sharp secondaries with only occasional intercalatories, so that the ratio of secondaries to primaries is 2.2:1. This ornamentation is very similar to that of *Stephanoceras skidegatense* (Whiteaves); *Stephanoceras itinsae* (McLearn) on the other hand has longer, less sharp primaries and finer and denser secondary ribs.

This form probably represents the *Chondroceras oblatum* Zone.

Stephanoceras sp. cf. *S. skidegatense* (Whiteaves, 1876) (microconch)

Plate 6.4, figures 4-9

Material. Latex mould of one side of incomplete specimen (GSC 94424) collected by H.W. Tipper in 1978 from northwest slope of Chikamin Mountain (GSC loc. C-53525), UTM grid reference 279188, Chikamin Mountain 1:50 000 topographic sheet, NTS 93 E/6 (near loc. 1 in Fig. 6.1B). In addition, several external moulds (GSC 94425-94428) collected by us from the Smithers Formation, northwest side of Chikamin Mountain (GSC locs. C-146163, C-146165, C-146166, C-146167), UTM grid references 279189 and 276182 respectively, Chikamin Mountain 1:50 000 topographic sheet, NTS 93 E/6 (Fig. 6.1B, locs. 1, 2).

Description. The mould (Pl. 6.4, fig. 4) has the flanks of three successive whorls and part of the venter on the last whorl exposed. A change in ornamentation and moderate egression near the end of this outermost whorl indicate that it is probably part of the mature body chamber of a microconch.

Whorls are moderately evolute, umbilicus representing 43-45 per cent of shell diameter; umbilical seam runs along line of tubercles except where minor egression begins over last quarter-whorl. Whorls depressed, with broadly arched venter and strongly convex flanks rounding to umbilical seam without development of a shoulder.

Primary ribs on inner whorls strong, sharp, evenly spaced (8 or 9 in a half-whorl), curved and slightly prorsiradiate, terminating in sharp, prominent tubercles. Two secondaries arise from each tubercle and there is nearly always an intercalated rib, so that secondaries outnumber primaries 3:1. On last preserved whorl, primaries increase to 13 and 14 in a half-whorl, tubercles become obsolescent and density of secondaries decreases to two for each primary. Primaries remain strong and curved, bifurcating at approximately half-whorl height into very strong, sharp secondaries.

Several additional partial moulds (Pl. 6.4, figs. 5-9) collected by us from the northwest side of Chikamin Mountain have the same rounded whorl sections and ribbing patterns as described above, and are assigned to this species.

Discussion. The closest microconch known from Western Canada is *Stephanoceras skidegatense* from the dark siltstone member at the base of the Richardson Bay Formation (Hall and Westermann, 1980; Cameron and Tipper, 1985). This species is characterized by strong ribbing on inner whorls bearing sharp tubercles, and depressed whorls with convex flanks; on the body chamber the ribbing remains very strong, but the ratio of secondary/primary ribs is reduced to 2:1, as on the specimens described above. The *Stephanoceras skidegatense-Chondroceras defontii* faunule, which occurs at Richardson Bay, Queen Charlotte Islands, cannot be placed in stratigraphic relation to other faunas in the Richardson Bay Formation and has not yet been found elsewhere; however, it is clearly of late Early Bajocian age (Humphriesianum Standard Zone). Microconchs of *Zemistephanus* have a somewhat similar morphology to the present specimen, but they have straighter, broader ribs with large, conical tubercles on inner whorls.

Stephanoceras variabilis
(Imlay, 1964) microconch

Plate 6.4, figure 10; Plate 6.5, figures 5-7

Normannites (*Itinsaites*?) *variabilis* Imlay, 1964.

Material. One body chamber fragment with aperture preserved (unfigured) collected by S. Duffell in 1949 from an elevation of 1676 m (5500 ft.) on the southwest side of Chikamin Mountain (GSC loc. 17194; in the vicinity of loc. 2 in Fig. 6.1B). One external mould of the lower flanks of a complete whorl (GSC 94429) collected from same locality by L. Diakow in 1987 (GSC loc. C-143379). Two specimens (including GSC 94436) were collected by H. Tipper from Fossil Canyon on the north shore of Tahtsa Reach (GSC loc. C-53554; approximate UTM grid reference 345552, Whitesail Reach 1:50 000 topographic sheet, NTS 93 E/10). Although the precise stratigraphic level of these last specimens is not known, they likely came from very close to our localities 1 and 2 in Figure 6.1C.

Description. The latex mould (Pl. 6.4, fig. 10) shows short, but slightly curved, strong primary ribs ending below midflank in small, rounded tubercles. On the earlier part of the last preserved whorl, secondary ribs outnumber primaries 3.3:1, but near the adoral end of this whorl, where egression is just beginning, the ratio becomes 2.5:1 with an increasing proportion of bifurcating ribs without intercalatories. Secondary ribs are strong and rounded, slightly prorsiradiate on upper flank.

One of the specimens from Fossil Canyon (Pl. 6.5, figs. 5-7) has two segments of the body chamber preserved in three dimensions, one with a short, lateral lappet indicating it is a complete microconch. Whorls rounded (H/W = 0.79 - 0.86), moderately involute (U% = 39), with rounded flanks and steep, curved umbilical walls. Primary ribs fine, sharp, almost straight, with slight anterior curvature, ending in small, pointed tubercles; 13 to 16 in a half-whorl on phragmocone. Secondary ribs also fine and sharp, most arising by furcation at tubercles, outnumbering primaries 4:1 on earlier part of last phragmocone whorl and 3:1 on its ultimate part; they curve very slightly forward on upper flanks and cross straight over broadly rounded venter without weakening. Body chamber fragment has short, anteriorly concave primaries with small, rounded tubercles situated a little below midflank, which give rise to three strong, rounded secondary ribs that become coarser and more widely spaced immediately before aperture.

