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ADVANCE FORMATION: STRATIGRAPHY AND BIOSTRATIGRAPHY OF A NEW ORDOVICIAN FORMATION FROM THE ROCKY MOUNTAINS, NORTHEASTERN BRITISH COLUMBIA

B.S. Norford, J. Jin and B.S. Norford,
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Cover Illustration
Profile of Advance Mountain, Skoki–Advance–Upper Ordovician Quartzite–Nonda units.

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Authors' addresses

Thomas E. Bolton
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
K1A 0E8

Robert J. Elias
Department of Geological Sciences
The University of Manitoba
Winnipeg, Manitoba
R3T 2N2

Jisuo Jin and Paul A. Johnston
Royal Tyrrell Museum of Palaeontology
P.O. Box 7500
Drumheller, Alberta
T0J 0Y0

B.S. Norford
Geological Survey of Canada
3303 - 33rd Street N.W.
Calgary, Alberta
T2L 2A7

David M. Rohr
Department of Geology
Sul Ross State University
Alpine, Texas 79832
U.S.A.

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PREFACE

This volume recognizes and describes the Advance Formation, a rock unit unique in western Canada that preserves records of geological time lost elsewhere to erosion associated with later unconformities. Its description provides new information on the geological history of northeastern British Columbia, an area of active exploration for mineral and energy resources. Abundant fossil brachiopods are associated with several other fossil groups, including some of the oldest known solitary corals in North America. Rigorous taxonomic descriptions of individual species provide important benchmarks for comparison with successions of sedimentary rocks worldwide. Comparing the correlations provided by Advance Formation fossil studies refines the calibration between correlation schemes based on brachiopods, conodonts, corals and graptolites.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

PRÉFACE

Dans le présent volume, est reconnue et décrite la Formation d'Advance, unité rocheuse unique de l'Ouest canadien ayant conservé des indices géochronologiques qui ont été effacés ailleurs par une l'érosion associée à des discordances ultérieures. Sa description révèle de nouvelles informations sur l'histoire géologique du nord-est de la Colombie-Britannique où l'exploration des ressources minérales et énergétiques est active. Les brachiopodes fossiles qui y abondent sont associés à plusieurs autres groupes de fossiles, dont certains coraux solitaires parmi les plus anciens d'Amérique du Nord. La description taxonomique rigoureuse de chacune des espèces permet d'établir des repères importants pour une comparaison avec des successions de roches sédimentaires dans le monde entier. La comparaison des corrélations faites dans le cadre des études des fossiles de la Formation d'Advance a contribué à affiner les schémas de corrélation basés sur les brachiopodes, les conodontes, les coraux et les graptolites.

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

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Paul A. Johnston

Summary

The northern Rocky Mountain Lower Paleozoic rocks consist of carbonates deposited in the shallow waters of the MacDonald Platform, and the coeval slope and basin facies of the Kechika Trough to the west of the platform. Unconformities are common within the succession, both on the platform and in the trough. A prominent unconformity is at the base of an Upper Ordovician "quartzite and dolomite unit" that is laterally equivalent to the lower part of the Beaverfoot Formation of the central and southern Rocky Mountains. At many localities, this unconformity rests on Middle Ordovician horizons within the Skoki Formation, but to the northwest it cuts down into the Lower Ordovician Kechika Group.

In a small region east of the main reaches of Williston Lake, rocks younger than the Skoki Formation are preserved below this unconformity at Advance Mountain, Mount Burden and a few other localities. These rocks are virtually unique in the Canadian Cordillera and a new name, Advance Formation, is proposed for them. The formation consists of platy, nodular carbonate and shale and has a maximum known thickness of 68 m.

There were three depositional episodes, reflected in the varying lithology. The lowest part consists of very fine grained limestone (partly dolomitic) with substantial argillaceous content. The limestone is thinly bedded, wavy bedded, and weathers platy and nodular. Interbedded limy shales are prominent in the basal beds, but become less common upward. The middle part is more dolomitic, with only minor shale interbeds; layers of greyish black chert nodules are common. The uppermost part (preserved only at Advance Mountain) is very recessive and consists of thinly bedded argillaceous dolomite and shale. All of these lithologies are typical of a depositional environment of moderate depth, but there are no indications of any turbidites or tempestites. Regional considerations and the substantial carbonate content leads to an interpretation of deposition on a very gently inclined slope rather than within the basinal environments of the central parts of the Kechika Trough farther to the west. The macrofauna consists of abundant articulate brachiopods together with echinoderm and sponge debris and rare gastropods, solitary corals, trilobites, bryozoans, ostracodes, cephalopods, pelecypods, and inarticulate brachiopods. Despite extensive search, no graptolites have been found. Some of the fossils were probably transported — the single specimen of the coral *Paliphyllum* is abraded. However, most brachiopod and pelecypod shells are almost entire and many are still articulated, indicating little current action and transport for many beds. The gastropod assemblage is similar paleoecologically, at the generic and family level, to Upper Ordovician assemblages in the Cincinnati Arch region that are thought to have lived in proximal or mid-shelf environments but with depths of water below fair-weather wave base. Tabulate corals are absent, likely indicating that the depositional environment was too deep or too muddy for them to survive.

Collectively, the faunas indicate a late Caradoc age for the Advance Formation; probably younger than the Copenhagen Formation of Nevada and older than the upper member of the Jones Ridge Limestone of Yukon Territory and Alaska. This late Middle Ordovician (probably Kirkfieldian to Shermanian) age is supported by identifications and correlations of associated conodonts, corals, bryozoans, gastropods, and pelecypods.

The silicified brachiopod fauna of the Advance Formation includes early occurrences of a number of Edenian species together with late occurrences of Chazyan and early Mohawkian species. Brachiopods from the upper part of the formation seem to be slightly younger than those in the lower beds, whose fauna includes species of *Bimuria, Christiania, Leangella* and *Paurorthis*. This assemblage is characteristic of the *Bimuria* Fauna of the Scoto-Appalachian Faunal Province, but it also includes some taxa typical of western North America. The brachiopods indicate a late Caradoc age (late Mohawkian: Rocklandian to Shermanian).

Conodonts from the Advance Formation are thermally altered to Conodont Alteration Index 4.5. Faunules from the lowest part of the type section most probably are Rocklandian to Shermanian in age. Faunules from higher in the type section only indicate a general late Middle or

Late Ordovician age. Above these and above the disconformity at the top of the Advance Formation, a diagnostic conodont faunule is present 27 to 34 m above the base of the overlying "quartzite and dolomite unit". This faunule includes *Amorphognathus ordovicicus* and *Gamachignathus hastatus* and its age is late Richmondian or Gamachian. Below the Advance Formation at its type section, a faunule from the top beds of the Skoki Formation is Middle Ordovician in age, possibly Blackriverian.

Solitary rugose corals of the Advance Formation include an indeterminate form in the basal beds, and new species of *Paliphyllum* a little higher, and species of *Grewingkia* in the main part. The new species of *Paliphyllum* is probably the earliest representative of this dissepimented genus. It is most similar to some latest Caradoc to earliest Ashgill specimens from the Siberian Platform. The new species of *Grewingkia*, one of the earliest members of the genus, is considered to be ancestral to *Grewingkia robusta* (Whiteaves) known from the Edenian to Richmondian rocks of cratonic North America. The Advance corals are consistent with an age assignment of Rocklandian to early Edenian and probably later within this interval rather than earlier.

The bryozoan assemblage consists of eight trepostome genera, each of which is known elsewhere from Middle and Upper Ordovician rocks. However, in the central and eastern United States, occurrences together of *Atactoporella, Cyophotrypa, Homotrypa* and *Parvohallopora* are most common in the late Middle and early Late Ordovician.

Trilobites are very rare and only generic determinations are possible of *Ceraurus, Decoroproetus*, (?)*Dolichoharpes*, and (?)*Failleana*. Combining the constraints of their generic ranges, a general Caradoc age is indicated (late Blackriverian to early Maysvillian). Most of the gastropods found in the Advance Formation are small and belong to long-ranging genera. However, *Liospira* cf. *L. vitruvia* (Billings) and *Ophiletina angularis* Ulrich and Schofield are known elsewhere in upper Trentonian (Kirkfieldian to Shermanian) rocks. Pelecypods are very few in number, but substantiate a general Kirkfieldian to early Edenian age for the lower half of the Advance Formation.

In relation to other faunas in western ancestral North America, the Advance faunas are older than those of the Red River Formation of Manitoba and younger than those of the Copenhagen and Lehman formations of Nevada. Combining the correlations provided by the various groups of fossils, a Kirkfieldian to Shermanian age (late Caradoc) is most likely for the Advance Formation. Most or all of Edenian time and part or all of Maysvillian time appears to fall within the hiatus reflected by the overlying unconformity.

Sommaire

Les roches du Paléozoïque inférieur des Rocheuses septentrionales sont composées de roches carbonatées déposées en eaux peu profondes sur la plate-forme de MacDonald et du faciès de talus et de bassin contemporain de la cuvette de Kechika à l'ouest de la plate-forme. Les discordances sont fréquentes dans la succession, que ce soit sur la plate-forme ou dans la cuvette. Une discordance évidente s'observe à la base d'une unité de «quartzite et de dolomie» de l'Ordovicien supérieur qui est latéralement équivalente à la partie inférieure de la Formation de Beaverfoot dans le centre et le sud des Rocheuses. À nombre d'endroits, cette discordance repose sur des horizons de l'Ordovicien moyen dans la Formation de Skoki, mais au nord-ouest, elle découpe le Groupe de Kechika de l'Ordovicien inférieur.

Dans une petite région à l'est des principaux bras du lac Williston, des roches plus récentes que la Formation de Skoki sont encore présentes au-dessous de cette discordance au mont Advance, au mont Burden et à quelques autres localités. Ces roches sont pratiquement uniques dans la Cordillère canadienne; c'est pourquoi un nouvelle appellation, la «Formation d'Advance», est proposée pour les désigner. La formation se compose de roches carbonatées et de shales noduleux en plaquettes et son épaisseur maximale connue est de 68 m.

On observe trois épisodes de sédimentation dans une lithologie variée. La partie basale consiste en un calcaire à grain très fin (en partie dolomitique) à forte teneur en argile. Le calcaire est finement lité et ondulé et forme par altération des plaques et des nodules. Les shales calcaires interstratifiés dominent dans les couches basales, mais se rarifient vers le haut. La partie intermédiaire est plus dolomitique, ne contenant que quelques interstratifications de shale; les couches de nodules de chert noir grisâtre sont fréquentes. La partie sommitale (qui n'est présente qu'au mont Advance) est très régressive et se compose de dolomie et de shale argileux finement lités. Toutes ces lithologies sont représentatives d'un milieu de sédimentation de profondeur moyenne, mais elles ne contiennent pas d'indications de la présence quelconque de turbidites ou de tempestites. Des considérations régionales et la forte teneur en carbonates inclinent à proposer une sédimentation sur un talus à pente douce plutôt que dans les bassins des parties centrales de la cuvette de Kechika plus à l'ouest. La macrofaune comprend d'abondants brachiopodes articulés ainsi que des débris d'échinodermes et d'éponges et de rares gastéropodes, coraux solitaires, trilobites, bryozoaires, ostracodes, céphalopodes, pélécypodes et brachiopodes inarticulés. Malgré des recherches poussées, on n'a découvert aucun graptolite. Certains fossiles ont probablement été transportés — le seul spécimen du corail *Paliphyllum* est érodé par abrasion. Cependant, la plupart des coquilles de brachiopodes et de pélécypodes sont presque entières et plusieurs sont encore articulées, indiquant un faible courant et un transport minime dans de nombreuses couches. L'association de gastéropodes présente, tant au niveau du genre que de la famille, une paléoécologie semblable à celle des associations de l'Ordovicien supérieur dans la région de l'arche de Cincinnati où les fossiles auraient vécu dans des milieux proximaux ou de plate-forme continentale intermédiaire mais à des profondeurs dépassant la zone de battement des vagues de beau temps. Comme les coraux tabulés sont absents, le milieu de sédimentation était probablement trop profond ou trop boueux pour leur survie.

Collectivement, les faunes indiquent un âge du Caradocien tardif pour la Formation d'Advance; elle est probablement plus récente que la Formation de Copenhagen du Nevada et plus ancienne que le membre supérieur du Calcaire de Jones Ridge au Yukon et en Alaska. Cet âge de la fin de l'Ordovicien moyen (probablement du Kirkfieldien au Shermanien) est corroboré par des identifications et des corrélations de conodontes, de coraux, de bryozoaires, de gastéropodes et de pélécypodes associés.

Les brachiopodes silicifiés de la Formation d'Advance incluent des occurrences précoces d'un nombre d'espèces édeniennes ainsi que des occurrences tardives d'espèces du Chazyen et du Mohawkien précoce. Les brachiopodes de la partie supérieure de la formation semblent être légèrement plus jeunes que ceux des couches inférieures dont la faune inclut des espèces de *Bimuria*, *Christiania*, *Leangella* et *Paurorthis*. Cette association est caractéristique de la faune à *Bimuria* de la province faunistique scoto-appalachienne, mais elle inclut en outre certains taxons typiques de l'ouest de l'Amérique du Nord. Les brachiopodes indiquent un âge du Caradocien tardif (Mohawkien tardif : du Rocklandien au Shermanien).

Les conodontes de la Formation d'Advance sont thermiquement altérés à l'indice d'altération des conodontes 4,5. Les faunules de la partie basale du stratotype datent fort probablement du Rocklandien au Shermanien. Les faunules présentes dans les parties plus élevées du stratotype n'indiquent qu'un âge général de la fin de l'Ordovicien moyen ou de l'Ordovicien tardif. Au-dessus de celles-ci et au-dessus de la discordance au sommet de la Formation d'Advance, une faunule de conodontes diagnostique est présente entre 27 et 34 m au-dessus de la base de l'«unité de quartzite et de dolomie» sus-jacente. Cette faunule inclut *Amorphognathus ordovicius* et *Gamachignathus hastatus* et son âge remonte au Richmondien tardif ou au Gamachien. Au-dessous de la Formation d'Advance, au niveau de son stratotype, une faunule dans les couches supérieures de la Formation de Skoki date de l'Ordovicien moyen, peut-être du Blackrivérien.

Les rugosas solitaires de la Formation d'Advance comprennent une forme indéterminée dans les couches basales, une nouvelle espèce de *Paliphyllum* un peu plus haut et une espèce de *Grewingkia* dans la partie principale. La nouvelle espèce de *Paliphyllum* est probablement le représentant le plus ancien de ce genre à dissépiment. Il est très semblable à certains spécimens du Caradocien terminal à l'Ashgillien initial de la plate-forme sibérienne. La nouvelle espèce de *Grewingkia*, l'un des plus anciens membres du genre, est considérée comme l'ancêtre de *Grewingkia robusta* (Whiteaves) décelé dans les roches édeniennes à richmondiennes du craton nord-américain. L'âge des coraux de la Formation d'Advance correspond à l'intervalle allant du Rocklandien à l'Édenien précoce et probablement plus tard que plus tôt dans cet intervalle.

L'association de bryozoaires comporte huit genres de trépostomes, dont chacun a été décelé ailleurs dans des roches de l'Ordovicien moyen et supérieur. Cependant, dans le centre et l'est des États-Unis, les occurrences combinées d'*Atactoporella*, *Cyophotrypa*, *Homotrypa* et *Parvohallopora* sont surtout fréquentes dans la fin de l'Ordovicien moyen et le début de l'Ordovicien tardif.

Les trilobites sont très rares et seules sont possibles les déterminations des genres de *Ceraurus*, *Decoroproetus*, (?)*Dolichoharpes* et (?)*Failleana*. En combinant les données sur leur intervalle de genre, un âge général du Caradocien est indiqué (Blackrivérien tardif à Maysvillien précoce). La plupart des gastéropodes découverts dans la Formation d'Advance sont petits et appartiennent aux genres correspondant à un intervalle long. Toutefois, *Liospira* cf. *L. vitruvia* (Billings) et *Ophiletina angularis* Ulrich et Schofield ont été découverts ailleurs dans le Trentonien supérieur (du Kirkfieldien au Shermanien). Les pélécypodes sont peu nombreux mais ils confèrent un âge général du Kirkfieldien à l'Édénien précoce à la moitié inférieure de la Formation d'Advance.

Relativement aux autres faunes présentes dans l'ouest du protocontinent nord-américain, les faunes d'Advance sont plus anciennes que celles de la Formation de Red River au Manitoba et plus récentes que celles des formations de Copenhagen et de Lehman au Nevada. Selon les corrélations établies entre les différents groupes de fossiles, il est des plus probables que la Formation d'Advance est d'âge kirkfieldien à shermanien (Caradocien tardif). Tout l'Édenien ou presque et le Maysvillien, en tout ou en partie, coïncident avec le hiatus de la discordance sus-jacente.

STRATIGRAPHY AND BIOSTRATIGRAPHY OF THE ADVANCE FORMATION, A NEW UPPER MIDDLE ORDOVICIAN UNIT, NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA

B.S. Norford

Abstract

The Advance Formation is a thin stratigraphic unit (up to 68 m thick) in the Williston Lake region of British Columbia. The unit has very restricted lateral distribution beneath a regional sub-Upper Ordovician (Ashgill) unconformity. The formation consists of thinly bedded carbonates and shales deposited in a slope environment during late Caradoc (probably Kirkfieldian to Shermanian) time. Rocks of this age and lithology are unique in western Canada. The Advance Formation contains rich faunas of brachiopods and conodonts showing both North American and European affinities. Solitary corals, trilobites, bryozoans, gastropods, pelecypods, cephalopods, and echinoderm debris are accessory components of the macrofaunas.

Résumé

La Formation d'Advance est une unité stratigraphique mince (ne dépassant pas 68 m d'épaisseur) que l'on trouve dans la région du lac Williston en Colombie-Britannique. Son extension latérale est très restreinte au-dessous d'une discordance régionale subjacente à l'Ordovicien supérieur (Ashgillien). La formation se compose de roches carbonatées et de shales finement lités déposés dans un milieu de talus durant le Caradocien tardif (probablement du Kirkfieldien au Shermanien). Les roches de cet âge et de cette lithologie sont uniques dans l'Ouest canadien. La Formation d'Advance contient des faunes abondantes de brachiopodes et de conodontes ayant des affinités à la fois nord-américaines et européennes. Des coraux solitaires, des trilobites, des bryozoaires, des gastéropodes, des pélécypodes, des céphalopodes et des débris d'échinodermes sont des composantes accessoires des macrofaunes.

INTRODUCTION

The Lower Paleozoic rocks of the northern Rocky Mountains consist of carbonate rocks deposited in the shallow waters of the MacDonald Platform and the coeval slope and basinal facies of the Kechika Trough adjacent to the west (Fig. 1; Norford, 1991). Unconformities are common within the succession, both on the platform and in the trough (Cecile and Norford, 1992). A prominent unconformity occurs at the base of the Upper Ordovician "quartzite and dolomite unit" (Norford, 1991). This unit is laterally equivalent to the lower part of the Beaverfoot Formation of the central and southern Rocky Mountains (Figs. 2, 7). At many localities the "quartzite and dolomite unit" unconformably overlies Middle Ordovician horizons within the Skoki Formation and, to the northwest, has cut down into older rocks of the Lower Ordovician Kechika Group (Norford, 1991, Fig. 8).

In a small region east of the main reaches of Williston Lake, however, rocks younger than the Skoki Formation are preserved below this unconformity at Advance Mountain, Mount Burden and at a few other localities (Figs. 1–5, 7, 8). These upper Middle Ordovician rocks are unique in the Canadian Cordillera and have been mentioned in earlier literature (Barnes, Norford and Skevington, 1981, col. 9; McMechan, 1987, p. 11, Pl. 4; Norford, 1991, p. 48, Figs. 2, 7, 8). The informal "limestone, dolomite and shale unit" (Norford, 1991) is now formally described as the Advance Formation.

The type section on Advance Mountain (see Appendix 1) shows the maximum known thickness of 68 m. The formation consists of platy and nodular carbonates and shales. Its abundant and diverse silicified brachiopod fauna is formally described in the companion paper by Jin and Norford and indicates a Caradoc age for the Advance Formation. This late Middle Ordovician age is supported by identifications and correlations of associated assemblages of conodonts, corals, trilobites, bryozoans, gastropods and pelecypods [see Bolton, Elias, Jin and Norford, Johnston, and Rohr (*all this volume*), and appendices

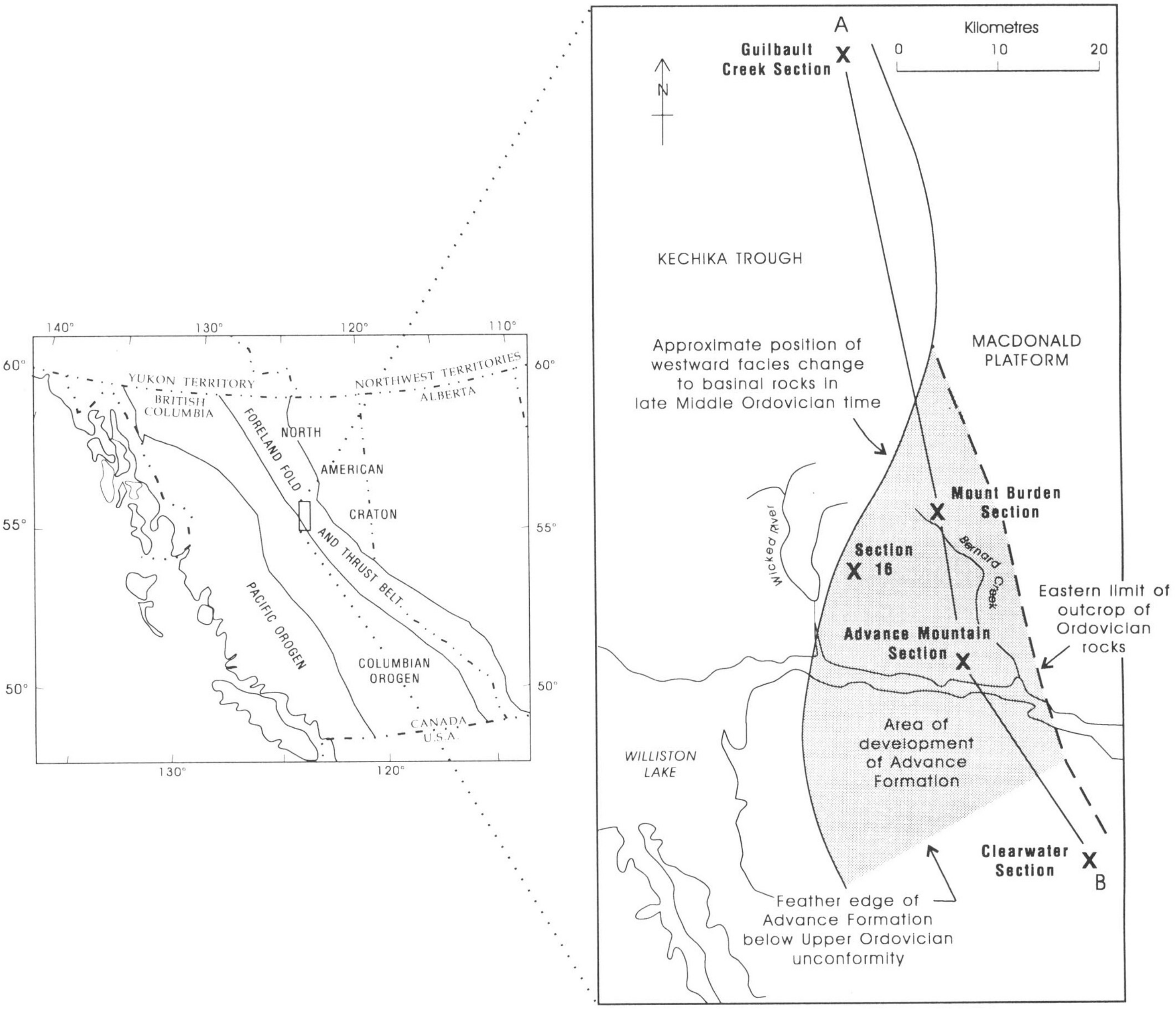

Figure 1. Locality map and distribution of the Advance Formation. A–B is line of section of Figure 2.

by these authors, C.R. Barnes, G.S. Nowlan and R.S. Tipnis].

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

The Advance Formation underlies the "quartzite and dolomite unit" disconformably although the contact is concordant without signs of erosion at both Advance Mountain and Mount Burden (Fig. 2). Upper beds at Advance Mountain are cut out at Mount Burden and the whole formation is missing at the Clearwater Section (Fig. 2). The basal contact between the Advance Formation and the Skoki Formation is more problematic. It is concordant at both Advance Mountain and Mount Burden but there is an abrupt change in lithology from shallow water dolomites to limy shales and argillaceous limestones (Figs. 2, 5). At Mount Burden, the uppermost Skoki bed weathers a different colour from those below and this difference may reflect subaerial exposure and weathering before deposition of the Advance Formation. Biostratigraphic evidence from several groups of fossils indicates the age of the Advance Formation is Kirkfieldian to Shermanian and the youngest age known for the Skoki Formation is Blackriveran. Rocklandian time may thus be represented by a hiatus at the Skoki–Advance contact (Fig. 7).

The measured thickness of the Advance Formation is 68 m at Advance Mountain (Fig. 2), 46.5 m at

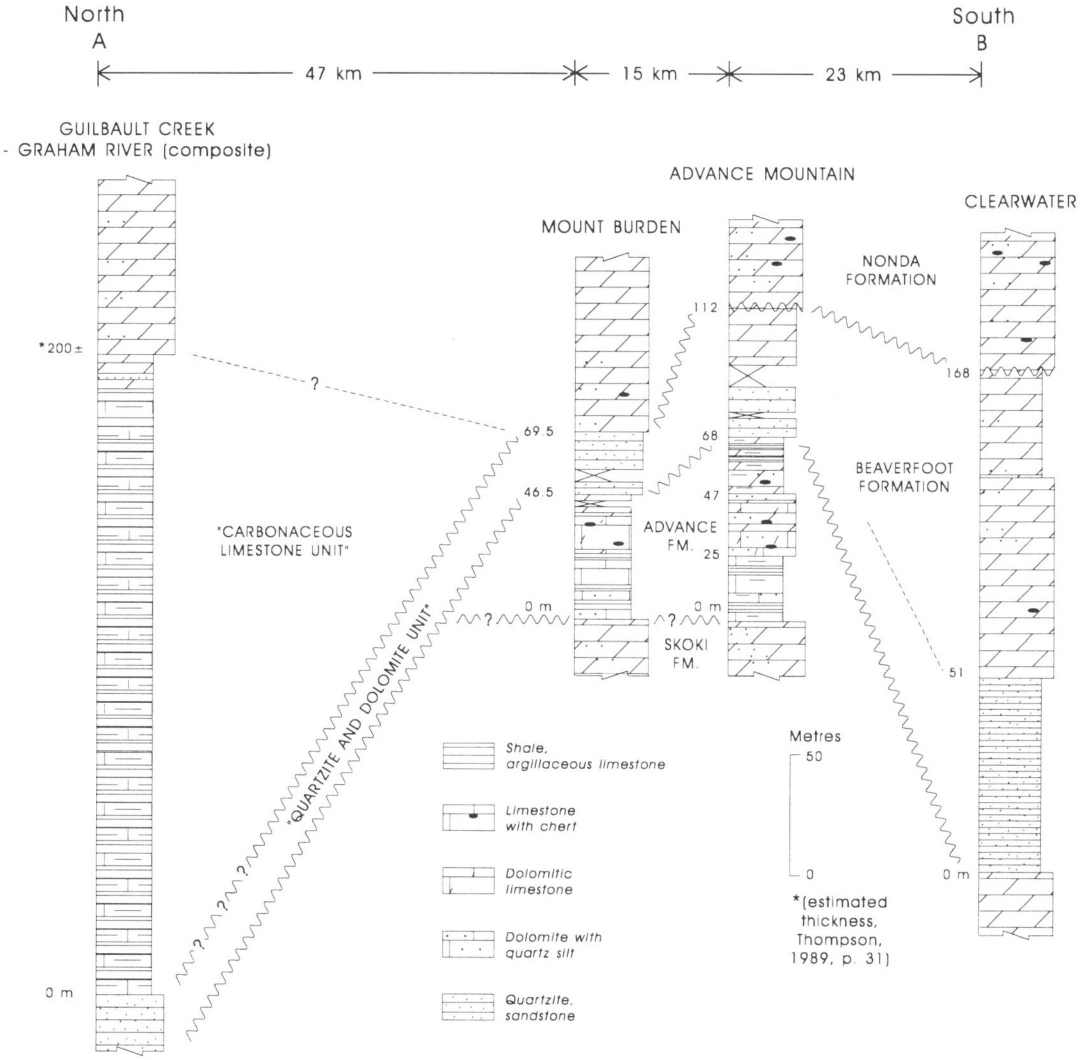

Figure 2. *North–south regional cross-section. (See Figure 1 for location.)*

Mount Burden (Fig. 2) and about 50 m at Section 16 (Thompson, 1989, p. 112). With allowance for the deeper erosion beneath the overlying unconformity at Mount Burden, the successions are very similar at the two stratigraphic sections that have been studied in detail (Advance Mountain and Mount Burden). The lower beds (25–30 m thick) consist of thinly bedded and wavy bedded, platy and nodular weathering, very fine grained limestones (some dolomitic) with significant argillaceous content (Fig. 6). Interbedded limy shales are prominent in the basal part but become less common upward. The overlying 22 m are more dolomitic with only minor shale interbeds; layers of greyish black chert nodules are common. The uppermost beds (21 m thick at Advance Mountain) are very recessive and consist of thinly bedded argillaceous dolomites and shales. All of these lithologies are typical of a slope or basin environment of moderate depth but there are no indications of any turbidites or tempestites.

The substantial presence of carbonate rocks supports the interpretation of a slope environment of very gentle inclination rather than the basinal environments of the central parts of the Kechika Trough farther west (Unit OR4 of the Road River Group, Cecile and Norford, 1979; Norford, 1991, Fig. 7).

The silicified macrofauna consists of abundant articulate brachiopods together with echinoderm and sponge debris, and rare gastropods, solitary corals, trilobites, bryozoans, ostracodes, cephalopods, pelecypods and inarticulate brachiopods. Some of these probably were transported and the only specimen of the coral *Paliphyllum* is abraded. However, most

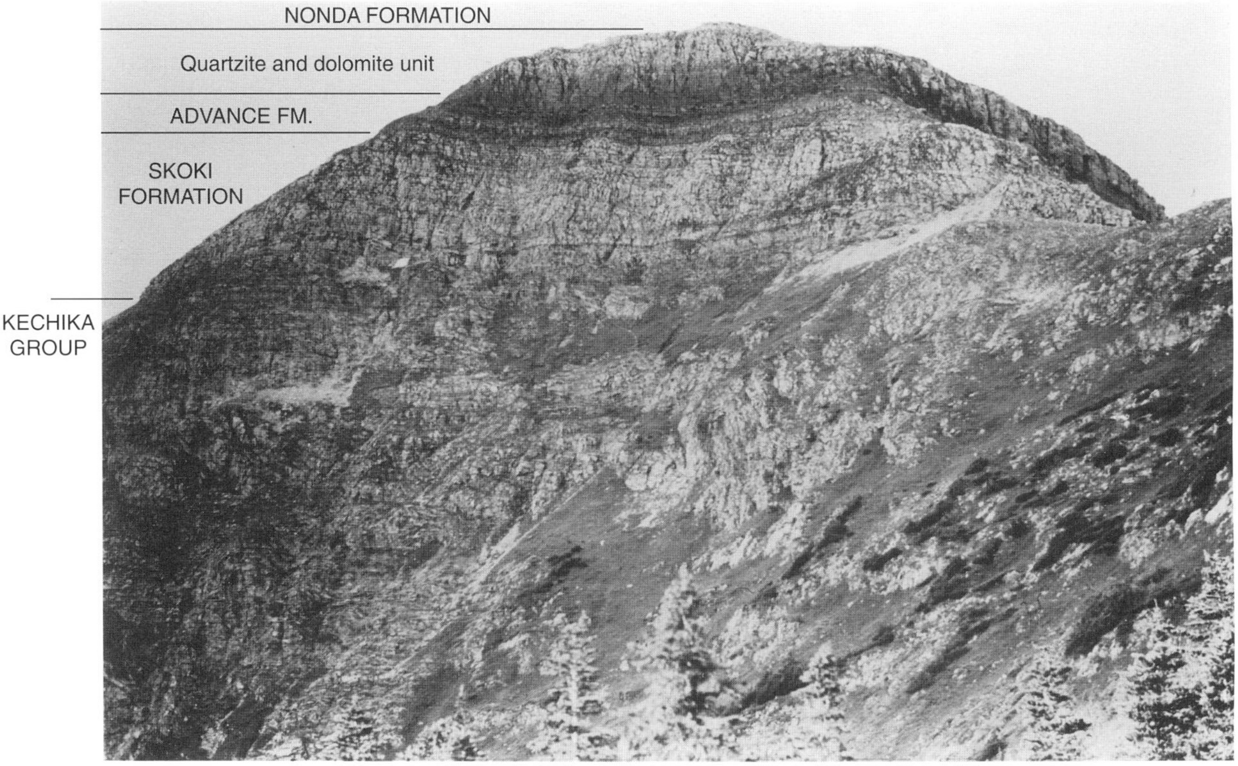

__Figure 3.__ Advance Mountain Section from the east, the Advance Formation and the "quartzite and dolomite unit" form the crest of the ridge (ISPG photo. 4008–1).

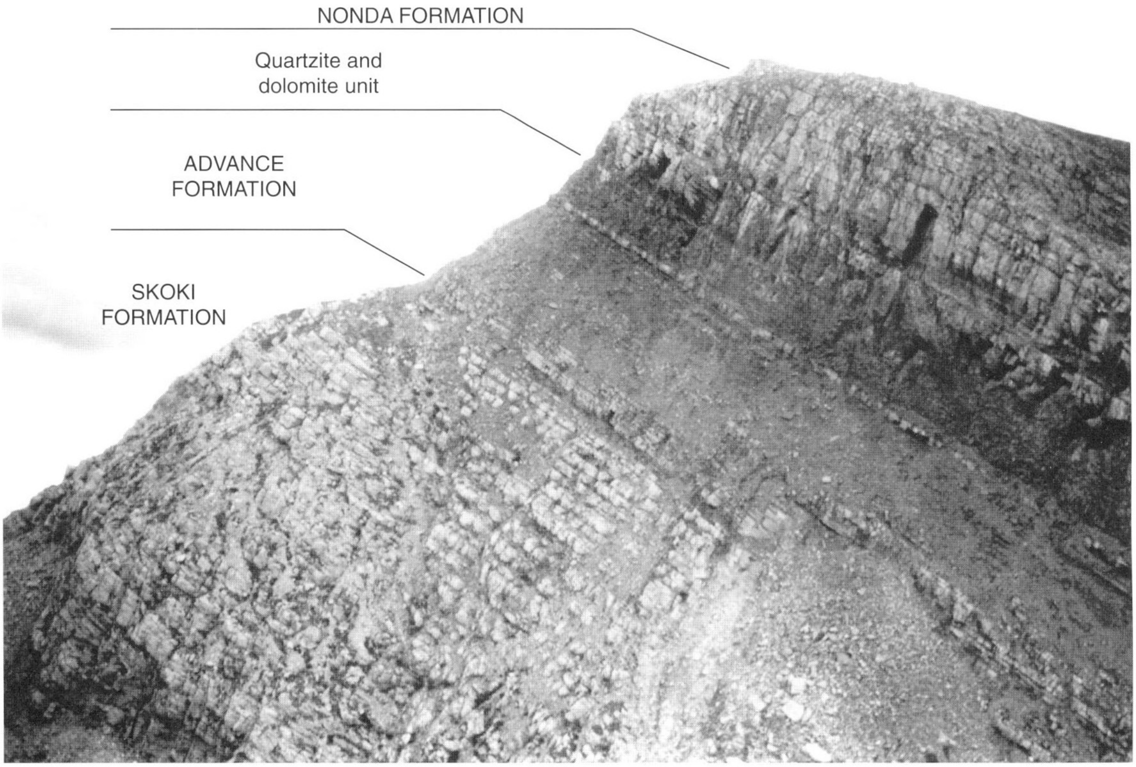

__Figure 4.__ Advance Mountain Section from the north (ISPG photo. 4008–3).

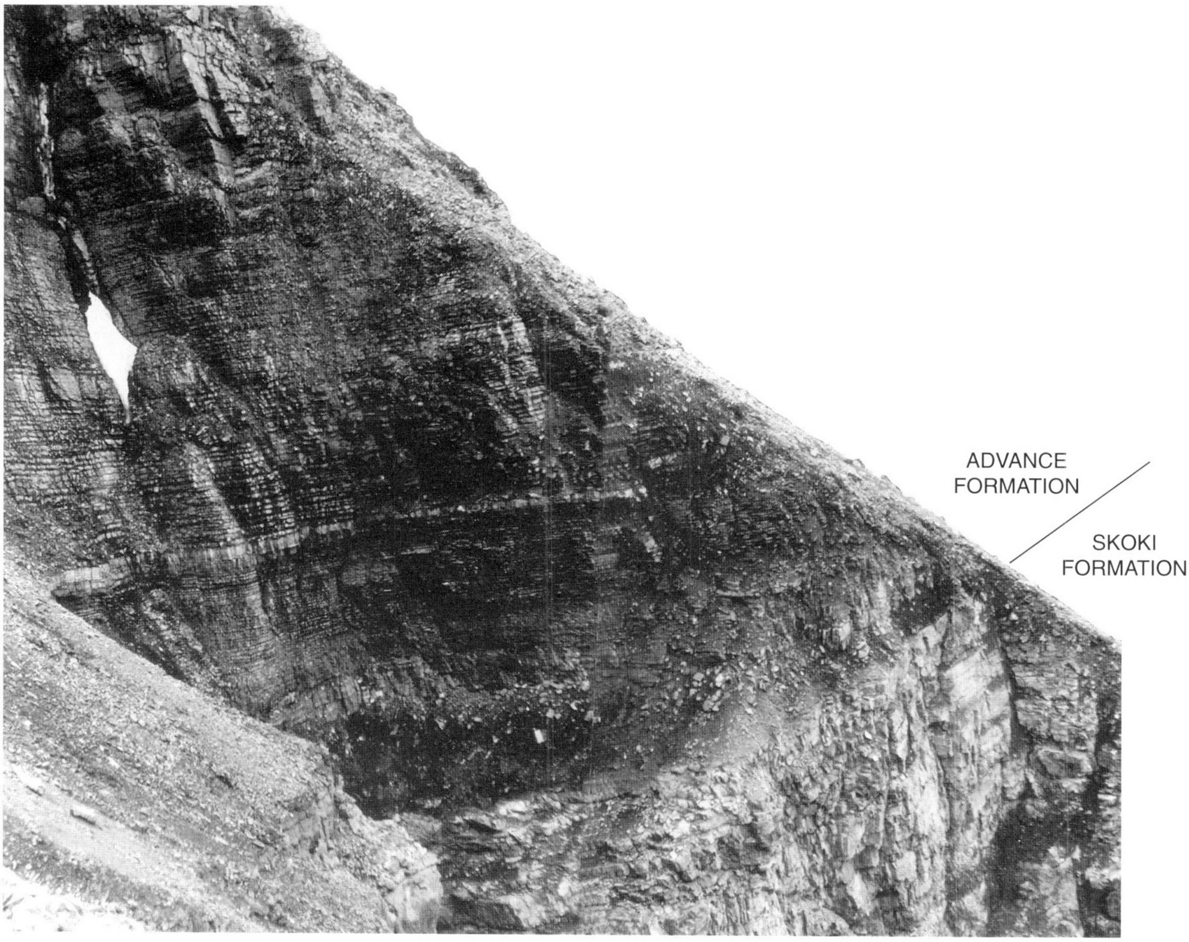

Figure 5. *Mount Burden Section, lower part of the Advance Formation and the underlying top beds of the Skoki Formation (composite of ISPG photos. 4008–4, 4008–5).*

brachiopod shells are almost entire and many are still articulated, indicating little current action and transport in many beds. Tabulate corals are absent, a likely indication that the depositional environment was too deep or too muddy for them to flourish. No graptolites have been found.

BIOSTRATIGRAPHY

From its stratigraphic position (Figs. 2, 7), the Advance Formation is older than the Late Ordovician *Bighornia–Thaerodonta* Fauna that is present regionally in the lower part of the "quartzite and dolomite unit" (Cecile and Norford, 1979), and younger than any part of the Skoki Formation. Conodonts recovered from the "quartzite and dolomite unit" within the Advance Mountain Section indicate a late Richmondian to Gamachian age (see Appendix 3). In the northern Rocky Mountains, the lower part of the Skoki Formation is well dated as latest Early Ordovician (latest Ibexian, late Arenig) and early Middle Ordovician (Whiterockian). Conodonts from higher parts of the formation indicate Chazyan and Blackriveran ages (R.J. Tipnis, pers. comm., 1978; see also Appendix 3, GSC loc. C-78635), thus setting a limit to the age of the overlying Advance Formation.

Regional relationships allow identification of Unit OR4 (Cecile and Norford, 1979) of the graptolitic Road River Group as the equivalent of the Advance Formation within the basinal facies. Unit OR4 has not been dated precisely but appears to span the *Climacograptus bicornis* and *Orthograptus quadrimucronatus* zones (Caradoc to early Ashgill).

The articulate brachiopod fauna of the Advance Formation includes early occurrences of a number of Edenian species together with late occurrences of Chazyan and early Mohawkian species (Jin and Norford, *this volume*). The upper part of the formation may be younger than the lower beds which contain species characteristic of the *Bimuria* Fauna of the Scoto-Appalachian Faunal Province but also some taxa found in western North America. Collectively the

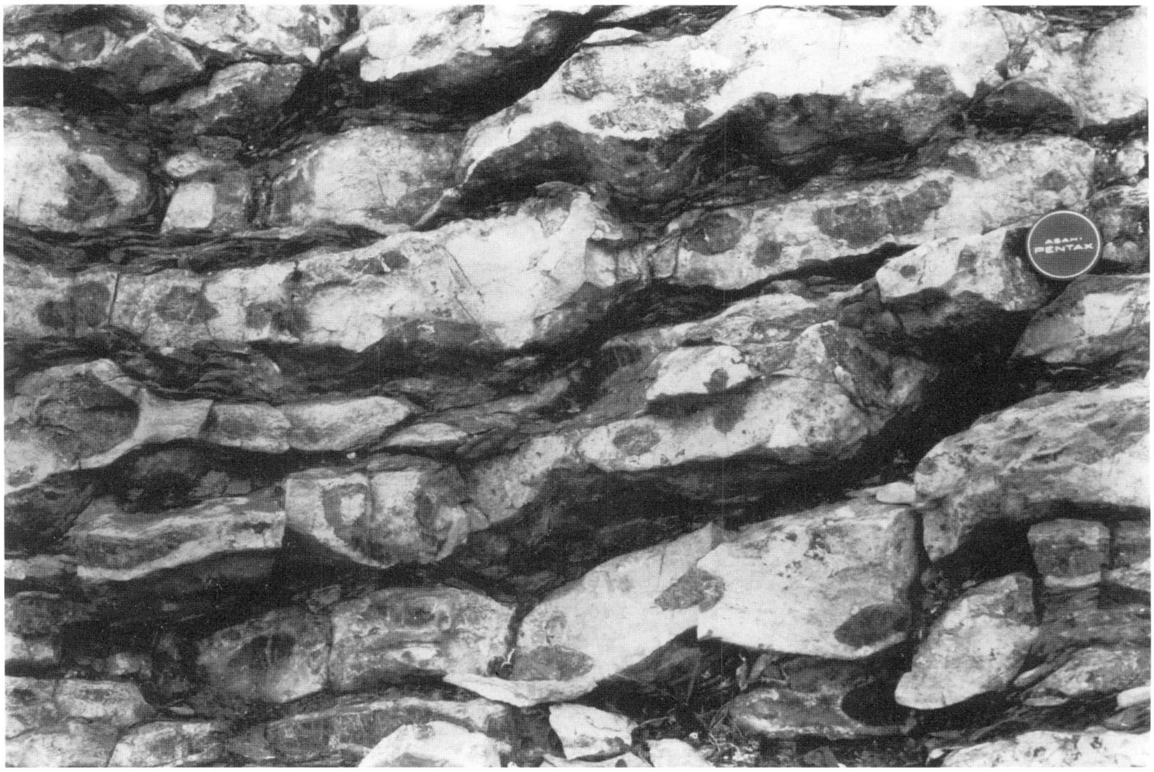

Figure 6. Nodular limestone and shale of the Advance Formation near Mount Crysdale (ISPG photo. 1820–14 by M.E. McMechan).

brachiopods indicate late Caradoc age (late Mohawkian: Rocklandian–Shermanian). Small inarticulate brachiopods are common in the samples processed for conodonts.

The conodonts from the Advance Formation are thermally altered to a Conodont Alteration Index of 4.5. Nowlan considers the faunules from the lowermost 16.5 m of the type section of the Advance Formation to be Blackriveran to Shermanian in age (see Fig. 8 and Appendix 3). Faunules from the middle part (20.5–46.0 m) of the type section indicate a general late Middle or Late Ordovician age. However, faunules from the top beds (62.5–66.5 m) probably are no older than Kirkfieldian. Above these and above the disconformity at the top of the Advance Formation, a diagnostic conodont faunule is present 27 to 34 m above the base of the overlying "quartzite and dolomite unit". This faunule includes *Amorphognathus ordovicicus* and *Gamachignathus hastatus* and its age is late Richmondian or Gamachian (Appendix 3, GSC loc. C-78642). Below the Advance Formation at its type section, a faunule from the uppermost 6.5 m of the Skoki Formation is Middle Ordovician in age, possibly Blackriveran (Fig. 8 and Appendix 3, GSC loc. C-78635).

Trilobites are very rare and only generic determinations are possible. *Calyptaulax* sp. is present at the spot locality west of Bernard Creek (Appendix 3, GSC loc. C-56101); the genus ranges from Llanvirn to Ashgill. The following taxa occur within the interval 10.5 to 46 m above the base of the Advance Formation at Advance Mountain (Appendix 3, GSC locs. C-78638 and C-78640): *Ceraurus* sp., *Decoroproetus* sp., *Dolichoharpes*? sp., and *Failleana*? sp.

In the southwestern District of Mackenzie, *Ceraurus* first appears in the *Ceraurus gabrielsi* Zone and ranges up at least to the *Whittakerites planatus* Zone (Fig. 7; Ludvigson, 1979). *Failleana* commences somewhat lower, in the *Ceraurinella nahanniensis* Zone and extends up into the *Ceraurus mackenziensis* Zone. *Decoroproetus* is a long ranging genus but the oldest known species, *D. fearnsidesi* (Bancroft), is from Welsh Llandeilo rocks (Owens, 1973). Combining the constraints of the ranges of the trilobite genera, a general Caradoc age is indicated (late Blackriveran to early Maysvillian).

The bryozoan assemblage (Bolton, *this volume*) consists of eight trepostome genera, each of which is known elsewhere from Middle and Upper Ordovician rocks. However, in the central areas of the North

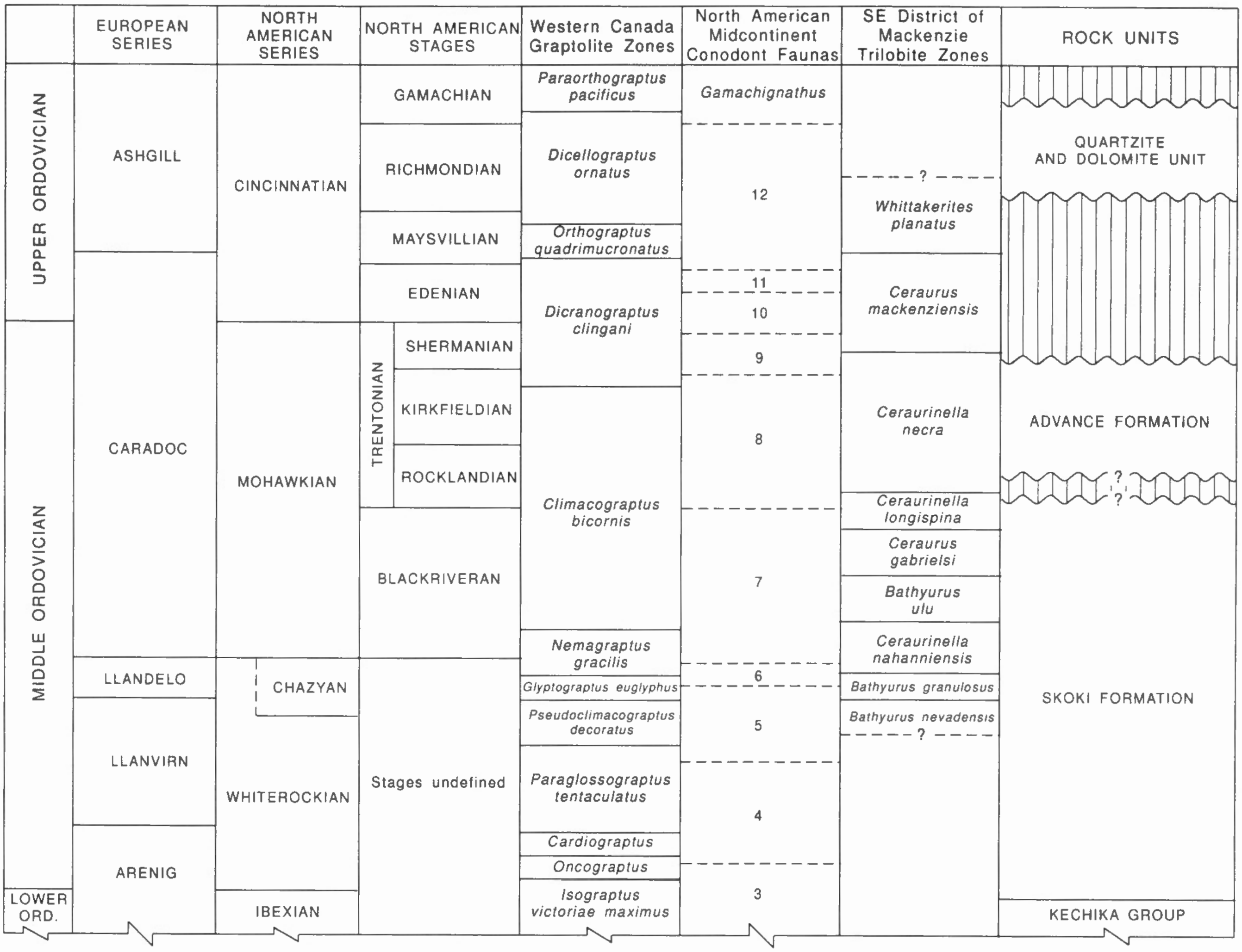

Figure 7. *Stratigraphic units and correlation chart.*

American craton, occurrences of *Atactoporella, Cyophotrypa, Homotrypa* and *Parvohallopora* together are most common in the late Middle and early Late Ordovician.

Pelecypods are very few in number but substantiate a general Kirkfieldian to early Edenian age for the lower half of the Advance Formation (Johnston, *this volume*). At the generic and family level the assemblage is similar to Upper Ordovician assemblages in the Cincinnati Arch region that are thought to have lived in proximal or mid-shelf environments below fair weather wave base.

The presence of solitary corals in the Advance Formation has significant biostratigraphic implications (Elias, *this volume*). An indeterminate form occurs in the basal beds, *Paliphyllum norfordi* n. sp. a little higher, and *Grewingkia burdenensis* n. sp. in the main part. In Europe and in Siberia, the earliest known solitary corals are in the Viruan Stage (Neuman, 1984) and the Chum'skaya Unit (Ivanovsky, 1987), both thought to include beds of Llanvirn age. In North America, the oldest documented solitary corals are from rocks in Vermont assigned to the Chazyan Crown Point Formation (Welby, 1961), and from the Blackriveran and Rocklandian Braeside beds and Paquette Rapid beds of southeastern Ontario (Wilson, 1948; Steele and Sinclair, 1971). The new species of *Paliphyllum* is probably the earliest representative of this disseppimented genus that is known elsewhere only from Late Ordovician rocks of Siberia. *Grewingkia burdenensis* is one of the oldest known species of the genus and appears to be ancestral to the Edenian to Richmondian species *Grewingkia robusta* (Whiteaves). Thus the solitary corals indicate that the age of the main part of the Advance Formation is Rocklandian to early Edenian and probably younger within this interval rather than older.

Most of the gastropods found in the Advance Formation are small and belong to long ranging

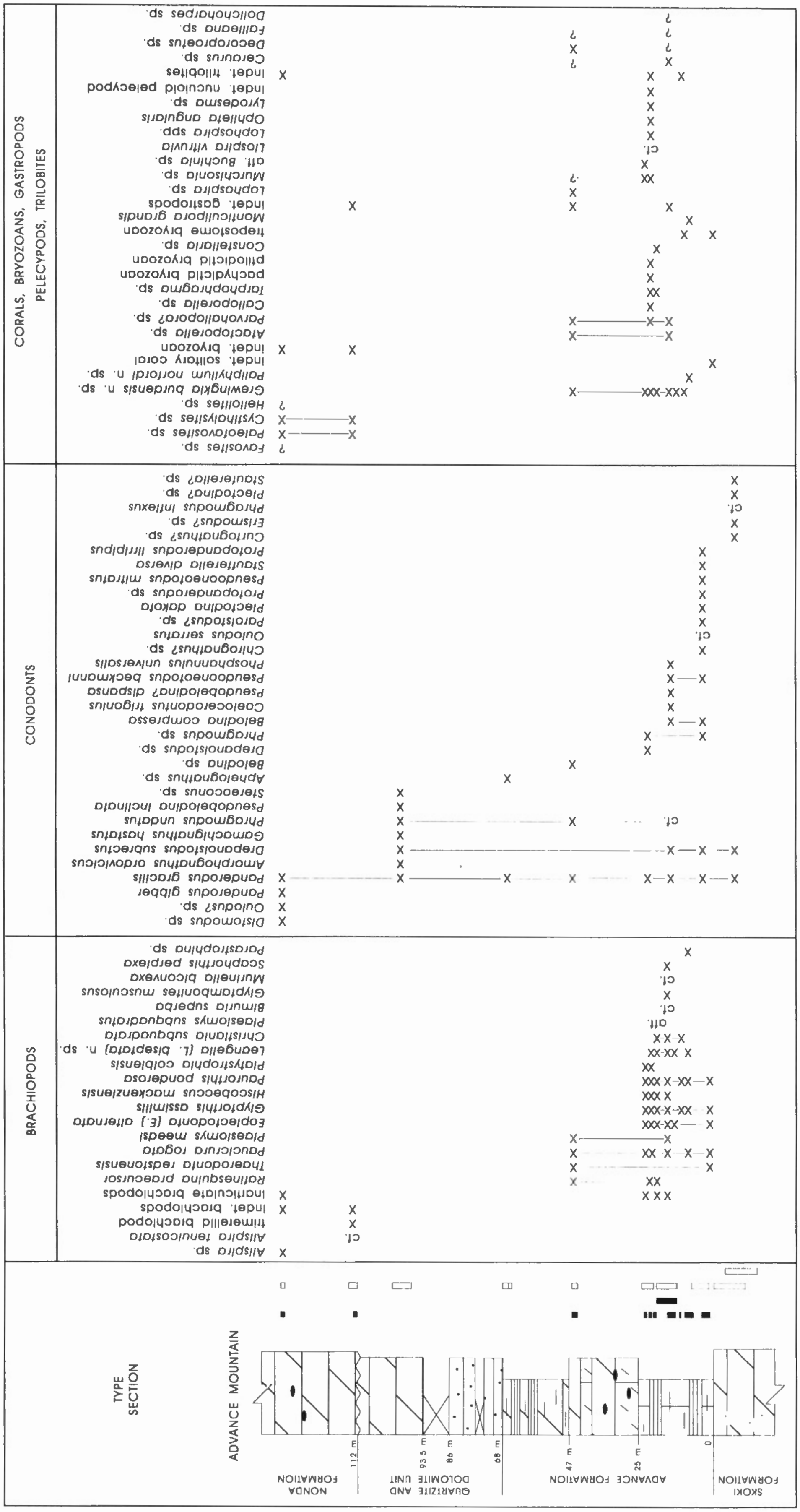

***Figure 8.** Occurrences of taxa within the type section of the Advance Formation (solid squares indicate macrofossil collections; open squares, microfossil collections).*

genera. The two taxa that have been identified to the species level are known elsewhere in upper Trentonian (Kirkfieldian–Shermanian) rocks (Rohr, *this volume*).