Discussion. Ribbing style and density on the two specimens from Chikamin Mountain closely resemble the body chamber of the holotype of Imlay's species (Imlay, 1964, Pl. 13, fig. 15), which shows similar modifications approaching the adult aperture. The phragmocone whorls of the complete specimen from Fossil Canyon (Pl. 6.5, figs. 6, 7), preserved as an external mould, are very similar to those of Imlay's finer-ribbed variants (Imlay, 1964, Pl. 14, figs. 12, 14). The species occurs throughout the Fitz Creek Siltstone in southern Alaska (Imlay, 1964, p. 45) associated with an ammonite fauna that Hall and Westermann (1980) used as the basis for the *Stephanoceras kirschneri* Zone.

A similar large microconch stephanoceratid from southern Alaska, described by Imlay (1961) as *Dettermanites vigorosus* has a depressed whorl section and coarser, less dense ribbing, especially on the inner whorls. It came from the Bowser Member of the Tuxedni Formation where the associated ammonites are *Oppelia* (*Liroxyites*) *kellumi* and *Megasphaeroceras rotundum*, indicating a Late Bajocian age (Subfurcatum Standard Zone).

Genus *Zemistephanus* McLearn, 1927

Zemistephanus richardsoni (Whiteaves, 1876)
(macroconch, ?microconch)

Plate 6.3, figures 1, 2, 5, 6

See Hall and Westermann, 1980, p. 25, for synonymy of *Z. richardsoni*.

Material. One complete macroconch (GSC 83529), the last quarter-whorl before the aperture, heavily encrusted with oysters and large serpulid tubes and numerous oyster shells also attached to umbilical areas prior to preparation; collected in 1986 by M. Mihalynuk at locality 5 in Figure 6.1C (same as our more recent GSC loc. C-168519); from UTM grid reference 391576, Whitesail Reach 1:50 000 topographic sheet, NTS 93 E/10. Several additional fragmental specimens (e.g., GSC 83527) collected by us at the same locality and one partial external mould from about 100 m downstream at locality 4 in Figure 6.1C; UTM grid reference 389575 (GSC loc. C-168519). Another large, very poorly preserved external mould was found in a large boulder on Chikamin Mountain (GSC loc. C-146167), from UTM grid reference 279189, Chikamin Mountain 1:50 000 topographic sheet, NTS 93 E/6 (Fig. 6.1B, loc. 1).

Description. The almost complete macroconch (Pl. 6.3, figs. 5, 6) has a diameter of 144 mm, the last half-whorl of the body chamber showing marked egression and consequent constriction in whorl width. Aperture is not preserved but the strength of the secondary ribbing declines just before the end of the specimen, where fine striations are developed. Phragmocone cadicone, whorls strongly depressed (H/W = 0.51-0.61) at end of phragmocone with deep, crater-like umbilicus representing 40-42 per cent of shell diameter. Umbilical walls very steep and convex, rounding abruptly at position of tubercles onto very broad, evenly rounded venter (Pl. 6.3, fig. 5).

Last septum occurs three quarters of a whorl before aperture, and at this point egression of whorl begins, with relative umbilical width increasing to 45 per cent and then 48 per cent of shell diameter, whereas relative whorl width decreases from 52 per cent of shell diameter at end of phragmocone to 41 per cent near aperture. Whorl cross-section becomes less depressed, H/W values increasing to 0.66-0.72, and umbilical wall becomes much less steep.

Primary ribs throughout are broad, rectiradiate undulations of the umbilical wall, terminating in large, sharp, and conical tubercles at one third of whorl height on marked ventrolateral shoulder. On shell, these tubercles are from four to five mm high, but on internal mould appear only as low, rounded protuberances. Number of primaries increases gradually from 6 to 8 in a half-whorl at end of phragmocone, then to 9 and finally 13 on body chamber, where they lose some relief and become slightly prorsiradiate. Secondary ribs much finer at all stages, outnumbering primaries 5.5:1 on phragmocone and 4:1 on body chamber, crossing almost straight over the venter with only slight forward projection. Fine striations superimposed on secondaries just behind aperture, though most of this area is obscured by attached epizoans.

Other large macroconchs (unfigured; one of them designated as specimen GSC 94437 from GSC loc. C-168518) have crater-like umbilicus with almost vertical umbilical walls; large, conical tubercles situated on strongly curved umbilical shoulder; broadly rounded upper flanks and venter; and faint, dense secondary ribs typical of genus. Due to extremely poor preservation these specimens can only tentatively be placed in *Z. richardsoni*.

Smaller specimen (Pl. 6.3, figs. 1, 2) is probably a microconch because the ratio of secondary to primary ribs is 2.5:1, which is characteristic of late phragmocone whorls of microconchs of *Z. richardsoni* (Hall and Westermann, 1980, p. 29, Pl. 2, figs. 1-4).

Discussion. These specimens closely resemble, in coiling, whorl proportions, and ornamentation of both phragmocone and body chamber, specimens described by Hall and Westermann (1980) from the type locality at MacKenzie Bay, Maude Island. The high, sharp, conical nodes are an important new feature not seen in previously described specimens, all of which were internal moulds. The fine striae developed on the holotype are only seen just before the aperture in this specimen.

The species is known from the Queen Charlotte Islands (Whiteaves, 1876; McLearn, 1929; Hall and Westermann, 1980) and southern Alaska (Imlay, 1964) and was made the index species for a subzone in the upper part of the

Stephanoceras kirschneri Zone. The occurrence of *Zemistephanus* associated with *Stephanoceras* on the northwest side of Chikamin Mountain indicates a higher range for *Zemistephanus* than was previously known.

Zemistephanus sp. indet.

Plate 6.3, figures 3, 4

Material. A single mould (GSC 83528), entirely septate, from the Smithers Formation on the northwest slope of Chikamin Mountain (GSC loc. C-146163); locality 2 in Figure 6.1B, UTM grid reference 276182, Chikamin Mountain 1:50 000 topographic sheet, NTS 93 E/6.

Description. Entirely septate specimen with slight ventral crushing, reaching maximum diameter of about 40 mm. Coiling involute, with deep, crater-like umbilicus representing 38 per cent of shell diameter. Whorls depressed (H/W = 0.73), with broad, arched venter and strong ventrolateral shoulder. Umbilical wall very steep, convex, and becoming almost vertical as it approaches the umbilical seam.

Primary ribs on innermost whorls sharp, strongly prorsiradiate, fading toward umbilical seam, 11 to 12 in a half-whorl, terminating in sharp conical tubercles. At umbilical diameters greater than 9 mm, ribs become rectiradiate, less strongly curved, and less densely spaced with six to eight in a half-whorl. Here the ribs are fine, sharp crests on much broader undulations of the umbilical wall and are much narrower than the interspaces. Tubercles are relatively less well developed but remain sharp and conical. Secondary ribs on the last whorl are rounded, about as wide as interspaces, inclined gently forward over venter, and outnumbering the primaries 4:1.

Discussion. The depressed whorls with steep, convex umbilical walls, the style and density of the ribs and the tubercles are all very similar to the morphology and ontogenetic changes described for the inner whorls of *Zemistephanus richardsoni* (Whiteaves) by Hall and Westermann (1980, p. 26). However, without information on the morphology of the mature stages of the shell no firm species assignment can be made.

Class BIVALVIA

Subclass PALAEOHETERODONTA Newell, 1965

Order TRIGONIOIDA Dall, 1889

Superfamily TRIGONIACEA Lamarck, 1819

Family TRIGONIIDAE Lamarck, 1819

Subfamily MYOPHORELLINAE Kobayashi, 1954

Usage here follows that of Poulton (1979), who expanded the scope of this abundant and biostratigraphically important subfamily.

Genus *Myophorella* Bayle, 1878

Myophorella argo (Crickmay, 1933)

Plate 6.6, figures 1-3

Scaphogonia argo Crickmay 1930. *Myophorella argo* (Crickmay). Poulton, 1979.

Material. Three specimens (GSC 94439-94441) are figured from beds with *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves) on Chikamin Mountain (GSC loc. C-146167).

Discussion. This species has been described in detail by Poulton (1979) and the present, entirely typical material does not warrant additional description. The characteristic anterior row of nodes and short costae are well developed, and separated from the ribs of the main part of the flank. The ribs are ornamented with relatively high-standing, bead-like tubercles and are less distinctly separated from the anterior row of nodes compared with *M. dawsoni* (Whiteaves), which is of similar age and distribution. *Myophorella argo* is characteristic of *Stephanoceras*-bearing Lower Bajocian beds (Middle Bajocian in Poulton, 1979) from southern Alaska to California.

Myophorella sp. aff. *M. argo* (Crickmay)

Plate 6.6, Figures 4-7, 9, 10

Material. Many specimens, several of which are illustrated (GSC 94442-94445, 94447, 94448), from Chikamin Mountain, where they are associated with *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves) (GSC locs. C-146165, C-146166).

Discussion. Many specimens of *Myophorella* are not clearly identifiable with any described species. They exhibit strong, tuberculate ribs like those of *M. argo*, but the ribs are more strongly curved, as in *M. dawsoni.* The ribs extend entirely to the anterior end of the shell without interruption. These common, "generalized" forms appear to range through much of the Middle Jurassic.

Myophorella dawsoni (Whiteaves, 1878)

Plate 6.6, figure 8

Trigonia dawsoni Whiteaves, 1878a, 1878b, 1884.

Myophorella dawsoni (Whiteaves). Poulton, 1979.

Material. Many specimens are available from Cummins Creek, in beds with *Stephanoceras itinsae* (McLearn) and *Chondroceras oblatum* (Whiteaves). One (GSC 94446) is figured, from GSC locality C-146160.

Discussion. This species was described in detail by Poulton (1979), who indicated its widespread distribution in Lower Bajocian (Middle Bajocian in that report) strata of British Columbia and southern Alaska. The original locality, in the Bella Coola map area west of Whitesail Lake area, did not permit establishment of its stratigraphic range, which was established mainly by associations in the Smithers map area farther north.

Myophorella dawsoni is similar to *M. argo* (Crickmay), which has a similar geographic and stratigraphic distribution, but with which it is rarely associated. In *M. dawsoni*, the anterior row of nodes and short costae is not as distinctly separated from the ribs on the main part of the flank, which bear less prominent tubercles, and are straighter.

Genus *Vaugonia* Crickmay, 1930

Vaugonia(?) sp.

Plate 6.6, figure 11

Material. One fragment (GSC 94449) from Cummins Creek, from *Stephanoceras*-bearing beds within 6 m of the contact with *Sonninia*-bearing beds (GSC loc. C-146158).

Description. The dorsal and anterior parts of the shell are not available. The central part of the flank is apparently ornamented with closely spaced, subconcentric rows of small, rounded, low tubercles. The posterior part of the flank bears eight straight ribs oriented perpendicular to the ventral margin. They are finely corrugated by growth lines, and are separated by flat intercostal spaces about as wide as the ribs themselves. This posterior zone of vertical ribs does not extend to the umbo, but rather, the ribs become oblique toward the umbo, and the zone appears to be totally replaced by the central zone of concentric ribs. There is a narrow, vertical zone of transition between the differently ornamented central and posterior parts of the flank.

The marginal carina appears to be a simple edge near the umbos, a broader, rounded ridge posteroventrally. The posterior area is poorly preserved, apparently smooth.