Combining the correlations provided by the various groups of fossils, the Advance faunas are older than those of the Red River Formation of Manitoba and younger than those of the Copenhagen and Lehmen formations of Nevada. Kirkfieldian to Shermanian (late Caradoc) is the most likely age for the Advance Formation. Most or all of Edenian time and part or all of Maysvillian time appears to fall within the hiatus represented by the overlying unconformity.

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G.S. Nowlan and C.R. Barnes studied the collections of conodonts with R.S. Tipnis earlier providing some identifications and correlations. M.E. McMechan and R.I. Thompson made some of the fossil collections. B.D.E. Chatterton, M.P. Cecile, G.S. Nowlan, A.W. Norris and Reuben J. Ross, Jr. kindly commented on early drafts of the manuscript.

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APPENDIX 1

ADVANCE MOUNTAIN STRATIGRAPHIC SECTION

(Figs. 2–4, 8)

The eastern part of Advance Mountain presents good outcrops of the Advance Formation (type section) and the overlying "quartzite and dolomite unit". Elsewhere these two units commonly are poorly exposed between the resistant Skoki and Nonda formations. Dips are about 30 degrees, east-northeast; measurement 261 m of the section is located at the east cairn of the mountain (56°02′30″N, 123°21′W).

Unit	Description	Thickness (m)	Total from base
	Nonda Formation (341 m) (basal 64 m described)		
10	**Dolomite:** very fine grained, dark grey and grey, weathering light grey; thin bedded, platy and nodular, 1–10 cm. Chert nodules common above 122 m, locally amount to 1–15% of rocks. Minor dark grey weathering dolomites. Common corals, sparse brachiopods, trilobites, echinoderm debris, GSC locs. C-78648 (170–170.5 m), C-78647 (164–172 m), C-78646 (136–136.5 m), C-78645 (113.5–114 m), C-78644 (113–116 m)	61	176
9	**Dolomite:** very fine grained, weathering dark grey, rubbly, recessive; thin and wavy bedded, 5–15 cm. Abundant dolomite veins and vugs. Ghosts of large brachiopods and transported halysitid corals. Basal contact a concordant erosion surface with 60 cm of local relief	3	115
	"quartzite and dolomite unit" (44 m)		
8	**Dolomite:** fine to medium grained, dark grey, weathering light grey and very light grey, resistant; bedding 30–90 cm, some beds poorly laminated. GSC loc. C-78643 (107–111.5 m)	10	112
7	**Dolomite:** very fine grained, dark grey, weathering dull grey; thin bedded, 2–8 cm, basal beds platy. Echinoderm debris, GSC loc. C-78642 (95–102 m)	5.8	102
6	**Dolomite:** medium grained, dark brownish grey, weathering light grey and pale yellowish brown, rubbly; bedding 30–60 cm, some wavy lamination	2.7	96.2
5	Covered interval	7.5	93.5
4	**Dolomitic quartz sandstone** and **quartzite:** very pale greyish orange and light grey, weathering off-white and greyish orange, some beds rubbly; bedding 0.5–60 cm, some beds laminated and crosslaminated. At 79.5–80 m, quartz siltstones, speckled brownish grey and light brownish grey, weathering greyish red; bedding 2–4 cm with abundant trace fossils. Basal contact concordant	18	86
	Advance Formation (68 m)		
3	**Dolomite:** mostly argillaceous, very fine grained, brownish olive-grey, weathering yellowish brown, recessive, rubbly; thin bedded (1–5 cm), nodular with sparse wispy dark brownish grey laminae. Shaly partings amount to 20% of 64–66 m and also common from 57–64 m. Unit poorly exposed; covered interval at 60–61 m. GSC locs. C-78641 (64–66.5 m), C-205925 (62.5–65.5 m)	21	68
2	**Dolomite** and **dolomitic limestone:** some beds argillaceous, very fine to fine grained, dark brownish grey, weathering yellowish grey and very pale orange; bedding 20–50 cm. Greyish black chert nodules amount to 5–8% of most beds, many in layers. Dolomite dominates above 31 m. Abundant brachiopods, solitary corals, trilobites, GSC loc. C-78640 (44–46 m)	22	47
1	**Limestone:** argillaceous, aphanitic to very fine grained, dark grey, weathering light grey and dull grey, platy, recessive; bedding 2–20 cm, wavy, some beds nodular. Limy shale interbeds 10–15% of rocks, olive-grey, weathering dull olive-grey; bedding 0.5–3 cm. Rare greyish black chert nodules (with off-white coronae) in upper 5 m. Abundant brachiopods, echinoderm debris, solitary corals, trilobites, cephalopods; GSC locs. C-205924 (20.5–21.0 m), C-78639 (17.5–23 m), C-205923 (18.5–19.5 m), C-205922 (16.5–17.5 m), C-78638 (10.5–16.5 m), C-205921 (11–13 m), C-205920 (8.0–9.5 m), C-205919 (6–8 m), C-78637 (0–6 m), C-205918 (1–3 m), C-78636 (0–1.5 m). Basal contact concordant but underlying top 0.5 m of Skoki dolomites weathers dark yellowish orange instead of pale yellowish brown and could indicate an interval of exposure and weathering between the two formations	25	25
	Skoki Formation (uppermost beds)		
	Dolomite: with minor siliceous content, very fine to fine grained; brownish grey, weathering light grey and very pale yellowish brown, resistant; bedding 20–40 cm, some irregular wispy, silty and argillaceous laminations, some bedding planes with dark brown argillaceous partings. Echinoderm debris; GSC locs. C-76835 (top 6.5 m), C-205917 (-14.5 to -4.5 m). Similar rocks continue in outcrop below the measured section		

APPENDIX 2

MOUNT BURDEN STRATIGRAPHIC SECTION

(Figs. 2, 5)

The northern spur (56°11′N, 123°27′W) of Mount Burden together with the mountain itself expose a stratigraphic section from the uppermost Kechika Group to the Muncho–McConnell and higher Devonian formations. The rocks have a general southeasterly dip and the stratigraphic section contains a number of high-angled faults.

Unit	Description	Thickness (m)	Total from base
	Nonda Formation (347 m) (basal 51 m described)		
7	**Dolomite:** extremely fine grained, some beds with minor siliceous content, dark grey, weathering light grey, very pale orange and pale yellowish brown, resistant except at base; bedding 5–300 cm, some beds weathering blocky, some bedding planes stained red; with rare irregular siliceous partings in upper beds of unit. Shaly interbeds one per cent of basal 15 m of unit; greyish black chert nodules one to five per cent of interval 286–306 m. At 282–286 m, reccessive platy, nodular light grey dolomites. At 270–280 m, quartz silt and sand abundant as wispy layers in brownish olive-grey dolomite. Solitary, favositid and halysitid corals, brachiopods; GSC locs. C-60926 (296–296.5 m), C-60925 (291–291.4 m). Basal contact concordant, arbitrarily picked above quartzite and sandstone	51	321
	"quartzite and dolomite unit" (23 m)		
6	**Quartzite** and **dolomitic quartz sandstone:** fine to coarse grained, olive-grey and very light brownish grey, weathering light brownish grey and greyish orange, some beds friable; bedding 5-90 cm. Minor shale interbeds. At 251.5–253 m, dolomitic quartz siltstone, olive-grey, weathering yellowish brown, thin bedded. Covered interval at 253–257 m, *Receptaculites* sp. at 248 m. Basal contact concordant but not exposed	23	270
	Advance Formation (46.5 m)		
5	**Dolomite:** extremely fine grained, most beds with siliceous and argillaceous content, dark grey, weathering light olive-grey, light grey and very pale yellowish brown; bedding 5–15 cm, undulatory, some bedding planes with red stains, some beds weather rubbly. Less than five per cent shaly interbeds. At 235–237.5 m, greyish black chert nodules common. Covered interval at 243–247 m. Basal contact gradational with unit 4	12	247
4	**Limestone:** some beds dolomitic, extremely fine grained, many beds with argillaceous and siliceous content, dark grey, weathering yellowish grey and olive-grey, recessive; bedding 2.5–15 cm, somewhat nodular. Limy shale, dark grey and dark olive-grey, weathering dark grey, recessive, preponderant in basal beds, gradually less significant upward and amounting to three per cent of uppermost beds. At 227–229 m, greyish black chert nodules are 10 per cent of beds. Brachiopods, solitary corals, bryozoans, GSC loc. C-60924 (217–228 m). Basal contact concordant but not accessible for detailed examination	34.5	235
	Skoki Formation (200.5 m)		
3	**Dolomite:** very fine to fine grained, some beds with minor siliceous content, grey and light brownish grey, weathering light grey, light olive-grey and yellowish grey, some beds mottled, resistant; bedding 10–120 cm. At 140 m sparse oncolites. GSC loc. C-60923 (180–194 m)	86.5	200.5
2	**Dolomite:** very fine to fine grained, dark grey, weathering dull dark and light olive-grey, recessive, some beds rubbly; bedding 5–150 cm. Oncolites in some beds. Unit mostly covered in line of section but continuous outcrop visible in cliff face	23	114
1	**Dolomite:** very fine to fine grained, some beds with minor siliceous content, grey and dark grey, weathering light olive-grey, dull grey, pale yellowish brown and yellowish grey, resistant; bedding 5–90 cm, well developed. Quartz veins and dolomite stringers in many beds, some beds with wispy layers of quartz silt; many beds with oncolites, basal beds slightly limy and weathering flaggy. Rare, large gastropods and straight cephalopods, GSC loc. C-60922 (0–17 m). Basal contact apparently conformable, picked at start of less argillaceous rocks	91	91
	Kechika Group (only top beds studied, outcrop continues below)		
	Limestone: some beds somewhat argillaceous, aphanitic to very fine grained, grey, weathering grey and light olive-grey, some beds poorly foliated. Interbedded shale, limy, greyish black, cleavage well developed. GSC loc. C-60921 (from top 8 m)		

APPENDIX 3

REGISTER OF GEOLOGICAL SURVEY OF CANADA FOSSIL LOCALITIES

[Brachiopods identified by Jin and Norford, bryozoans by Bolton, conodonts by Nowlan (GSN), Barnes (CRB) and Tipnis (RST), corals by Elias and Norford, gastropods by Rohr, pelecypods by Johnston, trilobites by Norford (BSN).]

EAST OF WICKED RIVER; 56°08′N, 123°36′W, Section 16 of Thompson (1989, p. 112)

GSC loc. C-56085; 467.5 m, Advance Formation (40.5 m above base)
Parvohallopora? sp.
streptelasmid coral, indeterminate
Hiscobeccus mackenziensis Jin and Lenz
Paucicrura rogata (Sardeson)
Plaesiomys meedsi (Winchell and Schuchert)
Thaerodonta redstonensis (Mitchell and Sweet)

RIDGE TOP, WEST OF BERNARD CREEK; 56°08′N, 123°27′W (Thompson, 1989, p. 100)

GSC loc. C-56101; Advance Formation, spot locality
Parvohallopora? sp.
Grewingkia burdenensis n. sp.
gastropods
malletiid, modiomorphoid and ambonychiid pelecypods
Dinorthis cf. *D. holdeni* (Willard)
Eoplectodonta (*Eoplectondonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis Jin and Lenz
Paucicrura rogata (Sardeson)
Plaesiomys meedsi (Winchell and Schuchert)
Rafinesquina praecursor (Raymond)
Scaphorthis perplexa Cooper
Strophomena cf. *S. planumbonata* (Hall)
Thaerodonta redstonensis (Mitchell and Sweet)
Anazyga bellicostata n. sp.
Calyptaulax sp.
indeterminate trilobite

NORTHERN RIDGE OF MOUNT SELWYN; 56°01′N, 123°37′W (Thompson, 1989, p. 101)

GSC loc. C-56106; Advance Formation, spot locality
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Paucicrura rogata (Sardeson)
Plaesiomys aff. *P. subquadratus* (Hall)

MOUNT BURDEN SECTION; 56°11′N, 123°27′W

GSC loc. C-60926; 296–296.5 m, Nonda Formation (26–26.5 m above base)
indeterminate solitary and tabulate corals
Catenipora sp.
Favosites? sp.
Streptelasma? sp.
Age: probably Silurian (BSN)

GSC loc. C-60925; 291–291.4 m, Nonda Formation (21–21.4 m above base)
echinoderm debris
indeterminate corals, gastropod, brachiopod
Alispira? sp.
Age: Early Silurian, Llandovery (BSN)

GSC loc. C-60924; 217–228 m, Advance Formation (16.5–27.5 m above base)
echinoderm fragments
Cyphotrypa cf. *C. acervulosa* (Ulrich)
Homotrypa sp.
Parvohallopora? sp.
Grewingkia burdenensis n. sp.
Cyrtodonta sp.
Lyrodesma sp.
Vanuxemia hayniana (Safford)
inarticulate brachiopod
Dinorthis cf. *D. holdeni* (Willard)
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis Jin and Lenz
Oepikina sp.
Oxoplecia globularis Cooper
Paucicrura rogata (Sardeson)
Plaesiomys meedsi (Winchell and Schuchert)
Plaesiomys aff. *P. subquadratus* (Hall)
Platystrophia colbiensis Foerste
Scaphorthis perplexa Cooper
Strophomena cf. *S. planumbonata* (Hall)
harpidid trilobite
Aphelognathus cf. *A. floweri* Sweet
Drepanoistadus sp.
Panderodus gracilis (Branson and Mehl)
Phragmodus undatus Branson and Mehl
Pseudooneotodus beckmanni Bischoff and Sanneman

GSC loc. C-60923; 180–194 m, Skoki Formation barren conodont sample (CRB)

GSC loc. C-60922; 0–17 m, Skoki Formation (basal 17 m)
Bergstroemognathus sp.
Drepanoistodus aff. *D. suberectus* (Branson and Mehl)
Juanognathus variabilis (Serpagli)
Oepikodus intermedius (Serpagli)
Oistodus scalenocarinatus Mound
Paroistodus parallelus (Pander)
Periodon flabellum (Lindström)
Reutterodus cf. *R. andinus* (Serpagli)
Walliserodus australis Serpagli
Age: Early Ordovician, late Arenig (CRB)

GSC loc. C-60921; Kechika Group, top 8 m
Juanognathus variabilis (Serpagli)
Paroistodus parallelus (Pander)

Scolopodus rex Lindström
Walliserodus australis Serpagli
Age: Early Ordovician, middle to late Arenig (CRB)

ADVANCE MOUNTAIN SECTION; 56°02′N, 123°21′W

GSC loc. C-78648; 170–170.5 m, Nonda Formation (57–57.5 m above base)
Favosites? 3 spp.
Halysites sp.
Age: Silurian (BSN)

GSC loc. C-78647; 164–172 m, Nonda Formation (51–59 m above base)
conodont sample, unstudied

GSC loc. C-78646; 136–136.5 m, Nonda Formation (23–23.5 m above base)
echinoderm debris
bryozoans
Favosites? sp.
Cystihalysites sp.
Heliolites? sp.
Paleofavosites sp.
halysitid and solitary corals
undetermined inarticulate and articulate brachiopods
Alispira sp.
undetermined trilobites
Distomodus sp.
Oulodus? sp.
Panderodus gibber Nowlan and Barnes
P. gracilis (Branson and Mehl)
Age: Early Silurian, Llandovery (GSN) probably late Rhuddanian or Aeronian (BSN)

GSC loc. C-78645; 113.5–114 m, Nonda Formation (0.5–1 m above base)
bryozoan
solitary coral, undetermined
Cystihalysites 2 spp.
Paleofavosites sp.
gastropods
Alispira cf. *A. tenuicostata* Nikiforova
trimerellid brachiopod
undetermined brachiopods
Age: Early Silurian, late Rhuddanian or Aeronian (BSN)

GSC loc. C-78644; 113–116 m, Nonda Formation (basal 3 m)
conodont sample, unstudied

GSC loc. C-78643; 107–111.5 m, "quartzite and dolomite unit" (39–43.5 m above base)
barren conodont sample (RST)

GSC loc. C-78642; 95–102 m, "quartzite and dolomite unit" (27–34 m above base)
Amorphognathus ordovicicus Branson and Mehl
Drepanoistodus suberectus (Branson and Mehl)
Gamachignathus hastatus McCracken, Nowlan and Barnes
Panderodus gracilis (Branson and Mehl)
Phragmodus undatus Branson and Mehl
Pseudobelodina inclinata (Branson and Mehl)
Stereoconus sp.
Age: Late Ordovician, late Richmondian to Gamachian (GSN)

GSC loc. C-78641; 64–66.5 m, Advance Formation (64–66.5 m above base)
Aphelognathus sp.
Panderodus gracilis (Branson and Mehl)

GSC loc. C-205925; 62.5–65.5 m, Advance Formation (62.5–65.5 m above base)
Aphelognathus aff. *A. politus* (Hinde)
Belodina confluens? Sweet
Drepanoistodus suberectus Branson and Mehl
Panderodus gracilis (Branson and Mehl)
Panderodus cf. *P. bergstroemi* Sweet
Phragmodus? sp.

GSC loc. C-78640; 44–46 m, Advance Formation (44–46 m above base)
echinoderm fragments
indeterminate low-spired gastropod
Lophospira sp.
Murchisonia? sp.
Atactoporella sp.
Parvohallopora? sp.
Grewingkia burdenensis n. sp.
Paucicrura rogata (Sardeson)
Plaesiomys meedsi (Winchell and Schuchert)
Rafinesquina praecursor (Raymond)
Thaerodonta redstonensis (Mitchell and Sweet)
Ceraurus? sp.
Decoroproetus sp.
Failleana? sp.
Belodina sp.
Panderodus gracilis (Branson and Mehl)
Phragmodus undatus Branson and Mehl
blade conodont element, indet.

GSC loc. C-205924; 20.5–21.0 m, Advance Formation (20.5–21.0 m above base
echinoderm debris
Grewingkia burdenensis n. sp.
bellerophontacean gastropod aff. *Bucania*
Murchisonia (*Murchisonia*) sp.
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis Jin and Lenz
Paucicrura rogata (Sardeson)
Paurorthis ponderosa Cooper
Platystrophia colbiensis Foerste
inarticulate brachiopods
Aphelognathus sp.
Belodina sp.
Drepanoistodus suberectus Branson and Mehl
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. undatus* Branson and Mehl
oistodontiform element, indet.
Milaculum sp.

GSC loc. C-78639; 17.5–23 m, Advance Formation (17.5–23 m above base)
inarticulate brachiopods
Drepanoistodus sp.
Panderodus gracilis (Branson and Mehl)
Phragmodus sp.

GSC loc. C-205923; 18.5-19.5 m, Advance Formation (18.5-19.5 m above base)
echinoderm fragments
Calloporella sp.
Parvohallopora? sp.
Tarphophragma sp.
pachydictid and ptilodictid bryozoans
Grewingkia burdenensis n. sp.
Liospira cf. *L. vitruvia* (Billings)
Lophospira spp. 1 and 2
Murchisonia sp.
Ophiletina angularis Ulrich and Scofield
Lyrodesma sp.
indeterminate nuculoid pelecypod
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis Jin and Lenz
Leangella biseptata n. sp.
Paucicrura rogata (Sardeson)
Paurorthis ponderosa Cooper
Platystrophia colbiensis Foerste
Rafinesquina praecursor (Raymond)
indet. trilobite
Paroistodus sp.
Phragmodus? sp.
prioniodiniform element, indet.
Phosphannulus universalis Müller, Nogami and Lenz

GSC loc. C-205922; 16.5-17.5 m, Advance Formation (16.5-17.5 m above base)
echinoderm fragments
Constellaria sp.
Tarphophragma sp.
Grewingkia burdenensis n. sp.
straight cephalopod
indeterminate inarticulate brachiopod
Christiania subquadrata Hall
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis n. sp.
Leangella biseptata n. sp.
Paurorthis ponderosa Cooper
Plaesiomys aff. *P. subquadratus* (Hall)
Thaerodonta redstonensis (Mitchell and Sweet)
inarticulate brachiopods
Belodina sp.
Drepanoistodus sp.
Panderodus sp.

GSC loc. C-78638; 10.5-16.5 m, Advance Formation (10.5-16.5 m above base)
echinoderm fragments and sponge spicules
Atactoporella sp.
Parvohallopora? sp.
Grewingkia burdenensis n. sp.
ostracodes
gastropods
inarticulate brachiopods
Bimuria cf. *B. superba* Ulrich and Cooper
Christiania subquadrata Hall
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptambonites musculosus Cooper
Glyptorthis assimilis Cooper
Hiscobeccus mackenziensis Jin and Lenz
Leangella biseptata n. sp.
Murinella cf. *M. biconvexa* Cooper
Paucicrura rogata (Sardeson)
Paurorthis ponderosa Cooper
Plaesiomys meedsi (Winchell and Schuchert)
Scaphorthis perplexa Cooper
Ceraurus sp.
Decoroproetus? sp.
Dolichoharpes? sp.
Failleana? sp.
Belodina compressa (Branson and Mehl)
Coelocerodontus trigonius Ethington
Drepanoistodus suberectus (Branson and Mehl)
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. undatus* (Branson and Mehl)
Pseudobelodina? *dispansa* (Glenister)
Pseudooneotodus beckmanni (Bischoff and Sanneman)
blade and prioniodiniform conodont elements, indet.
Phosphannulus universalis Muller, Nogami and Lenz

GSC loc. C-205921; 11-13 m, Advance Formation (11-13 m above base)
trepostome bryozoan indet.
Grewingkia burdenensis n. sp.
Eoplectodona (*Eoplectodonta*) *alternata* (Butts)
Leangella biseptata n. sp.
trilobite fragments

GSC loc. C-205920; 8.0-9.5 m, Advance Formation (8.0-9.5 m above base)
echinoderm fragments
Monticulipora grandis Ulrich
Paliphyllum norfordi n. sp.
gastropods
Christiania subquadrata Hall
Glyptorthis assimilis Cooper
Paurorthis ponderosa Cooper
inarticulate brachiopods
Belodina? sp.
Drepanoistodus suberectus Branson and Mehl
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. inflexus* Stauffer
Protopanderodus sp.
Walliserodus sp.
Phosphannulus universalis Müller, Nogami and Lenz

GSC loc. C-205919; 6-8 m, Advance Formation (6-8 m above base)
echinoderm fragments
trepostome bryozoan indet.
gastropods
Glyptorthis assimilis Cooper
Leangella biseptata n. sp.
Parastrophina sp.
Paucicrura rogata (Sardeson)
Paurorthis ponderosa Cooper
inarticulate brachiopods
indeterminate tubes
Belodina compressa (Branson and Mehl)
Drepanoistodus suberectus Branson and Mehl
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. inflexus* Stauffer
Plectodina? sp.
Staufferella? sp.
Phosphannulus universalis Müller, Nogami and Lenz

GSC loc. C-78637; 0-6 m, Advance Formation (basal 6 m)
inarticulate brachiopods
Belodina compressa (Branson and Mehl)

Chirognathus? sp.
Drepanoistodus suberectus (Branson and Mehl)
Oulodus cf. *O. serratus* (Stauffer)
Panderodus gracilis (Branson and Mehl)
Paroistodus? sp.
Phragmodus sp.
P. cf. *P. inflexus* Stauffer
Plectodina cf. *P. dakota* Sweet
Protopanderodus sp.
Pseudooneotodus beckmanni (Bischoff and Sanneman)
P. mitratus (Moskalenko)
Staufferella divisa Sweet

GSC loc. C-205918; 1-3 m, Advance Formation (1-3 m above base)
echinoderm fragments
trepostome bryozoan indet.
inarticulate brachiopods
Eoplectodonta (*Eoplectodonta*) *alternata* (Butts)
Glyptorthis assimilis Cooper
Paucicrura rogata (Sardeson)
Paurorthis ponderosa Cooper
Thaerodonta redstonensis (Mitchell and Sweet)
Belodina compressa (Branson and Mehl)
Coelocerodontus sp.
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. inflexus* Stauffer
Plectodina sp.
Protopanderodus sp.
Pseudooneotodus mitratus (Meskalenko)
oistodontiform and platform elements, indet.

GSC loc. C-78636; 0–1.5 m, Advance Formation (basal 1.5 m)
indeterminate solitary rugose coral
inarticulate brachiopods
Panderodus gracilis (Branson and Mehl)
Phragmodus sp.
Pseudooneotodus? *beckmanni* (Bischoff and Sanneman)
Protopanderodus liripipus Kennedy, Barnes and Uyeno
eobelodiniform conodont element, indet.

GSC loc. C-78635; Skoki Formation (top 6.5 m)
Curtognathus? sp.
Drepanoistodus suberectus (Branson and Mehl)
Erismodus? sp.
Panderodus gracilis (Branson and Mehl)
Phragmodus cf. *P. inflexus* Stauffer
Plectodina? sp.
Staufferella? sp.
platform and ramiform conodont elements; indet.
Age: Middle Ordovician, possibly Blackriveran (GSN)

GSC loc. C-205917 Skoki Formation; 4.5–14.5 m below top
Drepanoistodus suberectus (Branson and Mehl)
Panderodus gracilis (Branson and Mehl)
Paroistodus sp.
Periodon? sp.
Phragmodus cf. *P. inflexus* Stauffer
belodiniform and platform elements, indet.
Age: Middle Ordovician, possibly Blackriveran (GSN)

UPPER MIDDLE ORDOVICIAN (CARADOC) BRACHIOPODS FROM THE ADVANCE FORMATION, NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA

J. Jin and B.S. Norford

Abstract

The brachiopod fauna of the newly established Advance Formation in the northern Rocky Mountains, British Columbia, comprises 20 genera and 22 species of orthid, strophomenid, pentamerid, rhynchonellid, and atrypid brachiopods, including two new species, *Leangella biseptata* and *Anazyga bellicostata*. The brachiopods are from 13 collections at five closely spaced localities. The presence of *Plaesiomys meedsi, Glyptorthis assimilis, Platystrophia colbiensis, Paucicrura rogata, Oxoplecia globularis, Glyptambonites musculosus, Eoplectodonta alternata*, and *Rafinesquina praecursor* strongly indicates a Trentonian age for the new formation. *Scaphorthis perplexa, Christiania subquadrata, Bimuria superba*, and *Murinella biconvexa* are typical elements of the Scoto-Appalachian *Bimuria* fauna of early Caradoc (latest Chazyan to Ashbyan) age, and occurrences of the same or similar species represent the first well preserved Scoto-Appalachian fauna known from the Canadian Rocky Mountains. Their occurrences in the Advance Formation extend the upper ranges of these species considerably upward into the Trentonian. The rhynchonellid genus *Hiscobeccus*, closely related to the well known *Lepidocyclus* and previously believed to be restricted to Cincinnatian rocks of North America, occurs abundantly in the Advance Formation, and thus its range is extended downward into the Trentonian.

Résumé

La faune de brachiopodes de la nouvelle Formation d'Advance dans les Rocheuses septentrionales en Colombie-Britannique, comprend 20 genres et 22 espèces d'orthidés, de strophoménidés, de pentamérides, de rhynchonellidés et d'atrypidés, y compris deux nouvelles espèces, *Leangella biseptata* et *Anazyga bellicostata*. Les brachiopodes proviennent de 13 collections de cinq localités peu espacés. La présence de *Plaesiomys meedsi*, *Glyptorthis assimilis*, *Platystrophia colbiensis*, *Paucicrura rogata*, *Oxoplecia globularis*, *Glyptambonites musculosus*, *Eoplectodonta alternata* et *Rafinesquina praecursor* indique fortement que la nouvelle formation remonte au Trentonien. *Scaphorthis perplexa*, *Christiania subquadrata*, *Bimuria superba* et *Murinella biconvexa* sont des éléments typiques de la faune scoto-appalachienne *Bimuria* du Caradocien précoce (du Chazyen terminal à l'Ashbyen); des occurrences de la même espèce ou d'une espèce semblable représentent la première faune scoto-appalachienne bien conservée connue dans les Rocheuses canadiennes. Les occurrences de cette espèce dans la Formation d'Advance remontent les intervalles supérieurs de ces espèces beaucoup plus haut dans le Trentonien. *Hiscobeccus*, genre rhynchonellidé étroitement apparenté au bien connu *Lepidocyclus* et que l'on croyait limité aux roches cincinnatiennes de l'Amérique du Nord, est abondant dans la Formation d'Advance de sorte que la limite inférieure de son intervalle est abaissée dans le Trentonien.

INTRODUCTION

Studies of Middle Ordovician articulate brachiopods and their biostratigraphy in eastern North America (Cooper, 1956) and in Scotland (Williams, 1962) were important factors in the delineation of the Scoto-Appalachian Faunal Province (see Jaanusson, 1979). During Caradoc time, a distinct brachiopod assemblage, the *Bimuria* Fauna, was present in the Appalachian Region (Cooper, 1956) in northern Ireland (Mitchell, 1977) and in Scotland (Harper, 1989) and included species of *Paurorthis, Leangella, Christiania* and *Bimuria*.

The *Bimuria* Fauna was largely restricted to the marine environments of the continental margins of ancient North America (Laurentia) and rarely penetrated far into the shallow seas of the cratonic platforms. However, only a few occurrences of the *Bimuria* Fauna have been reported from the western margin of the North American cratonic platform: *Bimuria* is known from the Copenhagen Formation of

Nevada (Cooper, 1956; Ross and Shaw, 1972), from the Mount Kindle and Jones Ridge formations (associated with *Christiania* in both) of the District of Mackenzie and the Yukon Territory, and from accreted terranes in California (associated with *Scaphorthis*) and Alaska (Potter, 1990, 1991).

On other continents, the *Bimuria* Fauna has been documented from northern Wales (Lockley, 1980), Siberia (Petrunina and Severgina, 1962; Kulkov and Severgina, 1989), Novaya Zemlya-Vaygach region (Bondarev, 1968), and South China (Liu et al., 1983; Zeng, 1988). In addition, *Christiania*, one of its characteristic components, has been reported from northern Wales (Hiller, 1980), eastern Australia (Percival, 1991), central Ural Mountains (Nasedkina, 1973), Siberia, Kazakhstan, Mongolia (Kulkov and Severgina, 1989), South China (Liu et al., 1983; Zeng, 1988), and northwestern China (Fu, 1982).

The present paper documents the presence of the *Bimuria* Fauna in the Advance Formation, which was deposited in a slope environment at the western margin of the North American craton. Detailed description of the stratigraphic sections of the Advance Formation, discussions of its age and the regional stratigraphy, and details of the occurrences of taxa are given in a companion paper (Norford, *this volume*). Acid preparation of samples from the formation at the Advance Mountain and Mount Burden sections yielded abundant, well preserved and diverse brachiopods. Many of the genera and species have distinct Scoto-Appalachian affinities and some are documented for the first time from western North America. The presence of *Paurorthis*, *Christiania, Bimuria, Murinella* and other Scoto-Appalachian faunal elements within the Advance Formation confirms the opinion that the *Bimuria* Fauna had an "amphicratonic" distribution in North America (Jaanusson, 1979).

AGE OF THE BRACHIOPOD FAUNA

Most of the studied collections of brachiopods from the Advance Formation were collected from relatively thick stratigraphic intervals during mapping programs but additional collections were made at a later date from thinner stratigraphic intervals in the lower part of the Advance Mountain section. Eleven collections are from specific intervals within stratigraphic sections at Advance Mountain (Fig. 1), Mount Burden (Fig. 2) and at Section 16 of Thompson (1989). The other two collections are from unmeasured outcrops of the formation. Three collections show high diversity of brachiopods (Norford, *this volume,* Appendix 3, GSC locs. C-56101, 11 species; C-69024, 12 species; C-78638, 12 species). The other collections have lower diversity, perhaps due to limited sampling or thinner sampled intervals.

Many species are present in both the lower and upper parts of the formation but some have been found only in the lower beds and others in the higher. The following species are present in the lower 17.5 m of the formation at Advance Mountain:

Species restricted to lower interval	**Species continuing above**
Bimuria cf. *B. superba*	*Eoplectodonta (Eoplectodonta) alternata*
Christiania subquadrata	*Glyptorthis assimilis*
Glyptambonites musculosus	*Hiscobeccus mackenziensis*
Murinella cf. *M. biconvexa*	*Leangella (Leangella) biseptata* n. sp.
Parastrophina sp.	*Paucicrura rogata*
Plaesiomys aff. *P. subquadratus*	*Paurorthis ponderosa*
	Plaesiomys meedsi
	Scaphorthis perplexa
	Thaerodonta redstonensis

The beds above 17.5 m at Advance Mountain and the collections from Mt. Burden (16.5–27.5 m above the base of the Advance Formation) and from near Bernard Creek (spot locality C-56101) contain the following species:

Species restricted to upper interval	**Species continuing from below**
Anazyga bellicostata n. sp.	*Eoplectodonta (Eoplectodonta) alternata*
Dinorthis cf. *D. holdeni*	*Glyptorthis assimilis*
Oepikina sp.	*Hiscobeccus mackenziensis*
Oxoplecia globularis	*Leangella (Leangella) biseptata* n. sp.
Platystrophia colbiensis	*Paucicrura rogata*
Rafinesquina praecursor	*Paurorthis ponderosa*
Strophomena cf. *S. planumbona*	*Plaesiomys meedsi*
	Scaphorthis perplexa
	Thaerodonta redstonensis

Thus two faunal assemblages can be discriminated, but their ages may be similar because many species continue from the older assemblage into the younger.

The lower assemblage of the Advance Formation contains four species that have been previously reported only from lower Porterfield (Chazyan to Blackriveran) rocks of the eastern United States: *Christiania subquadrata* Hall (Effna, Rich Valley, Airline, Athens, Botetourt, Little Oak, lower Edinburg

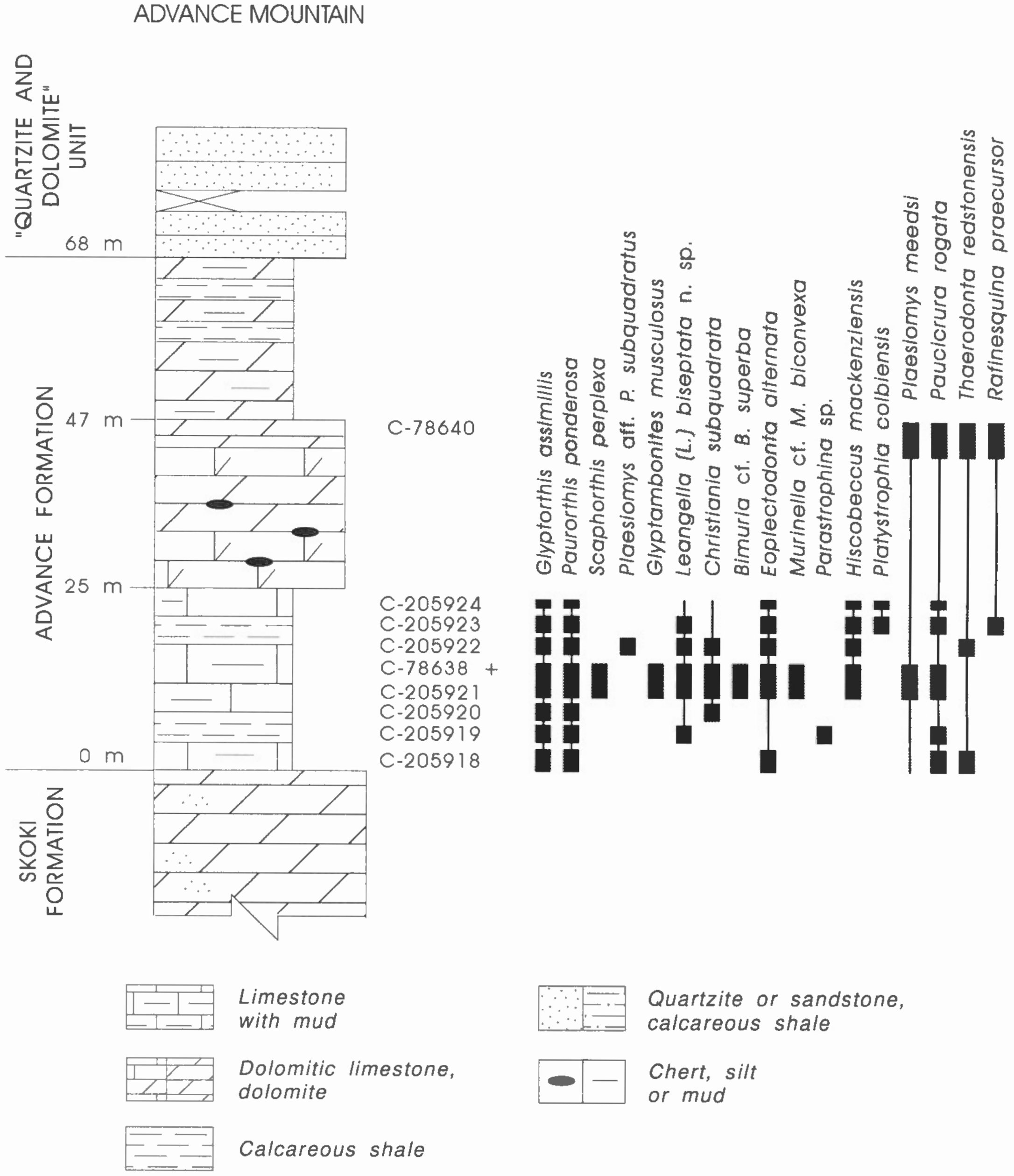

Figure 1. *Brachiopod occurrences in the type section of the Advance Formation, Advance Mountain, northern Rocky Mountains, British Columbia, lat. 56°02′N, long. 123°21′W. (For locality map, see Norford,* ***this volume****.)*

and Youngman units); *Bimuria superba* Ulrich and Cooper (Effna, Airline, Botetourt and Tellico units); *Glyptambonites musculosus* Cooper (Oranda Formation); and *Murinella biconvexa* Cooper (Hogskin Member of the Lincolnshire Formation).

Correlation of the Ashby, Porterfield and Wilderness stages of Cooper and Cooper (*in* Cooper, 1956) with the current scheme of North American Middle Ordovician stages follows Bergström et al. (1988) with the Porterfield ranging from the upper Chazyan to the lower Blackriveran and the Wilderness confined within the Blackriveran (Fig. 3). However, species of *Scaphorthis, Paurorthis, Christiania* and *Bimuria* are known from the mid-Trentonian of North America (Cooper, 1956, 1976). Although some of the brachiopod species of the lower assemblage have a general Porterfield aspect, other species indicate that the assemblage is younger. *Paucicrura rogata* and *Plaesiomys meedsi* are known from the Decorah Shale and *Hiscobeccus mackenziensis* and *Thaerodonta redstonensis* from the lower part of the Whittaker

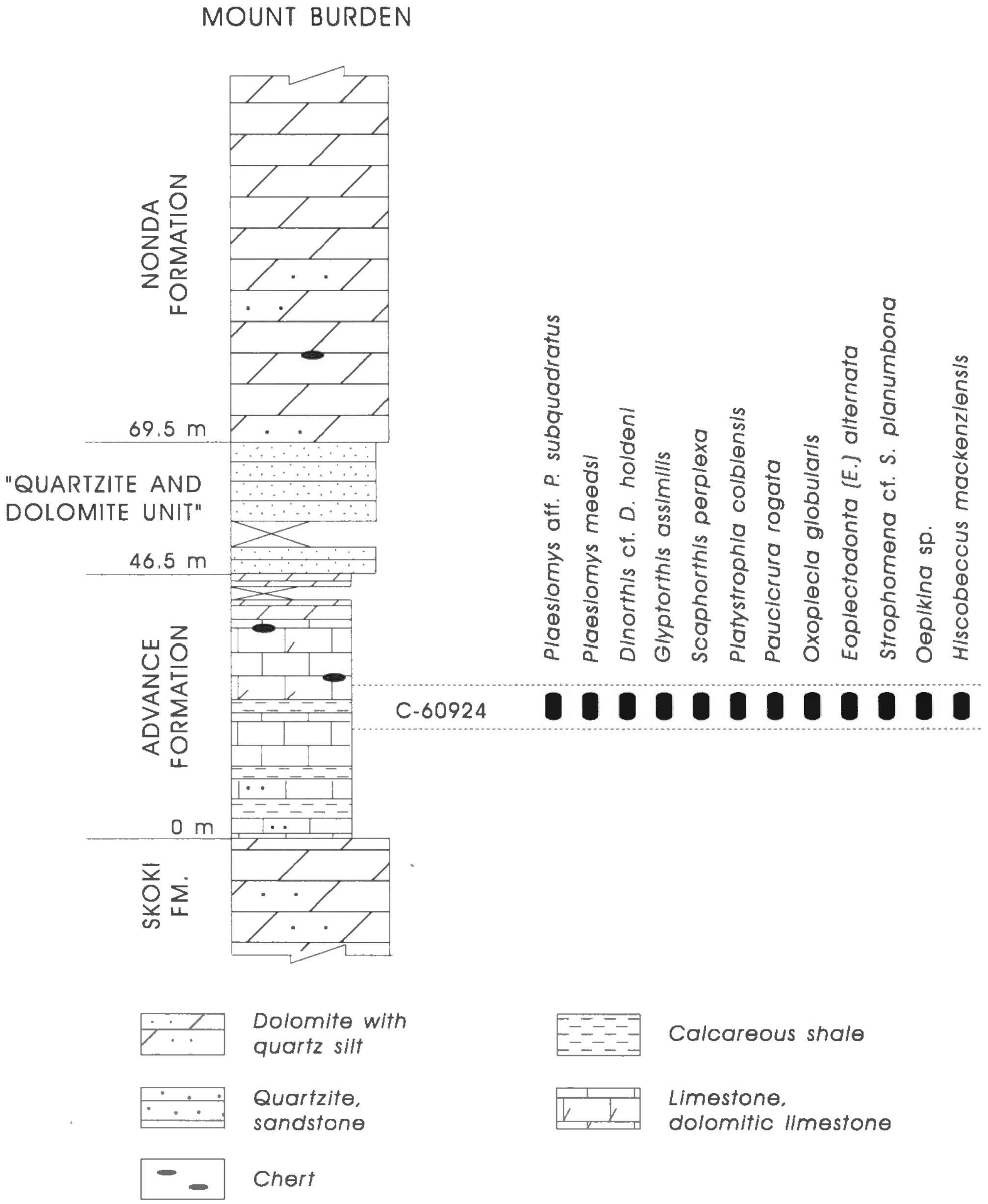

Figure 2. *Brachiopod occurrences in the Advance Formation, Mount Burden, northern Rocky Mountains, British Columbia, lat. 56°11′N, long. 123°27′W. (For locality map, see Norford,* ***this volume****.)*

Formation. Associated corals and conodonts also indicate a younger age. *Grewingkia burdenensis* n. sp. and *Paliphyllum norfordi* n. sp. are present (Elias, *this volume*) within the lower assemblage and conodonts from the basal 6 m of the type section of the Advance Formation are probably Rocklandian to Kirkfieldian in age (GSC loc. C-76837, Nowlan *in* Norford, *this volume*). The age of the lower assemblage is probably Kirkfieldian.

From their previously reported stratigraphic ranges, many of the species that are restricted to the upper assemblage of the Advance Formation indicate a Trentonian (Rocklandian-Shermanian) age: *Platystrophia colbiensis* Foerste (Lexington Limestone); *Oxoplecia globularis* Cooper (Martinsburg); and *Rafinesquina praecursor* Raymond (Trenton Group and Ottawa Formation). Many other brachiopod species of the upper assemblage have a general Trentonian (Rocklandian-Shermanian) aspect but *Hiscobeccus mackenziensis* and *Thaerodonta redstonensis* are known elsewhere only from the lower Whittaker Formation (*Ceraurus mackenziensis* Trilobite Zone, about late Kirkfieldian to Edenian;

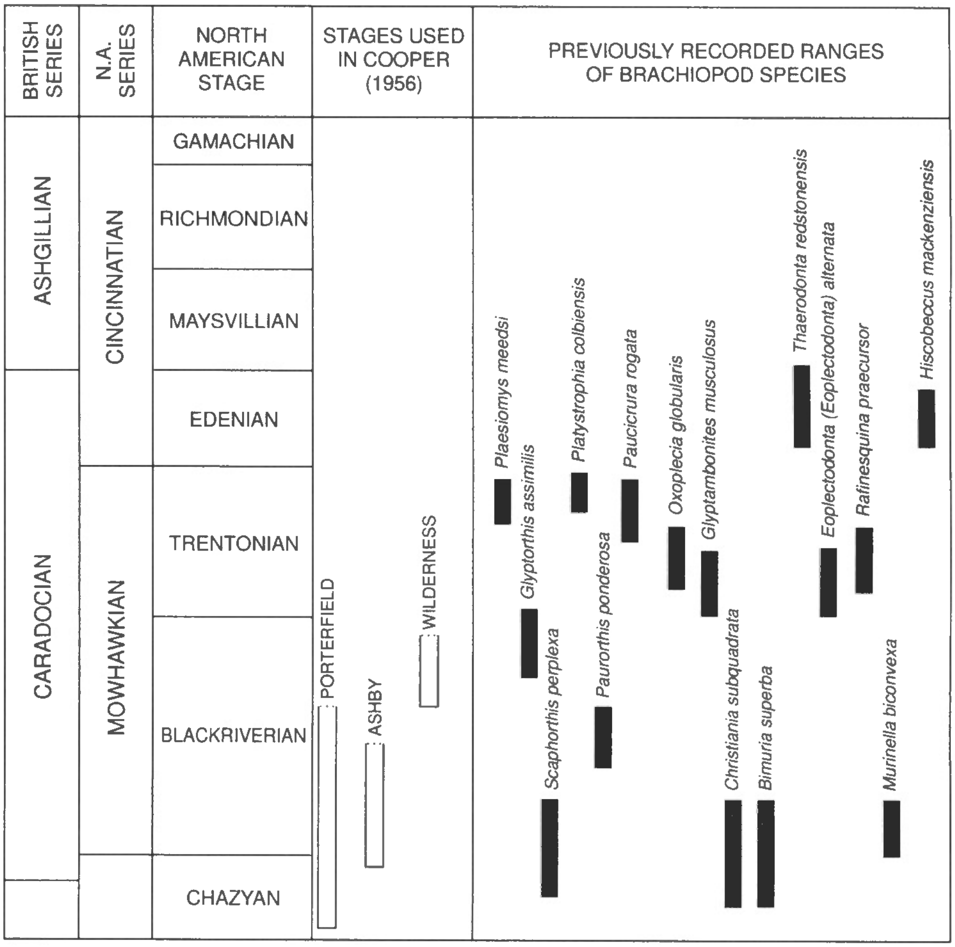

Figure 3. *Previously recorded ranges of brachiopod species that are identified from the Advance Formation. Stratigraphic and faunal data adopted mainly from Cooper (1956), Sloan (1987), Rice (1987), and Bergström et al. (1988).*

Ludvigsen, 1979; Mitchell and Sweet, 1989; Jin and Lenz, 1992). The most appropriate correlation is within the Shermanian to Edenian interval. The coral *Grewingkia burdenensis* n. sp. (Elias, *this volume*) is present within the upper assemblage. Associated conodonts indicate a probable Shermanian age for the lower part of the interval, and general late Middle to Late Ordovician age for the upper part (Nowlan *in* Norford, *this volume*).

In general, the brachiopod fauna of the Advance Formation shows strong affinities to faunas in the southern Appalachians reported by Cooper (1956) and shows some similarities to the fauna of the Decorah Shale of Minnesota and Wisconsin (Rice, 1987). One of the species (*Eoplectodonta alternata*) is also known from the Copenhagen Formation of Nevada (Ross and Shaw, 1972, p. 4) and two (*H. mackenziensis* and *T. redstonensis*) from the lower Whittaker Formation of the Mackenzie Mountains, so there are also affinities to western North America. Of the 22 species known from the Advance Formation, 15 are identified with taxa previously reported from the eastern and central United States. Most of these species have relatively short stratigraphic ranges and are very useful for dating. In Figure 3, species from GSC locs. C-69024, C-78638 and C-78640 are shown with their previously documented stratigraphic ranges: new species and tentatively identified taxa are not included. Although the known ranges span the interval late Chazyan to early Maysvillian, seven of the species have been reported previously only from rocks of Trentonian age (Rocklandian-Shermanian).

SYSTEMATIC PALEONTOLOGY

All type specimens used in the present study are deposited in the Type Collection of Invertebrate and Plant Fossils of the Geological Survey of Canada

(GSC). All descriptions of species are based on silicified specimens from the Advance Formation of the northern Rocky Mountains.

Plots of shell dimensions were computer-generated using the software programme Grapher, designed by Golden Software Inc., Golden, Colorado. Ontogenetic growth trends were plotted by Grapher with its linear, power, or logarithmic best-fit lines. Statistical data on shell dimensions can be found in Appendix 2.

Abbreviations used in the systematic paleontology section are as follows: D - depth, L - length, W - width, T - thickness, dv - dorsal valve, vv - ventral valve.

Order ORTHIDA Schuchert and Cooper, 1932

Family PLAESIOMYIDAE Schuchert, 1913

Genus *Plaesiomys* Hall and Clarke, 1892

Type species. Orthis subquadrata Hall, 1847. Richmond Group (Richmondian), Ohio (see Howe, 1966 for discussion of type specimens).

Plaesiomys sp. aff. *P. subquadratus* (Hall, 1847)

Plate 2, figures 1–7

Orthis subquadrata Hall, 1847, p. 126, Pl. 32A, figs. 1a–o.
Orthis subquadrata Hall; Meek, 1873, p. 94, Pl. 9, figs. 2b–g.
Plaesiomys subquadrata (Hall); Hall and Clarke, 1892, p. 196, Pl. 5A, figs. 17–19.
Orthis (*Dinorthis*) *subquadrata* Hall; Winchell and Schuchert, 1893, p. 428, Pl. 32, figs. 46-50.
Dinorthis (*Plaesiomys*) *subquadrata* (Hall); Schuchert and Cooper, 1932, p. 94, 96, Pl. 10, figs. 15, 17, 18, 24–26.
Plaesiomys subquadratus (Hall); Ross, 1959, p. 449, Pl. 55, figs. 1, 6, 12, 14, 15, 18, 19, 23. (Hall's original types illustrated.)
Plaesiomys cf. *P. subquadratus* (Hall); Howe, 1966, p. 247, Pl. 29, figs. 1–6.
Plaesiomys cf. *P. subquadratus* (Hall); Alberstadt, 1973, p. 21, Pl. 7, figs. 8a, b.
Plaesiomys subquadratus (Hall); Alberstadt, 1973, p. 22, Pl. 2, figs. 6–8.

Remarks. The only complete shell from the Advance Formation is 20.0 mm long, 23.4 mm wide, and 10.0 mm thick. It resembles *P. subquadratus* from the Cincinnatian rocks of Ohio (Hall, 1847; Meek, 1873), Minnesota (Winchell and Schuchert, 1893), and Texas (Howe, 1966) in its relatively large, subquadrate, nearly convexo-planar shell with fine (7 in 5 mm at anterior margin), bifurcating and intercalating costae. Meek (1873, p. 95) noted that in *P. subquadratus* the anterior increase of costae was nearly always by bifurcation in the ventral valve and by intercalation in the dorsal valve. The Rocky Mountains specimen exhibits the same pattern of costal increase (Pl. 2, figs. 1, 2). Internal structures, such as the short dental plates and septiform cardinal process with a crenulated, herringbone crest (Pl. 2, figs. 6, 7) of the Rocky Mountains specimen confirm its identity as *Plaesiomys*. It differs from typical *P. subquadratus* in its better developed sulcus in the anterior half of the ventral valve, which gives the shell a uniplicate anterior commissure, in its catacline ventral interarea (perpendicular to commissural plane), and lack of a dorsal sulcus. Typical *P. subquadratus* have a dorsal sulcus extending from beak to anterior margin and a nearly rectimarginate anterior commissure (see Ross, 1959, Pl. 55, figs. 1, 19).

The Rocky Mountains shell probably represents a new species of *Plaesiomys,* but more specimens are needed in order to determine its variation and relationship to typical *P. subquadratus.*

Collections. Total 4 specimens. GSC loc. C-56106 (1 broken shell); C-60924 (1 complete shell, 1 dorsal valve fragment); GSC loc. C-205922 (1 ventral valve).

Plaesiomys meedsi (Winchell and Schuchert, 1892)

Plate 2, figures 8–15

Orthis meedsi Winchell and Schuchert, 1892, p. 289.
Orthis minnesotensis Sardeson, 1892, p. 332, Pl. 5, figs. 14–17.
Orthis meedsi Winchell and Schuchert; Winchell and Schuchert, 1893, p. 427, Pl. 32, figs. 39–42.
Dinorthis meedsi (Winchell and Schuchert); Schuchert, 1897, p. 215.
Dinorthis (*Plaesiomys*) *meedsi* (Winchell and Schuchert); Schuchert and Cooper, 1932, p. 94.
Dinorthis (*Plaesiomys*) *meedsi* (Winchell and Schuchert); Rice, 1987, p. 152, Pl. 1, figs. 10a, b.

Type specimens. The two specimens illustrated by Winchell and Schuchert (1893) came from the upper Decorah Shale (see Rice, 1987), Trentonian, Minnesota.

Description (Advance material). Shell small to medium-sized, subquadrate, nearly equibiconvex; hingeline straight, extending for about four-fifths of shell width; anterior commissure rectimarginate or weakly sulcate. Ventral umbo small, low, barely extending posteriorly beyond hingeline, with minute beak; interarea well developed, about 1 mm high, as wide as hingeline, nearly catacline; delthyrium wide, open; valve with greatest convexity in umbonal area, but without carina, fold, or sulcus. Dorsal umbo flat, with minute median furrow developed anteriorly into shallow, poorly delimited sulcus; interarea low, orthocline. Entire shell covered by rounded costae, with bifurcation mainly on ventral valve and intercalation on dorsal valve (Pl. 2, figs. 12, 8, respectively), reaching about 7 in 5 mm at anterior margin.

Dimensions (mm).

	L	W	T/D
Hypotype GSC 103731	10.6	13.2	3.5 (shell)
Hypotype GSC 103732	10.0	13.6	1.3 (vv)

Teeth nodular, fairly strong; dental plates very low, short, divergent at about 90°, forming minute, pit-like dental cavities (Pl. 2, fig. 13); muscle field vaguely impressed, with semi-oval adductor scars enclosing slender adductor tracks. Notothyrial cavity of dorsal valve raised slightly above valve floor by thickening; cardinal process consisting of septiform shaft and crenulated, herringbone crest (Pl. 2, fig. 15); brachiophores platy, with pointed distal ends; muscle scars of dorsal valve poorly impressed.

Remarks. Specimens of *P. meedsi* from the Rocky Mountains resemble those from the Decorah Shale of Minnesota in their weakly biconvex shells, relatively coarse costae for the genus (despite their small size, the shells have 7–8 costae in 5 mm at anterior margin), catacline or subcatacline ventral interarea, and poorly developed fold and sulcus. *Plaesiomys germana* (Winchell and Schuchert, 1893) from the Decorah Shale is most similar to *P. meedsi* but differs in its greater biconvexity, finer costae, and somewhat better developed fold and sulcus. *Plaesiomys proavita* (Winchell and Schuchert, 1892) and its junior synonym, *P. planus* Wang, 1949 (see Alberstadt, 1973), also have weakly biconvex shells with relatively strong costae, but differ from *P. meedsi* in having a flatter ventral valve. The development of costae in *P. meedsi* is similar to that in *P.* aff. *P. subquadratus* in ventral bifurcation and dorsal intercalation.

Collections. Total 9 specimens. GSC loc. C-56085 (2 shells); C-56101 (1 dorsal valve); C-60924 (1 dorsal valve); C-78638 (1 dorsal valve); C-78640 (2 ventral valves, 2 dorsal valves).

Genus *Dinorthis* Hall and Clarke, 1892

Type species. Orthis pectinella Emmons, 1842. Trenton Limestone, New York.

Dinorthis cf. *D. holdeni* (Willard, 1928)

Plate 1, figures 1–9

Plectorthis holdeni Willard, 1928, p. 262, Pl. 1, fig. 5.
Dinorthis holdeni (Willard); Cooper, 1956, p. 395, Pl. 57, figs. 14–28.
Plaesiomys (*Dinorthis*) *holdeni* (Willard); Williams and Wright, 1965, p. H319, fig. 3c.

Type specimens. The holotype is from the Elway Formation, Ashby (early Caradocian), Tennessee (see Cooper, 1956).