Discussion. This type of *Vaugonia*, characterized by a posterior zone of vertical ribs, a central zone of horizontal ones, and a sharply bounded zone of gradation between the two, is rare in Canada and its biostratigraphic value is poorly known. A similar species occurs in probable Bajocian beds at the base of the Middle Jurassic section described by Frebold and Tipper (1973) at Tenas Creek, Smithers map area (Poulton, 1979) and in approximately equivalent beds elsewhere in British Columbia, so that this general type of *Vaugonia* may extend throughout the Bajocian.

Subclass PTERIOMORPHIA Beurlen, 1944

Order PTERIOIDA Newell, 1965

Suborder PTERIINA Newell, 1965

Superfamily LIMACEA Rafinesque, 1815

Family LIMIDAE Rafinesque, 1815

Genus *Plagiostoma* J. Sowerby, 1814

Plagiostoma hazeltonense McLearn, 1926

Plate 6.6, figure 15

Plagiostoma hazeltonense McLearn, 1926.

Material. One incomplete valve (GSC 94452) from Cummins Creek, where it occurs in beds with *Stephanoceras* (unfigured) about 30 m above *Chondroceras oblatum* (Whiteaves) (GSC loc. C-146162).

Description. The shell is large, gently convex, ornamented with prominent, but not particularly strong, wavy radial ribs. The ribs are closely spaced, largest in the central part of the shell. They are crossed with very fine, concentric growth lines that create a very finely corrugated appearance, some of which are stronger than others creating a broadly banded irregularity of the shell surface. The hinge area is not preserved.

Discussion. The specimen is entirely typical of *P. hazeltonense* and of other large species of *Plagiostoma.* Although the genus, rare in Western Canada, is long-ranging, large species such as this one appear to be characteristic of the Bajocian in Western Canada and have been used informally as Bajocian indices.

Superfamily PECTINACEA Rafinesque, 1815

Family PECTINIDAE Rafinesque, 1815

Camptonectes sp.

Plate 6.6, figure 13

Material. One small specimen (GSC 94451) with *Sonninia dominans* Buckman and *Sonninia tenuicostata* n. sp. from west of Andrews Bay (GSC loc. C-168517).

Discussion. This genus occurs occasionally in Middle Jurassic marine assemblages in Canada, but its biostratigraphic significance is not yet known. The present species is finer ribbed than most. The shell has been encrusted with fine serpulid worm tubes.

Order MYTILOIDA Ferrusac, 1822

Superfamily PINNACEA Leach, 1819

Family PINNIDAE Leach, 1819

Genus *Pinna* Linne, 1758

Pinna sp.

Plate 6.6, figure 12

Material. Many fragments from several localities at Cummins Creek. The specimen illustrated (GSC 94450) occurs with *Chondroceras oblatum* (Whiteaves) (GSC loc. C-146161).

Discussion. Never very abundant, *Pinna* is nevertheless a not uncommon component of Jurassic faunas throughout Western Canada. It has not yet been studied in detail, so its biostratigraphic value is totally unknown, but it is particularly conspicuous in the Lower Bajocian beds of the Whitesail Lake and Smithers map areas. This may be a result of the facies preserved. By analogy with the living conditions of modern species, the presence of *Pinna* confirms the low-energy, shallow marine environment indicated by the variety and abundance of associated bivalves and ammonites in these rocks. The only other species described from Western Canada, *Pinna amblyrhyncha* Crickmay (1930), is also Early Bajocian in age. Its apparently coarser, concentric growth lines compared with radial ribs may be an artifact of dissimilar and poorer preservation.

Order PHOLADOMYOIDA Newell, 1965

Superfamily PHOLADOMYACEA Gray, 1847

Family PHOLADOMYIDAE Gray, 1847

Pholadomya sp.

Plate 6.6, figures 14, 16

Material. One specimen (GSC 94453) from Cummins Creek, in a bed with abundant oysters in the interval containing *Stephanoceras* (GSC loc. C-146159).

Discussion. Pholadomya is a widespread, but rarely abundant component of Jurassic shallow marine assemblages. It has been little studied and its biostratigraphic value is not known, but individual species may be useful for correlation.

Family PLEUROMYIDAE Dall, 1900

Pleuromya(?) sp.

Plate 6.6, figure 17

Material. Poorly preserved specimens from many localities; one squashed specimen (GSC 94454) is illustrated from Cummins Creek, where it is associated with *Stephanoceras itinsae* (McLearn) (GSC loc. C-146160).

Discussion. Pleuromya and similar bivalves with generalized morphology are long-ranging, common components of Jurassic shallow marine assemblages in Western Canada. There is considerable variation in the forms present, but it is not yet known whether they have any biostratigraphic value.

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APPENDIX

FOSSIL LOCALITIES

All localities are within the Whitesail Lake map area (1:250 000; NTS 93E), UTM Zone 9u

GSC locality 17194. Southwest side of Chikamin Mountain, elevation 5500 ft. (1676 m). At or near GSC locs. C-143379, C-146163. *Stephanoceras kirschneri* Zone. Collected by S. Duffell, 1949. Fauna includes: *Stephanoceras variabilis* (Imlay).

GSC locality C-53525. Chikamin Mountain, UTM 279188. *Chondroceras oblatum* Zone. Collected by H.W. Tipper, 1978. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves).

GSC locality C-53554. Fossil Canyon, north side of Tahtsa Reach, 345552; Lat. 53°44′N, Long. 126°58′W. *Stephanoceras kirschneri* Zone. Collected by H.W. Tipper, 1978. Fauna includes: *Stephanoceras variabilis* (Imlay), *Stephanoceras* sp. cf. *S. variabilis* (Imlay), *Stephanoceras*(?) sp., *Chondroceras* sp.