Remarks. A few disarticulated valves from the Advance Formation are compared to *D. holdeni* on the basis of their relatively small, semicircular to subquadrate, weakly biconvex shell, with strongly apsacline to catacline ventral interarea, coarse costae (Pl. 1, figs. 1, 4, 6), platy brachiophores, and septiform cardinal process with a crenulated crest (Pl. 1, figs. 8, 9). Each valve has about 22 to 30 simple, rounded costae, comparable to those illustrated by Cooper (1956). As in the specimens described by Cooper (1956) from the Ashby rocks of Virginia and Tennessee, the ventral valve (Pl. 1, figs. 1–3) is flattened in the anterior half. The Rocky Mountains specimens differ from the Appalachian forms most notably in their smaller size (Appalachian forms are usually larger than 10 mm in length). The bilobate ventral muscle field extends to nearly one half of valve length in the Appalachian shells but to only one third of valve length in the Rocky Mountains specimens. The portions of interarea that cover posterior parts of the sockets have laterally divergent striations (Pl. 1, figs. 8, 9).

Dimensions (mm).

	L	W	Depth
Hypotype GSC 103721	6.1	8.0	2.0 (vv)
Hypotype GSC 103722	6.7	8.3	1.5 (dv)
Hypotype GSC 103723	6.0	8.7	1.5 (dv)

Collections. Total 8 specimens. GSC loc. C-56101 (1 ventral valve, 6 dorsal valves); C-60924 (1 dorsal valve).

Family DOLERORTHIDAE Öpik, 1934

Subfamily GLYPTORTHINAE
Schuchert and Cooper, 1931

Genus *Glyptorthis* Foerste, 1914

Type species. Orthis insculpta Hall, 1847. Richmondian rocks of Ohio.

Glyptorthis assimilis Cooper, 1956

Plate 1, figures 10–25

Glyptorthis assimilis Cooper, 1956, p. 361, Pl. 45, figs. 15–35; Pl. 49, figs. 27–32.

Type specimens. The type lot illustrated by Cooper (1956) is from the lower Ridley Formation, Blackriveran–Trentonian, Tennessee.

Description (Advance material). Shell medium-sized, average length not exceeding 20 mm, subquadrate to nearly semicircular, unequally biconvex with variably deeper ventral valve; hingeline straight, almost as wide as shell width; anterior commissure weakly sulcate. Ventral umbo generally wide, moderately convex, with wide apical angles (>100°); beak inconspicuous, erect; interarea relatively high, slightly narrower than hingeline, steeply apsacline at adult stage, approaching catacline in some younger forms; delthyrium large, devoid of any deltidial covering. Dorsal umbo small, flat, with narrow median furrow widening anteriorly to become sulcus; beak small, slightly incurved; interarea very low (about 1 mm in height), as wide as hingeline, orthocline. Entire shell covered by fine costae or costellae increasing by intercalation or bifurcation to reach 50 to 60 toward anterior margin in adult shells; costae or costellae having rounded crests and being notably unequal in size and thickness; growth lamellae coarse, imbricating, average 3 to 5 in 1 mm, punctuated by irregular, coarser growth interruptions near anterior margin.

Dimensions (mm).

	L	W	T/D
Hypotype GSC 103724	11.4	12.4	7.5 (shell)
Hypotype GSC 103725	4.4	6.9	3.5 (shell)
Hypotype GSC 103728	12.0	17.0	3.4 (dv)

Teeth strong, knob-like, with large, rounded fossettes and fine, comb-like ridges (Pl. 1, figs. 19, 21, 22); dental plates short, reduced, or fused to lateral shell wall by thickening; muscle field deeply impressed, with narrow, slender, adductor scars enclosed by elongate, oval diductor scars (Pl. 1, fig. 19), terminating anteriorly in raised margin and longitudinal ridges of vascular media (Pl. 1, figs. 19, 21, 22). Hinge sockets in dorsal valve large, with fine grooves corresponding to comb-like ridges on teeth; notothyrial cavity relatively small, shallow, bounded anteriorly by sharp ridge (Pl. 1, figs. 23–25); cardinal process thin, ridge-like, becoming swollen at anterior end in large forms (Pl. 1, figs. 23–25); brachiophores short, robust, platy; dorsal muscle field large, divided by thick median ridge, with circular anterior adductor scars flanked by slender, curved posterior adductor scars. Vascular canals well impressed, probably ventro-saccate and dorso-digitate (compare Pl. 1, figs. 19–25 to Williams and Rowell, 1965, p. H129, fig. 135, G).

Remarks. Shells of *Glyptorthis assimilis* from the Rocky Mountains show considerable ontogenetic changes. Immature forms tend to be much wider than long, with extremely apsacline ventral interarea approaching catacline (Pl. 1, figs. 15–18), and minimal anterior swelling of the septiform cardinal process. Relatively large shells become subquadrate in outline, with an approximately 45° apsacline ventral interarea (Pl. 1, figs. 10, 11, 19); the anterior end of the cardinal process swells to become almost bulbous.

In its subquadrate shell and relatively fine costae or costellae, *Glyptorthis assimilis* most closely resembles *G. bellarugosa* (Conrad, 1842); *G. costellata* Cooper, 1956; *G. uniformis* Cooper, 1956; and *G. virginica* Cooper, 1956. It differs from *G. costellata* and *G. virginica* in that these two species have a weakly apsacline ventral interarea approaching orthocline. *Glyptorthis bellarugosa* has a more pointed ventral umbo at adult stage than *G. assimilis.* Both *G. assimilis* and *G. uniformis* have a prominently apsacline ventral interarea, but *G. uniformis* has a somewhat semicircular shell with more uniform ribs and more prominent dorsal sulcus. *Glyptorthis pulchra* Wang, 1949 from the Maquoketa Shale of Iowa also has a subquadrate shell with relatively fine costae, but it can be distinguished from *G. assimilis* by its weakly biconvex shell with a nearly orthocline ventral interarea and deep dorsal sulcus. *Glyptorthis* cf. *G. pulchra* described by Ross (1959) from the Saturday Mountain Formation (Upper Ordovician) of Idaho similarly has a deep, angular dorsal sulcus and more rounded lateral margins than *G. assimilis.*

Collections. Total 75 specimens. GSC loc. C-56101 (18 disarticulated valves); C-56106 (2 fragments); C-60924 (5 complete specimens, 12 disarticulated valves); C-78638 (4 immature specimens); C-205918 (5 fragments); C-205919 (2 immature specimens); C-205920 (1 dorsal valve); C-205922 (2 ventral valves);

C-205923 (23 shells and valves); C-205924 (1 dorsal valve).

Family PLECTORTHIDAE
Schuchert and LeVene, 1929

Subfamily PLECTORTHINAE
Schuchert and LeVene, 1929

Genus *Scaphorthis* Cooper, 1956

Type species. Scaphorthis virginiensis Cooper, 1956. Chatham Hill Formation, upper Porterfield, Virginia.

Scaphorthis perplexa Cooper, 1956

Plate 2, figures 16–27

Scaphorthis perplexa Cooper, 1956, p. 504, Pl. 55, figs. 12–26.

Type specimens. The type lot illustrated by Cooper is from the Effna and Rich Valley formations, lower Porterfield, Virginia.

Description (Advance material). Shell generally small, with maximum length or width not exceeding 10 mm, subcircular in outline, unequally biconvex with ventral valve approximately twice as deep as dorsal valve; hingeline long, straight, slightly shorter than shell width; anterior commissure gently sulcate. Ventral umbo moderately convex, with wide apical angle (>120°) and small, erect to slightly incurved beak; greatest convexity located in median portion of valve but not forming carina; interarea high, about 3 mm in large forms, and as wide as hingeline; delthyrium completely open. Dorsal umbo varying from nearly flat to weakly convex, marked by minute median furrow widening anteriorly to become shallow sulcus; interarea low, less than 0.5 mm. Entire shell finely costellate, with irregular fila present in some interspaces; number of costellae increasing principally by intercalation toward anterior margin, reaching about 60; growth lines obscure, except for coarse growth interruptions developed at 0.5–1.5 mm intervals.

Dimensions (mm).

	L	W	T
Hypotype GSC 103734	6.4	7.6	3.5 (shell)
Hypotype GSC 103735	6.7	8.6	3.4 (shell)

Teeth small, slender, without well delimited fossettes; dental plates well developed, subparallel to each other; ventral muscle field and vascular canals poorly impressed. Notothyrial cavity of dorsal valve shallow; cardinal process septiform, blade-like; brachiophores consisting of short knobs; low median ridge present in posterior half of valve, dividing poorly impressed adductor scars (Pl. 2, fig. 26).

Remarks. Specimens from the Rocky Mountains are assigned to *S. perplexa* on the basis of their small, unequally biconvex shells, with a broad dorsal sulcus. The other two species described by Cooper (1956) from Porterfield rocks of Virginia and Maryland, *Scaphorthis kayi* and *S. virginiensis,* have notably larger shells with somewhat finer costae and deeper dorsal valves. *Scaphorthis sulcata* described by Wright (1964) from the Portrane Limestone (Ashgillian) of Ireland is distinctly different from the North American species by its small, sulcate shell with much coarser costae.

Collections. Total 12 specimens. GSC loc. C-56101 (1 entire shell, 2 broken valves); C-60924 (1 shell, 2 dorsal valves); C-78638 (1 shell, 4 valves).

Subfamily PLATYSTROPHIINAE
Schuchert and LeVene, 1929

Genus *Platystrophia* King, 1850

Type species. Terebratulites biforatus von Schlotheim, 1820. As noted by Cocks (1978), the type species is from the Ordovician of the Baltic region, but the exact locality and horizon are unknown.

Platystrophia colbiensis Foerste, 1910

Plate 3, figures 1–6; Plate 13, figures 18–22

Platystrophia colbiensis Foerste, 1910, p. 55, Pl. 4, figs. 2a, b.

Platystrophia colbiensis-mutata Foerste, 1910, p. 56, Pl. 4, figs. 3a, b.

Platystrophia colbiensis Foerste; McEwan, 1919, p. 414, Pl. 44, figs. 8–11.

Platystrophia colbiensis-mutata Foerste; McEwan, 1919, p. 414, Pl. 44, fig. 12.

Platystrophia colbiensis Foerste; Alberstadt, 1979, p. B9, Pl. 5, figs. 1–36; Pl. 7, figs. 36–38, 40, 41.

Type specimens. All specimens illustrated by Foerste (1910) for *P. colbiensis* and *P. colbiensis-mutata* are from the Lexington Limestone (Trentonian), Kentucky.

Description (Advance material). Shell medium-sized, subquadrate with small, transversely extended cardinal extremities, biconvex with ventral valve slightly deeper than dorsal valve; hingeline straight, coinciding with greatest shell width; anterior commissure uniplicate. Ventral umbo fairly low, with small, suberect beak; interarea low, less than 1.5 mm in height, with slightly concave surface, as wide as hingeline; delthyrium open; sulcus beginning from apex of valve, well delimited with sharp slopes; three subangular costae occupying posterior half of sulcus, increasing to six anteriorly through bifurcation (median costa) and intercalation (Pl. 3, fig. 2; Pl. 13, figs. 19, 21, 22). Dorsal umbo nearly as high as ventral one, moderately convex, with small, incurved beak; interarea similar to that of ventral valve, with open notothyrium; fold moderately high, beginning from apex, with flattened top and nearly vertical slopes, carrying four costae increasing to six anteriorly due to intercalation of median costae and bifurcation of outer costae (Pl. 3, fig. 1; Pl. 13, figs. 18, 21, 22). Each shell flank covered by nine or ten subangular costae with rare bifurcation or intercalation; fine growth lines present but not well preserved; two or three coarse growth lamellae developed near anterior margin.

Dimensions (mm).

	L	W	T
Hypotype GSC 103738	14.5	20.5	11.9 (shell)
Hypotype GSC 109198	6.0	7.8	3.6 (shell)

Teeth in ventral valve moderately strong, with fossettes on their inner dorsal surface; dental plates short, low, forming small dental cavities; muscle field small, oval, with raised lateral and anterior margins, without clearly differentiated adductor and diductor scars; genital areas on both sides of muscle field with papillae (Pl. 3, fig. 5). Notothyrial cavity in dorsal valve deep, with low, thin, ridge-like cardinal process; brachiophores thick, short, knob-like; pair of adductor scars elliptical, defined by grooved margins, isolated and tilting from each other at about 85° anterolaterally (Pl. 3, fig. 6); papillae present on posterolateral sides of adductor scars.

Remarks. Foerste (1910) distinguished *P. colbiensis-mutata* from *P. colbiensis* on the basis that *P. mutata* has more than four costae on the fold. As shown by Alberstadt (1979), however, *P. colbiensis* typically has four costae on the fold and three in the sulcus, but the number may increase in some larger forms through bifurcation and intercalation. The only complete shell from the Rocky Mountains is identified with *P. colbiensis* (larger forms with more than four costae in the sulcus) by its subquadrate, moderately biconvex outline with slightly extended cardinal extremities, sharply defined fold and sulcus but with a moderate relief, and internally by its small, elliptical, anterolaterally divergent adductor scars in the dorsal valve.

McEwan (1919) and Alberstadt (1979) gave thorough discussions and comparisons of *P. colbiensis* with similar congeneric species.

Collections. Total 5 specimens. GSC loc. C-60924 (1 shell, 1 fragment); C-205923 (1 immature shell, 1 ventral valve); C-205924 (1 immature shell).

Family PAURORTHIDAE Öpik, 1933

Genus *Paurorthis* Schuchert and Cooper, 1931

Type species. Orthambonites parva Pander, 1830. Upper Ordovician, Estonia.

Paurorthis ponderosa Cooper, 1956

Plate 4, figures 1–15

Paurorthis ponderosa Cooper, 1956, p. 971, Pl. 146, figs. 39–43; Pl. 149, figs. 44–53; Pl. 151, figs. 25–29.

Type specimens. The holotype figured in Cooper (1956, Pl. 146E, figs. 39–43) is from the lower Benbolt Formation, upper Porterfield, Virginia.

Description (Advance material). Shell medium-sized, average length of adult shell 10.5 mm, width 11.0 mm, thickness 6.8 mm, nearly equibiconvex or with slightly deeper ventral valve; hingeline straight, slightly shorter than maximum shell width; anterior commissure rectimarginate to gently sulcate. Ventral umbo narrow, strongly convex, extending 2–3 mm posterior of hingeline; beak small, incurved but not obscuring delthyrium; apsacline interarea relatively high, as wide as hingeline; deltidium or deltidial plates absent; greatest convexity of valve along median line but not forming carina, with sloping flanks. Dorsal umbo rather weakly convex, marked by minute median furrow extending and widening anteriorly to form shallow sulcus; interarea much lower than, but as wide as, that of opposite valve, apsacline. Entire shell finely fascicostellate, reaching more than two hundred (7–9 in 1 mm) at anterior margin; crests of costellae interrupted by short, regularly spaced projections and pits (Pl. 4, figs. 2, 14, 15), probably junctions of spines or frills with hollow costellae; fine growth lines not observed; coarse growth lamellae spaced at 0.5-1.5 mm intervals near anterior margin.

Dimensions (mm).

	L	W	T/D
Hypotype GSC 103742	10.5	11.0	6.8 (shell)
Hypotype GSC 103746	11.0	13.0	2.8 (dv)
Hypotype GSC 103745	10.7	12.8	2.2 (dv)
Hypotype GSC 103743	11.1	11.4	3.7 (vv)
Hypotype GSC 103744	9.1	10.4	3.8 (vv)

Teeth in ventral valve relatively small, slender, obliquely attached to ventral side of hingeline, with oval fossettes (Pl. 4, fig. 7); dental plates absent or poorly developed; muscle field small, almost confined to delthyrial cavity, bordered anteriorly by broad, low ridge (Pl. 4, fig. 6), without clearly defined diductor or adductor scars; vascular canals poorly preserved. Hinge sockets in dorsal valve sitting directly on valve floor, with weak distal ridges; notothyrial cavity large, deep, slightly raised anteriorly by shell thickening, with smooth floor or bearing fine, ridge-like cardinal process in some specimens; brachiophores short, robust, diverging from each other ventroanteriorly at about 75°; dorsal muscle field relatively large, with pair of elongate-oval adductor scars separated by thick, prominent median ridge (Pl. 4, figs. 10, 13); dorsal vascular system vaguely impressed, probably digitate (Pl. 4, fig. 13).

Remarks. Most species of *Paurorthis* are characterized by small shells (less than 10 mm in length or width). Three North American species (*P. ponderosa, P. magna* Cooper, 1956, and *P. gigantea* Cooper, 1956) are relatively large and have extremely fine costellae. The Rocky Mountains specimens are assigned to *P. ponderosa* on the basis of their medium-sized, finely fascicostellate shells with a poorly developed septiform cardinal process and a short median ridge in the muscle field of the dorsal valve. *Paurorthis gigantea* from the Mohawkian rocks of Nevada has elongate shells and is considerably larger (up to 19 mm long) than other congeneric species. *Paurorthis magna* has a stronger, septiform cardinal process and much longer median ridge dividing the muscle field of the dorsal valve. The regularly spaced projections and pits on rib crests, as seen in specimens studied herein, are common to all species of *Paurorthis* (Cooper, 1956; Williams, 1962, Pl. 12, fig. 41).

Collections. Total 41 specimens. GSC loc. C-78638 (16 specimens); C-205918 (1 fragment of ventral valve); C-205919 (2 immature specimens); C-205920 (1 ventral and 1 dorsal valve); C-205922 (4 immature specimens); C-205923 (5 ventral valves); C-205924 (11 shells and valves).

Family DALMANELLIDAE Schuchert, 1913

Genus *Paucicrura* Cooper, 1956

Type species. Orthis rogata Sardeson, 1892. Decorah Shale, lower Trentonian, Minnesota.

Paucicrura rogata (Sardeson, 1892)

Plate 4, figures 16-19; Plate 5, figures 1-21;
Figures 4, 5

Orthis rogata Sardeson, 1892, p. 331, Pl. 5, figs. 1-4.
Orthis (*Dalmanella*) *testudinaria*; Winchell and Schuchert (*non* Dalman, 1828), 1893, p. 441, Pl. 33, figs. 17-22.
Orthis rogata Sardeson; Sardeson (in part), 1897, p. 95, Pl. 4, figs. 2, 6, 8.
Dalmanella rogata (Sardeson); Schuchert and Cooper, 1932, p. 120, Pl. 17, figs. 2-5, 7, 13, 31.
Resserella rogata (Sardeson); Cooper, 1944, p. 353, Pl. 138, figs. 6, 7.
Paucicrura rogata (Sardeson); Cooper, 1956, p. 957, Pl. 157, figs. 18-24.
Paucicrura rogata (Sardeson); Williams and Wright, 1963, p. 29, Pl. 1, figs. 18, 20.
Paucicrura rogata (Sardeson); Williams and Wright, 1965, p. H336, figs. 213, 1a-d.
Paucicrura rogata (Sardeson); Chandlee, 1982, p. 205-211, Pl. 1-4 (one figure in each plate).
Paucicrura rogata (Sardeson); Rice, 1987, p. 156, Pl. 2, figs. 7a-e.

Type specimens. Sardeson assigned to *P. rogata* over a thousand specimens from the Decorah Shale and did not select a holotype. Schuchert and Cooper (1932, Pl. 17, figs. 7, 13) figured a specimen from the "Fucoid bed" of Ellsworth, Wisconsin, and labelled it as "Sardeson's holotype" (*ibid.*, p. 228). As pointed out by Rice (1987), however, Sardeson (1892, p. 331) clearly stated that his figured specimen was from "the *Orthisina* beds at Berne, Dodge County, Minnesota". Thus a lectotype needs to be selected from Sardeson's collection.

Description (Advance material). Shell relatively small, with average length 9.4 mm, width 10.5 mm, and thickness 3.7 mm (Fig. 4), subcircular, planoconvex to unequally biconvex with ventral valve more than twice as deep as dorsal valve (Fig. 5, see also Appendix 2);

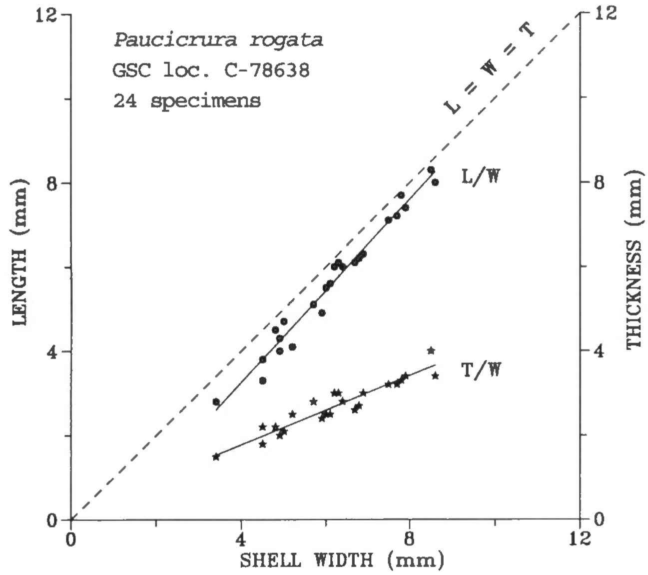

Figure 4. Plot of dimensions of complete shells of ***Paucicrura rogata*** *(Sardeson, 1892). Sample from GSC loc. C-78638. Note decrease in shell convexity (T/W ratios) during ontogeny.*

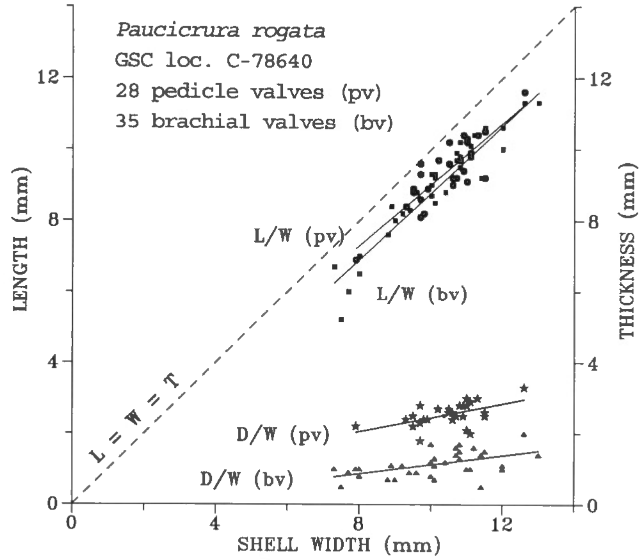

Figure 5. Plot of dimensions of disjunct valves of ***Paucicrura rogata*** *(Sardeson, 1892). Sample from GSC loc. C-78640. The ventral valves are notably deeper than the dorsal valves (D/W ratios).*

hingeline straight, attaining about one half to two thirds of shell width; anterior commissure rectimarginate to weakly sulcate. Ventral umbo small, narrow, slightly raised above hingeline; beak small, incurved but not arched over commissural plane; interarea low (generally less than 1 mm in height), apsacline; delthyrium completely open; median elevation present in umbonal area but rarely developing into well defined carina; valve gently sloping in marginal areas. Dorsal umbo flat to slightly convex, with minute beak; median furrow narrow, well delimited in umbonal area, becoming broad and shallow anteriorly. Entire shell costellate, number of costellae increasing anteriorly mainly by intercalation and secondarily by bifurcation in both valves, reaching up to 94 at margin of each valve; primary costellae (starting at apex) generally thicker than secondary or tertiary ones; growth lines fine (about 3 in 1 mm), obscured by silicification in most specimens, punctuated by coarser growth lamellae (or growth interruptions) at 1.5-2.5 mm intervals (Pl. 5, figs. 1, 2).

Interior of ventral valve: teeth strong, with relatively large fossettes on inner surfaces; dental plates well developed, forming narrow dental cavities, extending anteriorly for one third of shell length as low ridges arching laterally to enclose elongate, oval muscle field; diductor muscle scars elongate, flanking small adductor scars but not coalescing at anterior ends, thus forming anterior median notch (Pl. 5, figs. 12-15). Interior of dorsal valve: hinge sockets slightly elongate, divergent laterally; fulcral plates not developed; cardinal process consisting of main shaft (directed at approximately 90° to commissural plane) with trilobate to quadrilobate crest (posterior side) and concave base (anterior side) with median ridge; in some specimens, spur originating near base of shaft, pointing ventroanteriorly (Pl. 4, figs. 16, 17; Pl. 5, figs. 20, 21); brachiophores thick, generally 1.5-2.0 mm long, divergent from each other at 50 to 55° ventroanteriorly; median ridge broad, low, flanked by elongate, suboval adductor scars (Pl. 4, figs. 16-19; Pl. 5, figs. 16-21).

Remarks. Specimens from the Rocky Mountains are assigned to *Paucicrura rogata* on the basis of their planoconvex shells with relatively fine costellae, trilobate to quadrilobate cardinal process with a spur on the anterior side, and general configuration of muscle scars. In the collections examined, the cardinal process in about 90 per cent of the specimens has a concave surface on the anterior side of the shaft with a median ridge, but the spur, which may vary in shape from blunt to slender, occurs in less than five per cent of the specimens; the median lobe is notably higher and wider than the lateral lobes, and bifurcates with a narrow slit at adult stage, thus giving the cardinal process a quadrilobate appearance. In some specimens from the type area in Minnesota, the slitted median lobe and anterior spur of the cardinal process are also present (Rice, 1987; Williams and Wright, 1963).

In external morphology, *Paucicrura rogata* is most similar to *P. subplana* Cooper, 1956 from the Martinsburg Formation (Trentonian) of Virginia, but the internal structures of *P. subplana* are unknown. *Paucicrura matutina* Cooper, 1956 from the Edinburg and Shippensburg formations (Blackriveran) of eastern United States has ear-like cardinal extremities. *Paucicrura quadrata* (Wang, 1949 = *P. oklahomensis* Alberstadt, 1973) is common in the lower Maquoketa Shale of Iowa, Viola and Cape formations (Edenian) of Oklahoma, and in rocks of similar age in Missouri, Tennessee, and west Texas (Howe, 1988); it differs from *P. rogata* in its much finer costellae, more prominent ventral carina and dorsal sulcus. *Paucicrura sila* and *P. eximia* described by Williams (1962) from Caradoc rocks of southern Scotland are considerably smaller (< 5 mm in length) than *P. rogata*, and have much coarser costellae.

Collections. Total 513 specimens. GSC loc. C-56085 (29 shells and valves); C-56101 (47 complete shells, 107 disarticulated valves); C-56106 (3 broken valves); C-60924 (40 shells and valves); C-78638 (26 complete shells, 31 valves); C-78640 (18 shells, 166 valves); C-205918 (17 immature specimens); C-205919 (1 fragment); C-205923 (21 shells and valves); C-205924 (7 shells and valves).

Family TRIPLESIIDAE Schuchert, 1913

Genus *Oxoplecia* Wilson, 1913

Type species. Oxoplecia calhouni Wilson, 1913. Lower Utica Formation, Trentonian, Ottawa, Ontario.

Oxoplecia globularis Cooper, 1956

Plate 3, figures 7–18

Oxoplecia globularis Cooper, 1956, p. 544, Pl. 106, figs. 6–11.

Type specimens. The holotype is from the basal Martinsburg Formation (Trenton), Virginia.

Description (Advance material). Shell medium-sized, maximum length and width not exceeding 20 mm, transversely subelliptical in outline, unequally biconvex with deeper dorsal valve; hingeline long, straight, attaining about three quarters of shell width; anterior commissure prominently uniplicate. Ventral umbo moderately convex, smooth, with apical angles near 90° or slightly wider; beak erect to suberect; interarea well delimited, 2.5–3.0 mm high in adult specimens, as wide as hingeline; delthyrium covered by flat deltidium, with apical foramen (Pl. 3, figs. 7, 8, 11, 14, 16, 17); sulcus beginning 4 to 5 mm from apex, becoming deeper and wider anteriorly, bearing three or five simple, rounded costae. Dorsal umbo bulbous, showing greater convexity than ventral umbo, also smooth, with small, incurved beak nearly appressed onto hingeline; dorsal interarea absent; fold low but well delimited, beginning about 4 mm from beak, with four costae. Each shell flank occupied by eight to ten rounded costae anterior of umbonal area, with occasional bifurcation or intercalation; growth lines very fine, about six to eight in 1 mm, not well preserved in some specimens (Pl. 3, fig. 9).

Dimensions (mm).

	L	W	T/D
Hypotype GSC 103739	14.0	17.0	10.8 (shell)
Hypotype GSC 103741	13.6	15.5	3.9 (vv)

Teeth of ventral valve slender, rod-like; dental plates short, thin, forming subtriangular dental cavities; muscle field poorly impressed. Sockets of dorsal valve suspended from hingeline; cardinal process bifurcated, consisting of two rod-like posteroventrally curved projections (Pl. 3, fig. 13); brachiophores not preserved; muscle scars not observed.

Remarks. Specimens from the Rocky Mountains are assigned to *O. globularis* on the basis of their smooth umbones, rounded costae, and deeper and more convex dorsal valve than ventral valve. The holotype has four costae in the sulcus and five on the fold (Cooper, 1956, Pl. 106B, figs. 6–9). In the Rocky Mountain material, the number of costae in the sulcus varies from three to five. In its posteriorly smooth shell and anteriorly rounded costae, *O. globularis* resembles *O. holstonensis* (Willard, 1928); *O. gibbosa* Cooper, 1956; *O. plicata* Cooper, 1956; and *O. subborealis* (Davidson, 1883). *Oxoplecia holstonensis* and *O. gibbosa* from Porterfield rocks of Virginia have faint costae covering only the anterior half of the shell. *Oxoplecia plicata* from the Red Knobs Formation (Porterfield) of Tennessee has fine costae or costellae, with fairly coarse growth lines. *Oxoplecia subborealis* from the Caradoc rocks of Girvan, Scotland has a relatively short hinge line and coarse, subangular costae (Williams, 1962). *Oxoplecia mansiensis* Andreeva, 1977 from the Shchugor beds (Caradoc) of the northern Ural Mountains (Andreeva, 1977) also has a posteriorly smooth shell, but differs from *O. globularis* in having much finer costae (up to ten in the sulcus).

Collections. Total 7 specimens. GSC loc. C-60924 (2 shells, 5 disjunct valves).

Order STROPHOMENIDA Öpik, 1934

Superfamily PLECTAMBONITOIDEA Jones, 1928

Family LEPTELLINIDAE Ulrich and Cooper, 1936

Subfamily PALAEOSTROPHOMENINAE Cocks and Rong, 1989

Genus *Glyptambonites* Cooper, 1956

Type species. Glyptambonites musculosus Cooper, 1956. Oranda Formation, Trenton, Virginia.

Glyptambonites musculosus Cooper, 1956

Plate 6, figures 1, 2.

Glyptambonites musculosus Cooper, 1956, p. 715, Pl. 171, fig. 15; Pl. 175, figs. 9-13; Pl. 176, figs. 1-5.
Glyptambonites musculosus Cooper; Williams, 1965, p. H373, figs. 239, 8a-c.
Glyptambonites musculosus Cooper; Cocks and Rong, 1989, p. 108, fig. 54.

Remarks. Only one ventral valve is present in the collections from the Advance Formation. It is virtually identical to the ventral valves of *G. musculosus* illustrated by Cooper from the Oranda Formation of Virginia. Its size is well within the range of dimensions measured for the type lot. As in the type specimens, the valve is somewhat semicircular in outline, weakly convex, with a long, straight hingeline as the maximum valve width, and slightly extended, ear-like cardinal extremities (Pl. 6, fig. 1); the interarea is high and wide, with a small delthyrium apically covered by a minute pseudodeltidium; the shell is unequally parvicostellate, with the major, coarser costellae being uniformly spaced, increasing by intercalation to reach an average of six in 5 mm at the anterior margin, and the minor, extremely fine costellae evenly distributed, about six to eight between every two major costellae; the growth lines are fine, well developed in the anterior half of the valve; oblique to concentric rugae are also present, but not as well preserved as in the type specimens. Internally, the ventral valve resembles the types in its long, slender diductor muscle scars bounded by sharp ridges; the small, ovoidal adductor scars are flanked but not enclosed completely by the diductor scars, thus forming a deep notch at the anterior margin of the muscle field (Pl. 6, fig. 2). Posterolateral areas are marked with oblique ridges and grooves, probably as vascula genitalia; vascular canals in the anterolateral part of the valve assume a dendroidal pattern.

Dimensions (mm).

	L	W	D
Hypotype GSC 103758	19.8	26.5	2.8 (vv)

Collection. GSC loc. C-78638 (1 ventral valve).

Family LEPTESTIIDAE Öpik, 1933

Genus *Leangella* Öpik, 1933

Subgenus *Leangella* (*Leangella*) Öpik, 1933

Type species. Plectambonites scissa var. *triangularis* Holtedahl, 1916. Solvik Formation, Llandovery, Norway.

Leangella (*Leangella*) *biseptata* n. sp.

Plate 6, figures 3-19; Plate 13, figures 13-17;
Figure 6

Type specimens. Nine types: holotype, GSC 103759, paratypes, GSC 103760, 103761 (complete shells), 103762, 109197 (dorsal valves), 103763, 109194, 109195, 109196 (ventral valves).

Type locality and type stratum. GSC loc. C-78638, Advance Mountain, northern Rocky Mountains, British Columbia. Advance Formation.

Diagnosis. Strongly concavoconvex shells of *Leangella,* with relatively large, anteriorly free bema bearing two median ridges, without supporting septa underneath; median septum supporting rod-like, dorsally arched process in ventral valve.

Description. Shell small, with average length 4.3 mm, width 7.6 mm, thickness 2.2 mm (Fig. 6), transversely subelliptical to alate in ventral view, strongly concavoconvex; hingeline long, straight, coinciding with maximum shell width; anterior commissure rectimarginate to weakly sulcate. Ventral umbo low, moderately to strongly convex, with extremely obtuse apical β-angle and minute beak; interarea well developed, as wide as hingeline, orthocline; small delthyrium covered apically by pseudodeltidium,

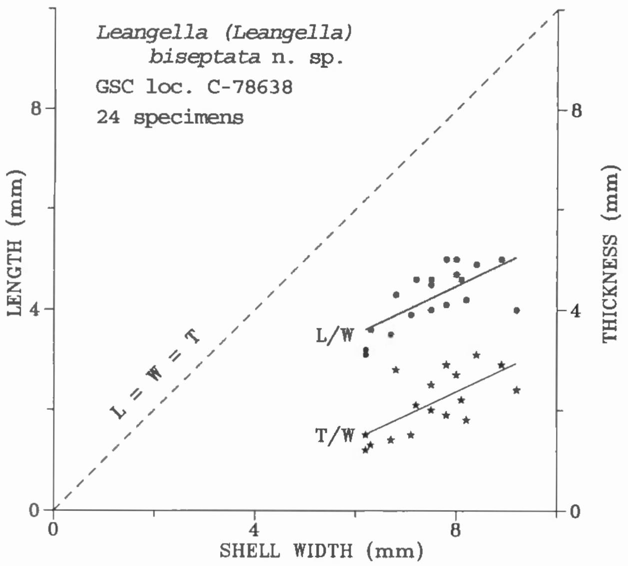

Figure 6. *Shell dimensions of* ***Leangella (Leangella) biseptata*** *n. sp. Sample from GSC loc. C-78638. The shells become less transverse (L/W ratios) and more convex (T/W ratios) during ontogeny. Note the wide range of variation in both L/W and T/W ratios.*

anteriorly open to accommodate cardinal process protruding from opposite valve; median area of valve more strongly convex than flanks but not forming carina; anterior and lateral margins curved smoothly to nearly perpendicular to dorsal direction. Dorsal umbo concave, conforming with general curvature of valve; beak barely distinguishable; interarea very low, as wide as hingeline, strongly apsacline to nearly catacline. Shell costellae rounded, sparsely spaced, five to seven on each valve; growth lines present near anterior margin but not well preserved.

Dental plates in ventral valve absent; teeth small, weak; muscle field well impressed, bearing median ridge, bounded anteriorly by raised edge; slender diductor scars diverging somewhat anterolaterally, flanking smaller, shorter adductor scars (Pl. 6, fig. 19); rod-like process originating immediately anterior of muscle field, extending anteriorly and arching dorsally, supported underneath by thin median septum (Pl. 13, figs. 13–16). Cardinal process in dorsal valve projecting posteroventrally from posterior margin of bema and hingeline, trilobate; brachiophores short, strongly divergent laterally, attached to posterolateral margins of bema; bema relatively large, extending anteriorly for over two thirds of valve length, bilobed in outline, with base elevated and free of valve floor for anterior two thirds (without median septum or septa supporting underneath), with upward curved margins and anterior margin well above valve floor (Pl. 6, fig. 18; Pl. 13, fig. 17); bemal disc carrying two median ridges on upper surface, together with an incipient one intercalating near anterior notch; peripheral rim (= platform of Cocks and Rong, 1989) well developed.

Remarks. The new species is most similar to *Leangella gibbosa* (Winchell and Schuchert, 1892) from the "Galena beds" (Stewartville Formation, Edenian), which may also have a bema bearing two median ridges; the bema in *L. gibbosa,* however, is usually much smaller relative to the valve size, and anteriorly connected to the valve floor by two septa. *Leangella gibbosa* was designated as the type species of *Diambonia* Cooper and Kindle, 1936, which was regarded by Cocks and Rong (1989) as a junior synonym of *Leangella. Leangella cylindrica* (Reed, 1917) reported by Harper (1989) from the Mill Formation (Pusgillian) of Girvan, Scotland shows similar shell shape and unequal parvicostellae; it differs from the new species in having a prominent ventral umbo. Internal structures of the Girvan species are not clearly known. *Diambonia discuneata* (Lamont, 1935) from the Lady Burn Formation (Rawtheyan) of Girvan has a bema bearing two median ridges, although the bema has a much smaller size (relative to valve size) than that of *L. biseptata* (see Harper, 1989, Pl. 18, fig. 9). Most other species of *Leangella* recognized by Cocks and Rong (1989) have a bema bearing a single median ridge and supported underneath by septa. The prominent, dorsally arched process in the ventral valve of the new species has not been observed in other congeneric species.

Collections. Total 85 specimens. GSC loc C-78638 (24 complete shells and disjunct valves); C-205919 (15 ventral valves); C-205921 (35 shells and valves); C-205922 (5 shells and valves); C-205923 (6 shells and valves).

Family CHRISTIANIIDAE Williams, 1953

Genus *Christiania* Hall and Clarke, 1892

Type species. Leptaena subquadrata Hall, 1883. Lower Porterfield, Tennessee.

Christiania subquadrata Hall, 1883

Plate 6, figures 20–30; Plate 7, figures 1–6;
Plate 13, figures 1–12

Leptaena subquadrata Hall, 1883, Pl. 46, figs. 32, 33.

Christiania subquadrata (Hall); Hall and Clarke, 1892, Pl. 15, figs. 32, 33; Pl. 15A, fig. 36; Pl. 20, figs. 18–20.

Christiania subquadrata (Hall); Hall and Clarke, 1895, p. 351, Pl. 6, figs. 13–18.
Christiania subquadrata (Hall); Schuchert, 1897, p. 181.
Christiania subquadrata (Hall); Cooper, 1956, p. 862, Pl. 214, figs. 6–39; Pl. 215, figs. 11, 12, 14–19; Pl. 221, figs. 7–15.
Christiania subquadrata (Hall); Williams, 1965, p. H391, figs. 251, 1a–e.
Christiania subquadrata (Hall); Nasedkina, 1973, p. 133, Pl. 23, figs. 19–21.
Christiania subquadrata (Hall); Liu et al., 1983, p. 277, Pl. 97, fig. 21.

Type specimens. Cooper (1956) stated that Hall and Clarke (1892) incorrectly listed the "Lower Helderberg Group, Perry County, Tennessee" as the type stratum and type locality. Hall's original specimens most likely came from the Arline Formation (lower Porterfield), near Friendsville, Tennessee, where *Christiania subquadrata* occurs in profusion.

Description (Advance material). Shell attains medium-size at adult stage, elongate, subquadrate, moderately concavoconvex; hingeline straight, slightly narrower than maximum shell width, with rectangular cardinal extremities at young stage becoming somewhat rounded at adult stage; anterior commissure nearly rectimarginate. Ventral umbo uniformly and moderately convex, with apical foramen opening to posteroventral direction in young specimens (Pl. 6, figs. 23, 28, 30); interarea well developed, steeply apsacline or nearly catacline; delthyrium covered by notably convex pseudodeltidium (Pl. 6, figs. 21, 30; Pl. 13, figs. 5, 6, 8); foramen apithyridid. Dorsal umbo with small, convex protegular node (Pl. 6, figs. 20, 25), anteriorly changing abruptly into depressed central area of valve; dorsal interarea absent. Entire shell devoid of radial ornaments; growth lines fine, well developed.

Dimensions (mm).

	L	W	T
Hypotype GSC 103767	14.2	10.4	— (dv)
Hypotype GSC 103768	12.4	8.0	— (dv)
Hypotype GSC 103764	6.5	5.5	1.9 (shell)
Hypotype GSC 103765	5.3	4.9	2.0 (shell)
Hypotype GSC 109188	15.6	10.5	6.2 (shell)
Hypotype GSC 109191	15.3	10.0	5.9 (shell)
Hypotype GSC 109189	13.0	10.6	4.1* (dv)
Hypotype GSC 109190	13.2	11.0	5.0* (dv)

* thickness including trans-muscle septa

Interior of ventral valve: small, posteriorly located muscle field and long grooves to incorporate trans-muscle septa of opposite valve (Pl. 13, figs. 8, 10); diductor or adductor muscle scars are poorly delimited. Interior of dorsal valve: slender socket ridges diverging laterally, nearly parallel to hingeline; cardinal process small, bilobate (Pl. 6, fig. 30; Pl. 13, figs. 11, 12); four major longitudinal (trans-muscle) septa, two on each side forming tight, U-shaped loop and posteriorly connected and capped by elevated adductor platforms (with cavities underneath); median septum thin and weak in small shells, extremely variable in larger shells from weakly developed (Pl. 13, figs. 4, 11) to nearly as strong as lateral septa (Pl. 7, figs. 4, 6; Pl. 13, fig. 3); adductor scars bearing oblique ridges and grooves (Pl. 7, figs. 4, 5; Pl. 13, fig. 11).

Remarks. Both Cooper (1956) and Williams (1962) stated that some species of *Christiania* may have extremely fine radial striae or costellae (6–8 in 1 mm) on the shell surface. In the silicified specimens of *C. subquadrata* from Tennessee and the Rocky Mountains, however, no such fine surface ornaments have been found.

As noted by Cooper (1956), *C. subquadrata* shows a wide range of variation in external morphology. Large shells tend to be much more pronouncedly elongate than small ones, mainly due to accelerated longitudinal growth at late growth stages. This is true also for the Caradoc species of *Christiania* from Scotland (Williams, 1962). Young shells of *C. subquadrata* have angular, ear-like cardinal extremities, whereas some adult shells have rounded ones. In the Advance specimens, the median septum in the dorsal valve is generally better developed than in those from Tennessee, although it is quite variable within specimens at both young and adult growth stages, from faint in some immature or mature shells to prominent in others (Pl. 7, figs. 2, 4, 6; Pl. 13, figs. 3, 4, 11). *Christiania subquadrata* from the Cherdyn horizon (lower Caradoc) of the central Ural Mountains has a shell outline and proportions (length/width ratio 1.3–1.6) similar to the North American materials, although Nasedkina (1973) mentioned forms being wider than those from North America and Vaygach and Pay-Khoya.

The new genus and new species *Christianella zhitangensis* proposed by Liang (*in* Liu et al., 1983), based on specimens from the Upper Caradoc Tangtou Formation of Anhui, South China, has the same external morphology as *Christiania*. Liang distinguished the new genus from *Christiania* by its peripheral rim in the ventral valve. As shown by Cooper (1956), however, *Christiania* has complex and highly variable ridges in the ventral valve. The Chinese materials of *Christianella* do not have well preserved internal structures, and may be synonymous with *Christiania.*

Collections. Total 66 specimens. GSC loc. C-78638 (25 specimens, mostly complete, immature shells and fragmentary adult dorsal valves); C-205920 (3 fragments); C-205922 (38 shells and fragments).

Family BIMURIIDAE Cooper, 1956

Genus *Bimuria* Ulrich and Cooper, 1942

Type species. Bimuria superba Ulrich and Cooper, 1942. Arline Formation, lower Porterfield, Tennessee.

Bimuria cf. *B. superba* Ulrich and Cooper, 1942

Plate 7, figures 7–18

Bimuria superba Ulrich and Cooper, 1942, p. 623, Pl. 90, figs. 13–18.

Christiania cf. *C. lamellosa* Butts 1942 (*non* Bassler, 1919), p. 42, Pl. 73, figs. 34–36.

Bimuria superba Ulrich and Cooper; Cooper, 1956, p. 771, Pl. 184, fig. 5; Pl. 210, figs. 5, 15, 16, 33, 34; Pl. 211, figs. 14–25.

Bimuria superba Ulrich and Cooper; Williams, 1965, p. H383, figs. 245, 2a–d.

Bimuria superba Ulrich and Cooper; Cocks and Rong, 1989, p. 100, figs. 46, 47.

Type specimens. The holotype and paratypes illustrated by Ulrich and Cooper (1942) were cited as being from the Strasburg Formation but subsequently determined by Cooper (1956) as being from the Arline Formation, near Friendsville, Tennessee.

Description (Advance material). Shell medium-sized, subsemicircular in dorsal view, strongly concavo-convex, transversely extended; hingeline straight, coinciding with maximum shell width; anterior margin rectimarginate. Ventral umbo strongly convex, rounded, with strongly incurved beak appressed onto hingeline; interarea low, about 1 mm in height, orthocline to anacline; delthyrium obscured by incurved beak; fold or sulcus absent, but median portion of valve showing greater convexity than flanks. Dorsal umbo and posteromedial part of valve strongly depressed; posterolateral parts almost flattened; interarea of same height and width as ventral interarea, catacline to weakly hypercline. Entire shell devoid of radial ornaments; umbonal portions covered by fine growth lines; anterior and lateral portions with frill-like, spiny comae (Pl. 7, figs. 7, 9, 15).

Dimensions (mm).

	L	W	T
Hypotype GSC 103769	11.3	13.8	4.7 (shell)
Hypotype GSC 103770	10.4	14.1	4.3 (shell)
Hypotype GSC 103771	11.2	14.0	4.4 (vv)

Interior of ventral valve devoid of dental plates; teeth thin, platy; muscle field poorly impressed in the only ventral valve in collection. Bema in dorsal valve elongate, oval with longitudinal striations, divided into two halves by sharp marginal ridges; median septum thin, well developed in posterior part of valve (Pl. 7, figs. 17); socket ridges strongly divergent laterally (Pl. 7, fig. 18); cardinal process not preserved due to breakage of beak area; brachiophores not observed.

Remarks. Specimens of *Bimuria* cf. *B. superba* from the Advance Formation resemble those from the Arline Formation of Tennessee in their elongate, suboval bema, thin median septum, and lack of fold and sulcus. The type specimens are relatively large (the holotype being 19.7 mm long, 22.2 mm wide, and 8.5 mm thick) and, as shown by their growth lines, tend to be strongly transverse at their early growth stages but become subquadrate at late stages. Shells from the Advance Formation are similar to the types at their younger stages in being transversely extended. Each lobe of the bema in *B. superba* shown by Cooper (1956) has a rounded anterior end. In the Advance collection, only two disarticulated dorsal valves are available for comparison. Unfortunately, one of them shows a bema with broken anterior ends (Pl. 7, fig. 18), which seem to be rounded; in the other valve, the thickened layer of the bema is peeled off at the anterior lateral margins of the bema, giving the anterior ends a pointed appearance. Both valves have incomplete posterior and anterior margins, and it is difficult to make detailed statistical calculations and comparisons as in Potter (1990, 1991). Cooper (1956, Pl. 211, figs. 14, 15, 17, 18) showed the presence of a well developed cardinal process in *B. superba.* Unfortunately, the apices of two disarticulated dorsal valves available in the Advance collection are broken, yielding no information about the cardinal process.

Bimuria superba is most similar to *B. buttsi* Cooper, 1956 and *B. lamellosa* (Bassler, 1919) in shell size and outline. *Bimuria lamellosa* from the Oranda Formation of Virginia may have faint radial costellae (Bassler, 1919, Pl. 49, fig. 4) and a wide bema (Cooper, 1956, Pl. 212, figs. 3, 4, 10). *Bimuria buttsi* from the Little Oak Formation of Alabama generally has a subrhomboidal bema, with a strong median septum. Potter (1990) recently reported three species, *Bimuria californiensis, B.* sp. 1 and *B.* sp. 2, from Llandeilo–

Ashgill beds of northern California and distinguished these from *B. superba* by their commonly developed fold and sulcus. *Bimuria gilbertella* (Potter, 1991) from Llandeilo-Caradoc rocks of west-central Alaska differs from other congeneric species in having an exterior dorsal median ridge and a ventral median depression. The Scottish species, *B. youngiana* (Davidson, 1870) as emended by Williams (1962), differs from North American species in having a prominent median fold developed in the anterior half of the ventral valve, thus giving the shell a sulcate anterior commissure.

Collections. GSC loc. C-78638 (2 complete shells, 3 disjunct valves).

Family SOWERBYELLIDAE Öpik, 1930

Genus *Thaerodonta* Wang, 1949

Remarks. Cocks and Rong (1989) listed *Thaerodonta* as a junior synonym of *Sowerbyella (Eochonetes)* Reed, 1917 on the basis that both genera have hinge denticles in the dorsal valve and corresponding hinge fossettes in the ventral valve. Previously, *Eochonetes* was distinguished from other sowerbyellids in having a ventral hingeline perforated by oblique canals. Cocks and Rong regarded these canals as insignificant taxonomic characters at the generic or subgeneric levels because they have been found only in about half the *Eochonetes* populations. The presence of hinge denticulations (dorsal denticles and ventral fossettes) has been regarded by Howe (1972, p. 440) as a diagnostic feature for *Thaerodonta*, although, as will be discussed below, denticulations do not occur in all members of the genus, contrary to Howe's (1972, p. 443) statement that "regardless of age, shape, size, variation, or species, . . . each ventral valve of *Thaerodonta* bears fossettes and each dorsal valve displays the corresponding denticles". *Thaerodonta* has been widely used in North American literature and, following Potter and Boucot (1992), is retained herein.

Thaerodonta redstonensis
(Mitchell and Sweet, 1989)

Plate 8, figures 1-19; Plate 9, figures 1-13;
Figure 7

Sowerbyella redstonensis Mitchell and Sweet, 1989, p. 83, Pl. 1, figs. 1-20.

Type specimens. The types came from the lower Whittaker Formation, Edenian, Mackenzie Mountains, Northwest Territories.

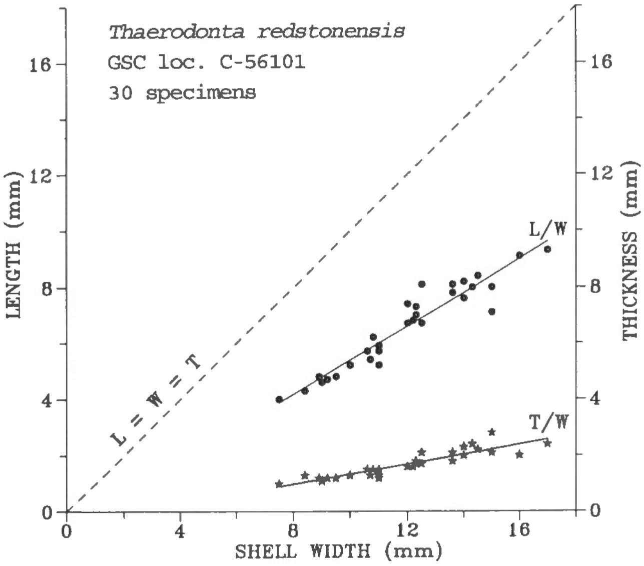

Figure 7. *Shell dimensions of* ***Thaerodonta redstonensis*** *(Mitchell and Sweet, 1989). Sample from GSC loc. C-56101. Both L/W and T/W ratios decrease slightly during ontogeny.*

Description (Advance material). Shell generally small, with average length 6.6 mm, width 12.0 mm, thickness 1.7 mm (Fig. 7), semielliptical in dorsal view, weakly to moderately concavoconvex in profile; hingeline straight, long, usually representing maximum shell width; anterior commissure commonly rectimarginate, rarely wavy (weakly and broadly sulcate or uniplicate). Ventral umbo flat to slightly convex, barely extending beyond hingeline; beak obsolete; fold or sulcus absent; interarea low, nearly as wide as hingeline, apsacline; delthyrium mostly open, with apical part lined by minute, marginal pseudodeltidium. Dorsal umbo depressed; interarea somewhat lower than ventral interarea, nearly catacline. Shell unequally parvicostellate, with costellae averaging 1 in 1 mm at anterior margin and five to seven extremely fine capillae between two adjacent costellae. Growth lines fine, punctuated by coarser growth lamellae near anterior margin.

Inner surface of both valves marked with numerous tubercles. Dental plates in ventral valve reduced to low ridges or absent; teeth slender, with well developed fossettes on their inner surfaces; accessory teeth generally absent, observed only in a small number of relatively large valves (Pl. 8, figs. 2, 3); four to seven hinge fossettes developed toward lateral portion of hingeline; pedicle callist undercut by small cavity, divided completely or partly by median septum (Pl. 8, figs. 3, 4, 7, 10, 12); muscle field bounded laterally by low ridges but not delimited clearly anteriorly; elongate, laterally divergent diductor scars divided by median septum forking anteriorly into two low ridges.

Dorsal interior: hinge denticles corresponding to fossettes of opposite valve; sockets and socket ridges narrow, slender, strongly divergent laterally; brachiophores short, pointed, attached to socket ridges (Pl. 8, figs. 18, 19; Pl. 9, figs. 2, 4); cardinal process trilobate, undercut by small cavity (Pl. 8, figs. 15, 17; Pl. 9, figs. 2–4); two central side septa originating from cavity underneath cardinal process, slightly diverging from each other anteriorly, dividing bema into two lobes, each with fine, longitudinal striations but rarely with well developed lateral septa; median septum generally absent, but developed in a few specimens as a low ridge (Pl. 8, figs. 18, 19).

Remarks. The species was established by Mitchell and Sweet (1989) based on specimens from the Mackenzie Mountains and assigned to *Sowerbyella* on the basis of its lacking accessory teeth and sockets. Howe (1972) listed two characteristics to distinguish *Thaerodonta* from *Sowerbyella*: presence of ventral hinge fossettes and dorsal denticles, and presence of accessory ventral hinge teeth and dorsal sockets, and stated that *Sowerbyella* did not have these articulating structures. The species described by Mitchell and Sweet poses a problem to Howe's criteria because it is intermediate between the two genera by having hinge denticles but lacking accessory teeth. Howe (1972) probably regarded hinge denticles more important than accessory teeth for *Thaerodonta* because, in the abstract of his paper, he stressed that ventral fossettes and dorsal denticles form a conclusive test for distinguishing the genus from *Sowerbyella* but did not mention the accessory teeth.

Specimens of *Thaerodonta redstonensis* from the Advance Formation resemble those from the Mackenzie Mountains in their bilobed bema with poorly developed lateral septa on its top and lateral margins, and in the weakly developed or absent median septum in the dorsal valve. Although Mitchell and Sweet (1989) stated the general presence of a dorsal median septum and lateral trans-muscle septa, five out the seven dorsal valves illustrated by them lack a median septum, and only one shows well elevated lateral septa (Mitchell and Sweet, 1989, Pl. 1, fig. 1). Other species of *Thaerodonta* similar to *T. redstonensis*, such as *T. recedens* (Sardeson, 1892); *T. saxea* (Sardeson, 1892); *T. clarksvillensis* (Foerste, 1924); *T. aspera* Wang, 1949; *T. digitata* Wang, 1949; and *T. magna* Howe, 1965, commonly have one or two lateral septa on each lobe of the bema (see Howe, 1979, 1988).

Specimens of *T. redstonensis* from the Mackenzie Mountains show some minor differences from the Advance materials: better differentiated unequal parvicostellae with stronger costellae, total lack of accessory teeth, and stronger lateral septa in some valves. In the Advance collections, ventral accessory teeth and dorsal lateral septa are observed in less than two per cent of the specimens.

Collections. Total 356 specimens. GSC loc. C-56085 (9 fragments); C-56101 (45 complete shells, 218 disjunct valves); C-78640 (72 specimens, mostly disjunct valves); C-205918 (10 fragments); C-205922 (1 ventral and 1 dorsal valve).

Genus *Eoplectodonta* Kozlowski, 1929

Subgenus *Eoplectodonta* (*Eoplectodonta*) Kozlowski, 1929

Type species. Sowerbyella precursor Jones, 1928 (= *Leptaena duplicata* J. de C. Sowerby, 1839; see Cocks and Rong, 1989), lower Llandovery, Wales.