GSC locality C-143379. 1.55 km on a bearing 275 degrees from Chikamin summit, UTM 628200 591740. *Stephanoceras kirschneri* Zone. Collected by L. Diakow, 1987. *Stephanoceras variabilis* (Imlay), *Stephanoceras*(?) sp., *Chondroceras*(?) sp.

GSC locality C-146156. Eastern tributary of Cummins Creek, south side of Troitsa Peak, UTM 307367. Crassicostatus Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Sonninia* (*Sonninia*) sp. cf. *S.* (*S.*) *tuxedniensis* Imlay, *Sonninia* (*Sonninia*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt), sonniniid ammonites, indet., stephanoceratid ammonites, indet., oysters.

GSC locality C-146157. Eastern tributary of Cummins Creek, south side of Troitsa Peak. Stratigraphically between GSC locs. C-146156 and C-146158. Collected by T. Poulton and R. Hall, 1987. Fauna includes: sonniniid ammonites, indet.

GSC locality C-146158. Eastern tributary of Cummins Creek, south side of Troitsa Peak, stratigraphically between GSC locs. C-146156 and C-146159, UTM 306369. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Vaugonia*(?) sp.

GSC locality C-146159. Eastern tributary of Cummins Creek, south side of Troitsa Peak. Beds rich in oysters, stratigraphically between GSC locs. C-146158 and C-156160. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Pholadomya* sp.

GSC locality C-146160. Eastern tributary of Cummins Creek, southeast of Troitsa Peak, UTM 305371. *Chondroceras oblatum* Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Stephanoceras itinsae* (McLearn), *Chondroceras oblatum* (Whiteaves), *Oxycerites* sp., *Myophorella dawsoni* (Whiteaves), *Pleuromya*(?) sp.

GSC locality C-146161. Eastern tributary of Cummins Creek, southeast of Troitsa Peak, UTM 305371. *Chondroceras oblatum* Zone, 0.6 m above GSC loc. C-146160. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Chondroceras oblatum* (Whiteaves), *Pinna* sp.

GSC locality C-146162. Eastern tributary of Cummins Creek, southeast of Troitsa Peak, stratigraphically above GSC locs. C-146160, C-146161. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Plagiostoma hazeltonense* McLearn.

GSC locality C-146163. West-northwest of peak of Chikamin Mountain, elevation 5500 ft. (1676 m), UTM 276182. *Chondroceras oblatum* Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatensis* (Whiteaves), *Zemistephanus* sp., *Chondroceras oblatum* (Whiteaves).

GSC locality C-146165. Northwest of peak of Chikamim Mountain, elevation 5500 ft. (1676 m), UTM 279189. *Chondroceras oblatum* Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatensis* (Whiteaves), *Chondroceras oblatum* (Whiteaves), *Myophorella* sp. aff. *M. argo* (Crickmay).

GSC locality C-146166. Northwest of peak of Chikamin Mountain, elevation 5500 ft. (1676 m), UTM 279189. *Chondroceras oblatum* Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves), *Myophorella* sp. aff. *M. argo* (Crickmay).

GSC locality C-146167. Northwest of peak of Chikamin Mountain, elevation 5500 ft. (1676 m), UTM 279189. *Chondroceras oblatum* (?) Zone. Collected by T. Poulton and R. Hall, 1987. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves), *Zemistephanus richardsoni* (Whiteaves), *Myophorella argo* (Crickmay).

GSC locality C-146168. Northwest of peak of Chikamin Mountain, elevation 5500 ft. (1676 m), UTM 279191. Collected by T. Poulton and R. Hall, 1987. Fauna include: *Zemistephanus* sp., *Emileia* sp.

GSC locality C-168517. Quarry on south side of logging road west of Andrews Bay, UTM 398641. Discites Zone. Collected by T. Poulton and R. Hall, 1988. Fauna includes: *Sonninia* (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman, *Sonninia tenuicostata* n. sp., *Camptonectes* sp., *Myophorella* sp. aff. *M. argo* (Crickmay), *Pleuromya* sp., *Lopha* sp., *Camptochlamys* sp., belemnites.

GSC locality C-168518. Mouth of small gorge along creek on north shore of Tahtsa Reach, UTM 389575. About 100 m downstream from GSC loc. C-168519. *Zemistephanus richardsoni* Zone. Collected by T. Poulton and R. Hall, 1988. Fauna includes: *Zemistephanus richardsoni* (Whiteaves).

GSC locality C-168519. Creek on south side of Mosquito Hills, UTM 391576. *Zemistephanus richardsoni* Zone. Collected by T. Poulton and R. Hall, 1988; previously collected by M. Mihalynuk, 1986. Fauna includes: *Zemistephanus richardsoni* (Whiteaves).

GSC locality C-168520. "Fossil Canyon", creek on north side of Tahtsa Reach, UTM 3450 5525. Collected by T. Poulton and R. Hall, 1988. Fauna includes: *Chondroceras* sp., *Stephanoceras itinsae* (McLearn), phylloceratid ammonites sp.

GSC locality C-168521. On road to north shore of Tahtsa Reach, UTM 402556. *Chondroceras oblatum* Zone. Collected by T. Poulton and R. Hall, 1988. Fauna includes: *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves).

PLATES 6.1 to 6.6

All figures are natural size.

All specimens are stored in the National Type Collection of the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario.

The first number, prefaced with GSC, indicates the accession number of the specimen in the Type Collection; the second, prefaced with GSC locality, refers to the GSC catalogue of fossil localities and the localities listed in the Appendix.

PLATE 6.1

Figure 1. *Sonninia* (*Sonninia*) sp. cf. *S.* (*S.*) *furticarinata* (Quenstedt)

Figured specimen GSC 89749, from GSC loc. C-146156.