Eoplectodonta (*Eoplectodonta*) *alternata* (Butts, 1942)

Plate 9, figures 14–27; Plate 10, figures 1–5

Sowerbyella alternata Butts, 1942, p. 109, Pl. 95, figs. 22, 23.
Sowerbyella sp. Butts, 1942, p. 109, Pl. 95, figs. 20, 21.
Eoplectodonta alternata (Butts); Cooper, 1956, p. 808, Pl. 184, figs. 1–3; Pl. 207, figs. 2–25; Pl. 208, figs. 1–18; Pl. 269, figs. 23–24.

Type specimens. The lectotype, selected by Cooper (1956), came from the Oranda Formation (Trentonian), Virginia. Butts (1942) listed the type locality as the Chambersburg Formation, but the name is no longer used in Virginia.

Description (Advance material). Shell usually medium-sized, rarely large, semicircular to subquadrate, moderately concavoconvex; hingeline straight, with ear-like cardinal extremities; prominent, oblique rugae developed in posterolateral areas of both valves in majority of specimens (Pl. 9, figs. 14, 15, 18, 19, 22); anterior commissure rectimarginate to wavy (sulcate). Ventral umbo low, rounded, moderately convex, raised slightly above hingeline, with inconspicuous beak; interarea well developed, orthocline; small delthyrium mostly open, covered only apically by minute pseudodeltidium (Pl. 9, figs. 23, 26); greatest convexity of valve located in central portion, sloping into flattened posterolateral areas; fold or sulcus absent, except for two or three gentle, radial undulations in some specimens (Pl. 9, fig. 22). Dorsal valve most concave in central area, with shallow median depression resembling sulcus; interarea also well developed, lower than ventral interarea, catacline. Entire shell unequally parvicostellate, with six to eight fine capillae between every two major costellae; growth lines not clearly visible, but coarse, irregular growth interruptions present.

Dimensions (mm).

	L	W	T/D
GSC loc. C-60924 (non-type)	13.0	22.2	3.3 (shell)
GSC loc. C-78638 (non-types)	12.8	19.6	4.3 (shell)
	12.7	22.8	4.1 (vv)

Entire inner surfaces of both valves marked by tubercles. Dental plates in ventral valve absent; teeth small, weak; hinge denticles confined to each side of cardinal area, varying in number from six to eight, absent in lateral portions of hingeline (Pl. 9, figs. 23, 24, 26, 27; Pl. 10, figs. 1, 2); pedicle callist undercut by two small cavities separated by median septum (Pl. 9, figs. 23, 24, 27; Pl. 10, figs. 1–2); Muscle field flabellate in outline, delimited laterally by ridges and divided by bifurcating median ridge, without clearly defined anterior boundary; diductor scars elongate, diverging laterally from each other, flanking small, slender adductor scars. Hinge sockets and socket ridges narrow, delicate, strongly diverging laterally; hinge fossettes circular, corresponding to denticles of ventral valve (Pl. 10, figs. 4, 5); brachiophores short, pointed (Pl. 10, figs. 3, 5); cardinal process trilobate, capping relatively deep cavity (Pl. 10, figs. 4, 5); two ridges, nearly parallel to hingeline, originating from cardinal cavity, merging onto thick median septum at about 1 mm anterior of hingeline; bema not clearly raised above valve floor, subcircular to elongate-oval in outline, divided into two halves by two strong central side septa (being highest and thickest anterior of their mid-length in some specimens), and bearing one side septum on each lobe (Pl. 10, figs. 3–5).

Remarks. In external morphology, specimens of *E. alternata* from the Advance Formation are identical to those illustrated by Cooper (1956) from the Oranda Formation, particularly in shell size, outline, and posterolateral rugae. The anteriorly swollen median septa and central side septa are common to specimens of both regions. Some of the Oranda specimens seem to have a greater number of ventral denticles and dorsal fossettes than the Rocky Mountains forms, but it is obvious that these hinge features are confined to, or better developed in, the cardinal portions of the hingeline. As indicated by Cooper (1956), the posterolateral rugae in *E. alternata* and other congeneric species of Ordovician age are fairly consistent, although similar rugae may be developed sporadically in many other sowerbyellid genera.

Most specimens of *E. alternata* from the Advance Formation are broken, with only a few complete valves and entire, immature shells. In comparison, specimens of *Thaerodonta redstonensis,* which shows a certain degree of homeomorphy to *E. alternata,* are preserved generally as complete shells or valves.

Collections. Total 141 specimens. GSC loc. C-56101 (4 broken valves); C-56106 (32 specimens, mostly damaged valves); C-60924 (20, mostly damaged valves); C-78638 (20 mostly damaged valves); C-205918 (3 fragments); C-205921 (20 shells and valves); C-205922 (2 ventral valves); C-205923 (30 shells and valves); C-205924 (10 shells and valves).

Superfamily STROPHOMENOIDEA King, 1846

Family STROPHOMENIDAE King, 1846

Subfamily STROPHOMENINAE King, 1846

Genus *Strophomena* de Blainville, 1825

Type species. Leptaena planumbona Hall, 1847. Hudson River Group, Cincinnati, Ohio. Cocks (1990) proposed *L. planumbona* as the type species to replace the poorly known *Strophomena rugosa* de Blainville, 1825, which is probably conspecific with *L. planumbona.* This porposal was formalized by ICZN Opinion 1671 (1992), and *S. rugosa* was thereby suppressed (for further discussion, see Rong and Cocks, 1994).

Strophomena cf. *S. planumbona* (Hall, 1847)

Plate 11, figures 12–18

Leptaena planumbona Hall, 1847, p. 112, Pl. 31B, figs. 4a–e.

Strophomena planumbona (Hall); Hall, 1859, p. 54, fig. 7.

Strophomena planumbona (Hall); Meek, 1873, p. 79, Pl. 6, figs. 3a–h.

Strophomena planumbona (Hall); Hall and Clarke, 1892, Pl. 9, figs. 15–17; Pl. 9A, figs. 8, 9.

Strophomena planumbona (Hall); Foerste, 1912, p. 73, Pl. 4, figs. 3a, b; Pl. 8, figs. 1a–e; Pl. 9, figs. 3a, b.

Strophomena planumbona (Hall); Cooper, 1944, p. 337, Pl. 130, figs. 21–24.

Strophomena planumbona (Hall); Wang, 1949, p. 23, Pl. 6D, figs. 1–7.

Strophomena planumbona (Hall); Caster, Dalvé, and Pope, 1961, Pl. 8, figs. 8–11.

Strophomena planumbona (Hall); Alberstadt, 1973, p. 45, Pl. 5, figs. 13, 14.

Strophomena planumbona (Hall); Howe, 1988, p. 216, figs. 6.30, 6.31.

Strophomena planumbona (Hall); Rong and Cocks, 1994, p. 677, Pl. 1, figs. 1–7, 9–11.

Type specimens. Lectotype, AMNH30247 (American Museum of Natural History), selected by Rong and Cocks (1994), is from the Hudson River Group, Cincinnati, Ohio.

Remarks. Specimens from the Advance Formation are compared to *S. planumbona* on the basis of two ventral valves and three fragments of dorsal valves. The ventral valves are typically resupinate, weakly geniculate, covered by very fine, unequal parvicostellae. The delthyrium is covered apically by a small, weakly convex pseudodeltidium and is open anteriorly. As in the specimens from the American mid-continent, the ventral muscle field is relatively small, subrhomboidal or subcircular, bearing a strong median ridge and a prominent groove on each side near the lateral margin (Pl. 11, figs. 16, 18). The Rocky Mountain forms deviate from the typical American specimens in that the ventral muscle field in some specimens is bounded anteriorly by a raised, concentric, banded platform. The ventral valves are less quadrate than the types. One of the broken dorsal valves shows a well developed chilidium, located posterior to the bilobate cardinal process (each lobe bearing two ridges on its crest), and another bears a long median septum and two trans-muscle septa on each side (Pl. 11, figs. 14).

Collections. GSC loc. C-56101 (2 ventral valves, 2 fragments of dorsal valves); C-60924 (1 ventral valve, 1 dorsal valve fragment).

Subfamily RAFINESQUINAE Schuchert, 1893

Genus *Rafinesquina* Hall and Clarke, 1892

Type species. Leptaena alternata Conrad, 1838 (superseding name *Leptaena trentonensis* Conrad, 1838; see Salmon, 1942 for explanation). Trenton rocks of New York.

Rafinesquina praecursor (Raymond, 1921)

Plate 10, figures 6–16; Plate 11, figures 1, 2.

Rafinesquina praecursor Raymond, 1921, p. 22, Pl. 7, fig. 5.

Rafinesquina praecursor (Raymond); Salmon, 1942, p. 582, Pl. 86, figs. 14, 15.

Rafinesquina praecursor (Raymond); Wilson, 1946, p. 74, Pl. 5, fig. 15.

Type specimens. The holotype, illustrated by Raymond, 1921 and by Wilson, 1946, came from middle Trentonian beds, Trenton, Ontario.

Description (Advance material). Shell medium-sized to relatively large, transversely extended, semicircular to subquadrate with ear-like cardinal extremities, moderately concavoconvex; hingeline straight, coinciding with greatest shell width; anterior commissure rectimarginate or broadly wavy. Ventral umbo weakly convex, with minute beak barely raised above hingeline; interarea well developed, weakly apsacline; delthyrium mostly open, covered only apically by small pseudodeltidium; posterolateral areas flattened; geniculation rounded (120–150°), beginning 14 to 18 mm anterior of ventral apex, without forming sharp geniculating ridge. Dorsal valve slightly concave in umbonal area, becoming flattened in central and posterolateral portions; interarea narrower than that of ventral valve, orthocline to slightly apsacline; geniculation corresponding to that of opposite valve. Entire shell covered by fine, unequal parvicostellae, with major ones evenly spaced (Pl. 10, fig. 6); thickened median costellae and posterolateral rugae uncommonly developed in ventral valves; growth lines poorly preserved.

Dimensions (mm).

	L	W	T/D
GSC loc. C-56101	19.5	22.8	6.2 (shell)
(nontypes)	15.8	24.3	5.8 (shell)
	15.0	21.3	4.0 (vv)
	18.5	23.4	4.6 (dv)
	16.0	21.2	3.1 (dv)
	17.0	24.4	— (dv)

Shell densely pseudopunctate, as shown by fine pits in coarsely silicified specimens (Pl. 10, figs. 8, 11). Dental plates absent in large forms, present but reduced in small forms; teeth small; muscle field oval to flabellate in outline, extending for about one third of valve length; rounded median ridge developed in apical part of muscle field, bifurcating anteriorly; each diductor scar usually bearing one prominent longitudinal ridge and minor striae; adductor scars small, slender (Pl. 11, figs. 1, 2). Socket ridges in dorsal valve short, slender; cardinal process consisting of two lobes, each with flat crest; chilidium small, concave medially (Pl. 10, figs. 15, 16); low notothyrial platform developing into broad median ridge, then becoming thin ridge to about mid-length of valve; adductor muscle scars well impressed posteriorly, poorly delimited anteriorly, marked by minor longitudinal ridges (Pl. 10, figs. 13–16).

Remarks. Specimens from the Advance Formation are assigned to *Rafinesquina* rather than *Megamyonia* because of their relatively small, striated, ventral muscle field extending for about one third of valve length. *Megamyonia* typically has an exceedingly large ventral muscle field, extending beyond mid-length and nearly to anterior margin of the valve (Wang, 1949). The shells from the Rocky Mountains are identified with *R. praecursor* on the basis of their medium to large size, semicircular outline with slightly extended cardinal extremities, and moderate, rounded geniculation (without sharply defined geniculating ridge). All these specimens are coarsely silicified and thus show little details of costellae and posterolateral rugae. The thickened median costella is obvious in the specimen of *R. praecursor* illustrated by Salmon (1942), but not so in the holotype shown by Raymond (1921) and Wilson (1946). A few relatively small specimens from the Advance Formation show short, posterolateral rugae and a slightly inflated median costa in the ventral valve.

Collections. Total 54 specimens. GSC loc. C-56101 (6 conjoined shells, 40 disjunct valves and fragments); C-78640 (7 broken shells, valves and fragments); C-205923 (1 shell).

Subfamily FURCITELLINAE Williams, 1965

Genus *Murinella* Cooper, 1956

Type species. Murinella partita Cooper, 1956. Bromide Formation, Mountain Lake Member, lower Porterfield, Oklahoma.

Murinella cf. *M. biconvexa* Cooper, 1956

Plate 11, figures 5–11

Murinella biconvexa Cooper, 1956, p. 845, Pl. 227, figs. 8–16.

Type specimens. Cooper's types came from the Hogskin Member (upper Lincolnshire Formation) of Tennessee. The Hogskin Member belongs to Cooper's Ashby Stage, which was dated by Bergström et al. (1988) as lower Mohawkian.

Remarks. Only two specimens are found in collections from the Advance Formation, one articulated shell and one dorsal valve, and both are damaged (Pl. 11, figs. 5–11). In external morphology, these specimens are virtually identical to *M. biconvexa* from Tennessee in that the shell is biconvex with a relatively low convexity, with fairly coarse, unequal parvicostellae, a fairly high, apsacline ventral interarea and convex deltidium. As typically in *Murinella,* the socket floor is fairly wide, bounded anteriorly by a curved ridge; the cardinal process is bilobate, with each lobe differentiated into two ridges on its crest. In the Rocky Mountain collections, no interiors of free ventral valves are available for study. The Advance specimens are tentatively compared to *M. biconvexa* because of limitation in their preservation and lack of information on the internal structures of the types described by Cooper (1956). Of the two Advance specimens, the shell with conjoined valves has somewhat better differentiated unequal parvicostellae than the disarticulated dorsal valve; but more specimens are needed to determine the range of variation in this character.

Murinella biconvexa differs from other congeneric species described by Cooper (1956) in its uniform convexity of both ventral and dorsal valves.

Dimensions (mm).

	L	W	T
Hypotype GSC 103798	11.8	15.0	3.5 (shell)

Collection. GSC loc. C-78638 (1 shell, 1 dorsal valve, both damaged).

Subfamily OEPIKINAE Sokolskaya, 1960

Genus *Oepikina* Salmon, 1942

Type species. Oepikina septata Salmon, 1942. Lebanon Formation, late Blackriveran to earliest Trentonian, Tennessee.

Oepikina sp.

Plate 11, figures 3, 4

Remarks. Only two fragments of dorsal valves are present in the collections from the Advance Formation. These show a certain similarity to *Oepikina septata* in having a long, strong median septum and lateral trans-muscle septa extending to near the anterior margin, and a well developed peripheral rim. They differ from *O. septata* externally in having finer costellae of two sizes, with the major ones more widely spaced. The cardinal area is not preserved and it is thus difficult to identify the specimens to species level.

Collection. GSC loc. C-60924 (2 broken dorsal valves).

Order PENTAMERIDA
Schuchert and Cooper, 1931

Family PARASTROPHINIDAE
Ulrich and Cooper, 1938

Genus *Parastrophina* Schuchert and LeVene, 1929

Type species. Atrypa hemiplicata Hall, 1847. Basal Trenton Limestone, Waterton, New York.

Parastrophina sp.

Plate 13, figure 23

Remarks. The single small specimen is an incomplete ventral valve that is assigned to *Parastrophina* because of its smooth posterior and relatively wide spondylium, which is sessile posteriorly and supported anteriorly by a low median septum. The spondylium is also similar to that of *Camerella* Billings, 1859, but the ventral umbo and beak are not so strongly arched as in *Camerella*. The Advance specimen has an umbo and palintrope that are directed posteriorly. More specimens are needed for more detailed identification, especially the dorsal interior to show the presence of alate plates.

Collection. GSC loc. C-205919 (1 ventral valve).

Order RHYNCHONELLIDA Kuhn, 1949

Family RHYNCHOTREMATIDAE Schuchert, 1913

Genus *Hiscobeccus* Amsden, 1983

Type species. Atrypa capax Conrad, 1842. Maysvillian, Richmond, Indiana (precise strata for neotype unknown, Amsden, 1983).

Hiscobeccus mackenziensis Jin and Lenz, 1992

Plate 12, figures 1-18; Figure 8

Hiscobeccus mackenziensis Jin and Lenz, 1992, p. 148, Pl. 10, figs. 1-20.

Type specimens. The types came from the lower Whittaker Formation, Edenian to lower Maysvillian, central Mackenzie Mountains, Northwest Territories.

Description (Advance material). Shell small to medium-sized, with average length 8.8 mm, width 8.9 mm, thickness 5.3 mm (Fig. 8), subelliptical to subtriangular, biconvex, with slightly deeper dorsal valve; hingeline short, curved, attaining less than one third of shell width; anterior commissure uniplicate. Ventral umbo moderately convex, narrow, with apical angle about 90°; beak pointed, suberect to slightly incurved; delthyrium open; sulcus rather narrow, beginning 4 to 5 mm from apex, bearing three (rarely four) simple, subrounded costae. Dorsal umbo generally of low convexity, marked by shallow median depression; fold well delimited in anterior half of

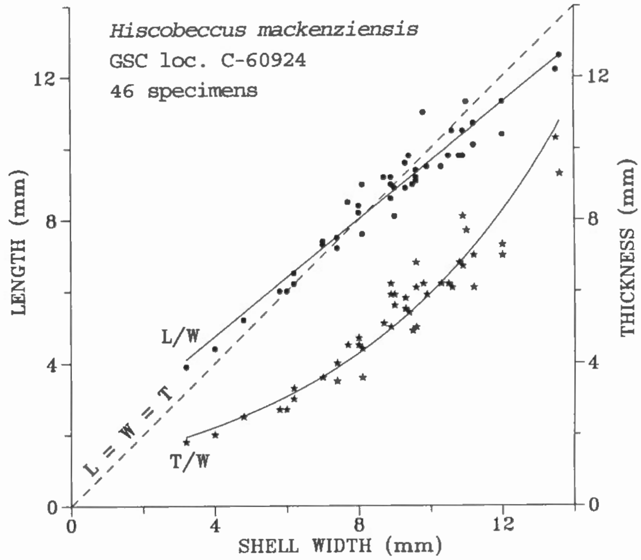

Figure 8. *Shell dimensions of* ***Hiscobeccus mackenziensis*** *Jin and Lenz, 1992. Sample from GSC loc. C-60924. Note that the average shells change from slightly elongate to transverse (T/W ratios) and from weakly convex to strongly convex (T/W ratios) during ontogeny.*

valve, carrying four (rarely five) costae. Each shell flank occupied by six or seven major, simple, subrounded costae; growth lamellae relatively fine, regularly spaced, absent or weakly developed in posterior portions of both valves.

Dental plates well developed, thin, forming narrow dental cavities (Pl. 12, fig. 17); teeth small, slender; muscle field poorly impressed. Septalium small, shallow; hinge plates narrow, triangular, strongly divergent from each other; cardinal process thin, septiform; median septum low, extending for about one third of valve length; crura radulifer.

Remarks. Specimens of *Hiscobeccus mackenziensis* from the Advance Formation are slightly larger on the average than those from the Mackenzie Mountains and show rapid increase in shell thickness (T/W ratios) at later growth stages (Fig. 8). The species shows some degree of similarity to *Rhynchotrema wisconsinense* (Sardeson, 1892) in having growth lamellae best developed in the anterior part of the shell. The concentric growth structures in *R. wisconsinense* are intermediate between growth lines and growth lamellae and present only in the anterior one third of the shell (see Jin and Lenz, 1992, Pl. 4, figs. 14-18). *Hiscobeccus mackenziensis* and *R. wisconsinense* may therefore be regarded as intermediate in form between *Hiscobeccus* and *Rhynchotrema,* both of which lack deltidial plates.

Collections. Total 203 specimens. GSC loc. C-56085 (3 immature shells, 3 broken shells and valves); C-56101 (43, mostly complete shells); C-60924 (100, mostly complete shells, some disjunct valves); C-78638 (2 shells); C-205922 (10 broken shells and fragments); C-205923 (14 shells and valves); C-205924 (28 shells and valves).

Order ATRYPIDA Rzhonsnitskaya, 1960

Family ZYGOSPIRIDAE Waagen, 1883

Genus *Anazyga* Davidson, 1882

Type species. Atrypa recurvirostra Hall, 1847. Middle Trenton Limestone, Martinsburg, New York (see Copper, 1977).

Anazyga bellicostata n. sp.

Plate 12, figures 19-27; Figure 9

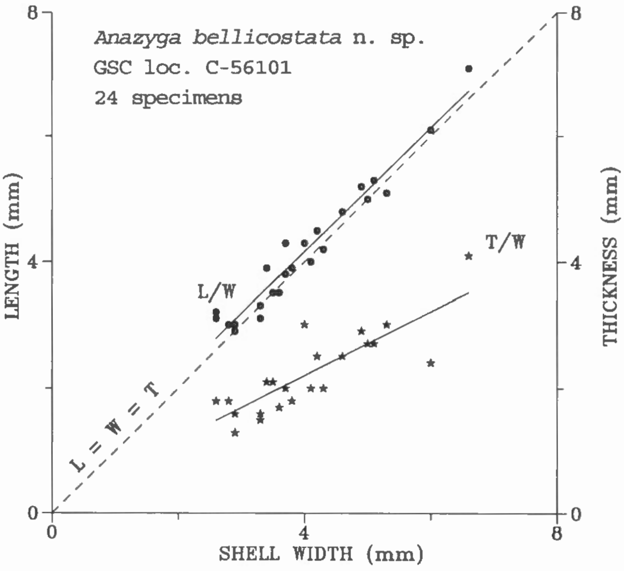

Figure 9. *Shell dimensions of* ***Anazyga bellicostata*** *n. sp. Sample from GSC loc. C-56101. Note the variation and slight decrease in shell convexity during ontogeny.*

Type specimens. Four types: holotype, GSC 103808 (conjunct shell), paratypes: GSC 103809 (shell), 103810 and 103811 (dorsal valves).

Type locality and type stratum. GSC loc. C-56101, spot locality, ridge top, west of Bernard Creek, 56°08′N, 123°27′W, Advance Formation.

Diagnosis. Slightly elongate, subrhomboidal, strongly ventribiconvex to planoconvex shell of *Anazyga,* with deep dorsal sulcus, broad ventral fold, and numerous (up to 40), fine, simple costellae on each valve.

Description. Shell small, slightly elongate, average length 4.2 mm, width 4.0 mm, thickness 2.2 mm, subrhomboidal in ventral view, strongly ventribiconvex to planoconvex; hingeline long, sloping anterolaterally, about four fifths of shell width; anterior commissure deeply and broadly sulciplicate.

Ventral umbo strongly and uniformly convex, with incurved beak arching over hingeline; interarea poorly defined; delthyrium open; median elevation beginning immediately anterior of apex, extending to anterior margin to form broad but poorly delimited fold. Dorsal umbo weakly convex to flat, bearing minute median groove; sulcus developed from umbonal groove, widening and deepening anteriorly, with narrow floor and broad slopes. Entire shell costellate, each valve bearing about 30 to 40 simple, rounded costellae. Growth lines poorly developed.

Interior of ventral valve: teeth small, knob-like; dental plates short, forming small dental cavities; muscle scars not observed. Interior of dorsal valve: hinge plates small, triangular, divergent from each other ventrally; crura slender, ribbon-like (Pl. 12, figs. 26, 27); jugum not observed; a few specimens show poorly preserved spiralia (orientation and number of whorls cannot be determined).

Remarks. The new species shows similarity to *A. mediocostellata* (Cooper, 1956) from the Sevier Formation (Blackriveran) of Tennessee and *A. deflecta* (Hall, 1847) from the middle Trenton beds of New York in its small, slightly elongate, subrhomboidal, strongly ventribiconvex shell with a deeply sulcate dorsal valve. It differs from these species in having notably finer and more numerous costellae, reaching up to 40 at the anterior margin of each valve, and a more deeply sulcate dorsal valve. *Anazyga matutina* (Cooper, 1956) from the Little Oak Formation of Alabama also has a deep dorsal sulcus, but it is unusually small, being less than 3.0 mm in length, with fewer costellae.

One of the specimens showed a pair of slender, ribbon-like crura connected to the first whorls of spiralia, which curve toward the lateral margin and then anteriorly into the silicified matrix. Unfortunately, the spiralia were poorly silicified and broke off before being photographed.

Collections. Total 63 specimens. GSC loc. C-56101 (62 shells and disjunct valves); C-78640 (1 shell).

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APPENDIX 1

LOCALITY DATA

GSC loc. C-56085. Lat. 56°08′N, long. 123°36′W. East of Wicked River, Section 16 of Thompson (1989, p. 100), 40.5 m above base of formation

Plaesiomys meedsi
Paucicrura rogata
Thaerodonta redstonensis
Hiscobeccus mackenziensis

GSC loc. C-56101. Lat. 56°08′N, long. 123°27′W. Ridge top, west of Bernard Creek (Thompson, 1989, p. 100)

Plaesiomys meedsi
Dinorthis aff. *D. holdeni*
Glyptorthis assimilis
Scaphorthis perplexa
Paucicrura rogata
Thaerodonta redstonensis
Eoplectodonta (*Eoplectodonta*) *alternata*
Strophomena cf. *S. planumbona*
Rafinesquina praecursor
Hiscobeccus mackenziensis
Anazyga bellicostata

GSC loc. C-56106. Lat. 56°01′N, long. 123°32′W. Northern ridge of Mount Selwyn (Thompson, 1989, p. 101)

Plaesiomys aff. *P. subquadratus*
Glyptorthis assimilis
Paucicrura rogata
Eoplectodonta (*Eoplectodonta*) *alternata*

GSC loc. C-60924. Lat. 56°11′N, long. 123°27′W. Mount Burden. 16.5–27.5 m above base of formation

Plaesiomys aff. *P. subquadratus*
Plaesiomys meedsi
Dinorthis cf. *D. holdeni*
Glyptorthis assimilis
Scaphorthis perplexa
Platystrophia colbiensis
Paucicrura rogata
Oxoplecia globularis
Eoplectodonta (*Eoplectodonta*) *alternata*
Strophomena cf. *S. planumbona*
Oepikina sp.
Hiscobeccus mackenziensis

GSC loc. C-78638. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 10.5–16.5 m above base of formation

Plaesiomys meedsi
Glyptorthis assimilis
Scaphorthis perplexa
Paurorthis ponderosa
Paucicrura rogata
Glyptambonites musculosus
Leangella (*Leangella*) *biseptata*
Christiania subquadrata
Bimuria cf. *B. superba*
Eoplectodonta (*Eoplectodonta*) *alternata*
Murinella cf. *M. biconvexa*
Hiscobeccus mackenziensis

GSC loc. C-78640. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 44–46 m above base of formation

Plaesiomys meedsi
Paucicrura rogata
Thaerodonta redstonensis
Rafinesquina praecursor

GSC loc. C-205918. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 1.0–3.0 m above base of formation

Glyptorthis assimilis
Paurorthis ponderosa
Paucicrura rogata
Thaerodonta redstonensis
Eoplectodonta (*Eoplectodonta*) *alternata*

GSC loc. C-205919. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 6.0–8.0 m above base of formation

Glyptorthis assimilis
Paurorthis ponderosa
Paucicrura rogata
Leangella (*Leangella*) *biseptata*
Parastrophina sp.

GSC loc. C-205920. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 8.0–9.5 m above base of formation

Glyptorthis assimilis
Paurorthis ponderosa
Christiania subquadrata

GSC loc. C-205921. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 11.0–13.0 m above base of formation

Leangella (*Leangella*) *biseptata*
Eoplectodonta (*Eoplectondonta*) *alternata*

GSC loc. C-205922. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 16.5–17.5 m above base of formation

Plaesiomys aff. *P. subquadratus*
Glyptorthis assimilis
Paurorthis ponderosa
Leangella (*Leangella*) *biseptata*
Christiania subquadrata
Thaerodonta redstonensis
Eoplectodonta (*Eoplectondonta*) *alternata*
Hiscobeccus mackenziensis

GSC loc. C-205923. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 18.5–19.5 m above base of formation

Glyptorthis assimilis
Paurorthis ponderosa
Platystrophia colbiensis
Paucicrura rogata
Leangella (*Leangella*) *biseptata*
Eoplectodonta (*Eoplectondonta*) *alternata*
Rafinesquina praecursor
Hiscobeccus mackenziensis

GSC loc. C-205924. Lat. 56°02′N, long. 123°21′W. Advance Mountain. 20.5–21.0 m above base of formation

Glyptorthis assimilis
Paurorthis ponderosa
Platystrophia colbiensis
Paucicrura rogata
Eoplectodonta (*Eoplectodonta*) *alternata*
Hiscobeccus mackenziensis

APPENDIX 2

STATISTICAL DATA OF SHELL MEASUREMENTS

L—shell length; W—shell width; T—shell thickness; L/W—length/width ratio; T/W—thickness/width ratio (shell convexity); AVG—average; STD—standard deviation; MAX—maximum; MIN—minimum.

Paucicrura rogata

	L	W	T	L/W	T/W
GSC loc. C-78638 (24 complete shells)					
AVG	5.63	6.18	2.67	0.90	0.43
STD	1.48	1.34	0.58	0.06	0.03
MAX	8.30	8.60	4.00	0.99	0.49
MIN	2.80	3.40	1.50	0.73	0.39
GSC loc. C-78640 (28 ventral valves)					
AVG	9.40	10.45	2.54	0.90	0.24
STD	0.90	10.90	0.32	0.05	0.03
MAX	11.60	12.60	3.30	0.99	0.29
MIN	6.90	7.90	1.80	0.80	0.18
GSC loc. C-78640 (35 dorsal valves)					
AVG	8.86	10.09	1.14	0.88	0.11
STD	1.43	1.44	0.35	0.05	0.03
MAX	11.30	13.00	2.00	0.94	0.17
MIN	5.20	7.30	0.50	0.69	0.04

Leangella biseptata

	L	W	T	L/W	T/W
GSC loc. C-78638 (24 complete shells)					
AVG	4.25	7.55	2.15	0.56	0.28
STD	0.58	0.84	0.59	0.05	0.06
MAX	5.00	9.20	3.10	0.64	0.41
MIN	3.10	6.20	1.20	0.43	0.19

Thaerodonta redstonensis

	L	W	T	L/W	T/W
GSC loc. C-56101 (30 complete shells)					
AVG	6.60	12.01	1.69	0.55	0.14
STD	1.48	2.33	0.45	0.04	0.02
MAX	9.30	17.00	2.80	0.65	0.19
MIN	4.00	7.50	1.00	0.47	0.11

Hiscobeccus mackenziensis

	L	W	T	L/W	T/W
GSC loc. C-60924 (46 complete shells)					
AVG	8.78	8.93	5.33	1.00	0.58
STD	1.90	2.25	1.83	0.07	0.07
MAX	12.60	13.60	10.30	1.22	0.76
MIN	3.90	3.20	1.80	0.87	0.44

Anazyga bellicostata

	L	W	T	L/W	T/W
GSC loc. C-56101 (24 complete shells)					
AVG	4.17	4.01	2.20	1.05	0.55
STD	1.05	1.04	0.62	0.07	0.09
MAX	7.10	6.60	4.10	1.23	0.75
MIN	2.90	2.60	1.30	0.94	0.40

PLATE 1

Figures 1–9. *Dinorthis* cf. *D. holdeni* (Willard, 1928).

1–3. GSC 103721, hypotype, ventral valve with damaged anterior edge, x5, GSC loc. C-56101.

4, 5, 9. GSC 103722, hypotype, dorsal valve with interior partly covered by matrix, figures 4, 5, x5; figure 9, x11. Note cardinal process with crenulated crest. GSC loc. C-56101.

6–8. GSC 103723, hypotype, dorsal valve, figures 6, 7, x5; figure 8, x12. Note well developed brachiophores and cardinal process with crenulated crest. GSC loc. C-56101.

Figures 10–25. *Glyptorthis assimilis* Cooper, 1956.

10–14. GSC 103724, hypotype, dorsal, ventral, lateral, posterior, and anterior views of complete shell, x4, GSC loc. C-60924.

15–18. GSC 103725, hypotype, dorsal, ventral, lateral, and posterior views of immature shell with catacline ventral interarea, x5, GSC loc. C-60924.

19. GSC 103726, hypotype, interior of dorsal valve showing muscle field and digitate vascular canals, x3, GSC loc. C-56101.

20–22. GSC 103727, hypotype, ventral valve showing two longitudinal ridges anterior of muscle field, figures 20, 21, x3; figure 22, x4, GSC loc. C-56101.

23. GSC 103728, hypotype, dorsal valve, x3, GSC loc. C-60924.

24, 25. GSC 103729, hypotype, dorsal valve with anteriorly inflated cardinal process, figure 24, x3; figure 25, x4, GSC loc. C-56101.

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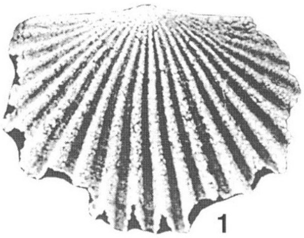
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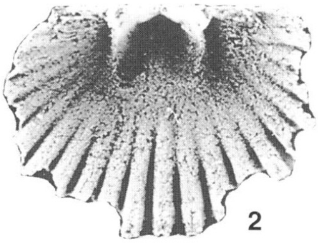
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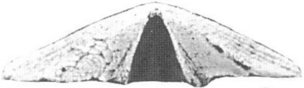
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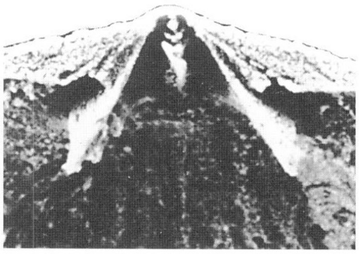
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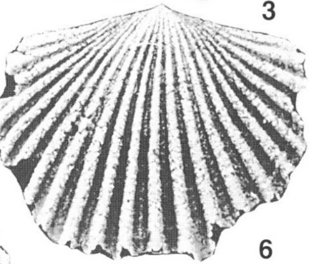
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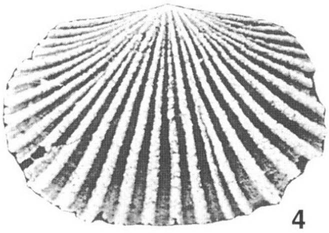
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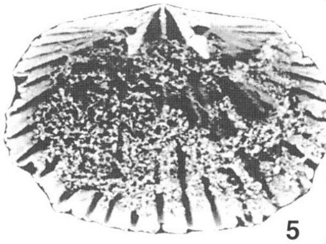
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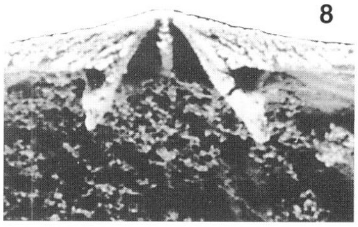
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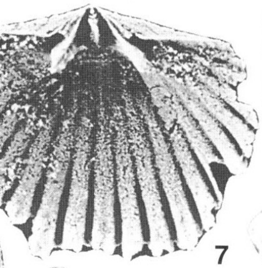
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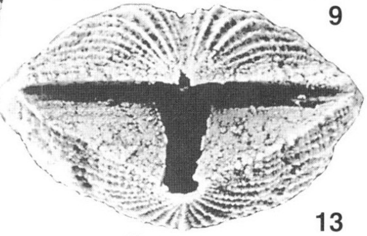
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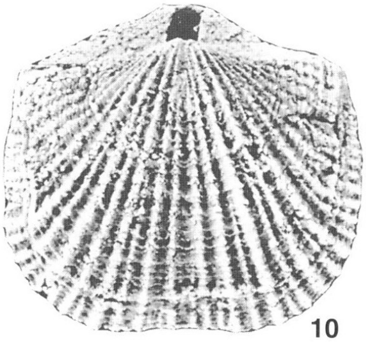
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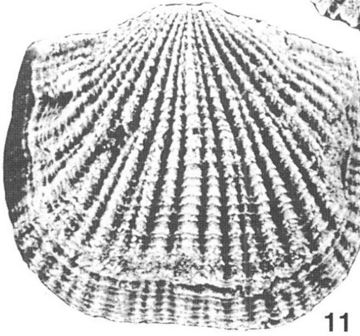
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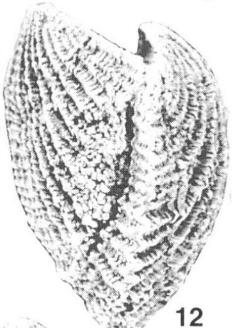
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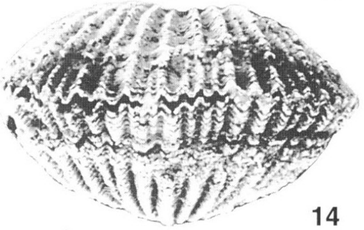
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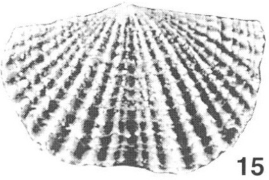
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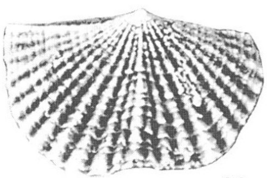
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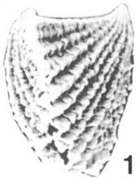
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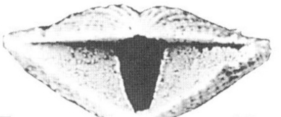
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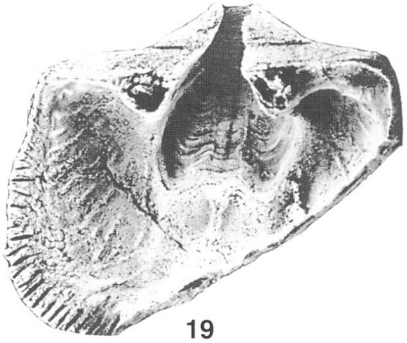
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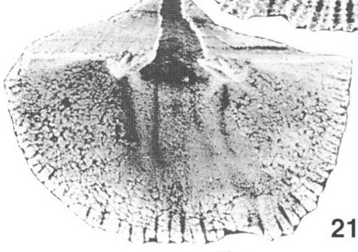
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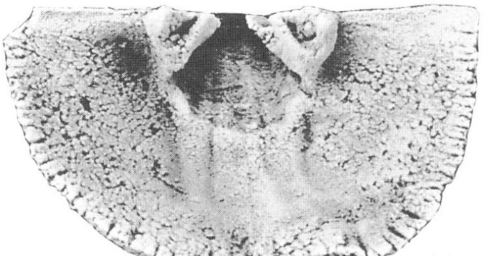
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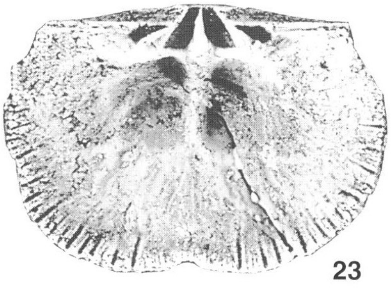
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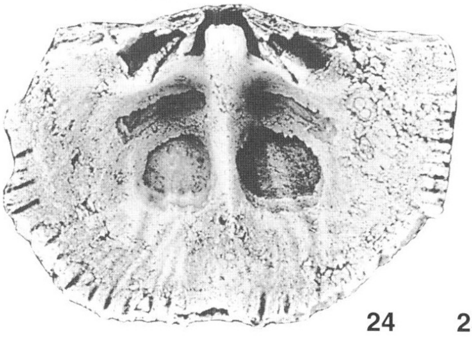
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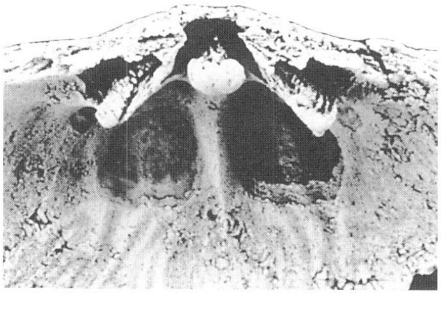
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PLATE 2

Figures 1–7. *Plaesiomys* aff. *P. subquadratus* (Hall, 1847).

GSC 103730, hypotype, complete shell obliquely fractured, ventral, dorsal, posterior, anterior, lateral, cardinal, and interior views respectively, figures 1–5, x2.5; figure 6, x10; figure 7 (photographed by separating shell along fracture), x5. Note prominent, catacline interarea in ventral valve. GSC loc. C-60924.

Figures 8–15. *Plaesiomys meedsi* (Winchell and Schuchert, 1892).

8–11. GSC 103731, hypotype, dorsal, posterior, anterior, and lateral views respectively, x3.5, GSC loc. C-56085.

12, 13. GSC 103732, hypotype, ventral valve, figure 12, x3.5; figure 13, x7. Note presence of short, anterolaterally divergent dental plates. GSC loc. C-78640.

14, 15. GSC 103733, hypotype, broken dorsal valve showing platy brachiophores and cardinal process with herringbone crest, figure 14, x3.5; figure 15, x10, GSC loc. C-78640.

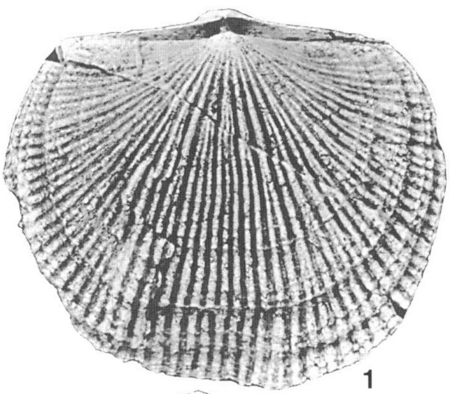
Figures 16–27. *Scaphorthis perplexa* Cooper, 1956.

16–19. GSC 103734, hypotype, dorsal, lateral, posterior, and anterior views of complete shell, x5, GSC loc. C-60924.

20–24. GSC 103735, hypotype, dorsal, ventral, lateral, posterior, and anterior views of partly damaged shell, x6, GSC loc. C-78638.

25, 26. GSC 103736, hypotype, dorsal valve with thin, ridge-like cardinal process, x5, GSC loc. C-60924.

27. GSC 103737, hypotype, anterior view of ventral valve with well developed dental plates, x7, GSC loc. C-78638.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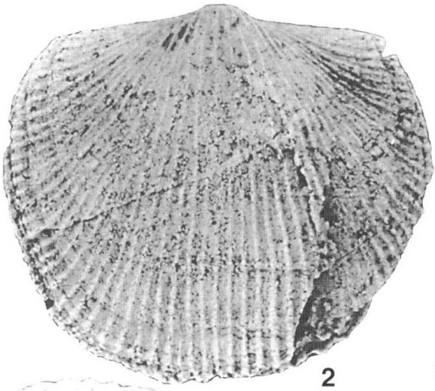
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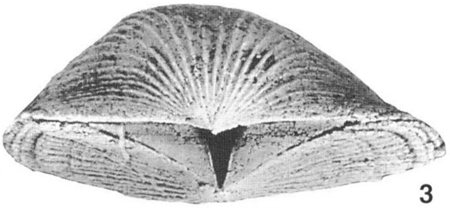
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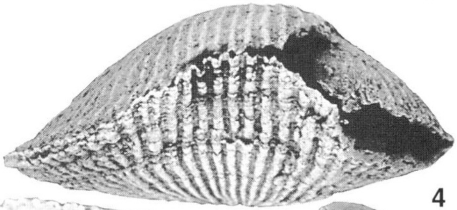
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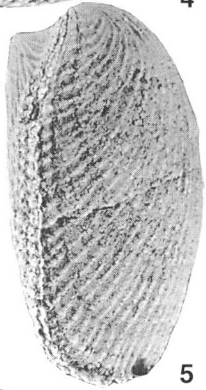
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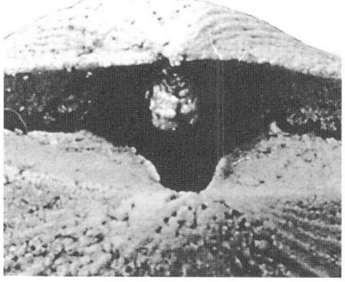
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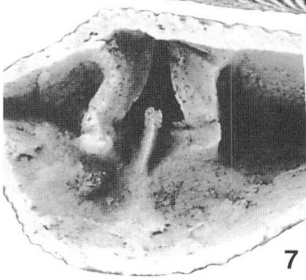
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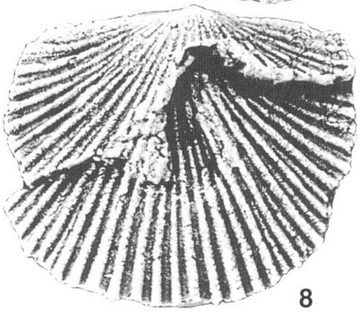
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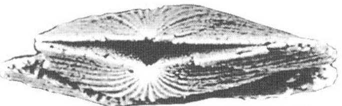
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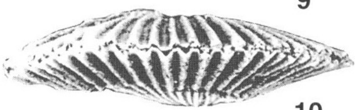
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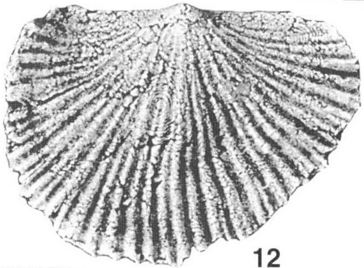
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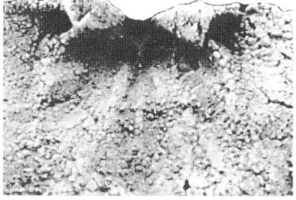
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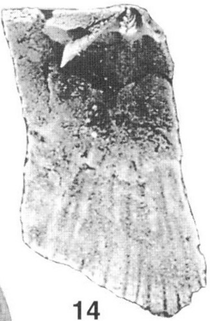
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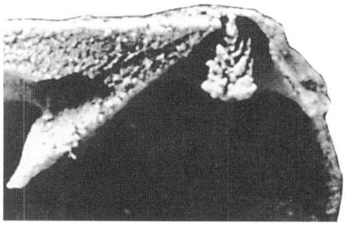
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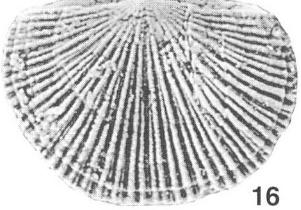
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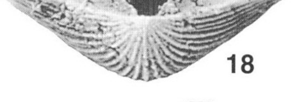
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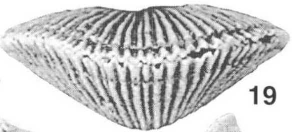
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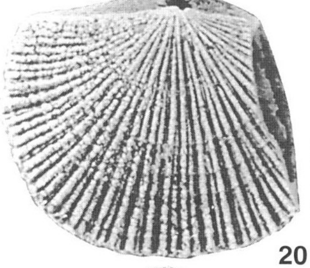
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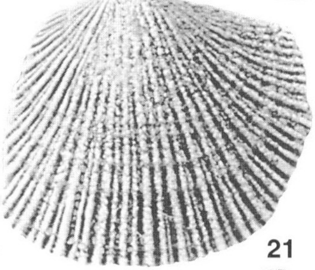
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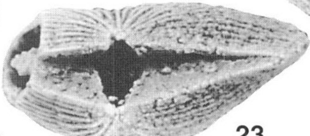
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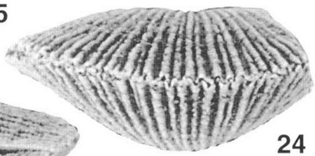
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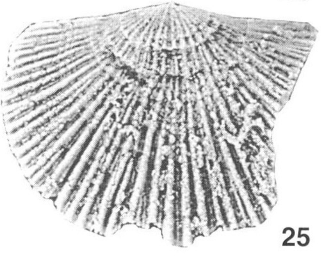
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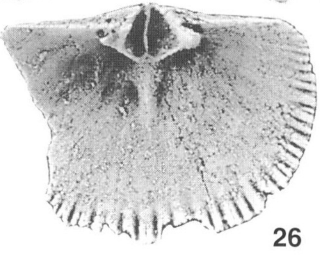
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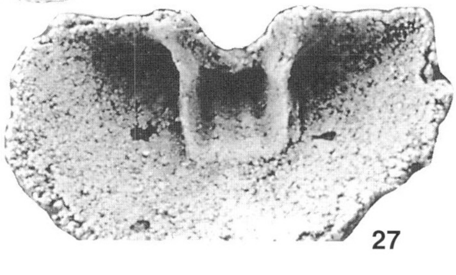
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PLATE 3

Figures 1–6. *Platystrophia colbiensis* Foerste, 1910.

GSC 103738, hypotype, dorsal, ventral, posterior, lateral, ventral interior, and dorsal interior views of nearly complete shell with separable valves, x3. Note oval adductor scars and nodular vascular markings in posterolateral areas of dorsal valve. GSC loc. C-60924.

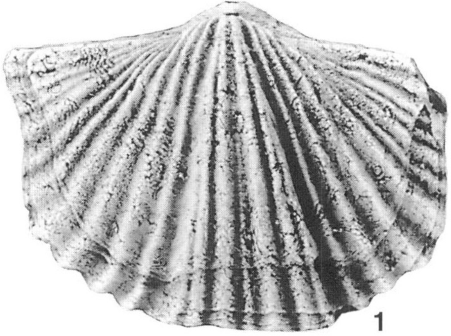
Figures 7–18. *Oxoplecia globularis* Cooper, 1956.

7–13. GSC 103739, hypotype, dorsal, ventral, lateral, posterior, anterior, and dorsal interior views of conjoined valves, figures 7, 9–12, x3; figure 8, x10 (showing pseudodeltidium); figure 13 (dorsal valve separated from ventral valve to show bi-forked cardinal process), x10, GSC loc. C-60924.

14, 15. GSC 103740, hypotype, ventral valve showing pseudodeltidium and dental plates, figure 14, x3.5; figure 15, x8, GSC loc. C-60924.

16–18. GSC 103741, hypotype, ventral valve, figure 16, x3; figures 17, 18, x8, GSC loc. C-60924.

PLATE 3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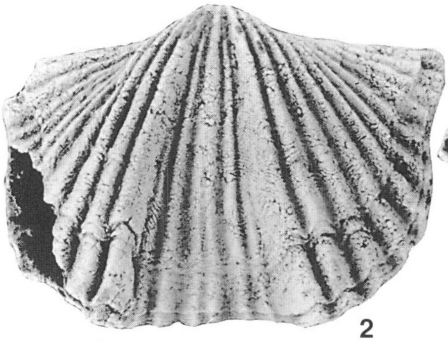
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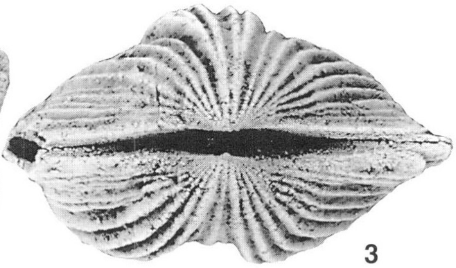
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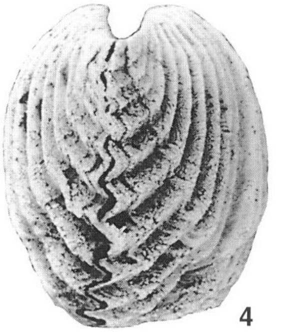
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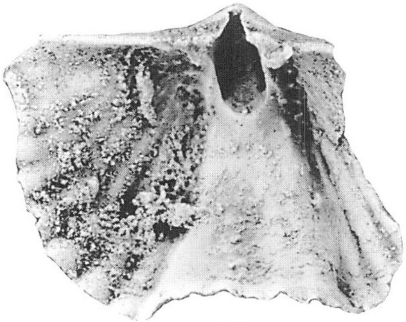
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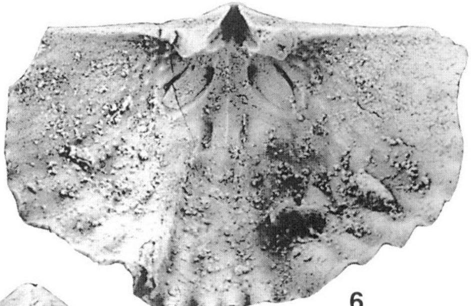
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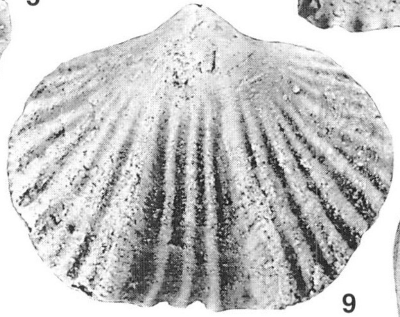
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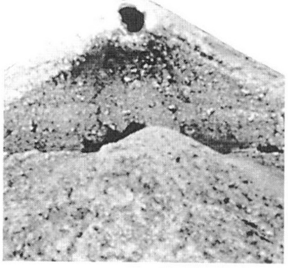
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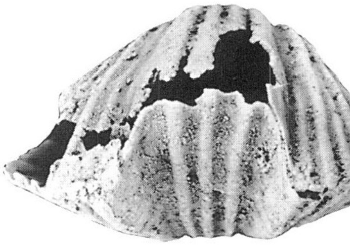
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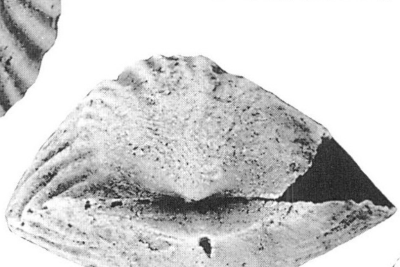
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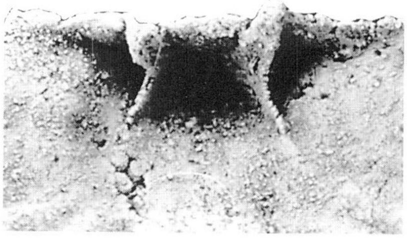
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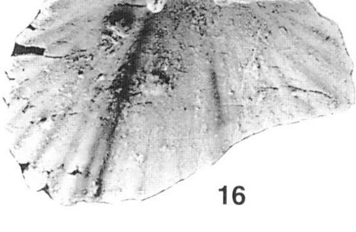
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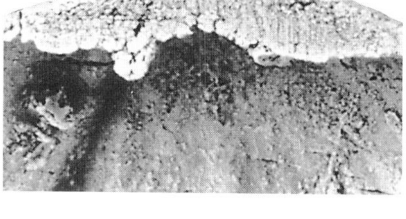
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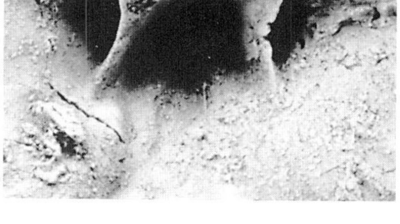
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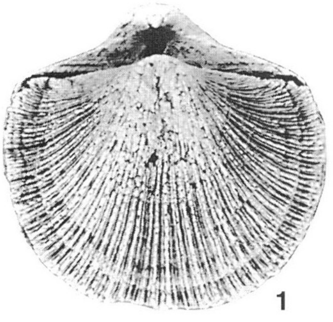
PLATE 4

Figures 1–15. *Paurorthis ponderosa* Cooper, 1956.

1–5.	GSC 103742, hypotype, dorsal, ventral, lateral, anterior, posterior views of complete shell, x4, GSC loc. C-78638.
6.	GSC 103743, hypotype, ventral valve, x4, GSC loc. C-78638.
7, 8.	GSC 103744, hypotype, ventral valve showing fossettes on inner sides of teeth, figure 7, x15; figure 8, x4, GSC loc. C-78638.
9–11, 15.	GSC 103745, hypotype, dorsal valve with perforated costellae (fig. 15) and thin, ridge-like cardinal process (fig. 11), figures 9, 10, x4; figure 11, x6; figure 15, x12, GSC loc. C-78638.
12–14.	GSC 103746, hypotype, dorsal valve, figures 12, 13, x4; figure 14, x12, GSC loc. C-78638.

Figures 16–19. *Paucicrura rogata* (Sardeson, 1892).

16, 17.	GSC 103747, hypotype, dorsal valve, figure 16, x4; figure 17, x10. Note trilobate cardinal process with spur underneath. GSC loc. C-78640.
18, 19.	GSC 103748, hypotype, dorsal valve with quadrilobate cardinal process without spur underneath, figure 18, x4, figure 19, x12, GSC loc. C-78638.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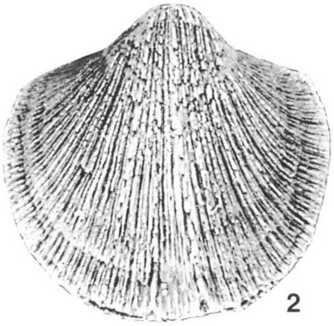
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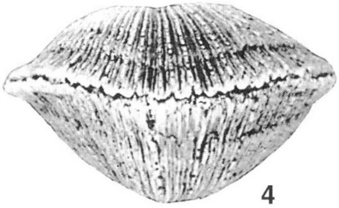
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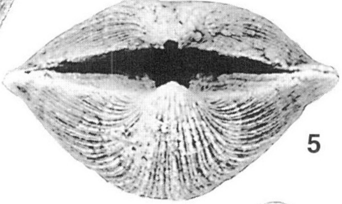
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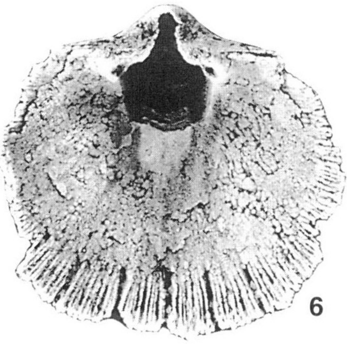
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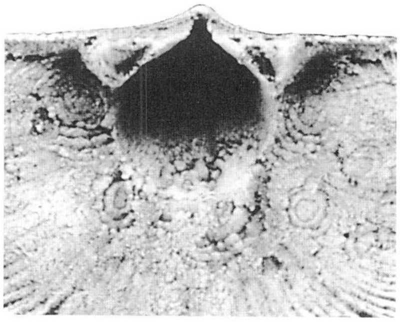
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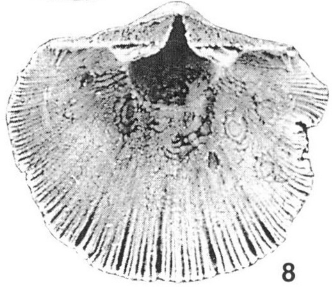
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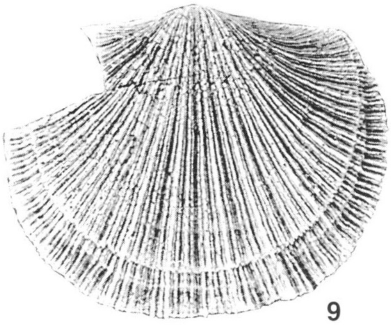
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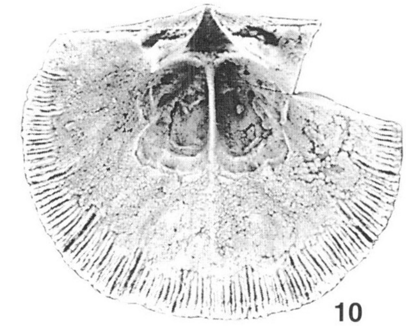
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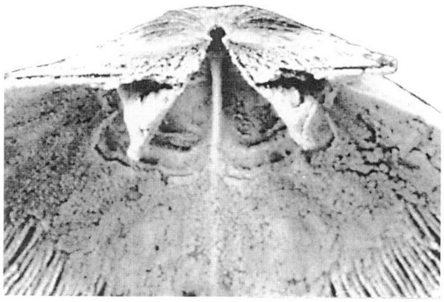
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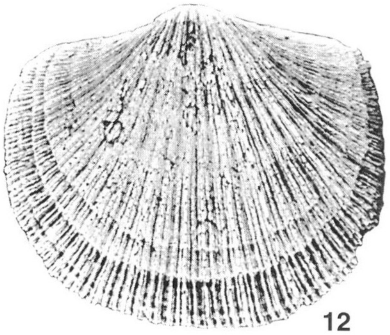
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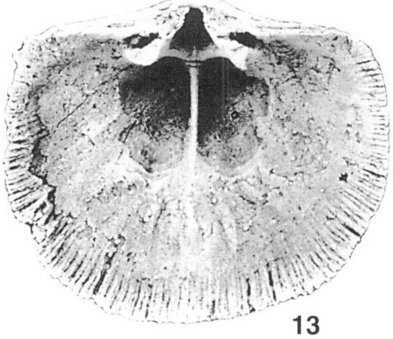
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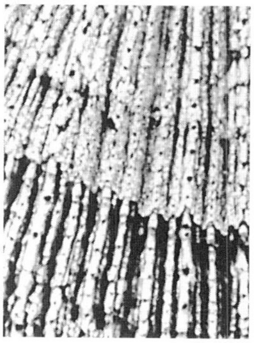
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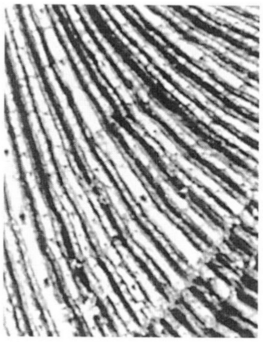
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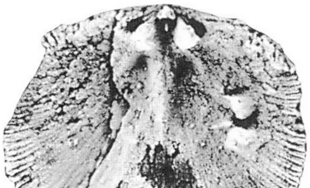
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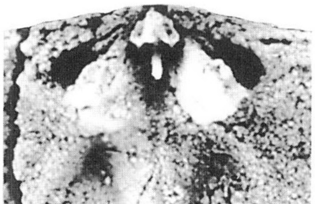
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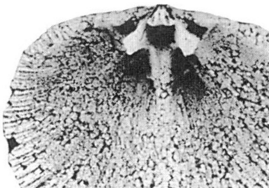
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PLATE 5

Figures 1–21. *Paucicrura rogata* (Sardeson, 1892).

1–5. GSC 103749, hypotype, dorsal, ventral, lateral, posterior, and anterior views of complete shell, x4, GSC loc. C-78640.

6–11. GSC 103750, hypotype, dorsal, ventral, lateral, posterior, anterior, and enlarged cardinal views of complete shell with slightly corroded ventral valve, figures 6–10, x4; figure 11, x10, GSC loc. C-78640.

12. GSC 103751, hypotype, interior of ventral valve showing muscle field, x4, GSC loc. C-78640.

13. GSC 103752, hypotype, interior of ventral valve, x4, GSC loc. C-78640.

14. GSC 103753, hypotype, interior of ventral valve showing muscle field with anterior notch, x4, GSC loc. C-78640.

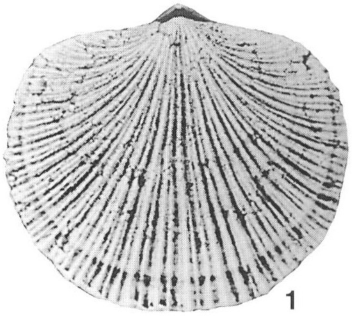
15. GSC 103754, hypotype, enlarged interior of ventral valve showing teeth, dental plates, and lateral muscle bounding ridges, x7.5, GSC loc. C-78640.

16, 17. GSC 103755, hypotype, dorsal valve showing undercut cardinal process with low median ridge, figure 16, x4; figure 17, x8, GSC loc. C-78640.

18, 19. GSC 103756, hypotype, dorsal valve showing trilobate cardinal process and platy brachiophores, figure 18, x4; figure 19, x10. GSC loc. C-78640.

20, 21. GSC 103757, hypotype, interior of dorsal valve, figure 20, x4; figure 21, x10. Note cardinal process with spur underneath. GSC loc. C-78640.

PLATE 5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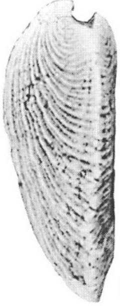
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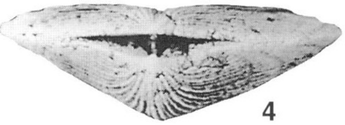
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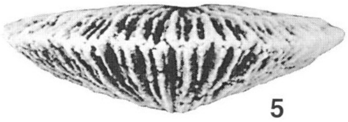
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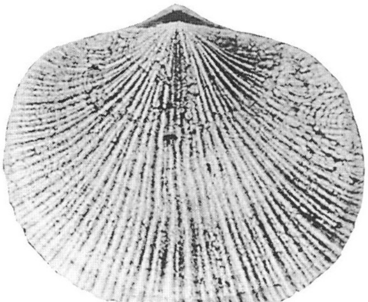
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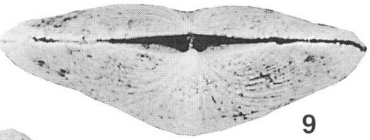
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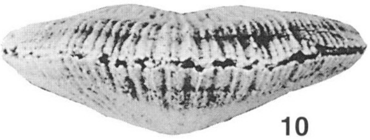
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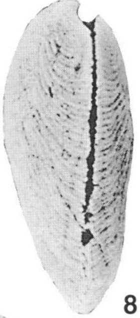
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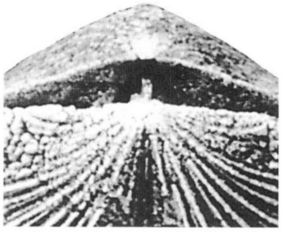
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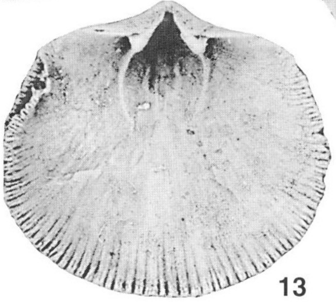
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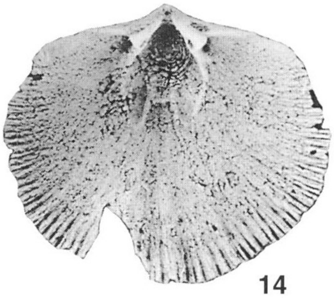
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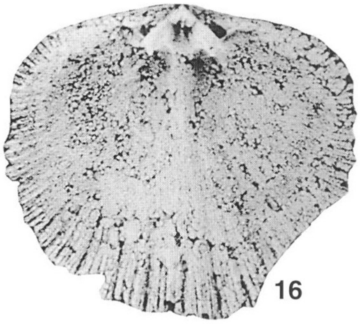
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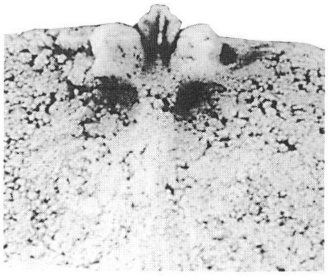
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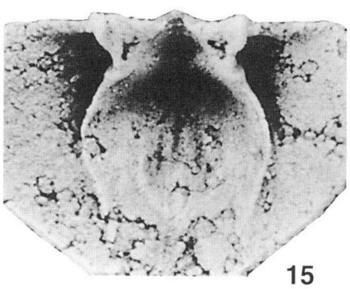
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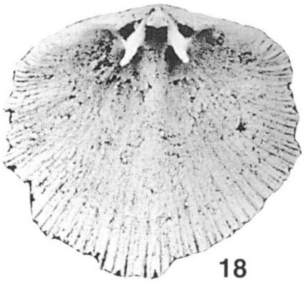
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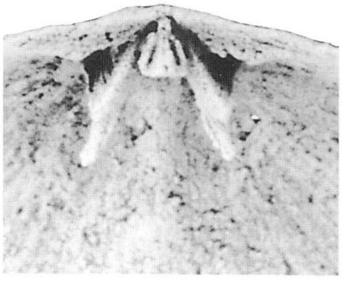
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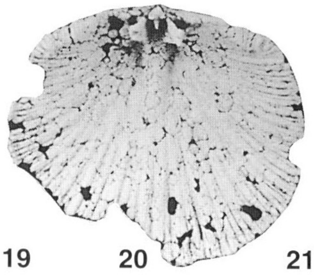
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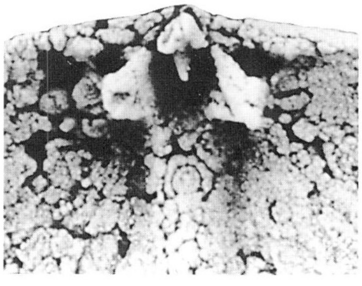


PLATE 6

Figures 1, 2. *Glyptambonites musculosus* Cooper, 1956.

GSC 103758, hypotype, exterior and interior of ventral valve showing fine, unequal parvicostellae and slender diductor muscle scars surrounded by posterior rugae and vascular canals, x2.5, GSC loc. C-78638.

Figures 3–19. *Leangella* (*Leangella*) *biseptata* n. sp.

3–7. GSC 103759, holotype, dorsal, ventral, lateral, posterior, and cardinal views of nearly complete shell, figures 3–6, x6; figure 7, x18, GSC loc. C-78638.

8–11. GSC 103760, paratype, tilted dorsal, ventral, posterior, and lateral views of anteriorly damaged shell, x6, GSC loc. C-78638.

12–16. GSC 103761, paratype, dorsal, ventral, lateral, posterior, and cardinal views, figures 12–15, x6; figure 16, x18, GSC loc. C-78638.

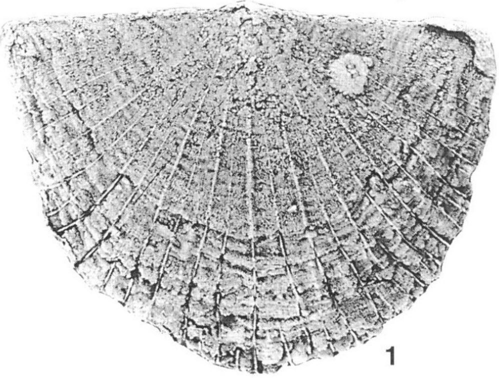
17, 18. GSC 103762, paratype, normal and tilted internal views of dorsal valve showing anteriorly free bema with pair of median ridges, figure 17, x7; figure 18, x10, GSC loc. C-78638.

19. GSC 103763, paratype, interior of ventral valve showing muscle field with arched anterior margin, x9, GSC loc. C-78638.

Figures 20–30. *Christiania subquadrata* (Hall, 1883).

20–24. GSC 103764, hypotype, dorsal, posterior, ventral, umbonal, and lateral views of immature shell, figures 20, 22, 24, x6; figures 21, 23, x11. Note apical foramen and well developed deltidium. GSC loc. C-78638.

25–30. GSC 103765, hypotype, dorsal, ventral, lateral, cardinal, anterior, and enlarged cardinal views of immature shell, figures 25–29, x6; figure 30, x12, GSC loc. C-78638.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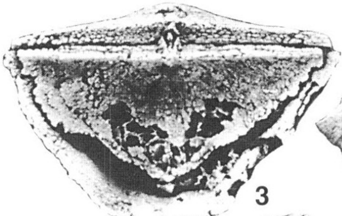
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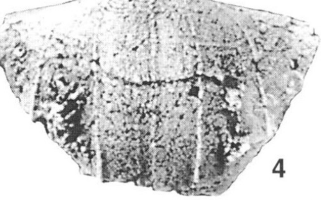
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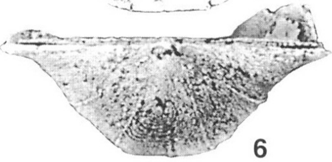
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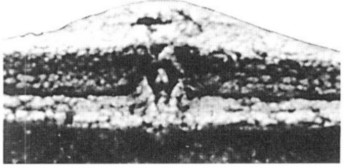
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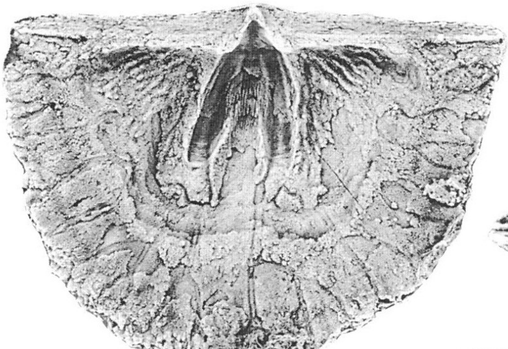
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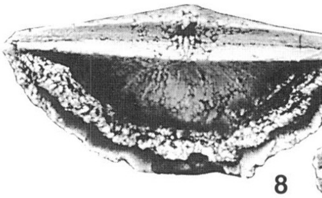
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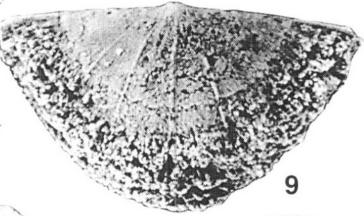
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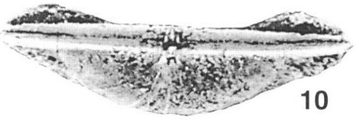
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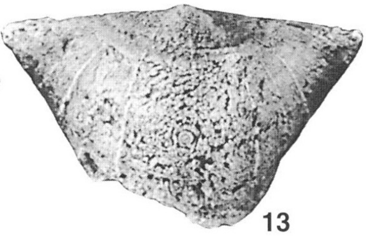
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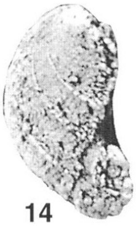
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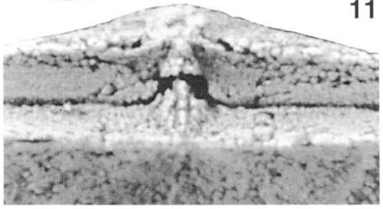
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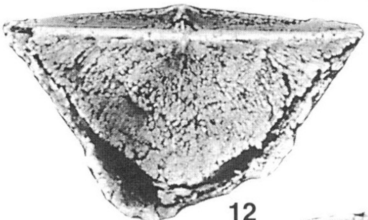
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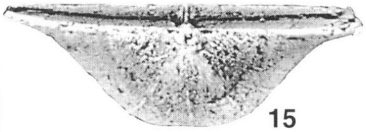
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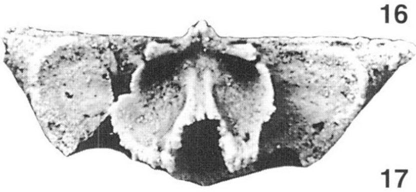
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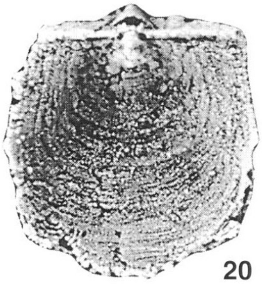
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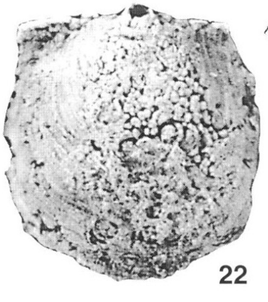
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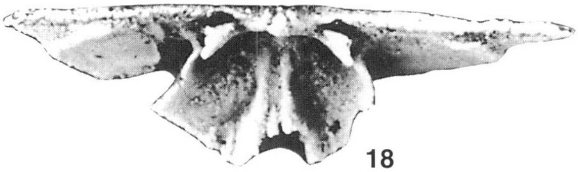
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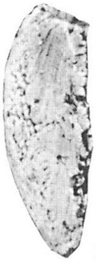
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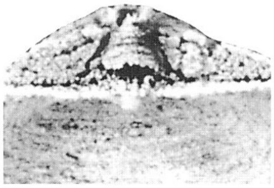
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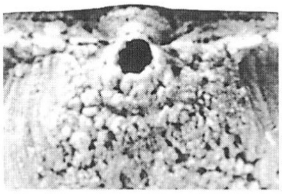
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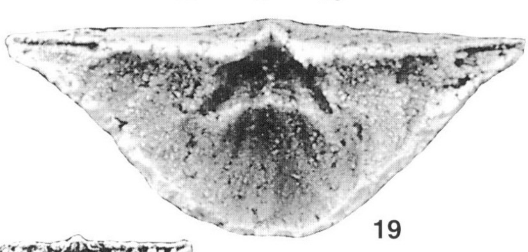
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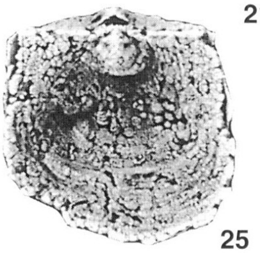
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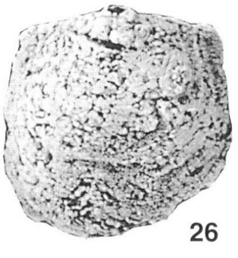
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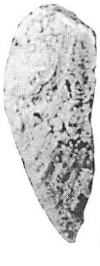
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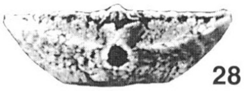
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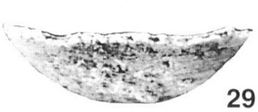
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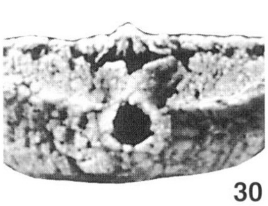
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PLATE 7

Figures 1–6. *Christiania subquadrata* (Hall, 1883).

1, 2. GSC 103766, hypotype, exterior and interior of dorsal valve with weak median septum, x6, GSC loc. C-78638.

3–5. GSC 103767, hypotype, exterior, interior, and enlarged cardinal views of dorsal valve with strong median septum, figures 3, 4, x4.5; figure 5, x7, GSC loc. C-78638.

6. GSC 103768, hypotype, dorsal valve with medium-strength median septum, x4.5, GSC loc. C-78638.

Figures 7–18. *Bimuria* cf. *B. superba* Ulrich and Cooper, 1942.

7–11. GSC 103769, hypotype, dorsal, ventral, lateral, posterior, and anterior views of complete shell, x4, GSC loc. C-78638.

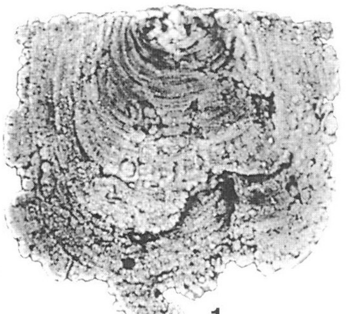
12–14. GSC 103770, hypotype, dorsal, ventral, and posterior views of shell partly covered by matrix, x4, GSC loc. C-78638.

15, 16. GSC 103771, hypotype, ventral valve, x4, GSC loc. C-78638.

17. GSC 103772, hypotype, interior of dorsal valve with bilobate bema, x5.5, GSC loc. C-78638.

18. GSC 103773, hypotype, half broken dorsal valve with mirror image, x5.5, GSC loc. C-78638.

PLATE 7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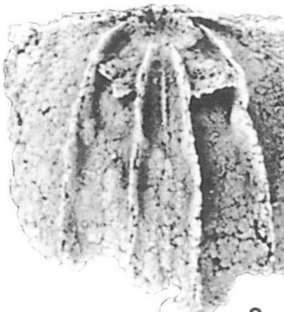
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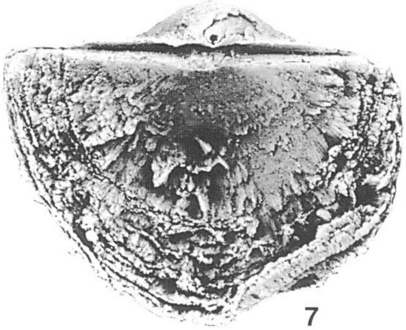
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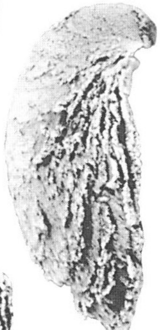
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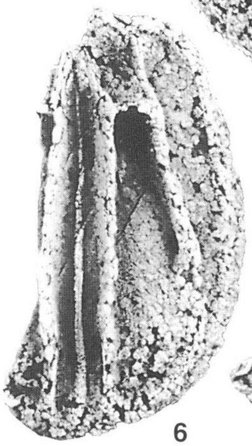
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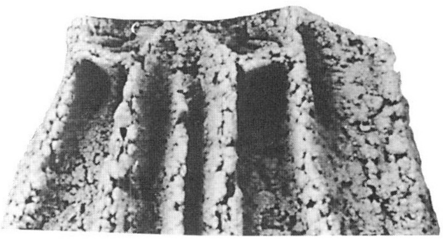
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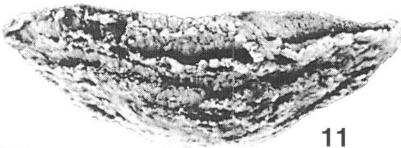
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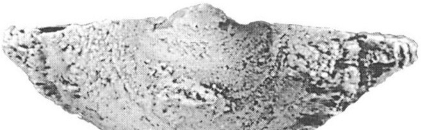
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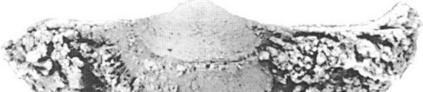
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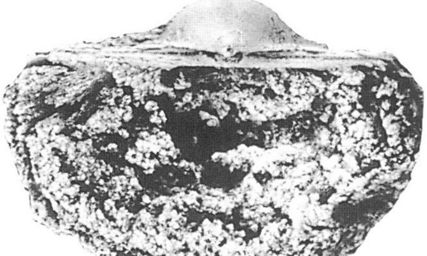
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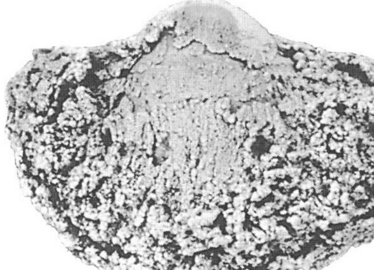
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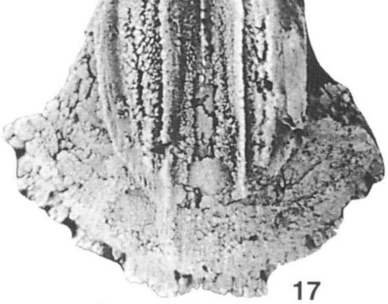
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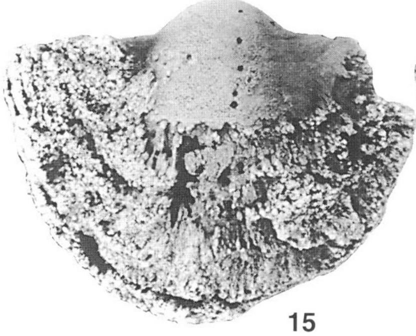
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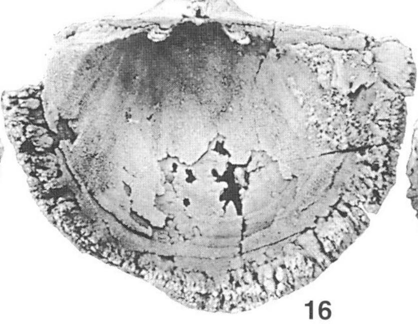
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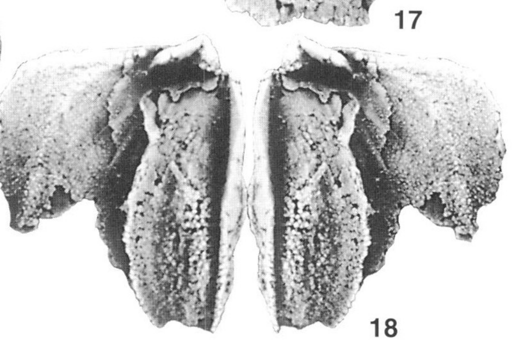
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PLATE 8

Figures 1–19. *Thaerodonta redstonensis* (Mitchell and Sweet, 1989).

1–4. GSC 103774, hypotype, exterior, interior, hingeline, and delthyrial cavity of ventral valve, figures 1, 2, x4; figure 3, x7; figure 4, x12. Note hinge fossettes in lateral portions of hingeline. GSC loc. C-56101.

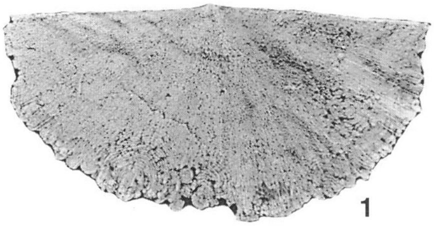
5–8. GSC 103775, hypotype, ventral valve showing bilobate muscle field, bifurcating median ridge, and shallow delthyrial notch undercut by rounded pit, figures 5, 6, x4; figure 7, x10; figure 8, x7, GSC loc. C-56101.

9, 10. GSC 103776, hypotype, ventral valve, figure 9, x4; figure 10, x11, GSC loc. C-56101.

11, 12. GSC 103777, hypotype, ventral valve, figure 11, x4; figure 12, x12, GSC loc. C-56101.

13–17. GSC 103778, hypotype, exterior, interior, cardinal process, hingeline, and posterior of dorsal valve showing hinge denticles (fig. 16) and trilobate cardinal process (fig. 17), figures 13, 14, x4; figures 15–17, x9, GSC loc. C-56101.

18, 19. GSC 103779, hypotype, interior of dorsal valve with weak median septum, figure 18, x4; figure 19, x10, GSC loc. C-56101.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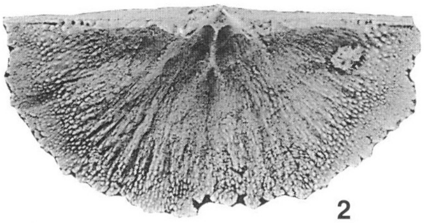
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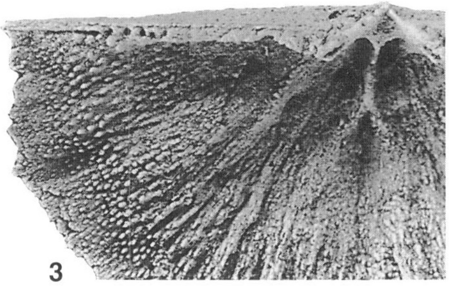
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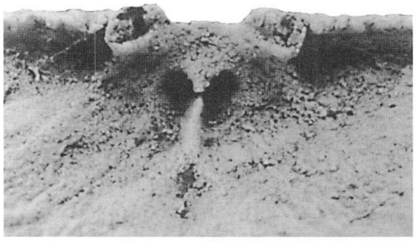
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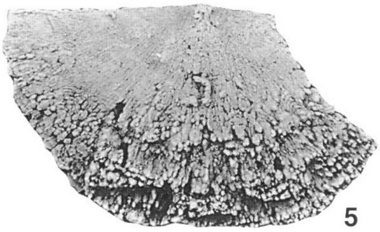
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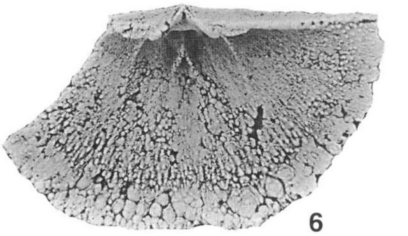
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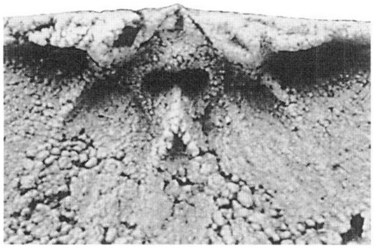
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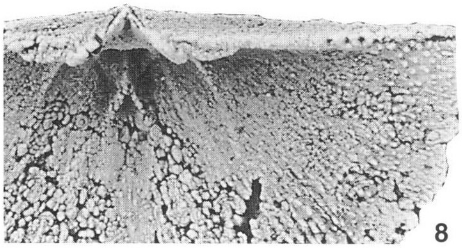
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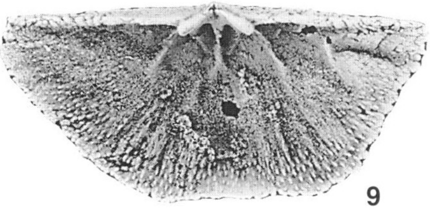
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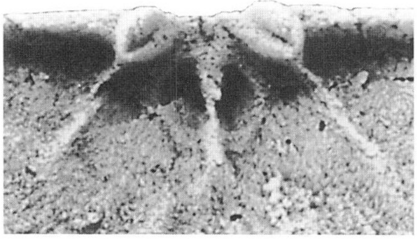
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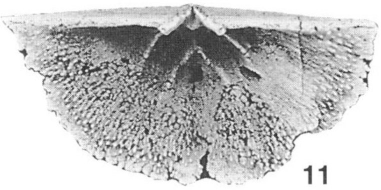
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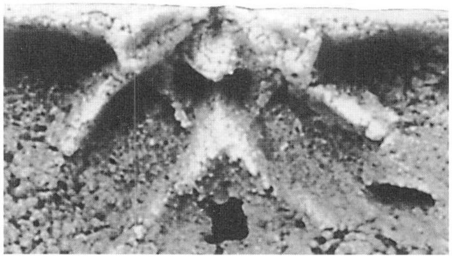
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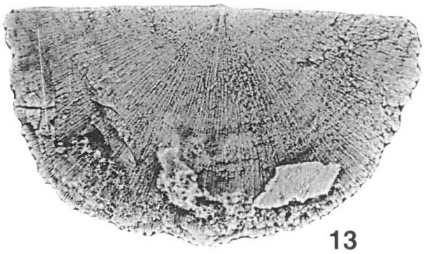
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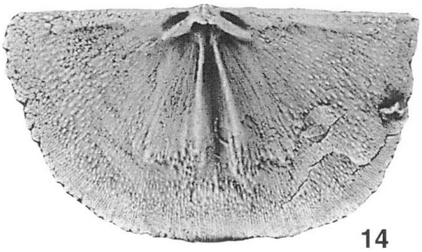
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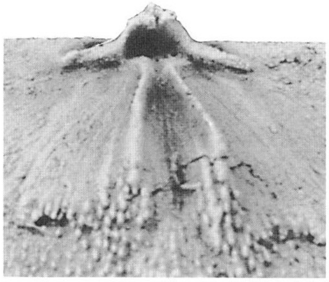
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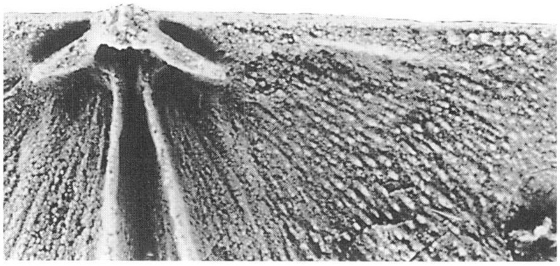
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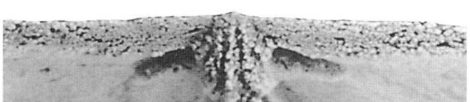
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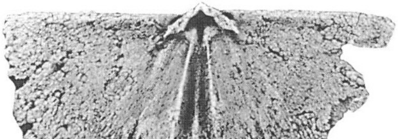
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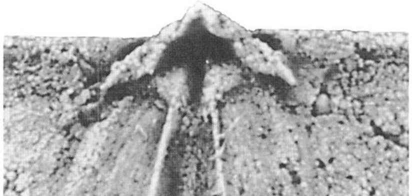
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PLATE 9

Figures 1–13. *Thaerodonta redstonensis* (Mitchell and Sweet, 1989).

1–3. GSC 103780, hypotype, dorsal valve, figures 1, 2, x4; figure 3, x12, GSC loc. C-56101.

4. GSC 103781, hypotype, dorsal valve with well preserved hinge denticles, x4, GSC loc. C-56101.

5–8. GSC 103782, hypotype, dorsal, ventral, lateral, and posterior views of partly broken shell, figures 5–7, x4; figure 8, x16, GSC loc. C-78640.

9–13. GSC 103783, hypotype, dorsal, ventral, lateral, anterior, and posterior views of complete shell, figures 9–12, x3; figure 13, x16, GSC loc. C-78640.

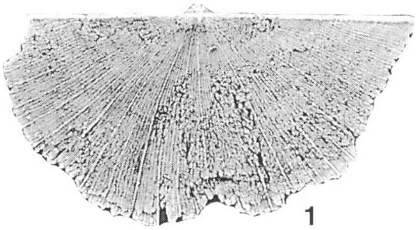
Figures 14–27. *Eoplectodonta* (*Eoplectodonta*) *alternata* (Butts, 1942).

14–17. GSC 103784, hypotype, dorsal, ventral, lateral, and posterior views of laterally damaged shell, x5, GSC loc. C-60924.

18–21. GSC 103785, hypotype, dorsal, ventral, lateral, and posterior views of anteriorly damaged shell, x4, GSC loc. C-78638.

22–24. GSC 103786, hypotype, large, gerontic ventral valve showing abraded unequal parvicostellae and hinge denticles in cardinal portion of hingeline, figures 22, 23, x3; figure 24, x6, GSC loc. C-60924.

25–27. GSC 103787, hypotype, ventral valve, figures 25, 26, x3.5; figure 27, x12, GSC loc. C-56101.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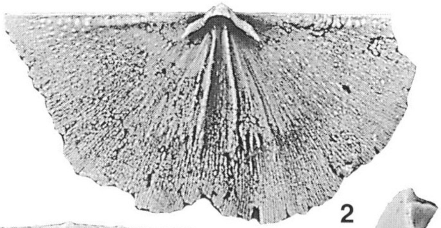
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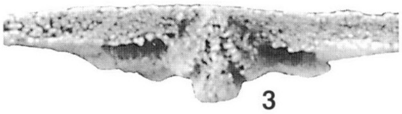
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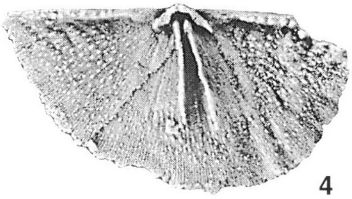
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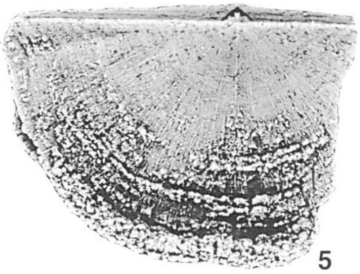
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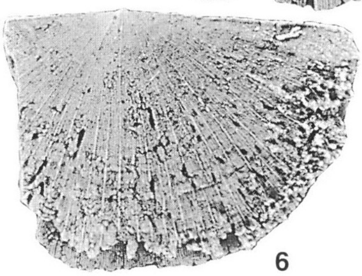
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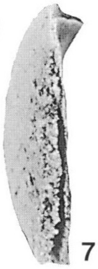
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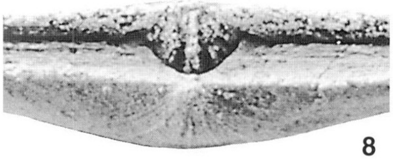
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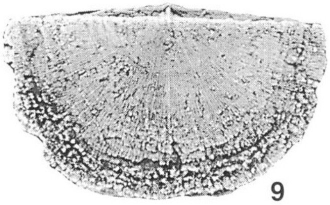
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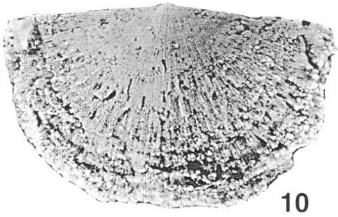
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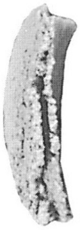
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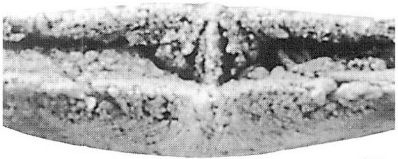
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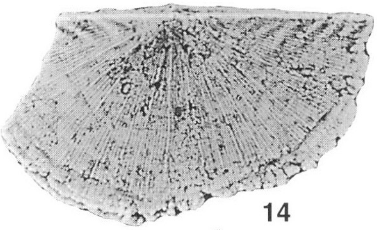
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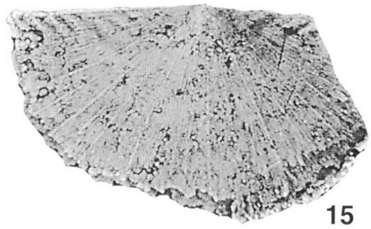
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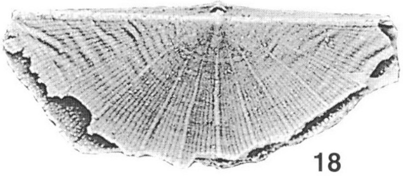
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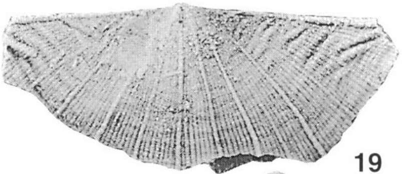
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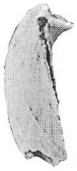
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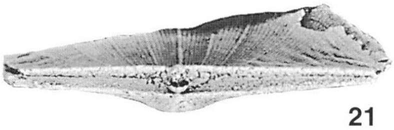
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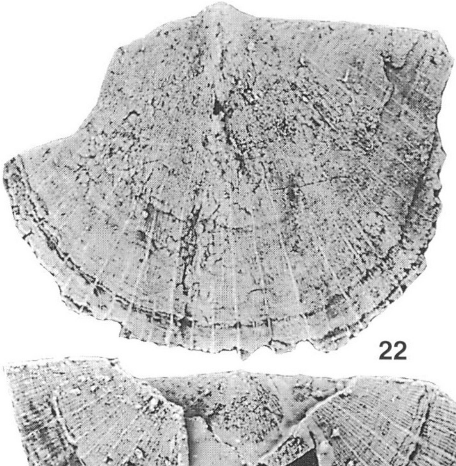
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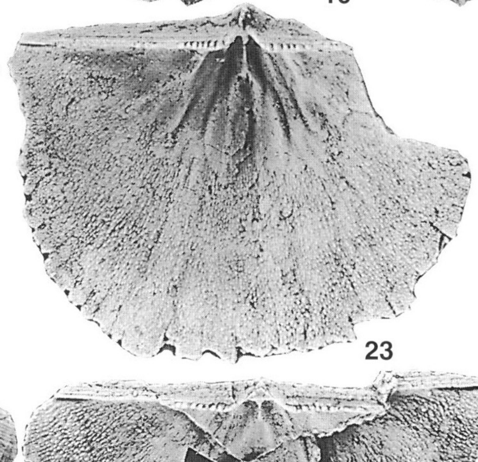
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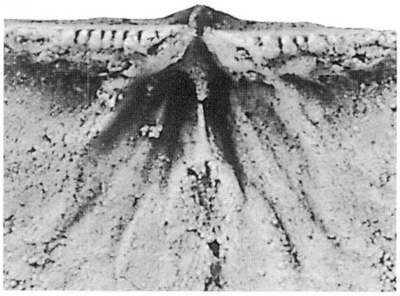
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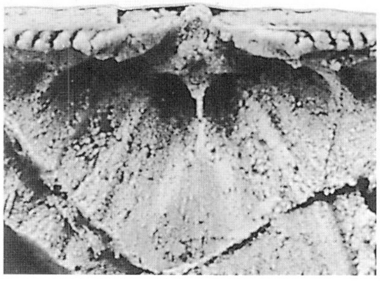
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PLATE 10

Figures 1–5. *Eoplectodonta* (*Eoplectodonta*) *alternata* (Butts, 1942).

1, 2. GSC 103788, hypotype, ventral valve, figure 1, x4; figure 2, x10, GSC loc. C-56106.

3. GSC 103789, hypotype, dorsal valve with prominent median septum, x4, GSC loc. C-60924.

4, 5. GSC 103790, hypotype, dorsal valve showing hinge fossettes in cardinal portion of hingeline, figure 4, x3.5; figure 5, x8, GSC loc. C-78638.

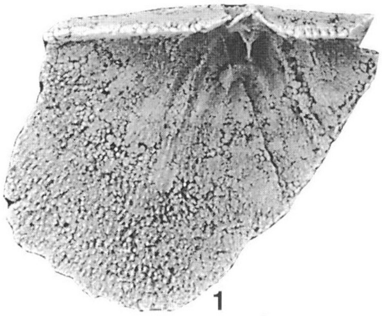
Figures 6–16. *Rafinesquina praecursor* (Raymond, 1921).

6–9. GSC 103791, hypotype, dorsal, lateral, ventral, posterior views of nearly complete shell, figures 6–8, x2.5; figure 9, x10, GSC loc. C-56101.

10–12. GSC 103792, hypotype, dorsal, ventral, and cardinal views of partly damaged shell, figures 10, 11, x2.5; figure 12, x5, GSC loc. C-56101.

13, 14. GSC 103793, hypotype, coarsely silicified dorsal valve, figure 13, x3; figure 14, x9, GSC loc. C-56101.

15, 16. GSC 103794, hypotype, coarsely silicified dorsal valve, figure 15, x2.5; figure 16, x7, GSC loc. C-56101.



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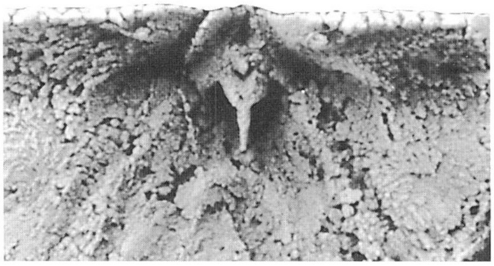

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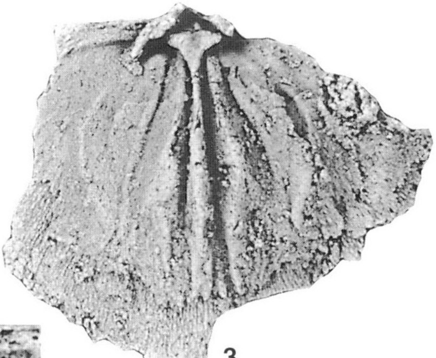

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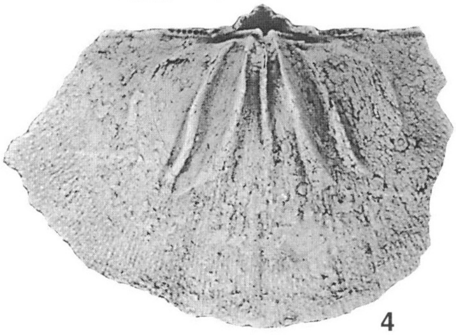

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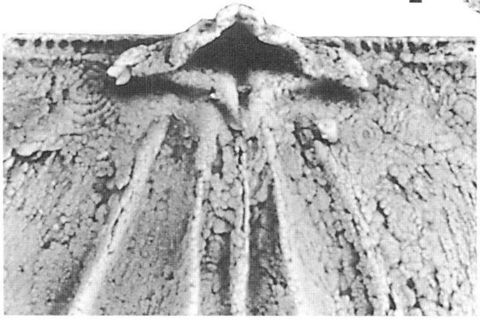

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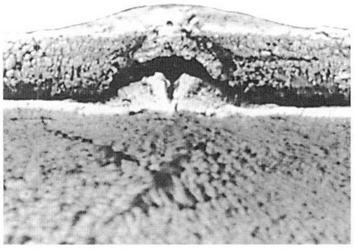

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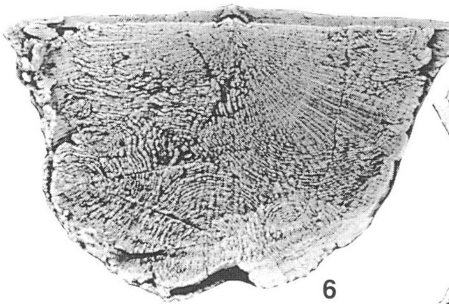

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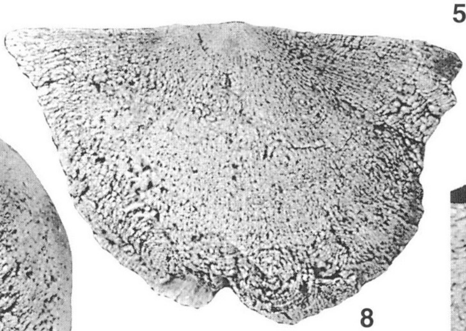

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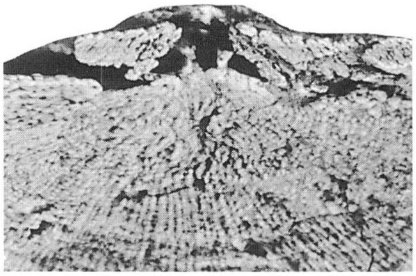

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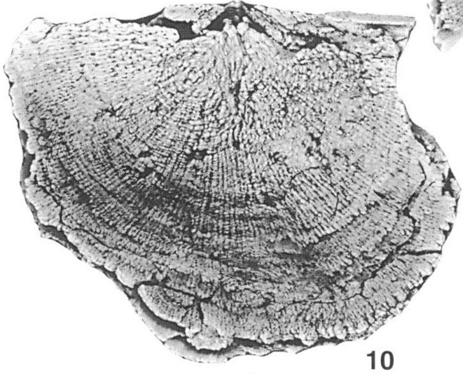

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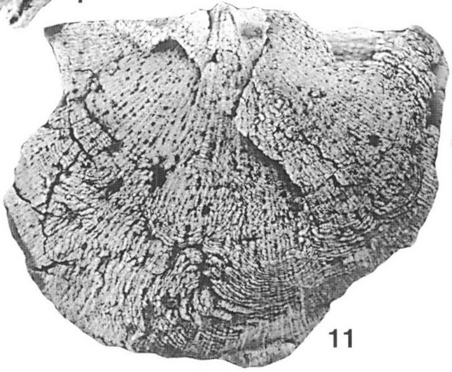

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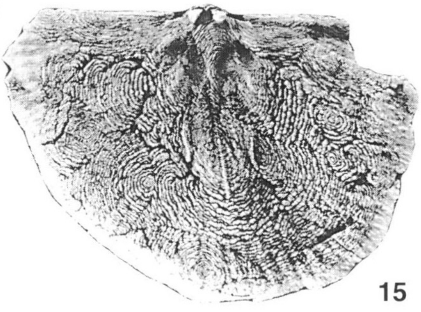

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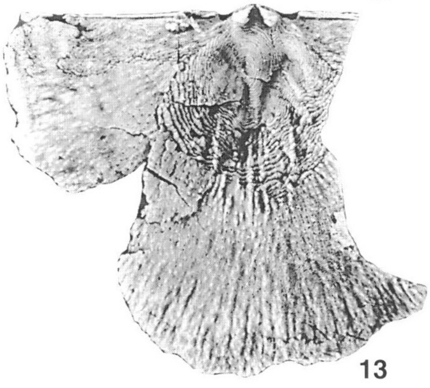

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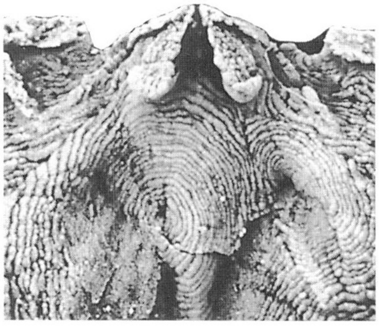

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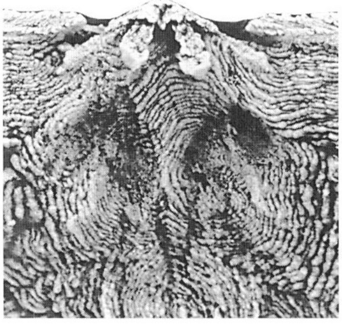

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PLATE 11

Figures 1, 2. *Rafinesquina praecursor* (Raymond, 1921).

1. GSC 103795, hypotype, ventral valve, x3, GSC loc. C-56101.

2. GSC 103796, hypotype, ventral valve, x3, GSC loc. C-56101.

Figures 3, 4. *Oepikina* sp.

GSC 103797, reference specimen, dorsal valve, x4.5, GSC loc. C-60924.

Figures 5–11. *Murinella* cf. *M. biconvexa* Cooper, 1956.

5–8. GSC 103798, hypotype, dorsal, cardinal, anterior, and lateral views of partly damaged shell, figures 5, 7, 8, x4; figure 6, x8, GSC loc. C-78638.

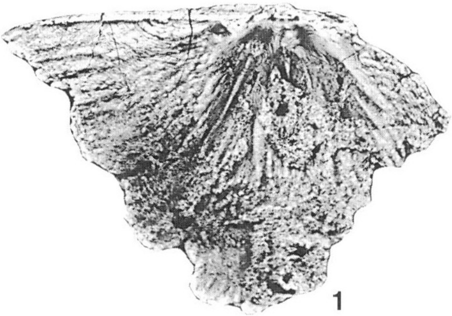
9–11. GSC 103799, hypotype, dorsal valve with well preserved cardinal process and broad hinge sockets, figures 9, 10, x4; figure 11, x11, GSC loc. C-78638.

Figures 12–18. *Strophomena* cf. *S. planumbona* (Hall, 1847).

12, 13. GSC 103800, hypotype, ventral valve, x2.5, GSC loc. C-60924.

14, 15. GSC 103801, hypotype, fragment of dorsal valve, figure 14, x4; figure 15, x9, GSC loc. C-60924.

16–18. GSC 103802, hypotype, ventral valve showing apical pseudodeltidium and muscle field with longitudinal and concentric ridges, figure 16, x2; figures 17, 18, x5, GSC loc. C-56101.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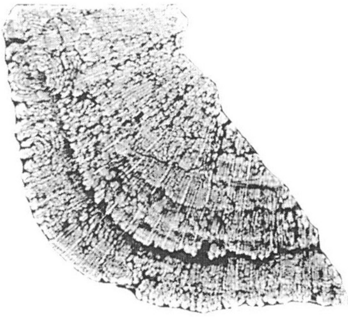
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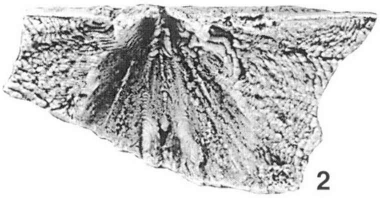
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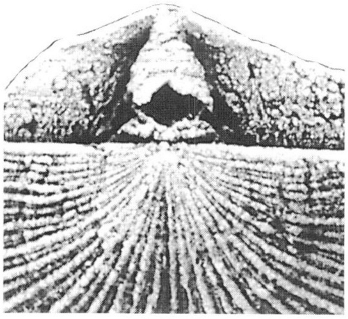
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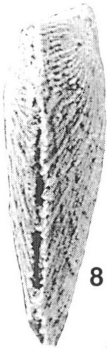
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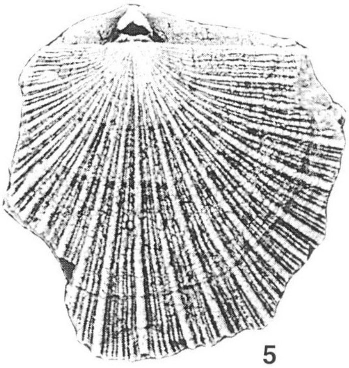
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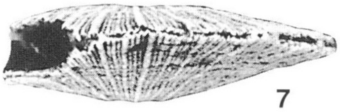
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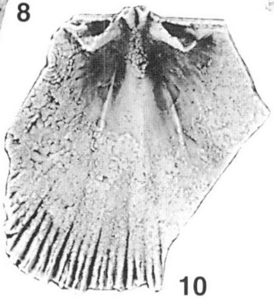
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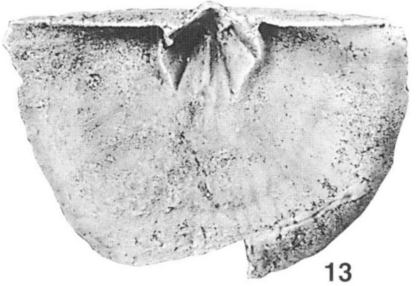
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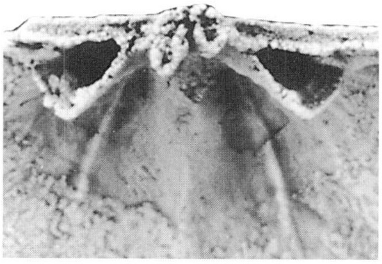
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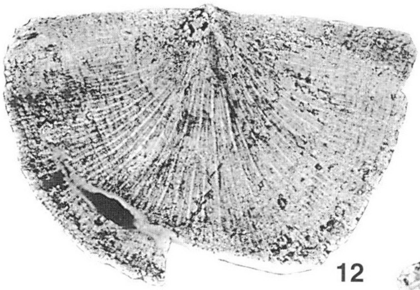
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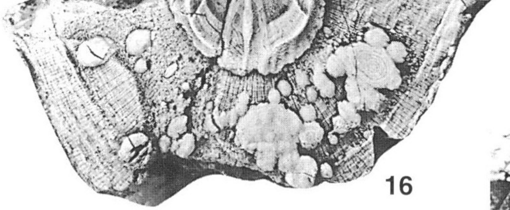
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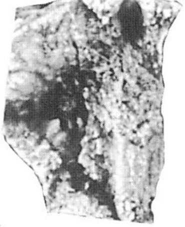
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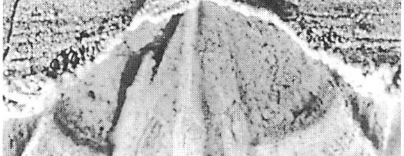
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PLATE 12

Figures 1–15. *Hiscobeccus mackenziensis* Jin and Lenz, 1992.

1–5. GSC 103803, hypotype, dorsal, ventral, lateral, anterior, and posterior views of complete shell, x4, GSC loc. C-60924.

6–10. GSC 103804, hypotype, dorsal, ventral, lateral, posterior, and anterior views, x4, GSC loc. C-60924.