Figures 2, 3, 6-13. *Sonninia tenuicostata* n. sp.

2. Cast of figured specimen GSC 92827, from GSC loc. C-168517.

3. Cast of figured specimen GSC 92828, from GSC loc. C-168517.

6, 7. Lateral and ventral views, cast of holotype, GSC 92829, from GSC loc. C-168517.

8. Figured specimen GSC 92830, from GSC loc. C-168517.

9. Figured specimen GSC 92831, from GSC loc. C-168517.

10, 11. Lateral and ventral views, figured specimen GSC 92832, from GSC loc. C-168517; partial cast.

12. Cast of figured specimen GSC 92833, from GSC loc. C-168517; with attached serpulid tube.

13. Cast of figured specimen GSC 92834, from GSC loc. C-168517.

Figures 4, 5. *Sonninia* (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman

4. Cast of figured specimen GSC 92835, from GSC loc. C-168517; with attached ostreiid(?) bivalve.

5. Cast of figured specimen GSC 92836, from GSC loc. C-168517.

PLATE 6.1

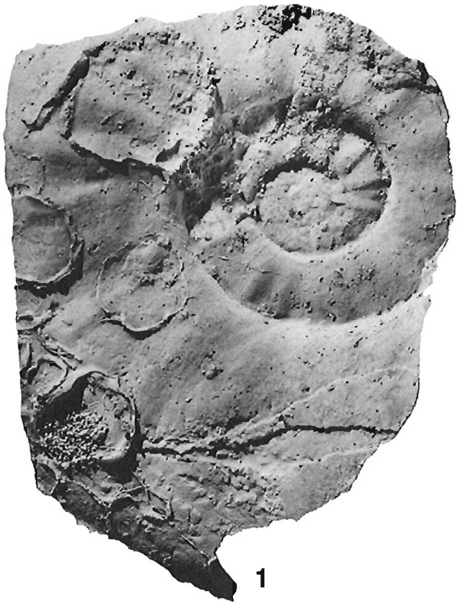
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PLATE 6.2

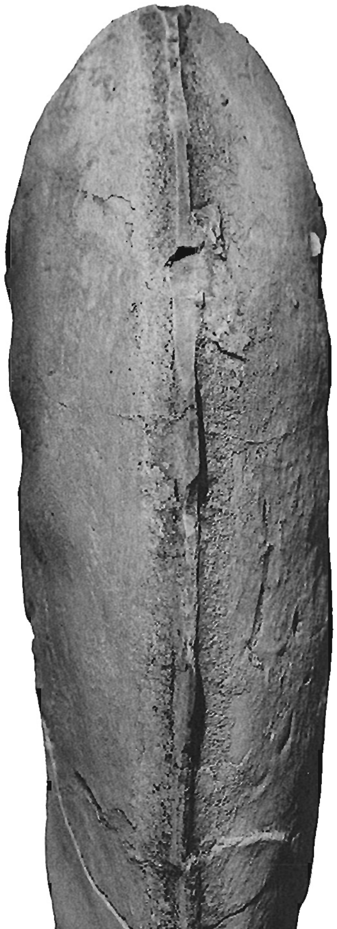
Figures 1-3. *Sonninia* (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman

1, 2. Ventral and lateral views, fragmentary figured specimen GSC 92837, from GSC loc. C-168517.

3. Figured specimen (entirely phragmocone) GSC 92838, from GSC loc. C-168517.

Figure 4. *Sonninia* (*Sonninia*) sp. cf. *S.* (*S.*) *tuxedniensis* Imlay

Figured specimen GSC 92839, from GSC loc. C-146156.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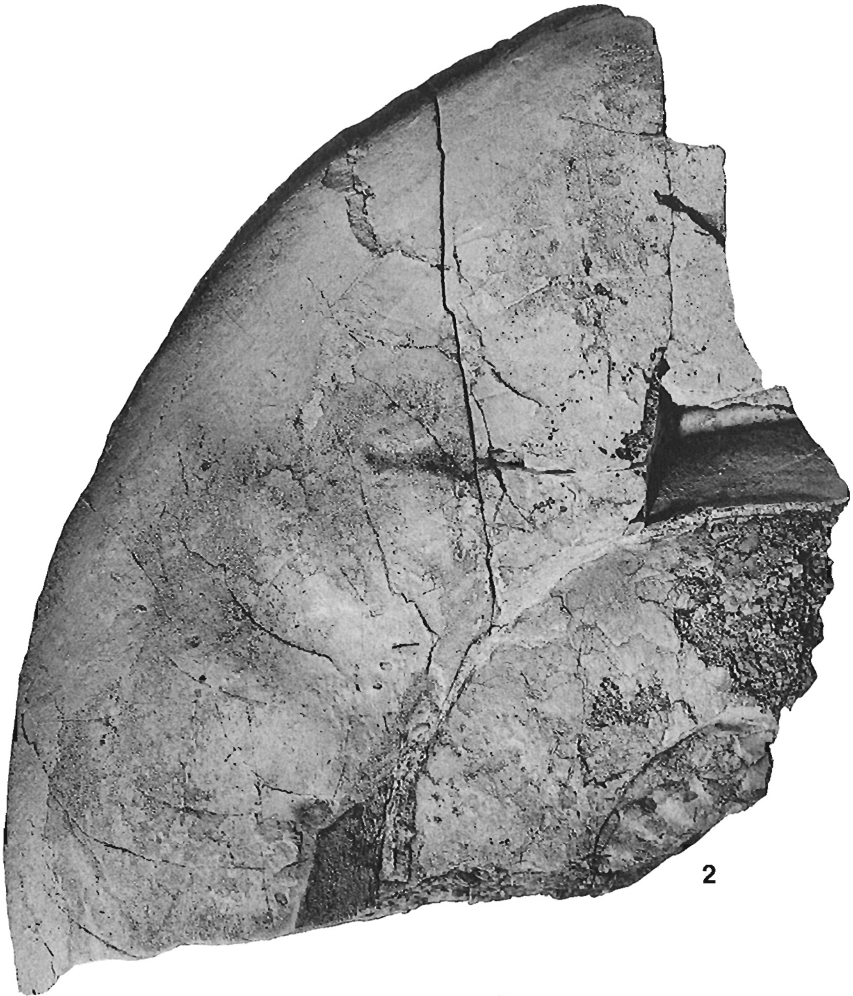
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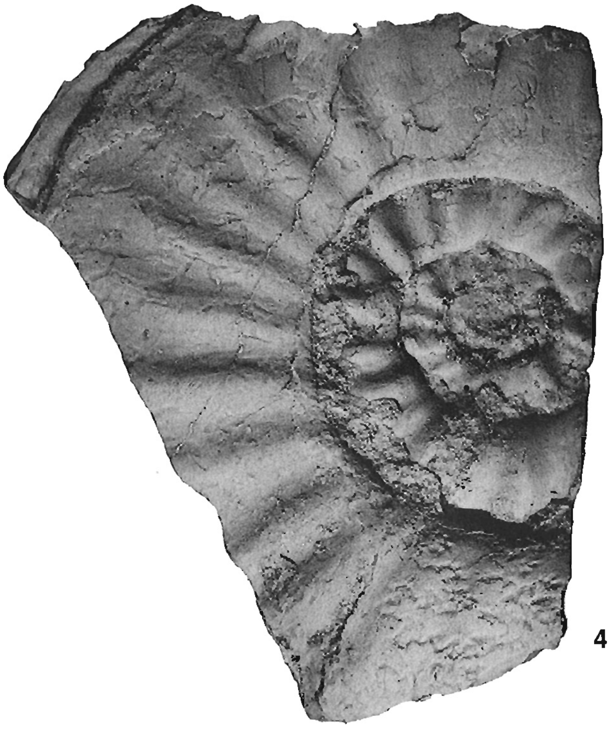
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PLATE 6.3

Figures 1, 2, 5, 6. *Zemistephanus richardsoni* (Whiteaves) (macroconch, ?microconch)

1, 2. Lateral and ventral views, cast of figured specimen GSC 83527, from GSC loc. C-168519.

5, 6. Ventral and lateral views, figured specimen GSC 83529, from GSC loc. C-168519; body chamber with encrusting (?)ostreiid bivalves and serpulid tubes.

Figures 3, 4. *Zemistephanus* sp. indet.

Lateral and ventral views, figured specimen GSC 83528, from GSC loc. C-146163.

Figures 7-9. Sonniniidae gen. et sp. indet.

7. Figured specimen GSC 83530, from GSC loc. C-146156.

8, 9. Ventral and lateral views, figured specimen GSC 94420, from GSC loc. C-146157.


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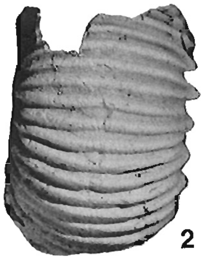
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PLATE 6.4

Figure 1-3. *Chondroceras oblatum* (Whiteaves) (macroconch, microconch)

1. Figured specimen GSC 94421, from GSC loc. C-146160.
2. Figured specimen GSC 94422, from GSC loc. C-146161.
3. Cast of figured specimen GSC 94423, from GSC loc. C-146165.

Figure 4-9. *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves) (microconch)

4. Cast of figured specimen GSC 94424, from GSC loc. C-53525.
5. Cast of figured specimen GSC 94425, from GSC loc. C-146163.
6. Figured specimen GSC 94426, from GSC loc. C-146165.
7. Cast of figured specimen GSC 94427, from GSC loc. C-146167.

8, 9. Lateral and ventral views, cast of figured specimen GSC 94428, from GSC loc. C-146166.

Figure 10. *Stephanoceras variabilis* (Imlay) (microconch)

Cast of figured specimen GSC 94429, from GSC loc. C-143379.

Figure 11. *Sonninia* (*Euhoploceras*) sp. cf. *S.* (*E.*) *dominans* Buckman

Figured specimen GSC 94430, from GSC loc. C-168517.

Figure 12. *Oxycerites* sp. indet.

Cast of figured specimen GSC 94431, from GSC loc. C-146160.


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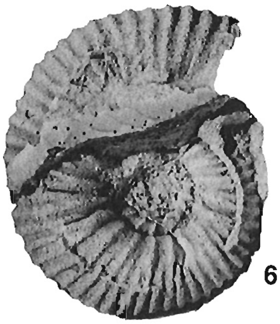
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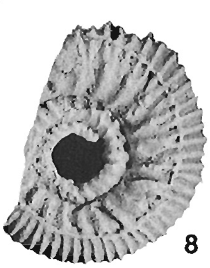
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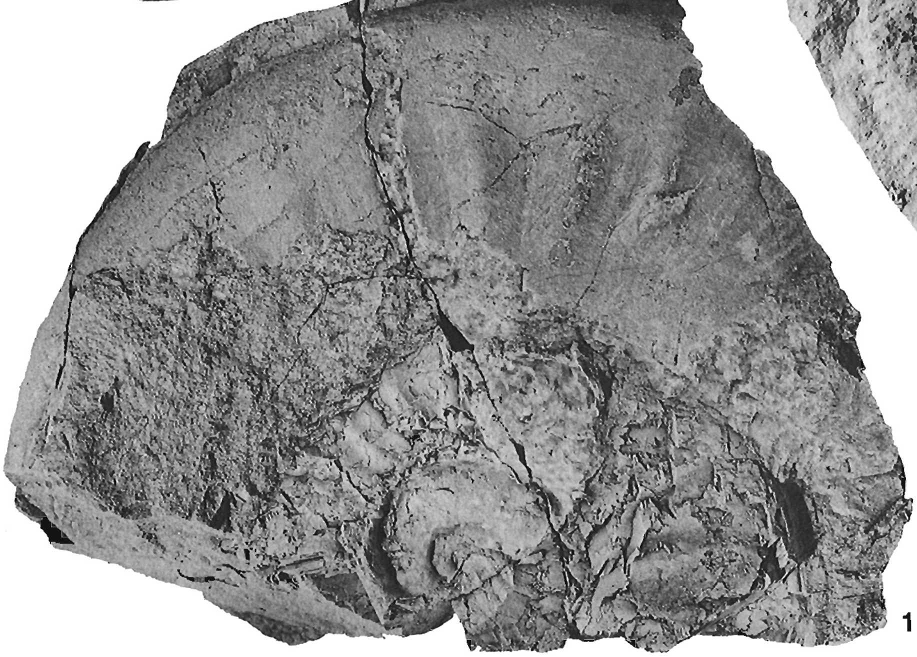
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PLATE 6.5