11–15. GSC 103805, hypotype, dorsal, ventral, lateral, posterior, and anterior views, x4, GSC loc. C-60924.

16, 17. GSC 103806, hypotype, ventral valve showing shallow muscle field and well developed dental plates, figure 16, x5.5; figure 17, x6, GSC loc. C-60924.

18. GSC 103807, hypotype, dorsal valve showing large hinge plates and blade-like cardinal process, x7, GSC loc. C-60924.

Figures 19–27. *Anazyga bellicostata* n. sp.

19–23. GSC 103808, holotype, dorsal, ventral, lateral, posterior, and anterior views of strongly sulcate and carinate shell, x5, GSC loc. C-56101.

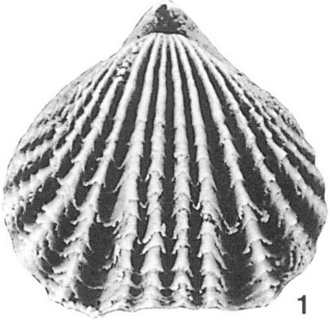
24, 25. GSC 103809, paratype, dorsal and anterior view of small shell, x8.5, GSC loc. C-56101.

26. GSC 103810, paratype, dorsal valve, x9, GSC loc. C-56101.

27. GSC 103811, paratype, dorsal valve, x7, GSC loc. C-56101.

Figure 28. Lingulid

GSC 103812, lingulid fragment preserved in burrow, x5, GSC loc. C-60924.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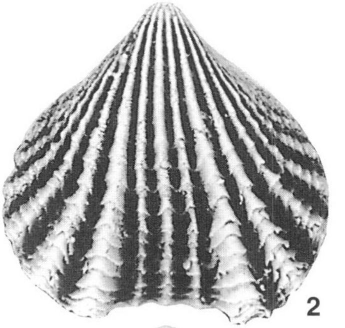
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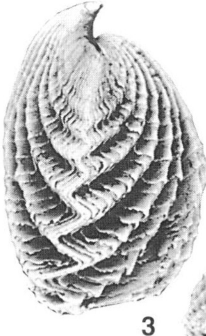
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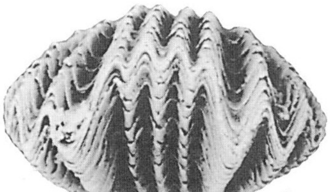
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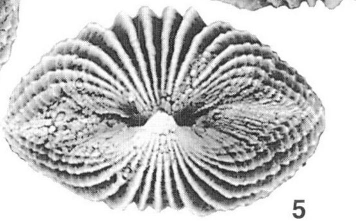
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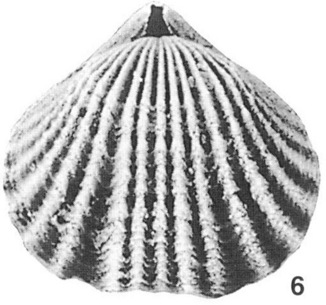
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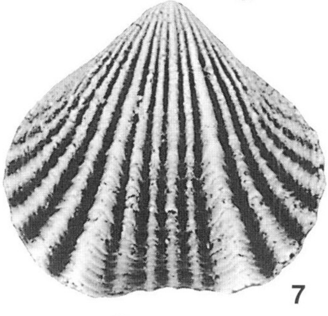
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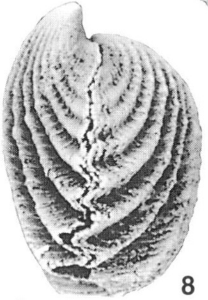
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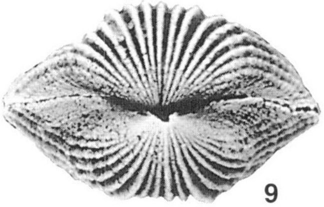
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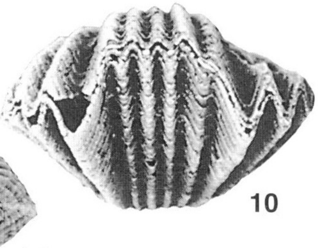
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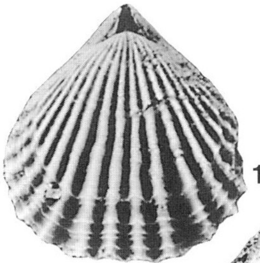
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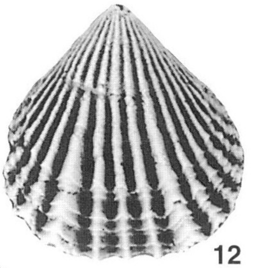
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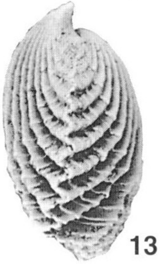
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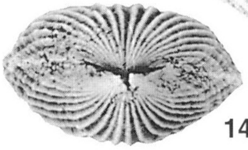
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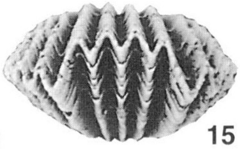
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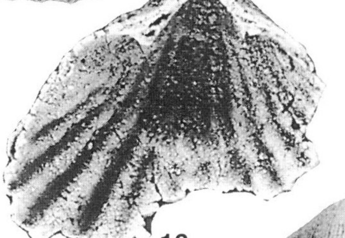
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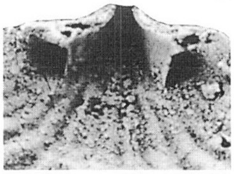
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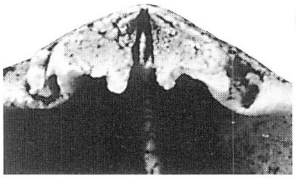
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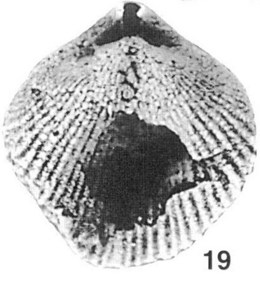
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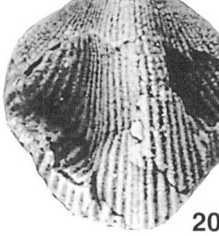
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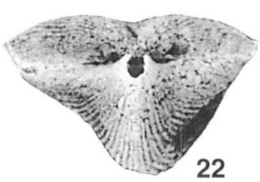
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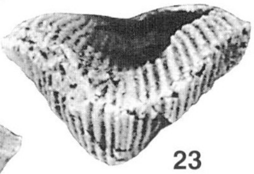
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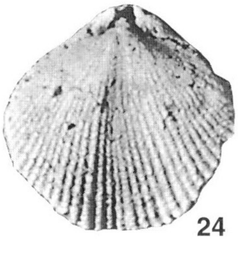
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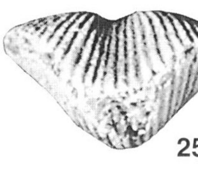
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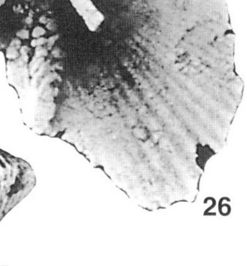
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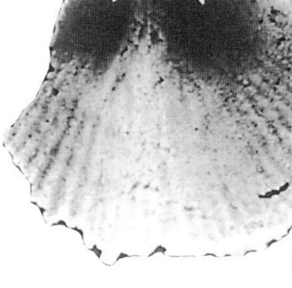
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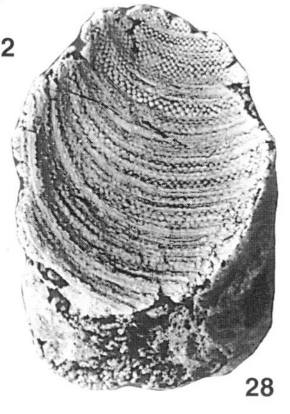
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PLATE 13

Figures 1–12. *Christiania subquadrata* (Hall, 1883).

1, 2. GSC 109188, hypotype, dorsal and ventral views of conjoined shell, with dorsal shell material exfoliated, traces of trans-muscle septa showing, x4, GSC loc. C-205922.

3. GSC 109189, hypotype, dorsal interior of mature individual with strong, blade-like median septum, x4, GSC loc. C-205922.

4. GSC 109190, hypotype, dorsal interior of mature individual with poorly developed median septum, x4, GSC loc. C-205922.

5–7. GSC 109191, hypotype, dorsal, lateral, and posterior views of partly damaged shell showing large, convex pseudodeltidium and epithyridid foramen, x4, GSC loc. C-205922.

8–10. GSC 109192, hypotype, internal, lateral, and tilted apical views (fig. 10) of ventral valve, figures 8, 9, x4; figure 10, x8, GSC loc. C-205922.

11, 12. GSC 109193, hypotype, interior of mature dorsal valve showing posteriorly directed, bilobate cardinal process and poorly developed median ridge, figure 11, x4; figure 12 (tilted view), x8, GSC loc. C-205922.

Figures 13–17. *Leangella* (*Leangella*) *biseptata* n. sp.

13. GSC 109194, paratype, interior of ventral valve showing rod-like process anterior to muscle field, x7, GSC loc. C-205921.

14, 15. GSC 109195, paratype, interior of incomplete ventral valve with median process arching dorsally, x9, GSC loc. C-205921.

16. GSC 109196, paratype, interior of incomplete ventral valve, with median process supported underneath by thin plate, x8, GSC loc. C-205921.

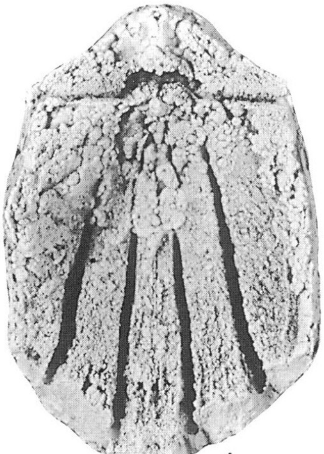
17. GSC 109197, paratype, interior of dorsal valve showing bema and peripheral rim, x8, GSC loc. C-205921.

Figures 18–22. *Platystrophia colbiensis* Foerste, 1910.

GSC 109198, hypotype, dorsal, ventral, lateral, anterior, and posterior views of immature shell, x6, GSC loc. C-205924.

Figure 23. *Parastrophina* sp.

GSC 109199, hypotype, interior of small ventral valve showing spondylium sessile posteriorly and supported anteriorly by low median septum, x12.5, GSC loc. C-205919.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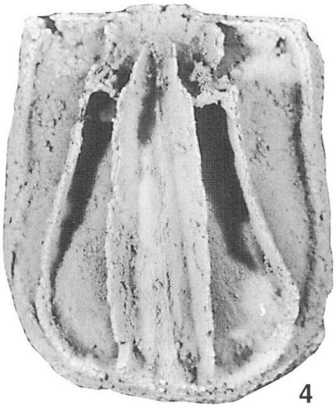
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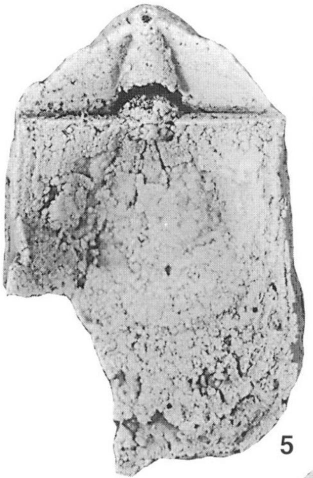
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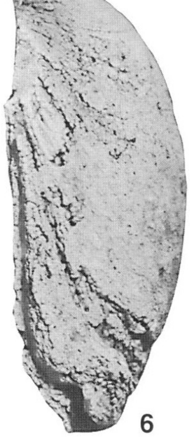
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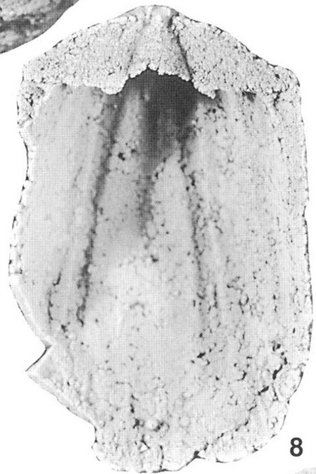
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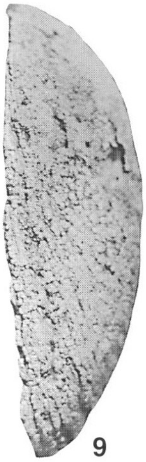
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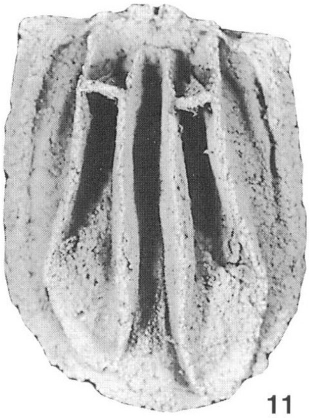
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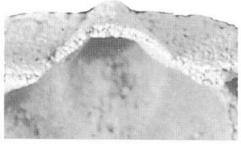
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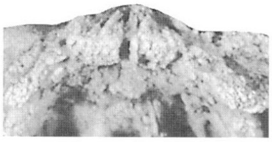
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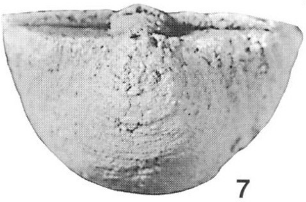
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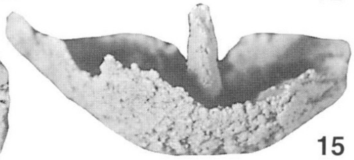
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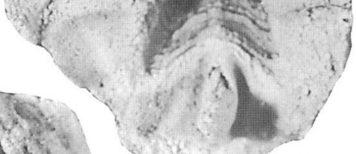
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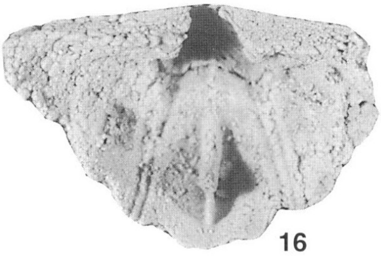
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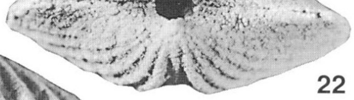
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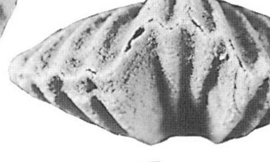
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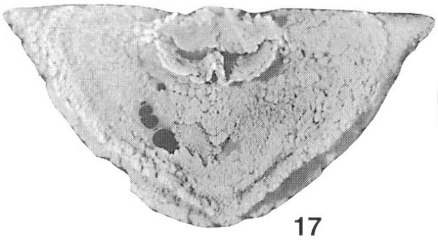
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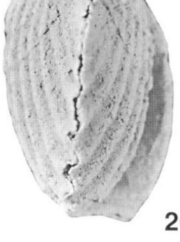
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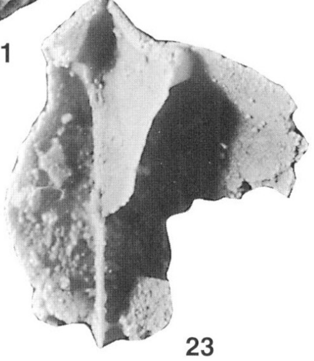
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CORALS OF THE ADVANCE FORMATION (UPPER MIDDLE ORDOVICIAN), NORTHERN ROCKY MOUNTAINS OF BRITISH COLUMBIA

Robert J. Elias

Abstract

All corals known from slope deposits of the Advance Formation are solitary rugosans. *Paliphyllum norfordi* n. sp., represented by a single specimen, and *Grewingkia burdenensis* n. sp., which is more common, are the only identifiable species. Diversity and abundance are low compared with the taxonomically different coral fauna in approximately coeval shelf deposits of the Johnson Spring Formation, California. *Grewingkia burdenensis* is considered to be the ancestor of *Grewingkia robusta*, a Late Ordovician species that was widely distributed within the Red River–Stony Mountain Province of cratonic North America. *Paliphyllum norfordi* is the earliest paliphyllid worldwide, and the only rugosan with dissepiments known from the Middle Ordovician of North America. It appears to be most similar to some representatives of *Paliphyllum* in the Dolbor Formation (uppermost Caradoc–lowermost Ashgill), Siberian Platform.

Coralla of *G. burdenensis* were subject to little current action or transportation. This species generally lived freely on soft substrates; sediment cohesion may have been low. In one stratigraphic interval, the presence of specimens with attachment structures suggests that the substrate may have been unfavourable for the coral's normal mode of life, or that more objects suitable for attachment were available than usual. The corallum of *P. norfordi* was subject to higher current energy and possibly transportation, and/or longer exposure before final burial. This coral was overturned, possibly due to current activity or substrate instability or both, and redirected its growth upward several times during life. It is the earliest North American solitary rugosan that had the ability to resume upward growth after being fully overturned.

Résumé

Tous les coraux connus provenant des dépôts de talus de la Formation d'Advance sont des tétracoralliaires solitaires. *Paliphyllum norfordi* n. sp. représenté par un seul spécimen, et *Grewingkia burdenensis* n. sp., qui est plus commun, sont les seules espèces identifiables. Ces coraux sont peu diversifiés et peu abondants comparativement à la faune corallienne de taxonomie différente que l'on trouve dans les dépôts de plate-forme continentale à peu près contemporains de la Formation de Johnson Spring en Californie. *Grewingkia burdenensis* est considéré comme l'ancêtre de *Grewingkia robusta*, une espèce de l'Ordovicien tardif qui était très répandue dans la Province de Red River–Stony Mountain du craton nord-américain. *Paliphyllum norfordi* est le plus ancien paliphyllidé dans le monde et le seul tétracoralliaire à dissépiments connu en Amérique du Nord qui date de l'Ordovicien moyen. Il semble être très semblable à certains représentants de *Paliphyllum* de la Formation de Dolbor (Caradocien sommital–Ashgillien basal) de la plate-forme sibérienne.

Les polypiers de *G. burdenensis* ont subi une faible action par les courants ou un faible transport. Cette espèce vivait en général librement sur des substrats tendres; la cohésion des sédiments a pu être faible. La présence, dans un intervalle stratigraphique, de spécimens dotés de structures d'attache laisse supposer que le substrat a pu ne pas être favorable au mode de vie habituel du corail ou que les objets servant d'attaches étaient plus abondants qu'à l'habitude. Le polypier de *P. norfordi* a subi l'action de courants de plus forte énergie et peut-être un transport ou une exposition plus longue avant son enfouissement final. Ce corail a été renversé par les courants peut-être ou à cause de l'instabilité du substrat ou les deux; il a redirigé sa croissance vers le haut à plusieurs reprises durant sa vie. C'est le premier tétracoralliaire solitaire d'Amérique du Nord à avoir la capacité de reprendre sa croissance vers le haut après avoir été complètement renversé.

INTRODUCTION

Middle Ordovician (Mohawkian) coral faunas are poorly known, especially from western North America where sand was deposited widely on the craton (Duncan, 1956; Ross, 1976, Figs. 8, 9). The discovery of corals within slope deposits of the Advance Formation in the northern Rocky Mountains of British Columbia is significant. *Grewingkia burdenensis* n. sp. shares an evolutionary lineage with corals in the Late Ordovician Red River–Stony Mountain Province, which occupied most of cratonic North America. *Paliphyllum norfordi* n. sp., the earliest known paliphyllid, appears to be most similar to some representatives of *Paliphyllum* Soshkina, 1955 of the early Late Ordovician of the Siberian Platform. The Advance Formation coral fauna differs considerably from the fauna in approximately coeval platform-margin shelf deposits of the Johnson Spring Formation in California.

The growth form and condition of the exterior surface of coralla in the Advance Formation provide information on the depositional environment.

CORALS OF THE ADVANCE FORMATION

Norford (*this volume*) summarizes evidence indicating the Advance Formation in the northern Rocky Mountains of British Columbia is late Middle Ordovician (Rocklandian-Shermanian) in age. This unit consists of carbonate rocks and shales that were deposited in a slope environment of moderate water depth, in a platform-edge setting along a passive continental margin. Corals are an accessory component of a macrofauna dominated by brachiopods. All are solitary rugosans: colonial rugosans and tabulates have not been found (see Appendix).

The identifiable coralla are assigned to two species: *Grewingkia burdenensis* and *Paliphyllum norfordi* (see Systematic Paleontology). Both are known only from the Advance Formation. *Paliphyllum norfordi* is represented by a single specimen from 8.0 to 9.5 m above the base of the Advance Mountain Section. *Grewingkia burdenensis* is more common. It occurs 10.5 to 46.0 m above the base of the Advance Mountain Section, 16.5 to 27.5 m above the base of the Mount Burden Section, and at an isolated outcrop west of Bernard Creek.

Faunal comparison

The Johnson Spring Formation in the Inyo Mountains of California is considered to be late Middle Ordovician (Rocklandian–Kirkfieldian) in age (Ross et al., 1982). It consists of interbedded carbonate rocks and quartzite, and was deposited in a shallow subtidal shelf environment with quartz sand channels on the outer margin of an extensive platform (Sloan, 1976). The Johnson Spring and Advance formations are of similar ages and were deposited along the same continental margin, although at widely separated locations and in different environments (shelf versus slope).

Pestana (1960) documented the corals of the Johnson Spring Formation. They occur in carbonate strata, and are the dominant, or an abundant, faunal constituent in some intervals (Sloan, 1976). Diverse solitary rugosans are present, as well as colonial rugosans and tabulates. This constrasts with the Advance Formation where corals are an accessory component of the macrofauna, their diversity is low, and all are solitary forms.

Coral faunas of the Johnson Spring and Advance formations also differ taxonomically. *Grewingkia whitei* Pestana, 1960 of the Johnson Spring Formation differs from *Grewingkia burdenensis* of the Advance Formation in attaining relatively large size and in having short, wavy major septa and a very large, loosely constructed axial structure (compare Pestana, 1960, Pl. 111, figs. 1, 2, with Pl. 1, fig. 14 herein). These two species are the only representatives of *Grewingkia* Dybowski, 1873 presently known from the Middle Ordovician of North America. They are not closely related. *Paliphyllum norfordi* of the Advance Formation, representing Paliphyllidae Soshkina, 1955, is the only rugosan with dissepiments known from the Middle Ordovician of North America.

Differences between the coral faunas of the Advance and Johnson Spring formations probably reflect, at least in part, the differences between slope and shelf environments.

Evolutionary relationships

Grewingkia burdenensis of the Advance Formation is very similar in many respects to *Grewingkia robusta* (Whiteaves, 1896) (see Discussion under *G. burdenensis* in Systematic Paleontology). These two species are considered to be closely related. *Grewingkia burdenensis* lived in a slope environment along the western continental margin of North America in the late Middle Ordovician (Rocklandian–Shermanian). *Grewingkia robusta*, a Late Ordovician (Edenian-Richmondian) species, was widely distributed within the Red River–Stony Mountain Province of cratonic North America (Elias, 1991).

It is inferred that *G. burdenensis* is ancestral to *G. robusta*. The evolutionary transition involved the following changes: 1) an increase in the variability of corallum cross-sectional shape, to include pronounced triangulation and slight trilobation; 2) an increase in size of the axial region and a decrease in the number of highly contorted septal lamellae in the axial structure at comparable corallum diameters; and 3) an increase in the size attained by coralla, accompanied by the development of tabellae and a large, complex axial structure in the late ontogenetic stage of *G. robusta*. *Grewingkia robusta*, in turn, gave rise to numerous species in the Red River-Stony Mountain Province (Elias, 1985, p. 17, 18).

Within the cratonic interior of western North America, Upper Ordovician deposition began, and the Red River-Stony Mountain Province originated, during a major transgression in the Edenian (Elias, 1991). *Grewingkia robusta* appeared at that time. A significant hiatus separates Middle and Upper Ordovician sequences on the western craton (Sweet, 1984, Fig. 3). *Grewingkia burdenensis*, the ancestor of *G. robusta*, existed along the continental margin during that time. The Edenian transgression provided an opportunity for corals to disperse from the continental margin into the interior. Endemic cratonic species evolved from certain taxa previously restricted to the continental margin.

Paliphyllum norfordi of the Advance Formation is the earliest known representative of *Paliphyllum*. Other species of this genus occur in the Upper Ordovician of the Siberian Platform, Gorny Altai, Anticosti Island, and Sweden, and in the Lower Silurian (Llandovery) of Estonia, Tuva, Ohio-Indiana, and Iran (see Discussion under *P. norfordi* in Systematic Paleontology).

Paliphyllum norfordi is large, ceratoid to subcylindrical in form, and has thin septa and a small, simple, open axial structure with a median septal lamella. It appears to be most similar to some representatives of *Paliphyllum* in the Dolbor Formation (Upper Ordovician; uppermost Caradoc–lowermost Ashgill), Podkamennaya Tunguska River Basin, Siberian Platform. Some coralla of *Paliphyllum primarium* Soshkina, 1955, and certain ontogenetic stages in some other specimens of this species, have a simple, open axial structure (e.g., Ivanovsky, 1965, Pl. 22, fig. 3b; Sytova, 1979, Pl. 34, fig. 2). However, *P. primarium* typically develops a relatively complex axial structure (e.g., Ivanovsky, 1965, Pl. 22, fig. 3a; Hill, 1981, Fig. 96.2a). It has thicker septa than *P. norfordi*, attains a large number of septa at a smaller diameter, and has a smaller, broadly conical corallum. *Paliphyllum medius* Ivanovsky, 1965 is more cylindrical than typical specimens of *P. primarium*, but is otherwise similar and was considered to be a synonym by Sytova (1979). *Protocyathactis cybaeus* Ivanovsky, 1961 has been reassigned to *Paliphyllum*. It is relatively small, ceratoid or subcylindrical, with thin septa and a small, simple axial structure. Certain ontogenetic stages of one figured specimen have an open axial structure (e.g., Ivanovsky, 1963, Pl. 24, fig. 3a: recognized as synonymous with *P. primarium* by Sytova, 1979). However, a median septal lamella is not as distinct as in *P. norfordi*.

Other than *P. norfordi*, the only North American Ordovician species assignable with certainty to *Paliphyllum* is *P. ellisense* (Twenhofel, 1928). It occurs in shallow shelf, continental margin deposits of the Ellis Bay Formation (uppermost Ordovician; Gamachian), Anticosti Island, Québec. *Paliphyllum ellisense* is not closely related to *P. norfordi*. Coralla originally identified as *Phaulactis stummi* Nelson, 1963 occur in the upper part of the Chasm Creek Formation (Upper Ordovician; upper Richmondian), northern Manitoba. This is the earliest rugosan with dissepiments known from the cratonic interior of North America. Assignment of *P. stummi* to *Paliphyllum* (see Elias, 1982, p. 82) is questionable because of its prominent cardinal fossula, short cardinal septum in the late ontogenetic stage, and strong dilation of major septa within the tabularium on the cardinal side of the corallum (see Nelson, 1963, Pl. 13, fig. 8b-d). *Paliphyllum* is definitely present within the cratonic interior in the Brassfield Formation (Lower Silurian; mid-Llandovery), Ohio and Indiana (see Discussion under *P. norfordi* in Systematic Paleontology).

Paleoecology and taphonomy

Curvature of the growth axis is slight in *Grewingkia burdenensis* from the Advance Formation (e.g., Pl. 1, figs. 3, 6; Pl. 2, fig. 2). Such corals are thought to have lived in low-energy environments (Elias et al., 1988). Etched, silicified specimens of *G. burdenensis* with well preserved exterior surfaces were examined from collections made at GSC localities C-56101, C-60924, C-78638, C-78640, C-205921, and C-205922 (see Appendix). Fine growth lines are present on at least some of the individuals in each collection (e.g., Pl. 1, figs. 3, 4, 6, 7; Pl. 2, figs. 2, 3). Such coralla were not significantly abraded, indicating that exposure to currents and transportation before final burial were minimal (Elias et al., 1988). These inferences are consistent with other lines of evidence suggesting that the Advance Formation was deposited in moderate water depths where there was generally little current action and transportation (Norford, *this volume*).

Attachment structures are not present on specimens of *G. burdenensis* with well preserved apices from GSC localities C-56101, C-78638, C-78640, and C-205921. Based on their growth form, the life habit of such solitary rugosans can be categorized as liberosessile (Neuman, 1988). They lived freely on soft substrates. Some of the specimens in collections from GSC localities C-56101, C-78638, and C-78640 have slight, irregular bends in the growth axis, especially in early ontogenetic stages (e.g., Pl. 1, fig. 4). This indicates that growth was redirected following tilting of the corallum. Such reorientation could be due to current activity, but evidence stated previously suggests that energy levels were low. It is possible that the instability of some corals was related to low sediment cohesion. A small number of specimens have irregularities in growth lines, indicating that the calice rim was damaged and repaired during life, or that the calice rim became distorted as a result of contact with relatively large grains at the substrate surface (e.g., Pl. 1, figs. 3, 4).

All specimens of *G. burdenensis* with well preserved apices from GSC locality C-205922 have medium-sized attachment structures on the cardinal side (e.g., Pl. 2, figs. 2, 3). The life habit of such corals can be categorized as fixosessile (Neuman, 1988). Objects to which these coralla were attached are not preserved, but shapes of the attachment sites suggest shells with relatively smooth, slightly convex or concave surfaces. One of the objects had a curved margin (Pl. 2, fig. 3). In this stratigraphic interval, the substrate may have been unfavourable for the normal liberosessile mode of life of *G. burdenensis*, or the availability of objects that remained exposed on the sea floor and were suitable for attachment was greater than usual.

The single specimen of *Paliphyllum norfordi* from GSC locality C-205920 shows evidence of substantial abrasion, and possibly breakage, prior to burial. The thin outer wall is missing from most of the corallum, one side in the lower part of the specimen is absent (see Pl. 2, figs. 4–6), and the apical portion is also missing (see Pl. 2, fig. 12; the corallum ends between the position of transverse section 4 and the apical termination of the photograph). Compared with stratigraphic intervals containing *G. burdenensis*, this suggests greater intensity of abrasion due to higher current energy and, possibly, transportation, or longer exposure to abrasion due either to a lower sedimentation rate or to reworking before final burial, or both (see Elias et al., 1988). The specimen of *P. norfordi* is the only coral from the Advance Formation with an attached encruster; a tiny epizoic bryozoan on part of the corallum where the outer wall is preserved (Pl. 2, fig. 8). This indicates exposure above the substrate, but it is not known whether the bryozoan colonized the corallum before or after death of the polyp.

The corallum of *P. norfordi* has a contorted growth form with irregular, high-angle bends that go in different directions (Pl. 2, figs. 10, 12). This indicates that the coral was overturned and redirected its growth upward several times during life. Overturning may have been due to current activity or substrate instability, or both. This is the earliest North American solitary rugosan presently known that had the ability to grow upward after being fully overturned (see Elias, 1984; McAuley and Elias, 1990, p. 29).

SYSTEMATIC PALEONTOLOGY

Numbered specimens examined in this study are deposited in the Type Collection of Invertebrate and Plant Fossils of the Geological Survey of Canada (GSC), Ottawa.

Subclass RUGOSA Milne
Edwards and Haime, 1850

Order STAURIIDA Verrill, 1865

Suborder STREPTELASMATINA Wedekind, 1927

Family STREPTELASMATIDAE
Nicholson *in* Nicholson and Lydekker, 1889

Subfamily STREPTELASMATINAE
Nicholson *in* Nicholson and Lydekker, 1889

Genus *Grewingkia* Dybowski, 1873

Grewingkia burdenensis n. sp.

Plate 1, figures 1–16; Plate 2, figures 1–3

Grewingkia sp., Norford *in* Thompson, 1989, p. 100, 101.

Derivation of name. This species is named for Mount Burden in the northern Rocky Mountains of British Columbia, where the holotype was collected.

Holotype. GSC 103878 (Pl. 1, figs. 11–16), GSC loc. C-60924, Mount Burden Section (Norford, *this volume*, Appendix 3).

Paratypes. GSC 103879 (Pl. 1, fig. 2), 103880 (Pl. 1, figs. 9, 10), GSC loc. C-60924, Mount Burden Section; GSC 103881 (Pl. 1, figs. 6–8), 103882 (Pl. 1, figs. 3–5), GSC loc. C-78638, GSC 109304 (Pl. 2, figs. 2, 3), 109305 (Pl. 2, fig. 1), GSC loc. C-205922, GSC 103883, GSC loc. C-78640, all from Advance Mountain Section; GSC 103884 (Pl. 1, fig. 1), GSC loc. C-56101, ridge top, west of Bernard Creek (Norford, *this volume*, Appendix 3).

Other material. GSC 103885, 103886, GSC loc. C-60924, Mount Burden Section; GSC 103887, GSC loc. C-78638, GSC 109306, GSC loc. C-205921, GSC 109307, GSC loc. C-205922, GSC 109308, GSC loc. C-205924, GSC 103888-103890, GSC loc. C-78640, all from Advance Mountain Section; GSC 103891-103893, GSC loc. C-56101, ridge top, west of Bernard Creek (Norford, *this volume*, Appendix 3).

Occurrence. Advance Formation (upper Middle Ordovician; Rocklandian–Shermanian), northern Rocky Mountains of British Columbia.

Diagnosis. Grewingkia attaining medium size; transverse section virtually circular, very slightly triangulate. Septal dilation very great to complete in early stage, decreasing during ontogeny to nondilated in late stage. Cardinal septum long and conspicuous throughout ontogeny; tabulae depressed in narrow cardinal fossula. Axial structure in late stage small, with septal lobes at periphery and numerous highly contorted septal lamellae axially.

Description of coralla. Coralla are small to medium-sized; most are 5 to 10 mm in length. The largest specimen has a length greater than 25 mm (apex is missing) and a diameter of 25 mm at the top of the calice (Pl. 1, figs. 6–8). Coralla are trochoid and slightly curved, with a convex cardinal side (Pl. 1, figs. 3, 4, 6, 7; Pl. 2, figs. 2, 3). They are virtually circular in transverse section, but well preserved specimens show a very slight angulation at the position of the cardinal septum and immediately on the counter side of the two alar septa. On well preserved coralla, growth lines are present; septal grooves and interseptal ridges are absent to weakly developed. Eleven specimens have well preserved apices; eight lack attachment structures (e.g., Pl. 1, figs. 3, 4) and three have medium-sized attachment structures on the cardinal side of the corallum (e.g., Pl. 2, figs. 2, 3). Depth of the calice is 36 to 50 per cent of the corallum length (average = 44%, n = 5).

Ontogeny and internal structures. The relationship between number of major septa and corallum diameter is shown in Figure 1. In the early stage (Pl. 1, figs. 1, 9–11), the cardinal septum extends to the corallum axis, where other major septa meet around it. Major septa are very greatly to completely dilated; the cardinal septum is typically thicker than other major septa, especially axially. Minor septa are short.

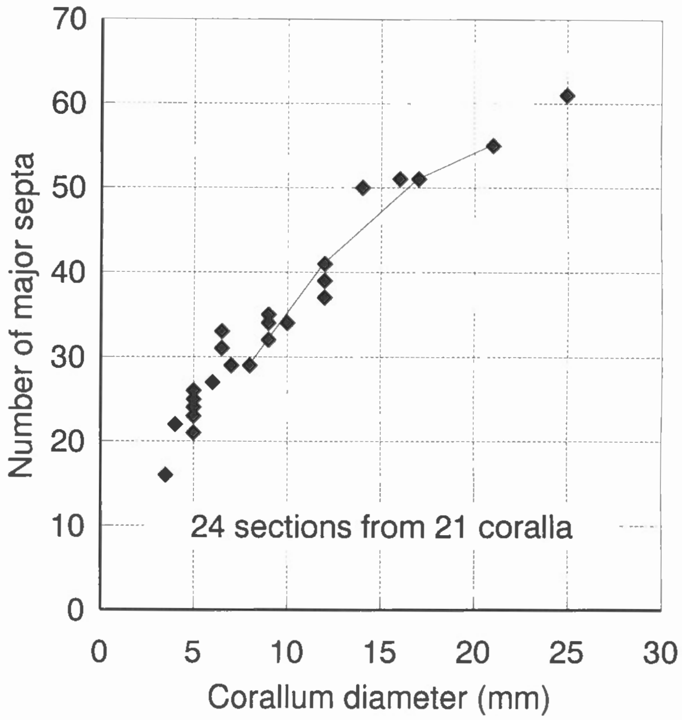

Figure 1. *Relationship between number of major septa and corallum diameter in* ***Grewingkia burdenensis*** *n. sp. from the Advance Formation, northern Rocky Mountains of British Columbia. Solid line connects data points from holotype GSC 103878 (GSC loc. C-60924).*

In the intermediate stage (Pl. 1, figs. 2, 5, 12, 13; Pl. 2, fig. 1), the cardinal septum remains very long. The counter septum may also be long, and may meet the cardinal septum axially. Other major septa extend to near the axis, where they commonly join in pairs or small groups. The small axial structure consists initially of lobes from the cardinal and counter septa, as well as a few lobes from other major septa and septal groups. This is followed by the appearance of a few septal lamellae. Elements of the axial structure are greatly dilated, and the lobe of the cardinal septum is especially prominent. The degree of septal dilation decreases, but may be slightly greater on the cardinal side than on the counter side of the corallum. The cardinal septum becomes thinner than other major septa on the cardinal side, and a long, narrow cardinal fossula develops. Minor septa increase in length, and may extend beyond the stereozone when major septa are only slightly dilated. Minor septa beside the counter septum may be longer than other minor septa.

In the late stage (Pl. 1, figs. 8, 14), the cardinal septum is long and is thinner than the other major septa below the base of the calice. All septa become nondilated within the calice. The cardinal fossula is narrow, but may expand slightly at the axial end. Its sides are formed by a series of contratingent major septa. The radius of the axial region is 20 to 30 per cent of the corallum radius. The axial structure consists of numerous highly contorted septal lamellae, with septal lobes at the periphery; the lobe of the cardinal septum may be very long. Width of the stereozone at the base of the calice is 15 per cent of the corallum radius. Length of the minor septa is 25 per cent of the corallum radius; minor septa extend well beyond the stereozone. Below the base of the calice, minor septa are contratingent to contraclined (Pl. 1, fig. 8). High in the calice, they are almost as long as the major septa.

Tabulae in the septal region are almost all complete (Pl. 1, figs. 15, 16). They are relatively straight in longitudinal section, although some are upturned where they meet the corallum wall. Tabular spacing is 0.2 to 1.0 mm. Tabulae are inclined up toward the axial region at an angle of 50 to 65 degrees (measured from a line perpendicular to corallum growth axis), but are depressed in the cardinal fossula, where they are inclined at an angle of 75 degrees.

Microstructure. In transverse thin section, the major septa are distinctly fibrous in all ontogenetic stages. From a medial position in the septum, the fibres curve outward in the direction of the corallum axis so that their convex sides face axially. Septal lobes and lamellae in the axial structure are fibrous. Within the stereozone, major and minor septa are in lateral contact along a contorted suture.

In longitudinal thin section, fibres in the stereozone are perpendicular to the outer wall or are slightly inclined toward the corallum axis. Tabulae consist of a thin basal layer and a thicker upper layer.

Discussion. The 21 coralla from the Advance Formation in the northern Rocky Mountains of British Columbia (documented above) most closely resemble *Grewingkia robusta* (Whiteaves, 1896). The latter species was studied most recently by Elias (1985), who provided a synonymy. It is known from the following Upper Ordovician units: Second Value Dolomite (middle Edenian-lowermost Maysvillian), Montoya Group, New Mexico and Texas (Elias, 1985, Figs. 5.1-5.16, 6.1-6.17); Selkirk Member (middle Maysvillian-lowermost Richmondian), Red River Formation, southern Manitoba (Elias, 1981, Pl. 3, figs. 1-12; Pl. 4, figs. 1-14); Portage Chute and Surprise Creek formations, Bad Cache Rapids Group (Edenian-lower Richmondian), northern Manitoba (Nelson, 1963, Pl. 8, figs. 1a, b, 2, 3a-f; Pl. 9, figs. 1a, b, 2a-c, 3a, b, 4; Nelson, 1981, Pl. 2, figs. 1-11; Pl. 6, figs. 1-8); and Bad Cache Rapids Formation (Edenian-lower Richmondian), Melville Peninsula, Northwest Territories (Bolton, 1977, Pl. 1, figs. 1, 8-10).

The number of major septa at a particular corallum diameter in specimens from the Advance Formation is comparable to that in *G. robusta* (compare Fig. 1 with Elias, 1985, Fig. 8). Values for coralla from the Advance Formation correspond to those for *G. robusta* from southern and northern Manitoba, where there is little variability in number of septa, and lie in the upper part of the range for *G. robusta* from New Mexico and Texas, where variability is considerable. The nature of the cardinal septum and fossula, the counter septum and other major septa, the minor septa, and septal dilation during ontogeny is the same for coralla of the Advance Formation as for those of *G. robusta*.

Specimens from the Advance Formation are small to medium-sized, whereas those of *G. robusta* are commonly much larger. Advance Formation coralla are virtually circular, but may be very slightly triangulate, in transverse section. In collections of *G. robusta*, some specimens are of comparable shape but the range of variability is much greater. Triangulation and especially the cardinal angulation may be pronounced, and some coralla are slightly trilobate. The axial structure in the late ontogenetic stage of Advance specimens is smaller and has more numerous and highly contorted septal lamellae than at comparable corallum sizes in *G. robusta*. In the late stage of *G. robusta*, when corallum size is greater than that attained by Advance specimens, the axial structure is large and very complex. Tabulae that occur in the septal region of Advance specimens in intermediate to late stages are almost all complete. Tabellae occupy the septal region in the late stage of *G. robusta*.

Coralla from the Advance Formation are closely similar to *G. robusta* in many respects. However, they differ from the latter species most notably in the range of variability of cross-sectional shape, and in size and complexity of the axial structure at comparable corallum sizes. They are therefore assigned to a new species, *Grewingkia burdenensis*.

Family PALIPHYLLIDAE Soshkina, 1955

Genus *Paliphyllum* Soshkina, 1955

Paliphyllum norfordi n. sp.

Plate 2, figures 4–12

Derivation of name. This species is named in honour of B.S. Norford, who discovered the unique specimen on which it is based.

Holotype and only specimen. GSC 109309 (Pl. 2, figs. 4–12), GSC loc. C-205920, Advance Mountain Section (Norford, *this volume*, Appendix 3).

Occurrence. Advance Formation (upper Middle Ordovician; Rocklandian–Shermanian), northern Rocky Mountains of British Columbia.

Diagnosis. Paliphyllum attaining large size; ceratoid to subcylindrical. Septa thin; minor septa long. Axial structure small, simple, open, with thin to slightly dilated median septal lamella; septal lobes rare. Dissepimentarium moderately wide.

Description of corallum. The corallum is large, with a length greater than 130 mm (apex is missing) and maximum diameter of 36 mm (Pl. 2, fig. 12). Growth form changes from ceratoid to subcylindrical during ontogeny, with irregular bends in different directions (not curved in the cardinal-counter plane). Minor rejuvenescence may accompany changes in growth direction. Where the wall is preserved, septal grooves and interseptal ridges are absent to weakly developed. The calice (incompletely preserved) is apparently shallow, possibly with a calicular pit (Pl. 2, fig. 10).

Ontogeny and internal structures. In all known stages (Pl. 2, figs. 4–9), septa are slightly wavy, thin, and taper slightly toward the axis. Major septa have a thickness of 0.1 to 0.2 mm at mid length; length is about 80 per cent of the corallum radius. The cardinal septum is indistinct (but can be recognized by the contratingent newly inserted major septa on either side); a fossula is not developed. The number of major septa is 52 at a corallum diameter of 30 mm (Pl. 2, fig. 8) and 55 at a diameter of 36 mm (Pl. 2, fig. 9). Minor septa are commonly contraclined to contratingent, and extend axially to the edge of or slightly beyond the dissepimentarium. The length of minor septa as a percentage of the length of major septa increases progressively from 38 per cent in the earliest known stage to 76 per cent in the latest. In one section, the minor septum on one side of the counter septum is almost as long as the major septa (Pl. 2, fig. 8).

The axial region is small in all known stages; its radius is about 20 per cent of the corallum radius. The axial structure is simple (Pl. 2, figs. 5, 7–9). Septal lobes are rare and adjacent major septa seldom join together except in one section (Pl. 2, fig. 8), where slightly dilated and slightly contorted septal lobes occur in the outer part of the axial region; these lobes arise from individual septa or from small groups of septa. A median septal lamella parallel to the cardinal-counter plane can be recognized in three transverse sections. In two of these sections (Pl. 2, figs. 7, 8), the slightly dilated and slightly contorted median lamella is connected to the cardinal septum and to major septa on the counter side of the axial region. In the third section (Pl. 2, fig. 9), the median lamella is thin, slightly wavy to curved, and is not connected to the cardinal septum or to major septa on the counter side of the axial region; several other thin, slightly wavy to curved septal lamellae and/or tabulae are also seen in the axial region.

The outer wall of the corallum is thin; its thickness is generally 0.1 mm (range 0.05–0.25 mm). A dissepimentarium is present in all known stages. It is regular concentric, with septa rarely interrupted near the periphery of the corallum. The number of series of dissepiments increases progressively from two or three in the earliest stage to about nine in the latest. Width of the dissepimentarium as a percentage of the corallum radius increases progressively from about 30 per cent in the earliest stage to 56 per cent in the latest. In longitudinal sections of the upper portion of the corallum (Pl. 2, figs. 10, 11), dissepiments are globose, moderately large, and thin; they are generally 2 to 4 mm long and 0.05 mm thick. Series of dissepiments are parallel to the corallum wall or slope down steeply toward the corallum axis.

Tabulae are present in all known stages. In longitudinal sections of the upper portion of the corallum (Pl. 2, figs. 10, 11), they are mostly incomplete. Tabulae are thin, generally 0.1 mm thick (range 0.02–0.15 mm); spacing is moderate, generally about 1 mm (range 0.3–4.0 mm). Between the dissepimentarium and axial region, tabulae are inclined up toward the axial region at an angle of about 40 degrees (measured from a line perpendicular to corallum growth axis). Some are upturned where they meet the dissepimentarium and downturned where they reach the axial region. In the axial region, tabulae are subhorizontal and irregularly wavy; some are depressed axially.

Microstructure. In transverse thin section, the septa and septal lobes are weakly fibrous. From a medial position in the septum, the fibres (where distinguishable) curve outward in the direction of the corallum axis so that their convex sides face axially. In longitudinal thin section, septal trabeculae are inclined up toward the corallum axis at an angle of about 35 degrees (measured from a line perpendicular to corallum growth axis).

Discussion. The corallum documented above is assigned to *Paliphyllum* Soshkina, 1955, because of its axial structure with a median septal lamella; its moderately wide, regular concentric dissepimentarium; its thin major septa; and its long minor septa that are commonly contraclined to contratingent. This unique specimen is sufficiently different from other coralla assigned to *Paliphyllum* (see below) to warrant erection of a new species, *Paliphyllum norfordi*. The most notable characters are its thin septa and small, simple, open axial structure with a median septal lamella; pali are not present.

Among other differences, *P. norfordi* has thinner septa and a smaller, simpler axial structure than the following species:

Paliphyllum ellisense (Twenhofel, 1928) from the Ellis Bay Formation (Upper Ordovician; uppermost Cincinnatian, Gamachian), Anticosti Island, Québec (Twenhofel, 1928, p. 119, Pl. 2, figs. 10-13; Elias, 1982, p. 82, 83, Pl. 15, figs. 12-22).

Paliphyllum suecicum Neuman, 1968 from the Boda Limestone (Upper Ordovician; uppermost Ashgill, Hirnantian), Siljan District, Sweden (Neuman, 1968, p. 231-237, Figs. 1a-c, 2a-f, 3a-g).

Paliphyllum soshkinae karinuense Kaljo, 1958 from the Raikküla Stage (Lower Silurian; middle Llandovery, Aeronian), Estonia (Kaljo, 1958, p. 110, 111, Pl. 3, figs. 1-9).

Paliphyllum suecicum brassfieldense Laub, 1979 from the Brassfield Formation (Lower Silurian; mid-Llandovery), Ohio and Indiana (Laub, 1979, p. 137-142, Pl. 4, figs. 8, 9; Pl. 19, figs. 1-3; Pl. 36, figs. 4, 5).

Paliphyllum regulare Laub, 1979 from the Brassfield Formation (Lower Silurian; mid-Llandovery), Ohio (Laub, 1979, p. 133-137, Pl. 20, figs. 3-5).

Among other differences, *P. norfordi* has thinner septa and a simpler axial structure than the following species:

Paliphyllum primarium Soshkina, 1955 from the Dolbor Formation (Upper Ordovician; uppermost Caradoc-lowermost Ashgill), Podkamennaya Tunguska River Basin, Siberian Platform (Soshkina, 1955, p. 122, Pl. 10, fig. 3a, b [see also Hill, 1981, Fig. 96.2a, b]; Ivanovsky, 1961, p. 204, 205, Pl. 3, fig. 2a-v; Ivanovsky, 1963, p. 72, 73, Pl. 18, fig. 1a-v; Sytova, 1979, p. 169, 170, Pl. 34, fig. 2; Pl. 35, fig. 1 [Sytova included as a synonym *Paliphyllum medius* Ivanovsky, 1965, p. 108 *partim*, Pl. 23, fig. 1a, b, *non* Pl. 23, fig. 2]); from the Chancharnisk Suite (Upper Ordovician; upper Caradoc), Kan River Basin, Gorny Altai (Tcherepnina, 1960, p. 390, Pl. O-13, fig. 1a, b); and from the Brassfield Formation (Lower Silurian; mid-Llandovery), Ohio (Laub, 1979, p. 124-133, Pl. 18, figs. 1-3).

Paliphyllum soshkinae soshkinae Kaljo, 1958 from the Juuru Stage (Lower Silurian; lower Llandovery, Rhuddanian), Estonia (Kaljo, 1958, p. 109, 110, Pl. 2, figs. 10-14), and from the Alash Formation (Lower Silurian; lower-middle Llandovery), western Tuva (Sytova and Ulitina, 1983, p. 69, 70, Pl. 7, fig. 3a-v).

Paliphyllum oblongaecystosum Saleh *in* Flügel and Saleh, 1970 from the lower "faunal-zone" (Silurian; probably Llandovery), Niur Formation, eastern Iran (Flügel and Saleh, 1970, p. 279, Pl. 1, figs. 4, 5).

Protocyathactis Ivanovsky, 1961 was proposed to accommodate *Protocyathactis cybaeus* Ivanovsky, 1961 from the Dolbor Formation (Upper Ordovician; uppermost Caradoc-lowermost Ashgill), Podkamennaya Tunguska River Basin, Siberian Platform (Ivanovsky, 1961, p. 205, 206, Pl. 3, fig. 3a, b; see also Laub, 1979, p. 154, 156, 157; Hill, 1981, Fig. 98.2a, b). *Protocyathactis* was subsequently considered to be a synonym of *Paliphyllum* by the original author (Ivanovsky, 1970, p. 121). Laub (1979, p. 143), however, suggested that it may be synonymous with *Cyathactis* Soshkina, 1955. A figured transverse section of the holotype of *P. cybaeus* (Ivanovsky, 1961, Pl. 3, fig. 3a; see also Hill, 1981, Fig. 98.2a) shows a median septal lamella that extends across the axial region and is oriented in the cardinal-counter plane (5 o'clock to 11 o'clock position in Hill's figure as determined from contratingent minor septa). This structure is characteristic of *Paliphyllum*.

Like *P. norfordi*, the holotype of *P. cybaeus* has thin septa and a small, simple axial structure; it differs in having a less open axial structure with septal lobes that join the median lamella. Another corallum identified as *P. cybaeus* was illustrated by Ivanovsky (1963, p. 73, 74, Pl. 24, fig. 3a-g; see also Ivanovsky, 1965, Pl. 24, fig. 2a-g; and placed in synonymy with *P. primarium* by Sytova, 1979, p. 169). This specimen resembles *P. norfordi* in having an open axial region, at least in the early and late stages (nature of the axial region in the intermediate stage is unclear in the figure). In the late stage, there appears to be a slightly dilated septal lamella connected to a major septum that may be the cardinal septum (11 o'clock position in the figure as suggested by contratingent septa on either side). This lamella does not extend across the axial region. Coralla of *P. cybaeus* have a maximum diameter of 20 mm, which is much smaller than *P. norfordi*. A median septal lamella is not as distinct in *P. cybaeus* as in *P. norfordi*.

Sclerophyllum Reiman, 1956 was proposed to accommodate *Sclerophyllum sokolovi* Reiman, 1956 from the Porkuni Stage (Upper Ordovician; uppermost Ashgill, Hirnantian), Estonia (Reiman, 1956, p. 37–39, Fig. 4, Pl. 10, figs. 5–9; see also Laub, 1979, p. 127–129; Hill, 1981, Fig. 97.2a–c). *Sclerophyllum* has been considered a synonym of *Paliphyllum* by some authors (see Neuman, 1968, p. 231), but that interpretation has been questioned because of the reticulate axial structure apparently lacking a median lamella or pali in *S. sokolovi* (Laub, 1979, p. 123). *Paliphyllum beishanense* Cao *in* Cao and Lin, 1982 was described from the Gongpoquan Formation (Middle–Upper Silurian), northern Gansu Province, China (Cao and Lin, 1982, p. 29, 30, Pl. 10, fig. 8a, b). It has a large, reticulate axial structure with a radius that is almost 50 per cent of the corallum radius. I am unable to confirm the generic assignment from available information. *Paliphyllum norfordi* has a smaller, simpler axial structure than *S. sokolovi* or *P. beishanense*.

It is apparent from the above discussion that there are uncertainties and differing opinions about the taxonomic affinities of some genera that may be synonymous with *Paliphyllum*, and some species and specimens that have been included within this genus. Resolution of these problems requires a comprehensive revision that is beyond the scope of the present study.

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APPENDIX 1

CORALS FROM THE ADVANCE FORMATION

ADVANCE MOUNTAIN SECTION; 56°02′N, 123°21′W, Advance Formation (68 m thick)

GSC loc. C-78640 (44-46 m above base)
Grewingkia burdenensis n. sp.

GSC loc. C-205924 (20.5-21.0 m above base)
Grewingkia burdenensis n. sp.

GSC loc. C-205923 (18.5-19.5 m above base)
indeterminate streptelasmatid

GSC loc. C-205922 (16.5-17.5 m above base)
Grewingkia burdenensis n. sp.

GSC loc. C-205921 (11-13 m above base)
Grewingkia burdenensis n. sp.

GSC loc. C-78638 (10.5-16.5 m above base)
Grewingkia burdenensis n. sp.

GSC loc. C-205920 (8.0-9.5 m above base)
Paliphyllum norfordi n. sp.

GSC loc. C-78636 (basal 1.5 m)
indeterminate solitary rugosan

RIDGE TOP, WEST OF BERNARD CREEK; 56°08′N, 123°27′W

GSC loc. C-56101 (isolated outcrop)
Grewingkia burdenensis n. sp.

SECTION EAST OF WICKED RIVER; 56°08′N, 123°36′W, Advance Formation (~50 m thick)

GSC loc. C-56085 (40.5 m above base)
indeterminate streptelasmatid

MOUNT BURDEN SECTION; 56°11′N, 123°27′W, Advance Formation (46.5 m thick)

GSC loc. C-60924 (16.5-27.5 m above base)
Grewingkia burdenensis n. sp.

PLATES 1 and 2

Specimens were coated with ammonium chloride for photographs of exterior views. Illustrations of transverse and longitudinal sections are positive photographs of thin sections. In views of calices and in transverse sections of *Grewingkia burdenensis*, the cardinal side of the corallum faces the bottom of the plate. All transverse sections are oriented as they appear looking down from the calicular end toward the apical end of the corallum. All longitudinal sections are oriented with the calicular end facing the top of the plate. Small numbers with arrows correspond to the illustrated sections with those numbers in the same plate, and show the position of the section.

PLATE 1

Figures 1–16. *Grewingkia burdenensis* n. sp.

1. GSC 103884, paratype, view of calice (stereopair), x3.5, GSC loc. C-56101.

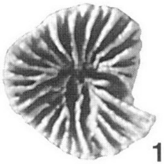
2. GSC 103879, paratype, view of calice (stereopair), x3, GSC loc. C-60924.

3–5. GSC 103882, paratype, alar view (cardinal side right), cardinal view, and view of calice (stereopair), x2.5, GSC loc. C-78638.

6–8. GSC 103881, paratype, alar view (cardinal side right), cardinal view, and view of calice (stereopair), x2, GSC loc. C-78638.

9, 10. GSC 103880, paratype, transverse sections, x4, GSC loc. C-60924.

11–16. GSC 103878, holotype, 11–14, transverse sections, x4; 15, 16, longitudinal sections (in cardinal-counter plane through cardinal fossula, cardinal side right), x4; GSC loc. C-60924.