Figures 1-4. *Stephanoceras itinsae* (McLearn) (macroconch)

1. Cast of figured specimen GSC 94432, from GSC loc. C-146160.
2. Figured specimen GSC 94433, from GSC loc. C-146160.
3. Cast of figured specimen GSC 94434, from GSC loc. C-146160.
4. Figured specimen GSC 94435, from GSC loc. C-168520.

Figures 5-7. *Stephanoceras variabilis* (Imlay) (microconch)

5. Figured specimen GSC 94436, from GSC loc. C-53554.

6, 7. Ventral and lateral views of cast of inner whorls of same specimen as in figure 5.

Figure 8. *Stephanoceras* sp. cf. *S. skidegatense* (Whiteaves) (macroconch)

Cast of figured specimen GSC 94438, from GSC loc. C-168521.


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PLATE 6.6

Figures 1-3. *Myophorella argo* (Crickmay)

1. Cast of figured specimen GSC 94439, from GSC loc. C-146167.
2. Cast of figured specimen GSC 94440, from GSC loc. C-146167.
3. Cast of figured specimen GSC 94441, from GSC loc. C-146167.

Figures 4-7, 9, 10. *Myophorella* sp. aff. *M. argo* (Crickmay)

4. Figured specimen GSC 94442, from GSC loc. C-146166.
5. Cast of figured specimen GSC 94443, from GSC loc. C-146166.
6. Cast of figured specimen GSC 94444, from GSC loc. C-146166.
7. Figured specimen GSC 94445, from GSC loc. C-146166.
9. Figured specimen GSC 94447, from GSC loc. C-146166.
10. Cast of figured specimen GSC 94448, from GSC loc. C-146165.

Figure 8. *Myophorella dawsoni* (Whiteaves)

Cast of figured specimen GSC 94446, from GSC loc. C-146160.

Figure 11. *Vaugonia*(?) sp.

Figured specimen GSC 94449, from GSC loc. C-146158.

Figure 12. *Pinna* sp.

Fragmentary figured specimen GSC 94450, from GSC loc. C-146161.

Figure 13. *Camptonectes* sp.

Cast of figured specimen GSC 94451, from GSC loc. C-168517; serpulid tubes attached.

Figures 14, 16. *Pholadomya* sp.

Lateral and dorsal views, figured specimen GSC 94453, from GSC loc. C-146159.

Figure 15. *Plagiostoma hazeltonense* McLearn

Cast of figured specimen GSC 94452, from GSC loc. C-146162.

Figure 17. *Pleuromya*(?) sp.

Dorsolateral view, partially flattened figured specimen GSC 94454, from GSC loc. C-146160.


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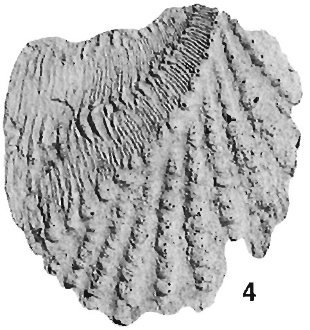
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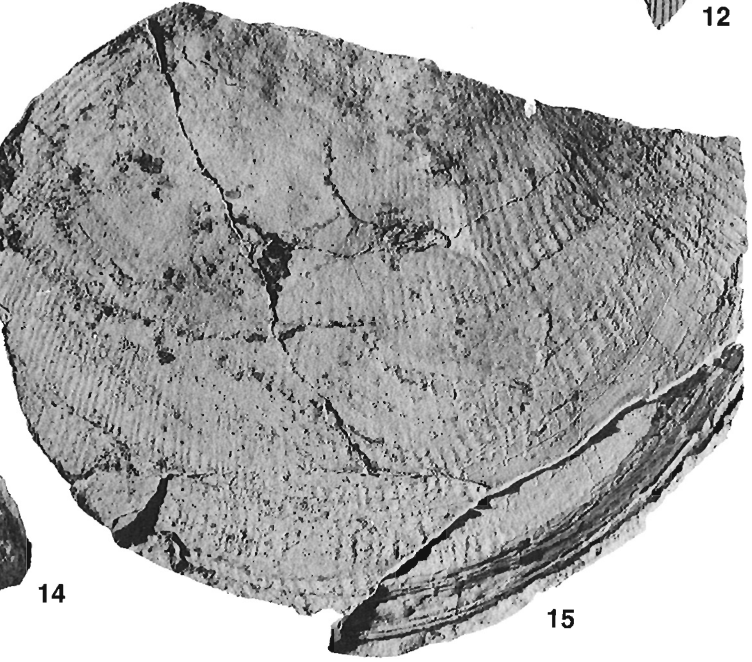
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