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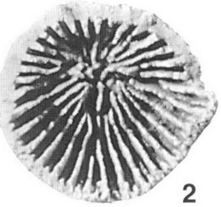

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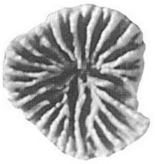

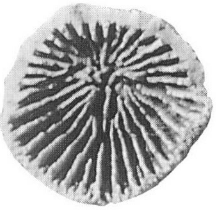

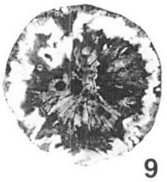

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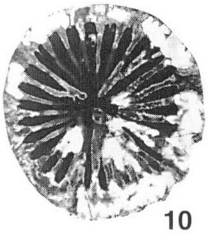

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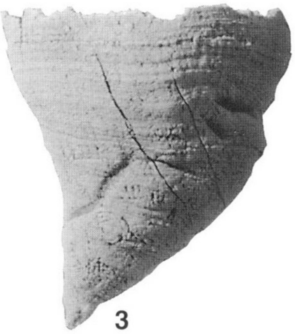

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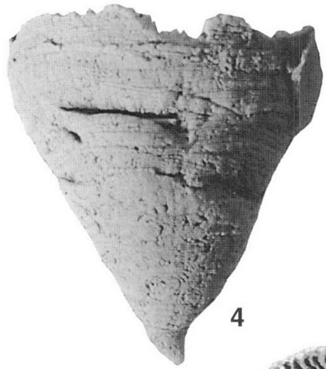

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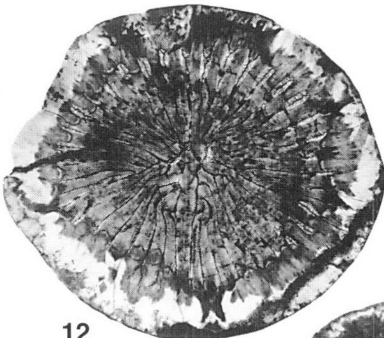

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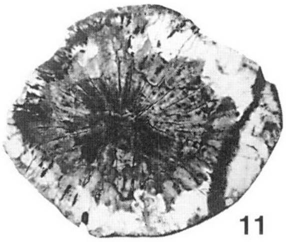

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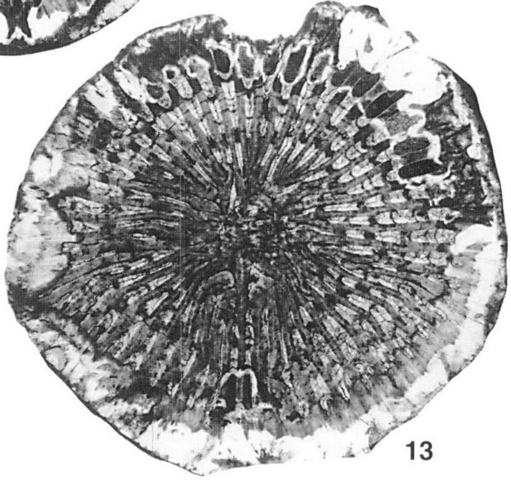

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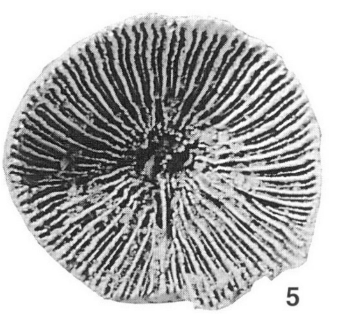

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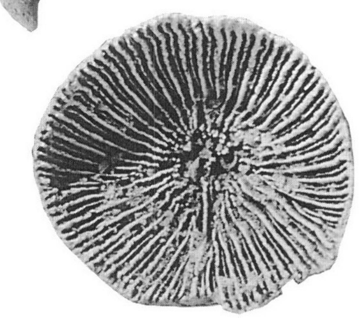

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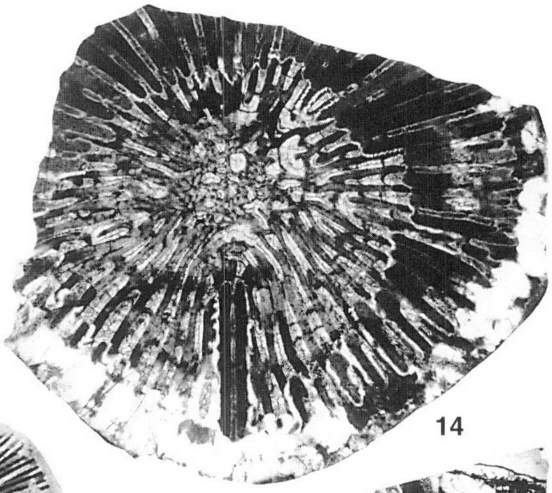

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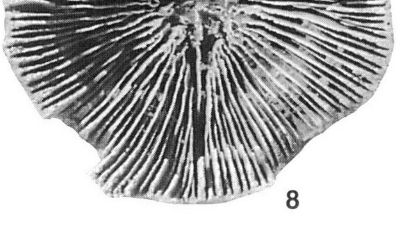

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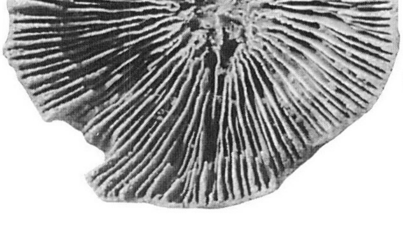

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PLATE 2

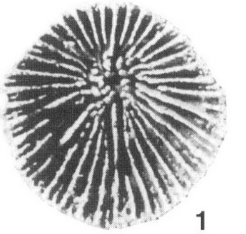
Figures 1–3. *Grewingkia burdenensis* n. sp.

1. GSC 109305, paratype, view of calice (stereopair), x2.5, GSC loc. C-205922.

2, 3. GSC 109304, paratype, alar view (cardinal side right), and cardinal view, x3, GSC loc. C-205922.

Figures 4–12. *Paliphyllum norfordi* n. sp.

4–12. GSC 109309, holotype, 4–9, transverse sections (side facing top of plate is top side of corallum as seen in 12; b = epizoic bryozoan, C = cardinal septum, K = counter septum), x2; 10, 11, longitudinal sections (10 in plane of curvature, side facing left is top centre of corallum as seen in 12; 11 in cardinal-counter plane, cardinal side right), x2; 12, view of corallum, x1; GSC loc. C-205920.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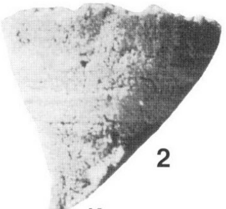
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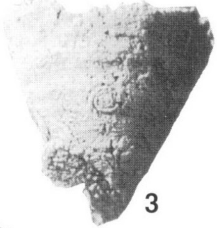
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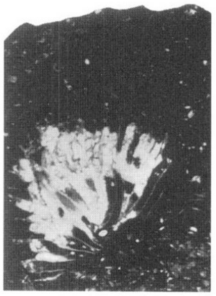
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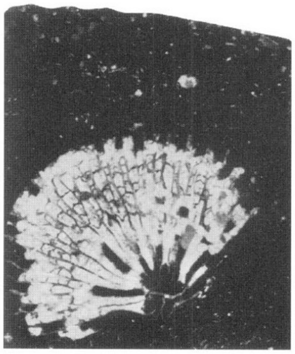
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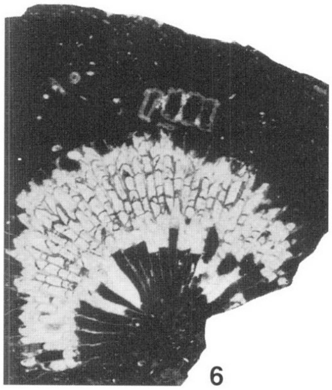
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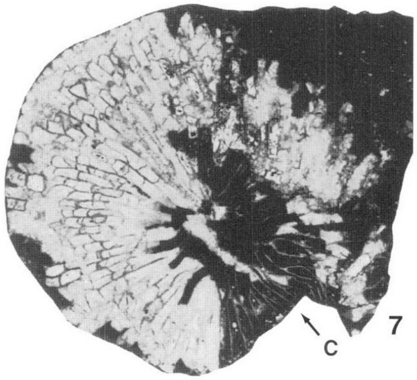
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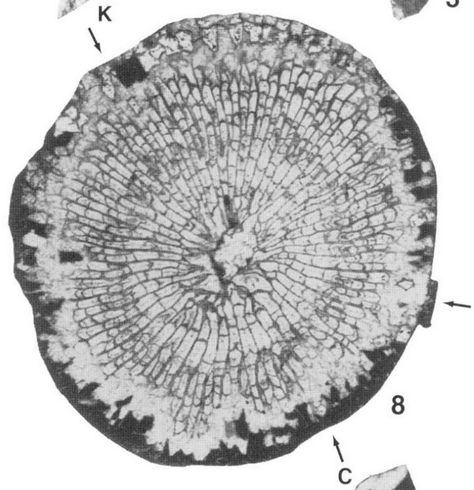
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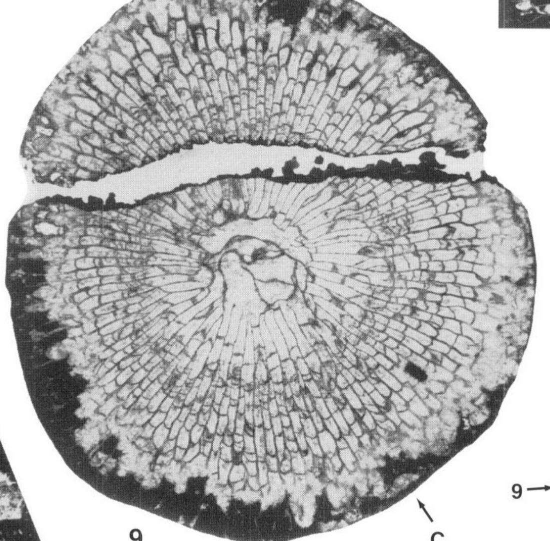
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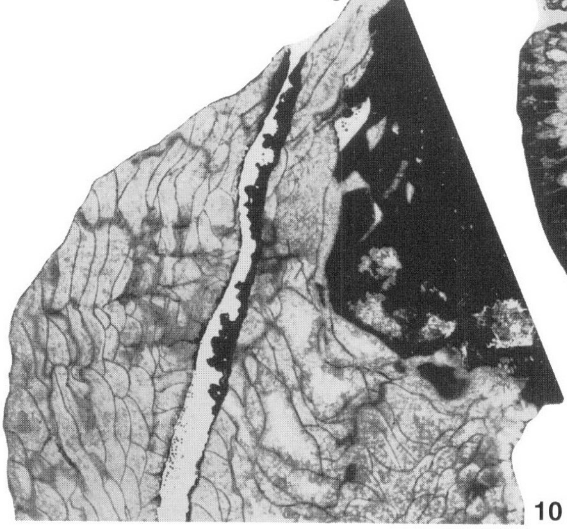
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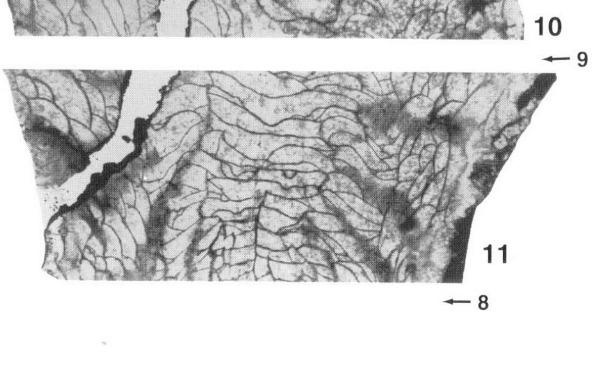
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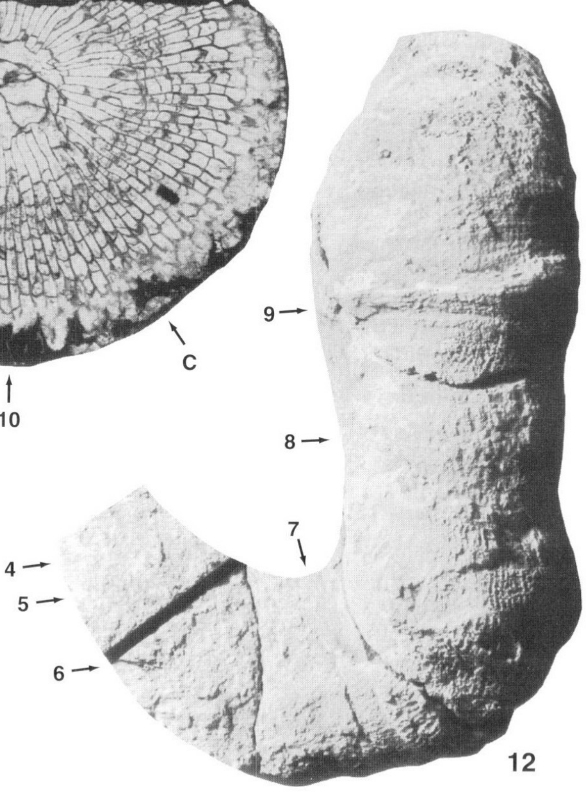
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MIDDLE ORDOVICIAN BRYOZOA FROM THE NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA AND THE SOUTHERN MACKENZIE MOUNTAINS, DISTRICT OF MACKENZIE

Thomas E. Bolton

Abstract

A trepostome bryozoan fauna composed of the genera *Cyphotrypa, Atactoporella, Homotrypa, Monticulipora, Constellaria, Calloporella, Parvohallopora*? and *Tarphophragma* is present in the upper Middle Ordovician Advance Formation of the northern Rocky Mountains, British Columbia. The new species *Diplotrypa cuffeyi* is described from older rocks (Chazyan) of the Esbataottine Formation of the southern Mackenzie Mountains, District of Mackenzie.

Résumé

Une faune de bryozoaires trépostomes composée des genres *Cyphotrypa*, *Atactoporella*, *Homotrypa*, *Monticulipora*, *Constellaria*, *Calloporella*, *Parvohallopora*? et *Tarphophragma,* est présente dans la Formation d'Advance de l'Ordovicien moyen supérieur dans les Rocheuses septentrionales, en Colombie-Britannique. La nouvelle espèce *Diplotrypa cuffeyi* est décrite à partir de roches plus anciennes (Chazyen) de la Formation d'Esbataottine dans le sud des monts Mackenzie, district de Mackenzie.

INTRODUCTION

Bryozoans are not abundant in Lower Paleozoic rocks of western Canada and very few descriptions have been published. Occurrences have been documented within faunal lists as generic determinations or as "bryozoan indet." The only formal descriptions have been by Ross (1982), who illustrated several taxa from Middle and Upper Ordovician successions in the southern Mackenzie Mountains, and by Bolton and Ross (1985), with details of the occurrence of *Sceptropora facula* Ulrich in the Upper Ordovician Whittaker Formation of the Avalanche Lake area, also in the Mackenzie Mountains. Like these previously described faunules, most of the specimens of bryozoans from the Advance Formation were derived from acid residues. Accordingly, specimens are few, most of the ramose trepostome zoaria are small, thin forms, and the preservation is mediocre. However, large colonies of *Cyphotrypa* and *Monticulipora* are unetched specimens from the Advance Formation. The colony of *Diplotrypa* from the Esbataottine Formation is also an unetched specimen.

BRYOZOANS OF THE ADVANCE FORMATION

The newly established Advance Formation (see Norford, *this volume*, for description and for data concerning the collections), confined to the Williston Lake region, northern Rocky Mountains, British Columbia, consists of up to 68 m of thinly bedded limestones, argillaceous dolomites and shales. It disconformably overlies the Middle Ordovician (Chazyan to mid-Mohawkian) Skoki Formation and is overlain by unnamed Upper Ordovician (mid-Maysvillian to Gamachian) quartzite and dolomite. The bryozoan fauna of the Advance Formation consists of:

Atactoporella sp.	(GSC locs. C-78638, C-78640)
Calloporella sp.	(GSC loc. C-205923)
Constellaria sp.	(GSC loc. C-205922)
Cyphotrypa cf. *C. acervulosa* (Ulrich)	(GSC loc. C-60924)
Homotrypa sp.	(GSC loc. C-60924)
Monticulipora grandis Ulrich	(GSC loc. C-205920)
Parvohallopora? sp.	(GSC locs. C-78638, C-78640, C-205923)
Parvohallopora? sp. indet.	(GSC locs. C-56085, C-56101, C-60924)
Tarphophragma sp.	(GSC locs. C-205922, C-205923)

Each of these genera range through the Middle and Upper Ordovician. However, in central North America, the co-occurrence of *Atactoporella*, *Cyphotrypa acervulosa* and *Homotrypa* is most common in rocks of late Middle Ordovician to early Late Ordovician age.

The thinly to medium bedded limestones that comprise the Esbataottine Formation are restricted to an area of the Mackenzie Mountains near Virginia Falls. Ross (*in* Ludvigsen, 1979) listed ten bryozoan genera and a number of unassigned forms from the Esbataottine Formation. The present paper describes *Diplotrypa cuffeyi* n. sp. from the lowest zone (early Middle Ordovician, late Chazyan) of the formation. This is the first record of the genus from western Canada.

SYSTEMATIC PALEONTOLOGY

The specimens described herein are deposited in the National Type Collection of Plant and Invertebrate Fossils of the Geological Survey of Canada, Ottawa.

Order TREPOSTOMATA Ulrich, 1882

Family HETEROTRYPIDAE Ulrich, 1890

Genus *Cyphotrypa* Ulrich and Bassler, 1904

Type species. Leptotrypa acervulosa Ulrich, 1893, Galena Formation, Middle Ordovician (Kirkfieldian–Shermanian), Iowa and Minnesota, U.S.A.

Cyphotrypa cf. *C. acervulosa* (Ulrich), 1893

Plate 1, figures 1, 3, 4

cf. *Leptatrypa acervulosa* Ulrich, 1893, p. 318, Pl. 27, figs. 24, 25.
cf. *Cyphotrypa acervulosa* (Ulrich); Ulrich and Bassler, 1904, p. 30, Pl. 8, figs. 1–3.
cf. *Cyphotrypa acervulosa* (Ulrich); Brown, 1965, p. 986, Pl. 113, figs. 1–3.
cf. *Cyphotrypa acervulosa* (Ulrich); Karklins, 1984, p. 146, Pl. 15, figs. 3–5.

Type material. Figured specimen, GSC 106251; Advance Formation, 16.5–27.5 m above base, GSC loc. C-60924, Mount Burden, 56°11′N, 123°27′W, British Columbia.

Description. Zoarium globular, at least 35 mm in diameter. In tangential section, zooecia three- to six-sided, ranging from 0.24 to 0.32 mm in diameter to 0.36 to 0.40 mm in monticule (megazooecia); walls thin, amalgamate; more angulate, three- to four-sided mesozooecia-like apertures (immature zooecia?) rarely present, 0.12 to 0.14, rarely 0.20 mm in diameter; seven to eight zooecia commonly preserved in 2 mm, rarely nine or ten; 12 to 14 whole zooecia in 1 mm square; rare cluster of solid minute acanthopore-like structures located at junction points of zooecia, 0.06 to 0.08 mm in diameter.

In longitudinal section, zooecial walls thin, slightly undulating; zooecial diameter 0.20 to 0.38 mm; zooecia with horizontal diaphragms, three to four in 1 mm, varying from 0.28 to 0.40 mm in spacing. True mesozooecia not recognized; in thicker zooecial walls a suggestion of thin acanthopores(?).

Discussion. According to Brown (1965, p. 988) and Bork and Perry (1968b, p. 1064, 1065), *Cyphotrypa pachymuralis* Brown [Shermanian] is diagnosed by its moderately thick walls and few acanthopores, *C. acervulosa* (Ulrich) [Kirkfieldian–Shermanian], *C. frankfortensis* Ulrich and Bassler [Rocklandian–Shermanian], *C. informis* (Ulrich) [Blackriveran], *C. semipilaris* (Ulrich) [Maysvillian], *C. stidhami* (Ulrich) [Richmondian], and *C. wilmingtonensis* Ulrich and Bassler [Richmondian] by their thin walls and numerous acanthopores.

Cyphotrypa switzeriensis Karklins (1984, p. 145) [Shermanian] is close to *C. acervulosa* but differs in its crenulated zooecial walls, few diaphragms, and no acanthopores. The ramose *C. madisonenis* Brown and Daly [Maysvillian–Richmondian] has abundant diaphragms throughout, *C. americana* (Fritz) [Edenian] has larger zooecia (four in 2 mm length), and *C. waynensis* Utgaard and Perry [Richmondian] has smaller zooecia (eight to ten in 2 mm). The Advance Formation specimen is closest to *C. acervulosa*, but differs in possessing slightly smaller zooecia, seven to eight in the former compared to nine to eleven in the latter in 2 mm, thinner walls and fewer acanthopores.

Family MONTICULIPORIDAE Nicholson, 1881

Genus *Atactoporella* Ulrich, 1883

Type species. Atactoporella typicalis Ulrich, 1883, Kope Formation, Upper Ordovician (Edenian), Kentucky, U.S.A.

Atactoporella sp.

Plate 1, figures 2, 8

Type material. Figured specimen, GSC 106252; Advance Formation, 44–46 m above base, GSC loc. C-78640, Advance Mountain, 56°02′N, 123°21′W. British Columbia.

Description. Zoarium discoidal, fragment 23.6 mm thick. In tangential section, zooecia thin walled, ovate to subelongate, 0.22 to 0.28 mm in diameter; abundant large mesozooecia, three- to four-sided, 14 to 16 whole mesozooecia in 1 mm square; seven to eight zooecia preserved in 2 mm; 10 to 12 whole zooecia in 1 mm square; numerous large acanthopores with clear central lumen sited at zooecial corners and locally slightly inflecting adjoining zooecial walls to produce petaloid outline, 0.02 to 0.04 mm in diameter, 25 to 26 in 1 mm square.

In longitudinal section, zooecia locally recumbent at base then rising directly upward and relatively equal in diameter for length of zooecia; cystiphragms abundant, usually on one wall, 11 to 14 in 2 mm, but locally sufficient development of cystiphragms on both walls to almost completely fill a zooecium, other zooecia have abundant flat diaphragms, at least 13 to 14 in 2 mm; diaphragms more abundant and closer spaced in mesozooecia, 20 to 23 in 2 mm; walls thickened by long acanthopores.

Discussion. Well developed cystiphragms and local petaloid zooecial apertures within this described form suggest *Atactoporella* rather than the closely related taxon *Aspidopora*. The Shermanian–Edenian *Atactoporella newportensis* Ulrich (Karklins, 1984, p. I-26) has erect robust zoaria and the Richmondian *A. spicata* Bassler encrusting zoaria, both have thick walled zooecia and fewer diaphragms and cystiphragms, whereas the Edenian–Maysvillian *A. mundula* (Ulrich) (Brown and Daly, 1985, p. 25) and the Edenian *A. typicalis* (Ulrich) (Anstey and Perry, 1972, Pl. 4, fig. 3) have more petaloid zooecia and fewer cystiphragms than the present form. The Edenian *Aspidopora areolata* Ulrich has circular to subelliptical zooecia almost completely surrounded by mesozooecia, whereas the Gamachian *A. siluriana* Bassler (Bolton, 1986, p. 101 — as *Peronopora*) has more rounded to oval zooecia and fewer cystiphragms.

Genus *Homotrypa* Ulrich, 1882

Type species. Homotrypa curvata Ulrich 1882, Fairview Formation, Upper Ordovician (Maysvillian), Ohio, U.S.A.

Homotrypa sp.

Plate 1, figure 5

Type material. Figured specimen, GSC 106253; Advance Formation, 16.5–27.5 m above base, GSC loc. C-60924, Mount Burden, 56°11′N, 123°27′W, British Columbia.

Description. Zoarium small, ramose. In tangential section, zooecial apertures angular-elongate in deep section, walls thin; no mesozooecia.

In longitudinal section, zooecia erect, curving gradually from axial region (endozone) to zoarial surface where they open obliquely; walls thin, straight, equal thickness throughout; zooecia 0.20 to 0.22 mm in diameter in endozone, 0.16 to 0.20 mm in exozone; horizontal to slightly concave diaphragms sparse in endozone, three to five horizontal diaphragms in exozone of some zooecia, variable number of globose cystiphragms in others; no mesozooecia or acanthopores recognized.

Discussion. The well developed cystiphragms and diaphragms in the exozone strongly support the assignment of this specimen to *Homotrypa*. A closely allied form is *Homotrypa* sp. of Bork and Perry (1968b, p. 1055, Pl. 136, figs. 4, 5) from the Rocklandian–Kirkfieldian Guttenberg Formation of Wisconsin. *Homotrypa richmondensis* Bassler from the Richmondian Whitewater Formation (Utgaard and Perry, 1964, p. 58) is similar in longitudinal section but has fewer diaphragms, cystiphragms being dominant.

Genus *Monticulipora* d'Orbigny, 1850

Type species. Monticulipora mammulata d'Orbigny 1850, Fairmount Member, Fairview Formation, Upper Ordovician (Maysvillian), Ohio, U.S.A.

Monticulipora grandis Ulrich, 1886

Plate 3, figures 1, 2

Monticulipora grandis Ulrich, 1886, p. 78.
Monticulipora grandis Ulrich; Ulrich, 1895, p. 219, Pl. 15, figs. 1–6.
Prasopora grandis (Ulrich); Fritz, 1957, p. 31, Pl. 24, figs. 3, 4.
Monticulipora grandis Ulrich; Bork and Perry, 1968b, p. 1061, Pl. 136, figs. 8, 9.

Type material. Hypotype, GSC 110835; Advance Formation, 8.0–9.5 m above base, GSC loc. C-205920, Advance Mountain, 56°02′N, 123°21′W, British Columbia.

Description. Zoarium massive, semiglobular, 35 mm high and 40 mm wide at base. In tangential section, zooecia thin walled, polygonal, five- to seven-sided, average zooecia 0.28 to 0.37 mm in diameter with six and a half to seven and a half in 2 mm and seven to eight whole zooecia in 1 mm square; clusters of large zooecia range from 0.44 to 0.60 mm in diameter with four and a half to five in 2 mm and four whole zooecia in 1 mm square. Mesozooecia and acanthopores not developed.

In longitudinal section, walls of zooecia thin and slightly flexuous; zooecia with abundant, closely spaced horizontal diaphragms, 21 to 24 in 2 mm. Zones of overlapping cystiphragms present throughout zoarium, lining one or both sides of walls of zooecia, commonly connected by more widely spaced diaphragms.

Discussion. The Advance Formation specimen displays slightly larger zooecia than typical *M. grandis* (seven and part of an eighth normal zooecia in 2 mm and six or six and part of a seventh larger zooecia in 2 mm) from the Middle Ordovician (Kirkfieldian) Ion Formation of Iowa.

Family CONSTELLARIIDAE Ulrich, 1890

Genus *Constellaria* Dana, 1846

Type species. Constellaria florida Ulrich, 1882, Upper Ordovician (Richmondian), Ohio, U.S.A.

Constellaria sp.

Plate 4, figures 1, 2

Type material. Figured specimen, GSC 110838; Advance Formation, 16.5–17.5 m above base, GSC loc. C-205922, Advance Mountain, 56°02′N, 123°21′W, British Columbia.

Description. Zoarium ramose, cylindrical, 4.8 mm in diameter. In tangential section, zooecia round, usually isolated or in clusters of two to five, generally with thin walls but thicker in some larger zooecia; zooecia ranging 0.16 to 0.32 in diameter but most 0.20 to 0.24 mm, seven to seven and a half in 2 mm, 9 to 13 in 1 mm square; abundant angular to elongate mesozooecia as individuals or in large clusters. Acanthopores not developed.

In longitudinal section, walls of zooecia slightly flexuous, diaphragms horizontal, widely spaced throughout zoarium but closely spaced in narrow exozone where wall is slightly thickened.

Discussion. The genus *Constellaria* ranges from lower Middle Ordovician (*C. islensis* Ross, 1963) to upper Late Ordovician. At the species level, the Advance Formation specimen is quite different from any previously described constellarid.

Family HALLOPORIDAE Bassler, 1911

Genus *Calloporella* Ulrich, 1882

Type species. Calloporella harrisi Ulrich, 1883, Upper Ordovician (Richmondian), Ohio, U.S.A.

Calloporella sp.

Plate 3, figures 3–6

Type material. Figured specimens, GSC 110836, 110837; Advance Formation, 18.5–19.5 m above base, GSC loc. C-205923, Advance Mountain, 56°02′N, 123°21′W, British Columbia.

Description. Zoaria discoidal, 3 to 5 mm high. In tangential section, zooecia thin walled, oval and mostly in contact, normally 0.28 to 0.32 mm in diameter with clusters of larger zooecia 0.40 to 0.44 mm in diameter, usually six and a half in 2 mm and seven to nine whole zooecia in 1 mm square. Mesozooecia small, angular, located at zooecial interspaces. Acanthopores not developed.

In longitudinal section, walls of zooecia thin and continuous, locally recumbent for a short distance before turning upward, more commonly rising directly from the sediment; diaphragms horizontal to slightly oblique to zooecial walls, eight to ten in 2 mm; mesozooecia narrow, continuous with abundant, closely spaced horizontal diaphgrams.

Discussion. Representatives of the genus *Calloporella* have been described from both Middle Ordovician and Upper Ordovician strata throughout the Northern Hemisphere (Pushkin, 1981, Table 1). The only Canadian species described previously is *Calloporella* *vacua* Dyer from the Upper Ordovician Erindale Member of the Meaford Formation (Georgian Bay Formation, Richmondian) of southern Ontario (Dyer, 1925, p. 63). The Advance Formation specimens have fewer, smaller mesozooecia and more diaphragms than *C. vacua*. In longitudinal section they resemble *Mesotrypa distincta* Parks as figured by Fritz (1976, p. 7, Fig. 2A) from the Humber Member of the Dundas Formation (Georgian Bay Formation) of southern Ontario, but in tangential section they have fewer mesozooecia.

Genus *Parvohallopora* Singh, 1979

Type species. Monticulipora ramosa d'Orbigny, 1850, McMillan Formation, Upper Ordovician (Maysvillian), Ohio, U.S.A.

Parvohallopora? sp.

Plate 1, figures 6, 7

Type material. Figured specimen, GSC 106254; Advance Formation, 10.5-16.5 m above base, GSC loc. C-78638, Advance Mountain, 56°02′N, 123°21′W, British Columbia.

Description. Zoarium ramose, branching fragment 9 mm wide and more than 15 mm long. In oblique tangential section, zooecia polygonal, 0.20 to 0.24 mm in diameter; a few small mesozooecia between zooecia.

In longitudinal section, zooecia at surface range from 0.16 to 0.22 mm in diameter, with mesozooecia 0.06 mm in diameter, walls thin; a few horizontal diaphragms in endozone, more abundant in exozone and mesozooecia; no cystiphragms.

Discussion. Preservation prevents a certain species assignment.

Genus *Tarphophragma* Karklins, 1984

Type species. Monotrypella multitabulata Ulrich, 1866, Decorah Shale, Middle Ordovician (Kirkfieldian-Shermanian), Minnesota, U.S.A.

Tarphophragma sp.

Plate 4, figures 3-6

Type material. Figured specimens, GSC 110839-110841; Advance Formation, 16.5-17.5 m above base, GSC loc. C-205922 and 18.5-19.5 m above base, GSC loc. C-205923, Advance Mountain, 56°02′N, 123°21′W, British Columbia.

Description. Zoaria ramose, 3.2 to 7.6 mm in diameter. In tangential section, zooecia polygonal, five- to six-sided, 0.20 to 0.28 mm in diameter with seven or eight in 2 mm and 10 to 12 whole zooecia in 1 mm square. Mesozooecia few, angulate, located at junctions of zooecia. Acanthopores not developed.

In longitudinal section, walls straight, thick, zooecia curving gently outward, opening obliquely; horizontal to slightly curved diaphragms abundant throughout zoarium, evenly spaced in endozone, three to five in 1 mm, closer in narrow exozone. Mesozooecia rare, restricted to exozone.

Discussion. In the Advance Formation specimens, the diaphragms of the zooecia are consistently farther apart and the mesozooecia are fewer than in *T. multitabulata* (see Karklins, 1984, Pl. 32, figs. 1-5; Pl. 33, figs. 1-4).

Genus *Diplotrypa* Nicholson, 1879

Type species. Favosites petropolitanus Pander, 1830, Chasmops [Kullsberg] Limestone, Middle Ordovician, Estonia.

Diplotrypa cuffeyi n. sp.

Plate 2, figures 1-4

Type material. Holotype, GSC 106255; lower Esbataottine Formation 125 m above base (deep *Calyptaulax-Ceraurinella* biofacies; *Ceraurinella nahanniensis* Zone), Ludvigsen loc. A-125, east from saddle behind peak of Sunblood Mountain, 61°38′N, 125°44′W, southwestern District of Mackenzie (see Chatterton and Ludvigsen, 1976, Fig. 2).

Description. Zoarium massive, at least 138 mm long and 68 mm high, wrinkled epitheca. In tangential section, zooecia five- to six-sided, 0.40 to 0.52 mm in diameter with clusters of 0.60 to 0.64 mm, walls moderately thin, integrate, four and a half to five zooecia in 2 mm; rare triangular to quadrangular single small mesozooecia; no acanthopores.

In longitudinal section, zooecial walls uniformly moderately thin, straight, 0.32 to 0.52 mm and rarely

0.96 mm in diameter; a few short zones of beaded mesozooecia, small, predominantly 0.16 to 0.29 mm in diameter with a maximum of 13 in 2 mm; diaphragms flat to slightly concave or convex, one to three in 2 mm, mostly 0.32 to 0.88 mm apart, with a maximum of 1.60 mm.

Discussion. This is the first record of *Diplotrypa* from lower Middle Ordovician rocks of western Canada. The new species closely resembles *D. schucherti* Fritz (Pl. 2, figs. 5, 6) from the Rocklandian Lourdes Formation of western Newfoundland (Copeland and Bolton, 1977, p. 6; Davidheiser, 1980, Pl. 24, figs. 1–7; Pl. 25, figs. 1, 2; Pl. 26, figs. 1–3), differing in more widely spaced and more frequently curved diaphragms, fewer beaded mesozooecia, and slightly thicker walls. *Diplotrypa schindeli* Key [Chazyan], *D. catenulata* Coryell (Bork and Perry, 1968a, p. 339) [Blackriveran], *D. anchicatenulata* McKinney [Blackriveran] and *D. westoni* Ulrich [Edenian] all have a larger number of mesozooecia. It should be noted that Key (1991, p. 203) suggested that the second and third species, with *Batostoma*-like growth pattern, do not belong in *Diplotrypa sensu stricto*.

According to Ross (*in* Ludvigsen, 1979, p. 9), *Helopora* sp., *Pachydictya* sp., *Stictopora* sp. and phylloporinids accompany the trepostome bryozoans in this zone. The associated ostracode faunas in A-125 were detailed by Copeland (1974, 1982) and the trilobites by Chatterton and Ludvigsen (1976). An early Middle Ordovician (late Chazyan) age is suggested for the lower Esbataottine Formation in both studies.

Geographically, the closest Chazyan/Whiterockian (uppermost Arenig–Llanvirn) rocks with reported Bryozoa are in the Kanosh Shale and Lehman Formation, Pogonip Group of western Utah (Hinds, 1970). *Dianulites utahensis* Hinds (with abundant acanthopores but lacking mesozooecia) rather than *Diplotrypa*, characterizes the Utah succession and there is little similarity to the Esbataottine faunule.

Etymology. The species is named in honour of Roger J. Cuffey, in recognition of his many contributions to the studies of Paleozoic Bryozoa.

ACKNOWLEDGMENTS

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PLATES 1–4

PLATE 1

Advance Formation, British Columbia

Figures 1, 3, 4. *Cyphotrypa* cf. *C. acervulosa* (Ulrich).

GSC 106251, longitudinal, x20, and tangential, x40 and x20, sections, showing mesozooecia-like apertures locally developed, GSC loc. C-60924, Mount Burden.

Figures 2, 8. *Atactoporella* sp.

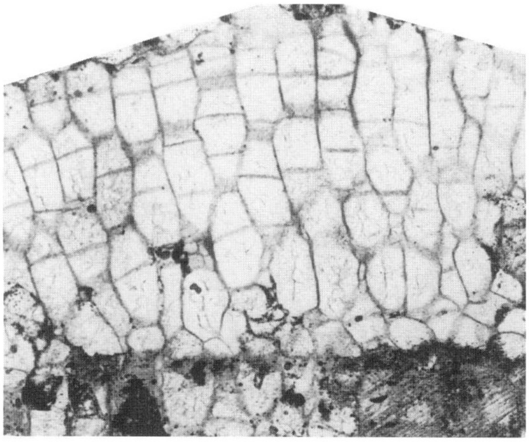
GSC 106252, tangential and longitudinal sections, x40, showing abundant acanthopores and cystiphragms, GSC loc. C-78640, Advance Mountain.

Figure 5. *Homotrypa* sp.

GSC 106253, longitudinal section, x40, showing well developed cystiphragms in some zooecia, GSC loc. C-60924, Mount Burden.

Figures 6, 7. *Parvohallopora*? sp.

GSC 106254, longitudinal and tangential sections, x20, showing rare small mesozooecia, GSC loc. C-78638, Advance Mountain.



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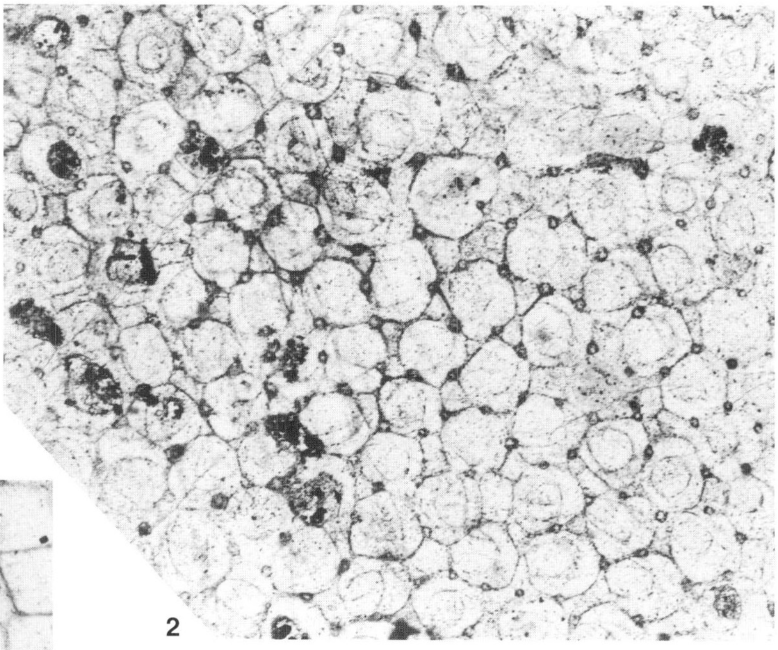

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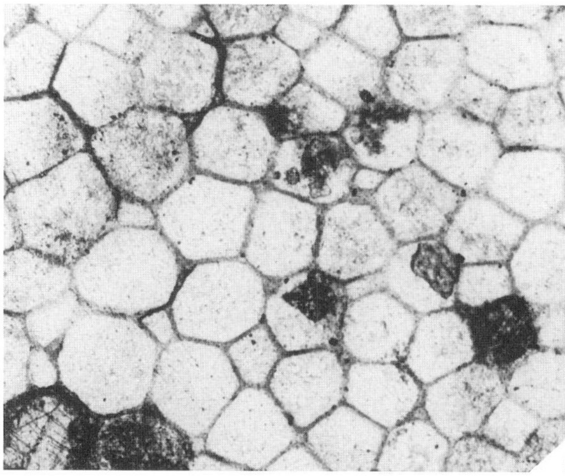

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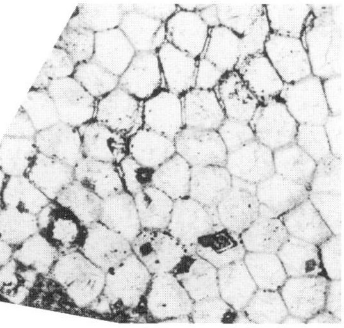

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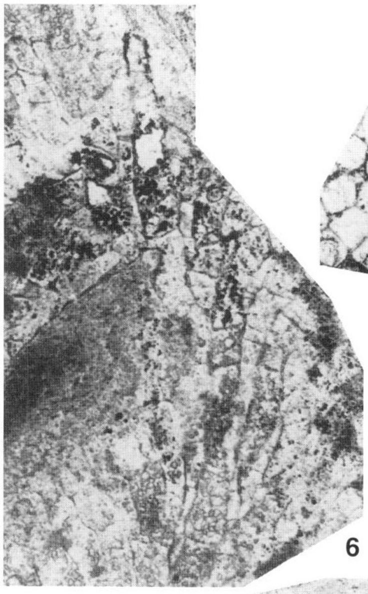

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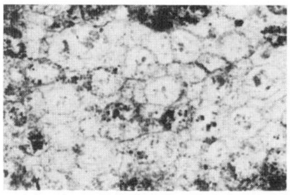

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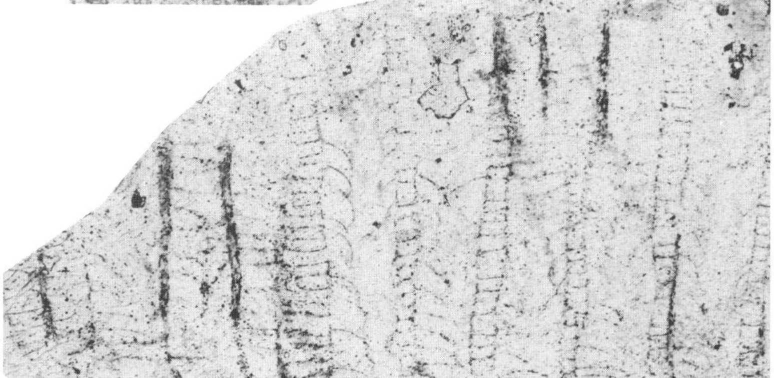

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PLATE 2

Esbataottine Formation, District of Mackenzie

Figures 1–4. *Diplotrypa cuffeyi* n. sp.

1. GSC 106255, holotype, longitudinal section, x20, showing a few short zones of beaded mesozooecia and variably spaced diaphragms. Ludvigsen locality A-125, behind peak of Sunblood Mountain, District of Mackenzie.

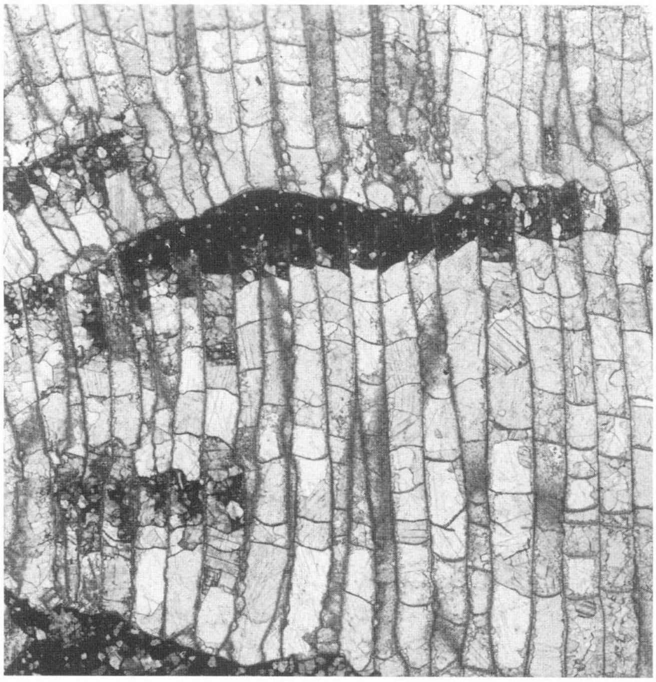
2, 3. Tangential sections, x40, of same specimen as fig. 1, with and without rare triangulate mesozooecia (lower right of fig. 3).

4. Shallow tangential section, x10, of same specimen as figs. 1, 2, showing clusters of large zooecia and local concentration (right centre) of triangulate mesozooecia.

Figures 5, 6. *Diplotrypa schucherti* Fritz.

5. GSC 106539, tangential section, x20, displaying numerous triangular and rectangular mesozooecia, hypotype, GSC loc. 94287, Member III, Lourdes Formation, Long Point Group, shore section 3.5 km NE. of Black Duck Brook Corners, western Newfoundland.

6. GSC 106540, longitudinal section, x20, showing scattered beaded mesozooecia and flat to concave diaphragms, hypotype, GSC loc. 94286, Long Point Group, shore section between Three Rock Point and Salmon Cove, western Newfoundland.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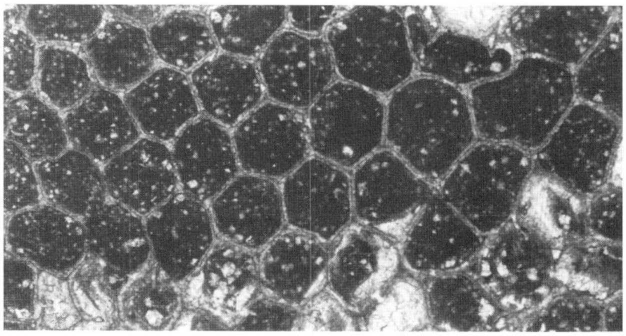
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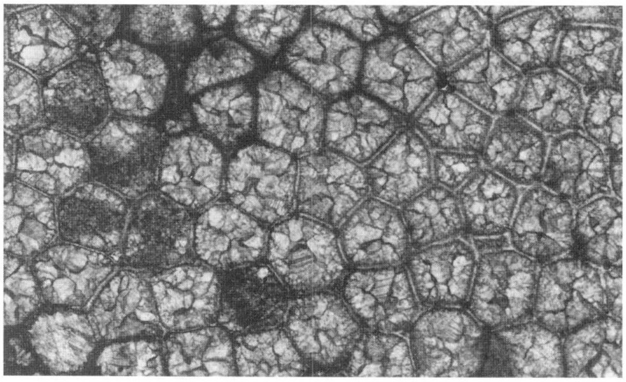
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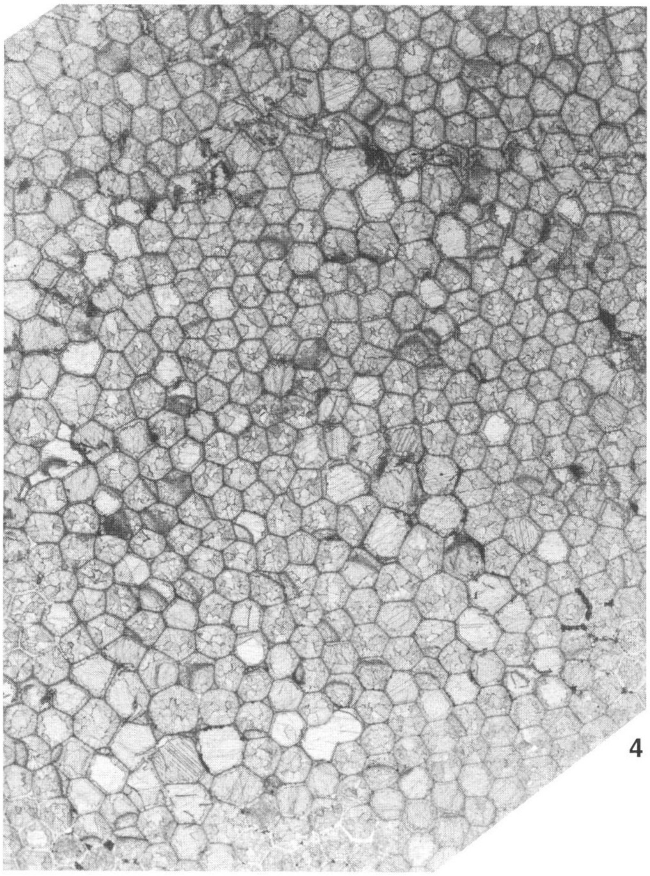
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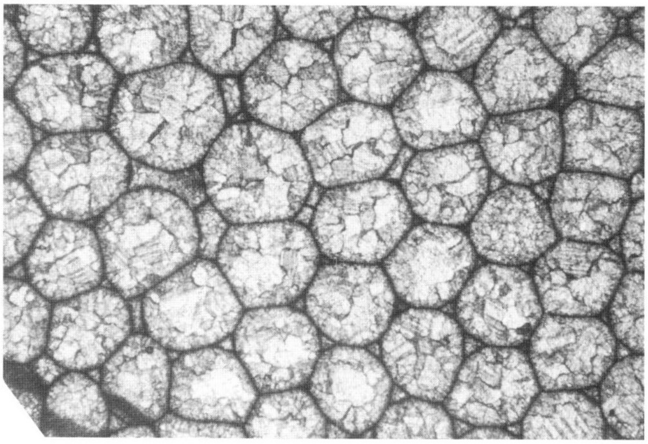
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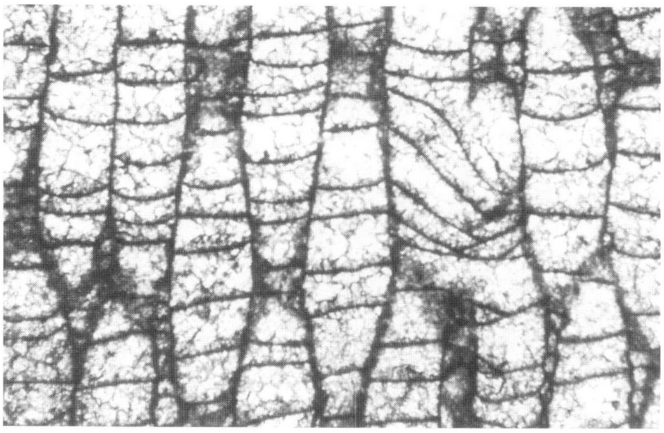
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PLATE 3

Advance Formation, British Columbia

Figures 1, 2. *Monticulipora grandis* Ulrich, 1886.

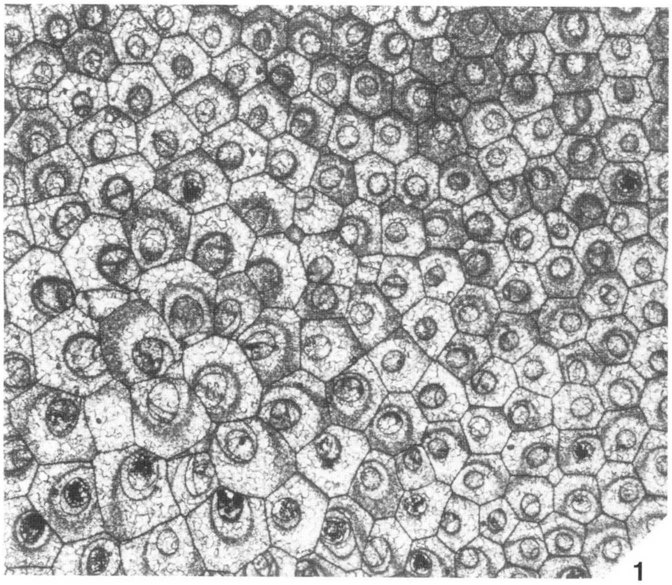
GSC 110835, hypotype, tangential and longitudinal sections, x20, showing a cluster of large zooecia (macula), the predominance of oval, centrally located cystiphragms, and closely spaced diaphragms throughout the zoarium, GSC loc. C-205920, Advance Mountain.

Figures 3–6. *Calloporella* sp.

Sections showing oval zooecia and abundant angular mesozooecia with closely space diaphragms.

3, 6. GSC 110836, tangential, x40, and longitudinal sections, x40, GSC loc. C-205923, Advance Mountain.

4, 5. GSC 110837, oblique tangential, x20, and longitudinal sections, x20, GSC loc. C-205923, Advance Mountain.



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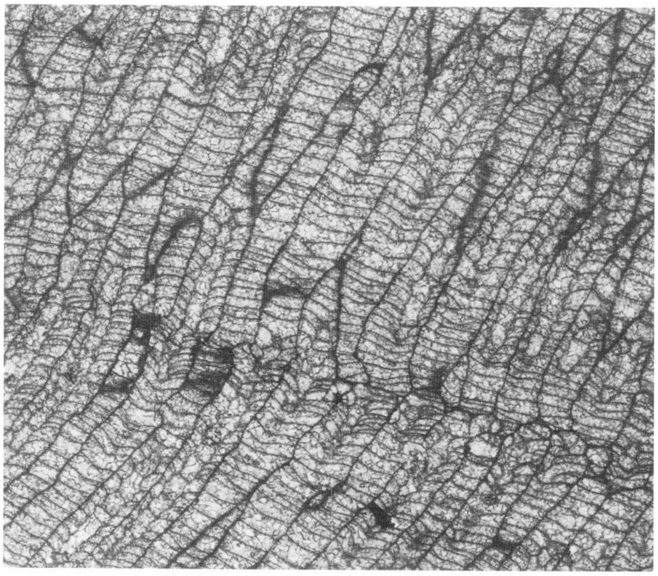

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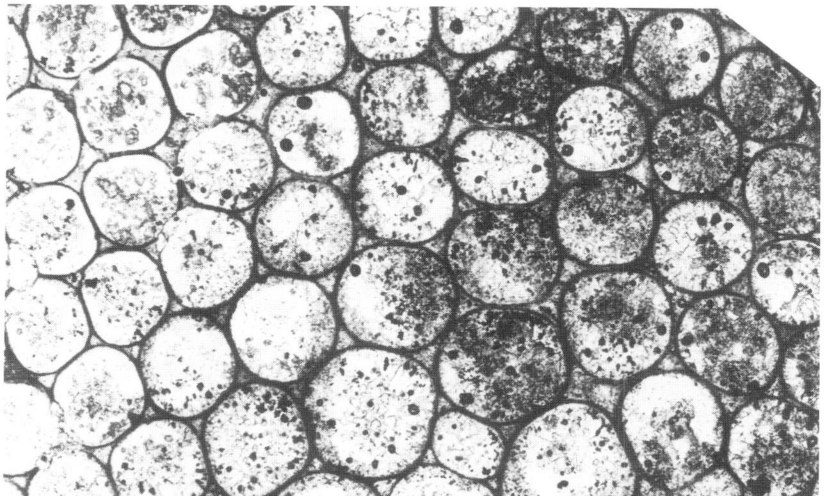

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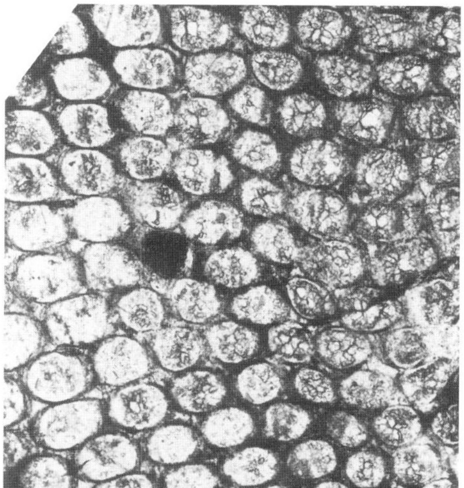

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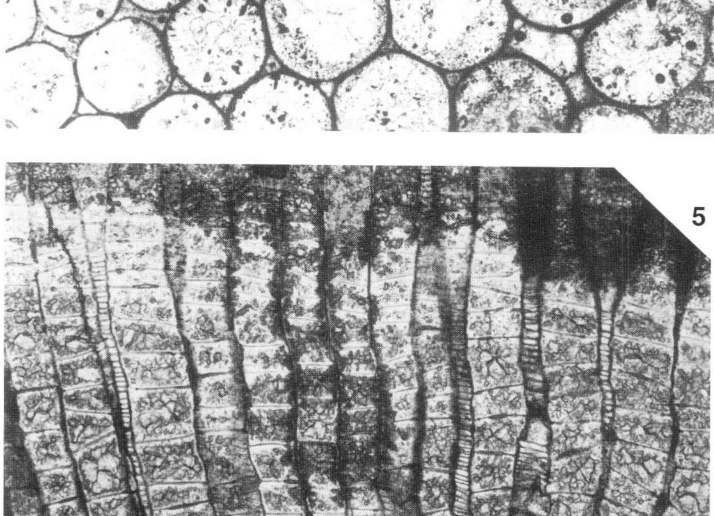

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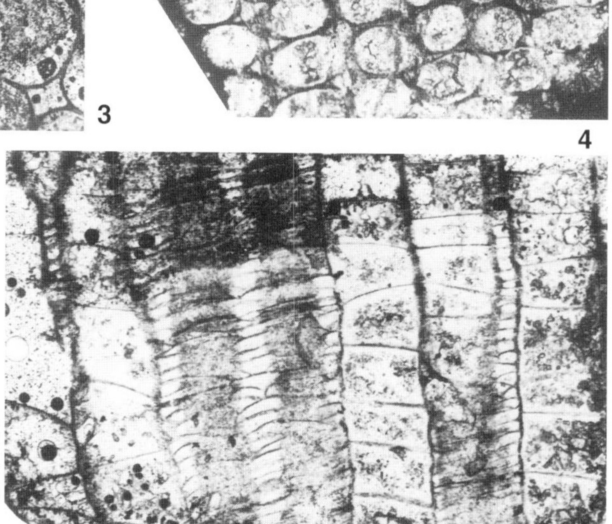

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PLATE 4

Advance Formation, British Columbia

Figures 1, 2. *Constellaria* sp.

GSC 110838, tangential, x40, and longitudinal sections, x20, showing round zooecia and abundant angular mesozooecia, GSC loc. C-205922, Advance Mountain.

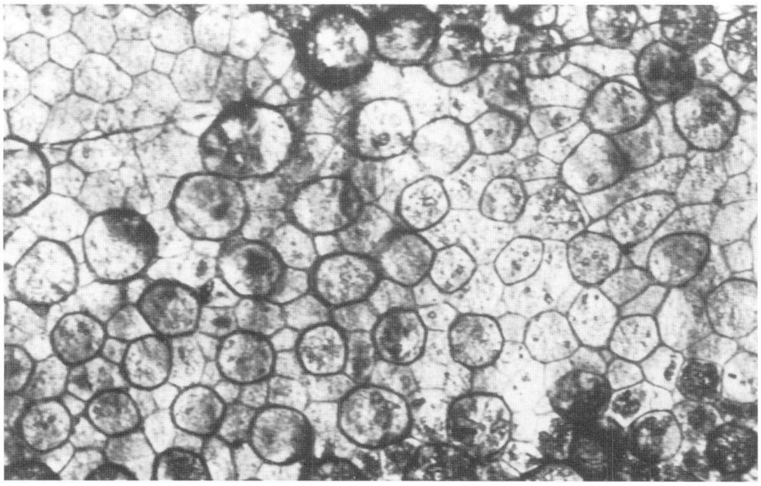
Figures 3–6. *Tarphophragma* sp.

Sections showing polygonal zooecia, a few angular mesozooecia, and abundant diaphragms throughout zoaria.

3, 5. GSC 110839, tangential, x20, and longitudinal sections, x20, GSC loc. C-205922, Advance Mountain.

4. GSC 110841, tangential section, x40, GSC loc. C-205923, Advance Mountain.

6. GSC 110840, longitudinal section, x20, GSC loc. C-205922, Advance Mountain.



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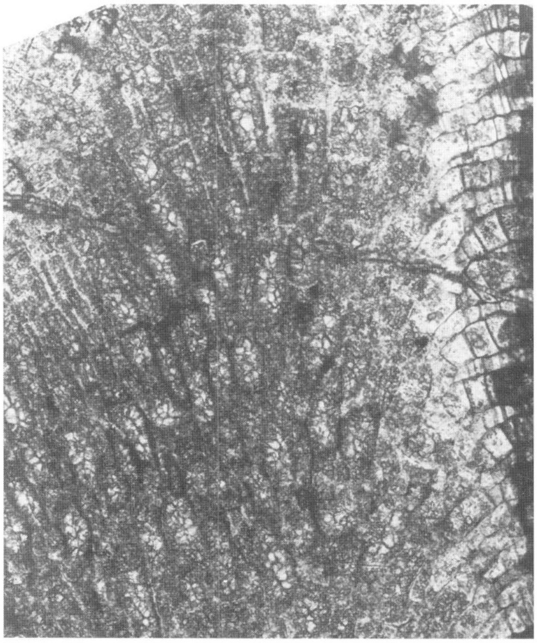

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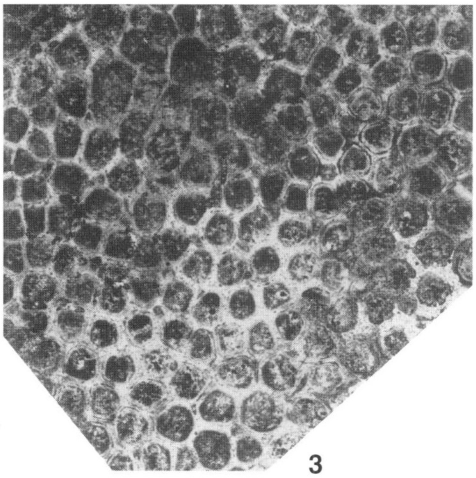

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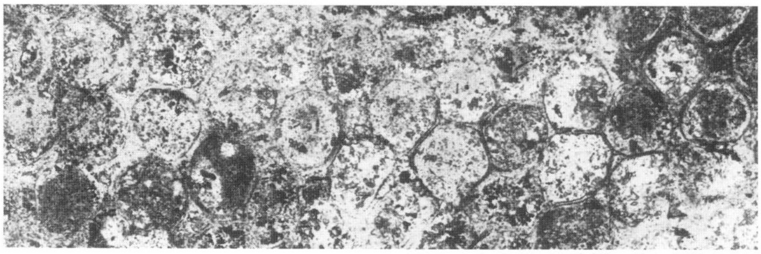

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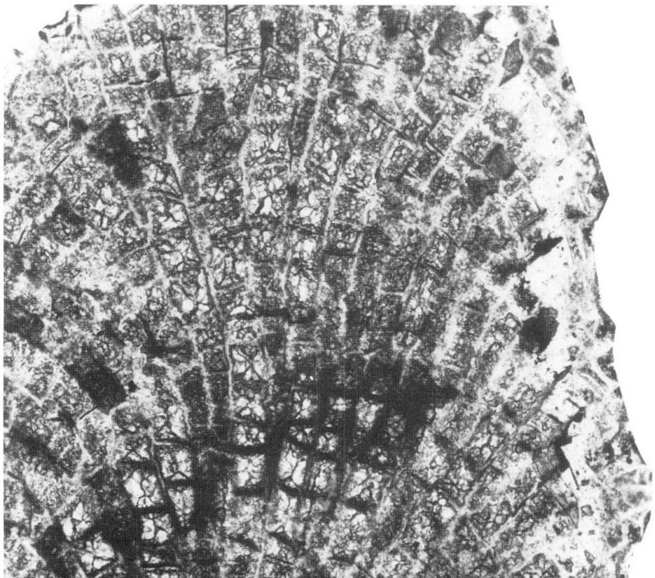

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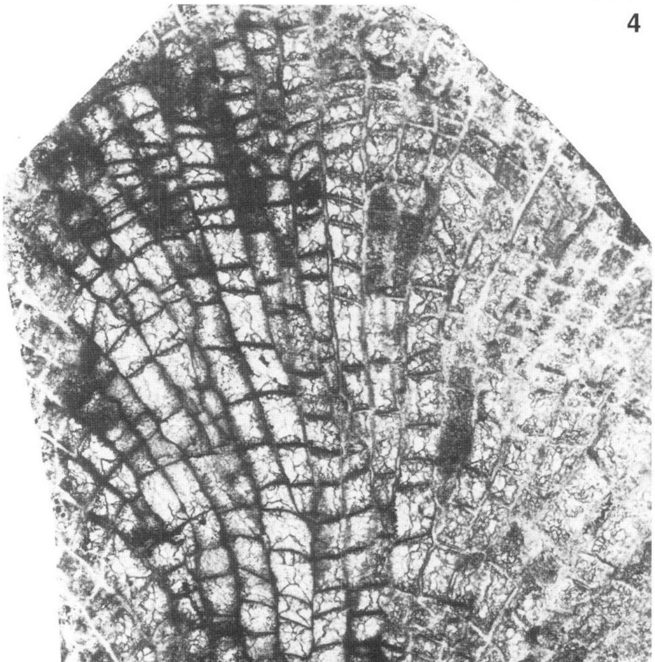

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NOTES ON LATE MIDDLE ORDOVICIAN GASTROPODS FROM THE ADVANCE FORMATION, NORTHEASTERN BRITISH COLUMBIA

David M. Rohr

Abstract

Small gastropods from etched residues of rocks from the Advance Formation represent *Liospira* cf. *L. vitruvia* (Billings), *Lophospira* spp., *Murchisonia* sp., *Ophiletina angularis* Ulrich and Scofield, and a bellerophontacean with affinities to *Bucania*. The assemblage indicates late Blackriveran to Shermanian age.

Résumé

De petits gastéropodes de résidus de roches corrodés de la Formation d'Advance représentent *Liospira* cf. *L. vitruvia* (Billings), *Lophospira* spp., *Murchisonia* sp., *Ophiletina angularis* Ulrich and Scofield et un bellerophontacé ayant des affinités avec *Bucania*. L'assemblage indique un âge s'échelonnant du Blackrivérien tardif au Shermanien.

STRATIGRAPHIC SETTING

The Advance Formation is confined to the Williston Lake region, northern Rocky Mountains, British Columbia, and consists of up to 68 m of thinly bedded limestones, argillaceous dolomites and shales (see Norford, *this volume*, for description and for data concerning the collections). Bounded by unconformities, the formation overlies the Middle Ordovician (Whiterockian to mid-Mowhawkian) Skoki Formation and underlies unnamed Upper Ordovician (mid-Maysvillian to Gamachian) quartzite and dolomite. Small silicified gastropods are present in the etched residues of many of the macrofossil collections but form a very minor component of the macrofauna of the Advance Formation. The following taxa have been identified from the type section of the formation:

GSC loc. C-78640, 44–46 m above base
  Lophospira sp.
  Murchisonia sp.
  indeterminate low-spired gastropods

GSC loc. C-205924, 20.5–21.0 m above base
  Murchisonia sp.
  bellerophontacean aff. *Bucania* sp.

GSC loc. C-205923, 18.5–19.5 m above base
  Liospira sp. cf. *L. vitruvia* (Billings)
  Lophospira spp. 1 and 2
  Murchisonia sp.
  Ophiletina angularis Ulrich and Scofield

The faunule from GSC loc. C-205923 is the only one with biostratigraphic significance and indicates a general late Blackriveran to Shermanian age. *Liospira vitruvia* is known from the Paquette Rapids Beds (lithostratigraphic subdivisions E and F of Steele-Petrovic, 1986) at Paquette Rapids, southeastern Ontario, that traditionally have been assigned either to the Chaumont Formation or the Rockland Formation (Wilson, 1951; Steele and Sinclair, 1971; Steele-Petrovich, 1986) and are late Blackriveran or Rocklandian in age. Mather (1917) observed the species in rocks on Wolfe Island, Ontario, now assigned to the Verulam Formation (Shermanian) by Liberty (1971). Shrock and Raasch (1937) reported the species from the Blackriveran near Kentland, Indiana. The only previous record of *Ophiletina angularis* is in Minnesota, where Ulrich and Scofield (1897) described it from rocks now assigned to the Prosser Member of the Galena Dolomite by Sloan and Webers (1987). Another species, *Ophiletina sublaxa* Ulrich and Scofield, 1987, is present in Blackriveran–Edenian rocks of the mid-continent area (Sloan and Webers, 1987), the Llandeilian of California (Rohr, 1980) and the Upper Ordovician of Alaska (Rohr, 1988).

SYSTEMATIC PALEONTOLOGY

Only one species is described and illustrated. The figured specimen is stored within the type collections of the Geological Survey of Canada, Ottawa.

Class GASTROPODA Cuvier, 1797

Superfamily EUOMPHALOIDEA
de Koninick, 1881

Family EUOMPHALIDAE de Koninick, 1881

Family HELICOTOMIDAE Wenz, 1938

Genus Ophiletina Ulrich and Scofield, 1897

Type species. Ophiletina sublaxa Ulrich and Scofield, 1897. The holotype, subsequently designated by Knight (1941), is from the Stones River Group (Platteville Formation of current usage), late Blackriveran.

Ophiletina angularis Ulrich and Scofield, 1897

Plate 1, figures 1–4

Ophiletina angularis Ulrich and Scofield, 1897, p. 1031, Pl. 74, figs. 43–46.

Material and Occurrence. A single shell (hypotype GSC 106543) from GSC loc. C-205923, Advance Formation, 18.5–19.5 m above its base, Advance Mountain, northeastern British Columbia.

Description. Small (11 mm in diameter), loosely coiled, discoidal shell with flat spire, wide umbilicus and strong growth lines and a U-shaped sinus on upper-outer edge of whorl. External whorl profile quadrilateral with carinae at lower-outer, upper-inner and upper-outer edges and at mid-whorl; interior of whorl nearly circular; upper and lower sutures incised; upper whorl surface slightly convex from suture to upper-inner carina, concave between upper carinae, side of whorl vertical and nearly plane with weaker carina at mid-whorl; base nearly horizontal near lower-outer carina, next curving with increasing convexity into umbilicus. Growth lines convex-forward between carinae except concave-forward on basal surface; aperture not preserved but growth lines indicate a scalloped margin with a U-shaped sinus at upper-outer edge.

Discussion. Only two species have been assigned to the genus *Ophiletina*. Ulrich and Scofield (1897) described *Ophiletina angularis* from the "Phyloporina bed" now assigned to the Prosser Member of the Galena Dolomite by Sloan and Webers (1987) at Cannon Falls, Minnesota. The type species of the genus, *Ophiletina sublaxa* Ulrich and Scofield, 1897, has been reported from the Blackriveran through Edenian of Minnesota, Wisconsin, Illinois, and Tennessee (Ulrich and Scofield, 1897; Sloan and Webers, 1987), Blackriveran of Indiana (Shrock and Raasch, 1937), Llandeilian of California (Rohr, 1980) and from the Upper Ordovician of Alaska (Rohr, 1988). This species differs from *O. angularis* in the uncoiling of the final whorls. As noted by Ulrich and Scofield (1897), no shell found in the Ordovician of North America is likely to be confused with *O. angularis*.

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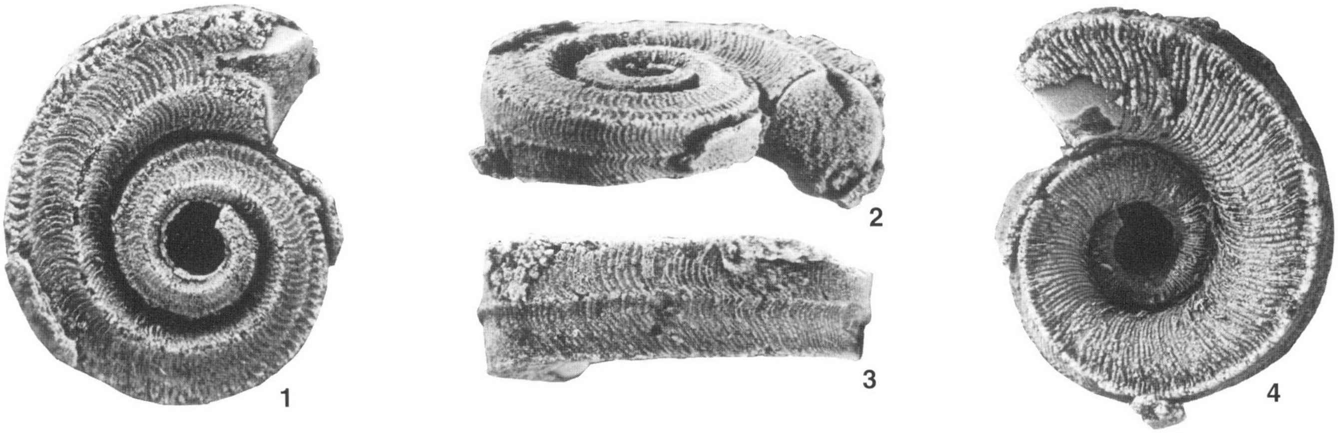
PLATE 1

Figures 1–4. *Ophiletina angularis* Ulrich and Scofield

GSC 106543, hypotype, apical, oblique apertural, side, and basal views, x5, GSC loc. C-205923, Advance Formation, British Columbia.

PLATE 1



MIDDLE ORDOVICIAN (CARADOC) PELECYPODS FROM THE ADVANCE FORMATION, BRITISH COLUMBIA

Paul A. Johnston

Abstract

The newly recognized Advance Formation (Caradoc) of British Columbia has yielded pelecypods representing seven species: *Lyrodesma* sp., *Cyrtodonta* sp., *Vanuxemia hayniana* (Safford), and indeterminate species of Nuculoida, Malletiidae, Ambonychiidae, and Modiomorphoida. Comparisons with Ordovician pelecypod assemblages and their associated depositional environments in eastern North America indicate that the Advance Formation pelecypods inhabited shallow proximal to mid-shelf environments below fair-weather wave base. The Advance Formation pelecypods are of Scoto-Appalachian biogeographic affinity, indicating that a uniform pelecypod fauna inhabited laterally continuous platform environments across most of Laurentia during the Caradoc. Pedal protractor scars in *Vanuxemia hayniana* indicate that the myophoric notch allowed the protractor muscle to pass through the plane of the hinge at high angles of shell gape. *Lyrodesma* is shown to have a schizodid-like ligament and is therefore transferred to the Trigonioida.

Résumé

La Formation d'Advance (Caradocien) de désignation récente en Colombie-Britannique a livré des pélécypodes représentant sept espèces : *Lyrodesma* sp., *Cyrtodonta* sp., *Vanuxemia hayniana* (Safford) et des espèces indéterminées de Nuculoida, Malletiidae, d'Ambonychiidae et de Modiomorphoida. En comparant des assemblages de pélécypodes de l'Ordovicien et leurs milieux de sédimentation associés dans l'est de l'Amérique du Nord, il ressort que les pélécypodes de la Formation d'Advance ont habité des milieux allant de milieux néritiques proximaux à des milieux de plate-forme continentale moyenne au-dessous du niveau de base des vagues de beau temps. Les pélécypodes de la Formation d'Advance ont une affinité biogéographique scoto-appalachienne qui indique qu'une faune uniforme de pélécypodes a habité des milieux de plate-forme latéralement continus dans la grande partie de la Laurentie durant le Caradocien. Des cicatrices de protracteur du pied dans *Vanuxemia hayniana* révèlent que l'encoche myophorique a permis au muscle protracteur de traverser le plan de la charnière du bord baîllant de la coquille selon un angle élevé. Étant donné que son ligament est de forme semblable à celle du schizodonte, *Lyrodesma* est classifié sous Trigonioida.

INTRODUCTION

Pelecypods from the newly recognized Advance Formation of British Columbia (Norford, *this volume*) are a significant addition to the meagre knowledge of Ordovician pelecypods from the western margin of North America. At least seven genera and species are represented (Table 1), but owing to a small sample size and generally poor preservation, only three genera, *Cyrtodonta* Billings, *Vanuxemia* Billings and *Lyrodesma* Conrad, and one species, *Vanuxemia hayniana* (Safford), can be identified with confidence.

PELECYPODS FROM WESTERN NORTH AMERICA

Pelecypods are important components of shallow, proximal to mid-shelf, benthic communities in the Middle–Upper Ordovician (Pojeta, 1971; Sepkoski and Miller, 1985; Frey, 1987a, b). Yet, surprisingly, Ordovician pelecypods are virtually undocumented from the western margin of North America and associated allochthonous terrains. This deficiency may be largely incidental, pelecypods having been occasionally noted in western Ordovician faunas but

TABLE 1

Pelecypods occurring in the Advance Formation, British Columbia

Taxa	Life Habit	Locality		
		C-56101	C-60924	C-205923
Nuculoida gen. et sp. indet.	I D			1
Malletiidae gen. et sp. indet.	I D	1		
Modiomorphoida gen. et sp. indet.	I B S	1		
Ambonychiidae gen. et sp. indet.	E (?N) B S	1		
Cyrtodonta sp.	I B S		2	
Vanuxemia hayniana (Safford)	E-pl B S		6	
Lyrodesma sp.	I S		1	1

Abbreviations under 'Life Habit': B, byssate; D, deposit feeder; E, epifaunal; I, infaunal; N, nestler; p, passive; S, suspension feeder. Numbers in columns under localities indicate numbers of specimens. Stratigraphic and geographic data for these Geological Survey of Canada localities are given in Norford (*this volume*).

not figured or described (e.g., Miller, 1930; Elias and Potter, 1984; Rohr and Potter, 1987). Judging from faunal lists in Miller (1930), the Lander Sandstone Member (Edenian) of the Bighorn Formation of Wyoming contains the most diverse Ordovician pelecypod fauna yet discovered in western North America. Miller listed 13 species referred to seven genera (some doubtfully): *Clinopistha, Ctenodonta, Cyrtodonta, Cleidophorus*?, *Vanuxemia*?, *Byssonychia* and *Whitella*.

Systematic accounts of Ordovician pelecypods from the western margin of North America are limited to: 1) description of a single ambonychiid specimen from the Upper Ordovician of British Columbia (Beaverfoot Formation, Ashgill) that was placed in *Byssonychia* Ulrich (Wilson, 1926), which Pojeta (1966, p. 161) subsequently showed to be a junior objective synonym of *Ambonychia* Hall; and 2) Walcott's (1884) descriptions of poorly preserved pelecypods from the upper part of the Pogonip Group of central Nevada, which is early Middle Ordovician (Whiterockian) in age (Langenheim and Larson, 1973). Walcott assigned these pelecypods to the following new species: *Tellinomya*? *hamburgensis, Tellinomya contracta, Modiolopsis occidens*, and *Modiolopsis pogonipensis*. Identifications of at least two of these taxa can be emended: judging from Walcott's figures (1884, Pl. 11, figs. 15, 15a), *T. contracta* is a species of *Ctenodonta*, as evident from its attenuated posterior margin (*Tellinomya* Hall is a suppressed senior objective synonym of *Ctenodonta* Salter and is a rejected junior homonym of *Tellinomya* Agassiz — see McAllester, 1968); and *T.*? *hamburgensis* has an elliptical, subequilateral shell and may be a babinkid or a cycloconchid rather than a nuculoid.

PELECYPODS FROM THE ADVANCE FORMATION

The pelecypods in this study were collected from the lower half of the Advance Formation at three localities: Advance Mountain (GSC loc. C-205923), west of Bernard Creek (GSC loc. C-56101), and at Mount Burden (GSC loc. C-60924) (Norford, *this volume*, Appendix 3; Jin and Norford, *this volume*, Fig. 2). These localities contain diverse assemblages of invertebrates, including brachiopods, bryozoans, solitary corals, gastropods and echinoderm debris; pelecypods are rare (Table 1).

The Advance Formation provides the first undoubted records of *Vanuxemia* and *Lyrodesma* from the western margin of North America, a significant geographic range extension for these genera. As discussed below, all of the Advance Formation pelecypods (to the taxonomic level they are identified) are known from coeval faunas of eastern North America, and thus, like the associated brachiopods, are of Scoto-Appalachian aspect (Jin and Norford, *this volume*). These taxonomic similarities indicate that a uniform pelecypod fauna inhabited continuous shelf platform environments across most of Laurentia during Caradoc time (Robert C. Frey, pers. comm., 1993).

Palaeoecology

The Advance Formation pelecypod fauna is characterized by low abundance and a low diversity of small (<30 mm in length) infaunal and epifaunal suspension feeders and infaunal deposit feeders

(Table 1). Interpretations of life modes given in Table 1 follow Pojeta (1971) and Frey (1987a, b); however, some of the pteriomorphs require additional comment.

The thick-shelled cyrtodontid pteriomorph, *Vanuxemia*, is thought to include both epibyssate and endobyssate species (Pojeta, 1971; Frey, 1980a, b), and some species of *Vanuxemia* seem to show intraspecific variation in these life modes (Frey, 1980a). Shell features of *Vanuxemia hayniana* from the Advance Formation indicate an epibyssate habit. Both internal moulds and silicified replicas of articulated shells are stable when resting on the broad anterior surface. In dorsal profile, the Advance Formation specimens are asymmetrical with the broadest part of the shell occurring anteriorly (Pl. 1, fig. 5), a criterion that Stanley (1972) found useful for distinguishing epibyssate from endobyssate pelecypods. Frey (1980a) noted the same epibyssate features in the Richmondian species, *Vanuxemia waynesvillensis* Frey, but found seemingly contradictory premortem epibiont patterns on some shells that indicated an endobyssate habit with the anterior part of the shell submerged in the substrate. A similar epibiont pattern occurs on some specimens of *Vanuxemia hayniana* (Pojeta, 1971, Pl. 8, fig. 14). However, this evidence does not necessarily imply that these animals were active burrowers. Morphological evidence, including the extreme antero-dorsal displacement of the anterior adductor scar and the markedly reduced anterior lobe, implies that the foot was much reduced. This, together with the gibbous shell and broad anterior surface, indicates that *Vanuxemia* was poorly adapted for burrowing. I suspect that these pelecypods were preferentially epibyssate but were often partly buried following episodes of sediment stirring (such as storms) or through more gradual sediment deposition and settling of the shell, and were poorly equipped to disinter themselves owing to the reduced foot: such pelecypods, then, were only *passively infaunal*. If so, this might account for heterogeneous epibiont distributions in certain populations of *Vanuxemia* with some individuals showing epibionts widespread on the shell exterior, but most with epibionts lacking anterodorsally (Frey, 1980a).

The Ambonychiidae likewise include both endobyssate and epibyssate species, with some of the latter possibly nestling in thickets of branching trepostome bryozoans (Pojeta, 1971; Frey, 1980a, b, 1987a). Even some ambonychiids showing morphological features normally associated with an epibyssate habit (i.e., reduced anterior lobe with terminal beaks) show epibiont distribution and orientation in outcrops interpreted as indicating an endobyssate habit (Frey, 1980b). The passive endobyssate habit suggested above for *Vanuxemia* may also apply to some of these ambonychiids. However, Frey (1980b) suggested a novel habit like that of the Recent pinnid, *Atrina*, for endobyssate ambonychiids. If so, one would expect in situ specimens to show the anterior margin oriented at a high angle to the bedding, as in *Atrina* (see Stanley, 1970, Fig. 43b); some of Frey's (1987a, Fig. 3.13) reconstructions show such an orientation. Others, however, show the anterior margin at a low angle or nearly horizontal, and unlike *Atrina*, the shell is mostly exposed, as if only lightly buried from sedimentation or settling (Frey, 1987a, Fig. 4.4).

Ambonychiids that Frey (1980b) regarded as undoubtedly epibyssate show broad cross-sectional profiles and carinate umbos. Surface details are not preserved in the ambonychiid from the Advance Formation, but the shell is very broad relative to shell length (Pl. 2, fig. 9) and it was likely epibyssate, or perhaps nestled in branching bryozoans.

The Advance Formation fauna is characterized by abundant articulate brachiopods and trepostome bryozoans with few individuals and species of pelecypods. Other minor components include gastropods, solitary rugose corals and trilobites. This association is similar to those of Maysvillian faunas in eastern North America that inhabited shallow-water (depths <30 m), skeletal-carbonate shelf environments below fair-weather wave base, and that were dominated by diverse articulate brachiopods and trepostome bryozoans, with pelecypods forming a minor component (Frey, 1987a). Frey noted that these skeletal-carbonate assemblages are readily distinguished from coeval, argillaceous, more offshore facies (depths still <30 m) that likely were periodically subject to high rates of sedimentation and were dominated by trilobites, monoplacophorans, nautiloids and diverse, often large, pelecypods. Pelecypod assemblages in the basal portion (Edenian) of the Cincinnatian Series in the Cincinnati area are also characterized by small taxa (normally <30 mm), which may reflect diminished nutrient supply or thixotropic mud bottoms (Frey, 1987a, and references therein). Unlike the Advance Formation, however, these assemblages contain a comparatively greater pelecypod diversity but a lower diversity of brachiopods (*ibid.*).

The composition of the pelecypod fauna of the Advance Formation does not indicate an outer shelf or slope environment of deposition. In their analysis of faunal distribution across Ordovician shelf environments, Sepkoski and Sheehan (1983) cited 18 outer shelf and/or slope communities described in 17 references (of which Bayer (1965) was not available for the present study). Seventeen of these communities, in approximate ascending stratigraphic order, are described in: Ross (1970), Goodwin Limestone and Ninemile Formation, outer shelf; Ross (1951, 1968), upper Garden City Formation, outer shelf to slope; Kay and Crawford (1964), Perkins Canyon Formation, slope; Kay (1962), Ross (1970) and McKee et al. (1972), Antelope Valley Limestone, outer shelf; Walker et al. (1980) and Cooper (1956), Whitesburg Formation, slope, and Lenoir Formation, outer shelf; Ludvigsen (1979) and Hayes (1980), *Ampyx-Triarthrus* biofacies, slope, and *Faillaena-Krausella* biofacies, outer shelf; Ross (1970) and Ross and Shaw (1972), Copenhagen Formation, outer shelf; Cooper and Cooper (1946) and Read (1980), Liberty Hall beds, slope, and Lantz Mills beds, outer shelf to slope; Kay and Crawford (1964), Caesar Canyon, slope; Titus and Cameron (1976), *Triarthrus* Community, slope, and *Geisonoceras* Community, outer shelf; Cisne (1973), Beecher's Trilobite Bed, slope; and Ross et al. (1979), Hanson Creek Formation, outer shelf.

Reference is made to pelecypods in only four of these 17 communities. Ross (1970) recorded the nuculoids *Ctenodonta* sp. and *Deceptrix* sp. at separate localities in outer shelf deposits of the Antelope Valley Limestone. The nuculoid, *Ctenodonta levata*, occurs in the *Geisnoceras* Community of the lowermost Denley Limestone, and the trigonioid, *Lyrodesma* sp., occurs in the *Triarthrus* Community of the Dolgeville Facies (Titus and Cameron, 1976). These authors interpreted these communities as slope and basin, respectively, whereas Sepkoski and Sheehan (1983) list them as outer shelf and slope, respectively. Rare specimens of the pteriomorph, *Caritodens* sp., and the anomalodesmatan, *Rhytimya* sp., occur in slope facies of Beecher's Trilobite Bed (Cisne, 1973). I suspect that *Caritodens* sp. is an allochthonous element in Beecher's Trilobite Bed. Functional morphological evidence indicates that most pterineid pelecypods (especially inequivalved forms having a prominent posterior auricle, as in *Caritodens*) attached to flexible organisms, most probably rooted phylloid algae, in shallow shelf environments (Johnston, 1993). If so, such pterineids would be easily transported into deeper water environments as passengers on detached pieces of algae. *Rhytimya* also may be allochthonous as it occurs in turbidite deposits at this site (Cisne, 1973).

From the above survey of deep-water outer shelf and slope communities, several aspects of Ordovician pelecypod distribution emerge: 1) pelecypods are only rarely encountered in slope and deep-water outer shelf deposits; 2) when present, they are not diverse, being represented by only one or two species; and 3) pteriomorph pelecypods are not definitely known in these environments, being represented by pterineid specimens that are probably allochthonous. However, pelecypods may be present in distal shelf environments that were relatively shallow. Hayes (1980) noted abundant molluscs (he did not specify whether these included pelecypods) in Middle Ordovician shelf-edge carbonate banks. Diverse Upper Ordovician pelecypod assemblages occur in relatively shallow water, mid-shelf, and perhaps even more distal, environments (Frey, 1987b, p. 263).

Pelecypods are not diverse in the Advance Formation, but are more diverse than in any of the Ordovician slope or deep-water outer shelf communities cited above. In addition, pteriomorphs are the most diverse and abundant of the pelecypod subclasses in the Advance fauna. Apart from *Lyrodesma*, which shows a pan-shelf/slope distribution (Frey, 1987a; Titus and Cameron, 1976), I am not aware of any deep outer shelf or slope occurrences of the Advance Formation pelecypod genera (or respective families for indeterminate genera). Therefore, the pelecypod data indicate relatively shallow inner or mid-shelf depositional environments (depths probably <30 m) for at least the pelecypod-bearing beds of the Advance Formation. Other aspects of the Advance fauna, including the relative completeness of the brachiopods and pelecypods and the frequency of articulated shells, together with sedimentological observations (Norford, *this volume*), indicate minimal reworking and transport, and thus a depositional environment below fair weather wave base. For comparison, the diverse pelecypod assemblages of the Late Ordovician Cincinnati Shelf (which include all the identified Advance Formation genera and families) are thought to have inhabited proximal to mid-shelf environments that were less than 30 m in depth but below fair weather wave base (Frey, 1987a, b).

Age

The pelecypod fauna of the Advance Formation supports a late Middle Ordovician (Rocklandian–Shermanian) age for the Advance Formation inferred from brachiopods and conodonts (Norford, *this volume*; Jin and Norford, *this volume*). On the basis of pelecypods alone, the Advance Formation could be no older than Whiterockian, as ambonychiids, which occur in the Advance Formation, are unknown before that time (Pojeta, 1971, 1978). The earliest occurrences of *Vanuxemia* are evidently Blackriveran (Bassler, 1915; Pojeta, 1987). *Vanuxemia* extends into the Richmondian but did not survive the Late Ordovician mass extinction (Frey, 1987a). The Advance species, *Vanuxemia hayniana*, is known elsewhere only from the Prosser Limestone (Shermanian) of Minnesota (Bassler, 1915), and the late Mohawkian (Kirkfieldian–Shermanian) and lower Edenian of the Cincinnati Arch area. Localities in the latter area include: the Catheys Formation (latest Shermanian–early Edenian) at Haynies, Tennessee (John Pojeta, Jr., pers. comm., 1993); the Cannon Limestone (late Kirkfieldian–Shermanian), Carthage, Tennessee; and the Curdsville Limestone Member (Kirkfieldian) and Perryville Limestone Member (Shermanian) of the Lexington Limestone, central Kentucky (Pojeta, 1971, Pls. 7, 8; 1978, Pl. 9; age data — Sweet and Bergström, 1976; Ross et al., 1982; Wahlman, 1992). Thus, *V. hayniana* indicates a Kirkfieldian to early Edenian age for at least the pelecypod-bearing beds at locality C-60924 in the lower half of the Advance Formation at Mount Burden (see Fig. 2 *in* Jin and Norford, *this volume*).

Other pelecypods in the Advance Formation are either too long ranging — *Lyrodesma* extends from the Lower Ordovician to the Lower Silurian (Pojeta, 1971; Harrison and Harrison, 1975) — or too imprecisely identified to be of biostratigraphic use.

SYSTEMATIC PALEONTOLOGY

The specimens described herein are deposited in the Type Collection of Invertebrate and Plant Fossils of the Geological Survey of Canada (GSC). Specimens described include silicified shells, natural moulds, and rubber casts. Figured specimens were whitened with ammonium chloride for photography. Abbreviations used for shell dimensions include: L, length; H, height; Z, length of hinge; D, greatest dimension; T, width of articulated shell.

Subclass PALAEOTAXODONTA Korobkov, 1954

Order NUCULOIDA Dall, 1889

Superfamily and family indeterminate

Genus and species indeterminate

Not figured

Material. GSC 109381, left? valve; GSC loc. C-205923 (Norford, *this volume*, Appendix 3).

Remarks. A minute, worn, fragmentary shell with nearly straight taxodont teeth is referred to the Nuculoida.

Superfamily NUCULANOIDEA Adams and Adams, 1858

Family MALLETIIDAE Adams and Adams, 1858

Genus and species indeterminate

Plate 3, figure 7

Material. GSC 103875, right valve, internal mould; GSC loc. C-56101 (Norford, *this volume*, Appendix 3).

Remarks. An incomplete internal mould shows chevron-shaped teeth and sockets. About 24 sockets, or remnants of sockets, are preserved on the posterior tooth row. A few minute teeth and sockets occur under the beak area. Anterior dentition and muscle scars are not preserved. The height of the mould is 6.8 mm. Length is indeterminate. Preserved parts of the shell outline, notably the elongate (but not rostrate) posterior end, together with the long posterior row of relatively uniformly sized teeth and sockets, are closely similar to comparable features in the malletiids, *Nuculites* Conrad and *Palaeoneilo* Hall and Whitfield, both of which are known from Middle Ordovician rocks in North America (Pojeta et al., 1986). The anterior lobe of the Advance specimen is insufficiently preserved to determine the presence of a myophoric buttress characteristic of *Nuculites*, preventing a generic assignment.

Subclass PTERIOMORPHIA Beurlen, 1944

Superorder PRIONODONTA MacNeil, 1947

Order ARCOIDA Stoliczka, 1871

Superfamily CYRTODONTOIDEA Ulrich, 1894

Family CYRTODONTIDAE Ulrich, 1894

Genus *Cyrtodonta* Billings, 1858

Type species. Cyrtodonta rugosa Billings, 1858 by subsequent designation, Williams and Breger, 1916, p. 149.

Cyrtodonta sp.

Plate 2, figures 3–8

Material. GSC 103872-3, articulated silicified shells; GSC loc. C-60924 (Norford, *this volume*, Appendix 3).

Description. Dorsal margin straight from posterior to umbos; rest of margin rounded; anterior lobe reduced; beaks prosogyrous; ornament consisting of faint comarginal growth lines and occasional growth rugae. Shell measurements: GSC 103872, L = 6.9 mm, H = 5.6 mm , T = 4.0 mm; GSC 103873, L = 5.7, H = 5 mm (estimated), T = 3.2 mm.

Remarks. Two small, articulated shells are assigned to *Cyrtodonta*. The straight dorsal margin and reduced anterior lobe readily distinguish these shells from palaeotaxodonts of comparable size. Juvenile specimens of *Vanuxemia* may be more like *Cyrtodonta* than adult shells (Steele and Sinclair, 1971). However, the Advance specimens referred to *Cyrtodonta* sp. are unlikely to be juveniles of *Vanuxemia hayniana* as the umbos are less gibbous and the shell is significantly longer in proportion to shell height (for *Cyrtodonta* sp., GSC 103872, L/H = 1.23; for *V. hayniana*, GSC 103866, L/H = 0.96).

Shells of *Cyrtodonta* sp. are slightly smaller but closely similar in outline to shells of *Cyrtodonta affinis minuta* Wilson of average size from the Leray-Rockland beds (upper Blackriveran-lower Rocklandian) on the Ottawa River (Wilson, 1956, Pl. 3, fig. 6; age — Barnes et al., 1981). Steele and Sinclair (1971) regarded *C. affinis minuta* a synonym (and presumably juveniles) of the much larger *Cyrtodonta rugosa* Billings. Similarities in outline are also evident with the younger (Ashgill) species *Cyrtodonta septentrionis* Hume from the Mount Kindle Formation of Great Slave Lake (Hume, 1926; age — Barnes et al., 1981), but the shells from the Advance Formation are smaller. In the absence of information about internal shell characters and size variation, the Advance specimens cannot be identified to species.

Genus *Vanuxemia* Billings, 1858

Type species. Vanuxemia inconstans Billings, 1858 by subsequent designation, Miller, 1889.

Vanuxemia hayniana (Safford) 1869

Plate 1, figures 1-8; Plate 2, figures 1, 2

Cyrtodonta hayniana Safford, 1869, Pl. F, fig. 1.
Cypricardites haynianus (Safford); Ulrich, 1892, fig. 25.
Cypricardites triangularis Sardeson, 1892, p. 338.
Vanuxemia hayniana (Safford); Ulrich, 1894, p. 557-558, fig. 36-4, Pl. 38, fig. 32; Pl. 40, figs. 20, 21.
Vanuxemia gibbosa Ulrich, 1894, p. 559.
Vanuxemia hayniana (Safford); Ulrich, 1897, p. 557-558, fig. 36-4, Pl. 38, fig. 32; Pl. 40, figs. 20, 21.
Vanuxemia gibbosa Ulrich, 1897, p. 559.
Vanuxemia hayniana (Safford); Grabau and Shimer, 1909, p. 414, fig. 535k.
Vanuxemia hayniana (Safford); Shimer and Shrock, 1944, p. 381, p. 147, figs. 13, 14, 17.
Vanuxemia gibbosa Ulrich; Pojeta, 1971, Pl. 7, figs. 9, 10; Pl. 8, figs. 3, 12, 14; Pl. 9, figs. 1, 4-7.
Vanuxemia hayniana (Safford); Pojeta, 1978, Pl. 9, figs. 1-5.
Vanuxemia gibbosa Ulrich; Pojeta and Runnegar, 1985, Figs. 15G, H.

Material. GSC 103866, silicified articulated shell; GSC 103867-9, articulated shells, internal moulds; GSC 103870, right valve, internal mould; GSC 103871, left valve, internal mould; total six specimens, all from GSC loc. C-60924 (Norford, *this volume*, Appendix 3).

Description (Advance Formation material). Shell gibbous, subtrigonal, equivalve, inequilateral; umbos strongly prosogyrous (Pl. 1, fig. 4), less obviously so on internal moulds (Pl. 1, fig. 7); cross-sectional profile cordate (Pl. 1, fig. 2); anterior surface broad, flattened (Pl. 1, fig. 5) to slightly rounded (Pl. 2, fig. 1); anterior lobe reduced; ornament consisting of comarginal growth lines, becoming obscure umbonally; ligament opisthodetic, duplivincular; right valve with three cardinal and three posterolateral teeth; cardinal teeth entirely posterior to beak; cardinal teeth lapping over posterior end of anterior adductor scar but not extending dorsally above main body of adductor scar; teeth and sockets with weak crenulations proximally; left valve dentition not observed.

Anterior adductor mounted on platform; platform with well developed myophoric notch; prominent shell thickening anterior to adductor platform (Pl. 1, fig. 3); anterior pedal retractor scar at junction of adductor platform and valve floor (Pl. 1, figs. 3, 7, 8; Pl. 2, fig. 2); subtle, variably developed grooves on underside of hinge plate posterior to myophoric notch (Pl. 1, fig. 3); pallial line pitted, deeply impressed anteriorly, and extending dorsally onto adductor platform anterior to shell thickening; pallial line and musculature not observed posteriorly.

Measurements for GSC 103866 (Pl. 1, fig. 1): L = 21.3 mm, H = 22.3 mm, T = 16.7 mm.

Remarks. Ulrich (1894, p. 559, 1897, p. 559) used the name, *Vanuxemia gibbosa*, for specimens from the Curdsville Limestone of Kentucky (see Bassler, 1915,

p. 1315), but he never formally described or figured them. John Pojeta, Jr. (per. comm., 1993) located Ulrich's original specimens and regards *Vanuxemia gibbosa* as a subjective junior synonym of *Vanuxemia hayniana* (Safford), which is followed here.

Specimens from the Advance Formation show no appreciable differences from specimens of *Vanuxemia hayniana* from the Cincinnati Arch area (Pojeta, 1971, 1978). The shape of the anterior margin of the Advance specimens is variable, ranging from flattened (Pl. 1, fig. 5) to gently rounded (Pl. 2, fig. 1); comparable variation is evident in the Cincinnati Arch material (cf. Pojeta, 1971, Pl. 8, figs. 12, 14; Pl. 9, figs. 4–7).

The dentition is visible in only one of the Advance specimens (Pl. 2, fig. 1). Although largely obscured by debris, weak crenulations occur on the walls of the teeth and sockets, except on the anterior surface of the anteriormost tooth and the posterior surface of the posteriormost tooth, which are smooth. Weak grooves of uncertain significance occur variably on the underside of the hinge plate; they are most obvious in GSC 103866 where they are inequally developed in the opposing valves (Pl. 1, fig. 3). In other specimens the grooves are fainter or obscure.

Function of the myophoric notch. An unusual feature of *Vanuxemia* is the extreme anterodorsal displacement of the anterior adductor scar. The scar may be mounted on a shell thickening, or actually raised onto a septum that is continuous with the hinge plate, as in *V. hayniana* (Pojeta, 1971; Frey, 1980a). In the Advance specimens, the pallial line is visible immediately anterior to the adductor scar (Pl. 2, fig. 1), and thus *V. hayniana* (and perhaps other septum-bearing species of *Vanuxemia*) is apparently unique among pelecypods in having the pallial line extend a short way onto the hinge plate. When a septum is present, a myophoric notch is developed on its ventral edge (Pl. 2, fig. 1). Pojeta (1971, p. 36) discussed the possible functional significance of the myophoric notch in *Vanuxemia* and noted that species without a septum show what he termed an "accessory scar" on the posterior edge of the adductor scar. He concluded (p. 36) that the notch in septum-bearing species "probably served as the seat and passageway of an accessory muscle". A homologous scar occurs at this position in some other cyrtodontids, and in umburrids and rhombopteriids; Johnston (1991, p. 312) interpreted this scar as the insertion of a pedal protractor muscle.

The Advance specimens are significant in showing an elliptical to crescent-shaped pedal protractor scar, one per valve, where the hinge plate meets the valve floor (Pl. 1, figs. 3, 7, 8; Pl. 2, fig. 2), a feature not previously documented in *Vanuxemia*. The scars are likely present in other species of *Vanuxemia*, but given the overhanging septum, they would not be easily visible in silicified specimens; the scars should, however, be evident as small symmetrically disposed protrusions on the anterior surface of well preserved internal moulds, as in the Advance material (Pl. 1, fig. 7). Given the nearness of this muscle scar to the myophoric notch, and the fact that no other pedal scars are evident anteriorly or in the umbonal cavity, there seems little doubt that the myophoric notch is, in fact, functionally associated with this muscle scar.

Because the protractor scar occurs slightly anterior to the myophoric notch (Pl. 1, fig. 8; Pl. 2, fig. 2), the muscle fibres were directed posteriorly and must have functioned to protract the foot. Were the scar for a pedal or byssal retractor, we would expect the scar to occur posterodorsal to the notch. The protractor scar and myophoric notch also are significant in showing that the foot was extruded high on the anterior margin. Were the foot extruded anteroventrally, the protractor muscles would be directed anteroventrally, nearly parallel with the sagittal plane, and thus would not impinge on the septum, making a myophoric notch unnecessary. A subtle byssal(?) sinus high on the anterior margin in some specimens of *Vanuxemia* appears to support this conclusion (Pojeta, 1971, p. 36, Pl. 9, fig. 7), although Johnston (1991) showed that a sinus at this position in pteriomorphs is not always associated with byssal extrusion.

Judging from the spatial relationship of the myophoric notch and protractor scar, the notch was likely functional only when the shell gaped. Because of the extreme anterodorsal position of the foot, the shell must have gaped widely when the foot (even though reduced) was extruded anterodorsally (in many pteriomorphs, a byssal gape or notch, absent in *Vanuxemia*, minimizes the angle of gape necessary to extrude the foot close to the hinge axis, Jackson, 1890, p. 328). When the shell gaped, the septum rotated with the valve away from the commissural plane and would have impinged on the pedal retractor muscle. However, because of the myophoric notch, the muscle passed through the plane of the septum rather than bending around it at a mechanically inefficient angle. Johnston (1993) documented an analogous functional complex in Recent and fossil trigoniids; these pelecypods show a hiatus in the dentition that allows the pedal elevator muscle to pass through the plane of the hinge plate when the shell gapes widely.

Order uncertain

Superfamily AMBONYCHIOIDEA Miller, 1877

Family AMBONYCHIIDAE Miller, 1877

Genus and species indeterminate

Plate 2, figures 9, 10

Material. GSC 103876, articulated shell, internal(?) mould; GSC loc. C-56101 (Norford, *this volume*, Appendix 3).

Remarks. A small, poorly preserved, equivalved shell with articulated valves shows an ambonychiid-like shell outline and lacks an anterior lobe. Preservation is inadequate to determine whether a byssal gape was present. Shell measurements, following Pojeta (1966), are as follows: L = 6.0 mm, H = 5.8 mm, Z = 4.5 mm, D = 6.7 mm, T = 4.3 mm, A (alpha angle) = 45°, G (gamma angle) = 75°. The Advance species may belong in any of five ambonychiid genera including *Ambonychia* Hall, *Anomalodonta* Miller, *Cleionychia* Ulrich, *Maryonychia* Pojeta, and *Psilonychia* Ulrich. All are known from the Middle and/or Upper Ordovician and have at least some species with length and height nearly equal and lacking an anterior lobe (Pojeta, 1966), as in the Advance species. The Middle Ordovician genus *Ambonychiopsis* Isberg is another possibility. Although shelled specimens of this genus have a weak anterior lobe, internal moulds do not always show this feature, and thus resemble the Advance specimen (Pojeta, 1966, Pl. 21, fig. 19; Pl. 22, fig. 3; Pl. 23, fig. 7; R.C. Frey, pers. comm., 1993).

Subclass HETEROCONCHIA Hertwig, 1895

Order TRIGONIOIDA Douvílle, 1912

Family LYRODESMATIDAE Ulrich, 1894

Remarks. Johnston and Goodbody (1988) noted that dental crenulations alone were insufficient to diagnose the Lyrodesmatidae from the Cycloconchidae. They suggested that ligament structure might be a useful character but found existing descriptions and figures ambiguous. I have since examined first hand an excellently preserved specimen of *Lyrodesma* figured by Pojeta (1971, Pl. 3, figs. 13–15). This specimen and a specimen of *Lyrodesma* described herein (Pl. 3, fig. 5) clearly show a short opisthodetic parivincular ligament groove bounded internally by a prominent nymph. This ligament is virtually identical with early schizodid and eoschizodid trigonioideans and is unlike that of cycloconchids, which show either a broad ligament area with no nymph, as exemplified by *Tanaodon* (Johnston, 1993, p. 117), or a weak nymph with a faint ligament groove, as exemplified by *Cycloconcha* (Waller, 1990). Consequently, the Lyrodesmatidae are here included in the Trigonioida rather than the Actinodontoida.

Unlike later trigonioids, a pedal elevator scar is apparently absent at the top of the umbonal cavity in *Lyrodesma* (Pl. 3, fig. 2; Pojeta, 1978, Pl. 6, figs. 3, 4). Instead, one (or more?) pedal elevators occur in the umbonal cavity of each valve on the underside of the hinge plate (Pl. 3, fig. 2; Pojeta and Runnegar, 1985, fig. 14D).

Genus *Lyrodesma* Conrad, 1841

Type species. Lyrodesma planum Conrad, 1841, established by monotypy (see Newell and LaRocque, 1969, p. 471).

Lyrodesma sp.

Plate 3, figures 1–5

Material. GSC 103874, silicified right valve; GSC loc. C-60924 (Norford, *this volume*, Appendix 3); GSC 109380, silicified left valve; GSC loc. C-205923 (Norford, *ibid.*).

Description. Shell outline unknown. Diagonal ridge prominent. Outer edge of corselet with radial costae (Pl. 3, fig. 4); rest of corselet smooth. Teeth crenulated (Pl. 3, fig. 1). Left valve with six teeth and six sockets; anterior tooth robust; posterior teeth longer than central and anterior teeth (Pl. 3, fig. 3); hinge of right valve incomplete. Anterior adductor scar high on shell near hinge (Pl. 3, fig. 1). Anterior pedal retractor scar deeply inset on anterior end of hinge plate (Pl. 3, fig. 3). Pedal elevator scar on underside of hinge plate (Pl. 3, fig. 2) of right valve,; not preserved in left valve. Ligament short, parivincular (Pl. 3, fig. 5).

Remarks. Although fragmentary, these specimens show the characteristic crenulated radiating cardinal teeth of *Lyrodesma* and thus cannot be confused with any other North American Ordovician pelecypod genera. Similarities are closest with *Lyrodesma subplanum* Ulrich (upper Shermanian–Edenian, Pojeta, 1978) and with *Lyrodesma acuminatum* Ulrich (Blackriveran, Pojeta, 1978), which, like the Advance Formation species, show a prominent diagonal ridge, radial costae on the corselet and elongate posterior teeth (cf. Pojeta, 1971, Pl. 3, figs. 5-8; 1978, Pl. 6, figs. 1, 7-13). However, the Advance species has fewer teeth and sockets than *L. subplanum* and, unlike *L. accuminatum*, the central cardinal teeth do not curve posteriorly.

Subclass ANOMALODESMATA Dall, 1889

Order MODIOMORPHOIDA Newell, 1969

Family indeterminate

Genus and species indeterminate

Plate 3, figure 6

Material. GSC 103877, incomplete right valve, internal mould: GSC loc. C-56101 (Norford, *this volume*, Appendix 3).

Remarks. A single fragmentary internal mould preserves the anterior half of the shell. Preserved parts of the outline indicate an originally modioliform shell that likely did not exceed 30 mm when complete. The Advance specimen is referred to the Modiomorphoida rather than the Pholadomyoida (which also includes modioliform shells) because of the deeply impressed anterior adductor scar (Pl. 3, fig. 6). The anterior adductor is only weakly impressed in Ordovician to Devonian pholadomyoids (see figures *in* Pojeta, 1971, 1978; Johnston, 1993).

The Modiomorphoida are here included in the Anomalodesmata following Waller (1990) and Johnston (1993).

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PLATE 1

Figures 1–8. *Vanuxemia hayniana* (Safford) 1869.

1–5. GSC 103866, silicified articulated shell, left lateral, posterior, internal umbonal (stereo pair, left upper arrow — grooves on underside of hinge plate; left middle arrow — pedal protractor scar; left lower arrow — anterior thickening; right upper arrow — posterior part of anterior adductor scar; right middle arrow — myophoric notch; right lower arrow — pallial line), anterodorsal and dorsal views, x3, GSC loc. C-60924.

6–8. GSC 103867, internal mould, articulated shell, right lateral, dorsal (arrows — pedal protractor scars) and anterior views (stereo pair, upper arrow — pedal protractor scar; lower arrow — myophoric notch), x3.3, GSC loc. C-60924.


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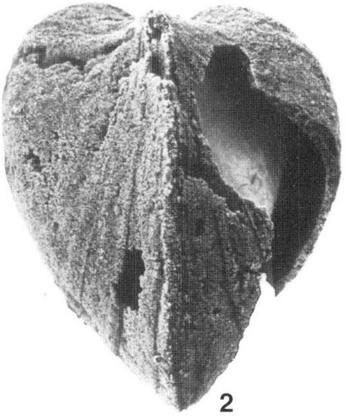
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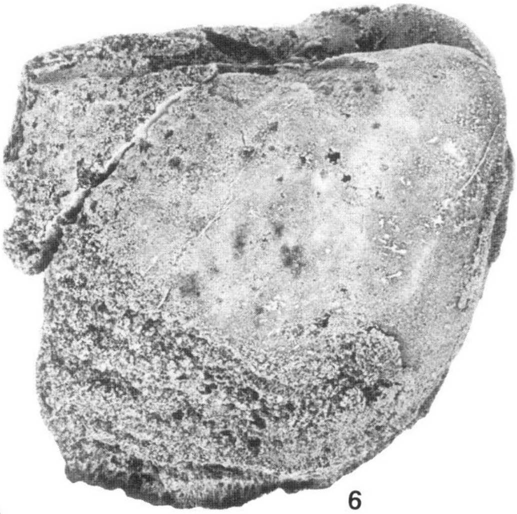
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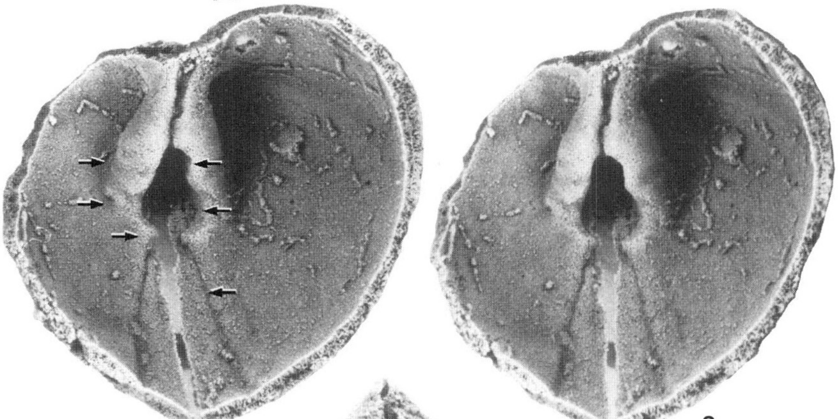
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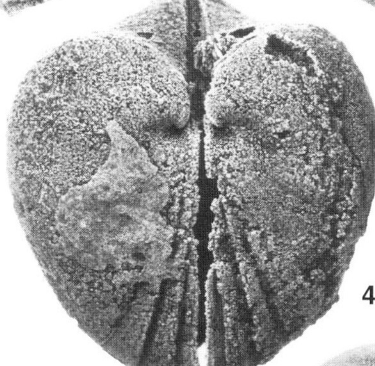
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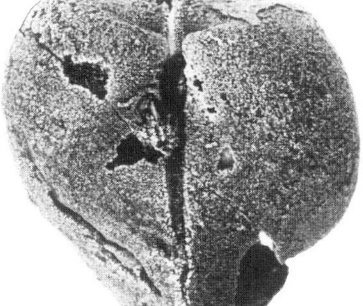
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PLATE 2

Figures 1, 2. *Vanuxemia hayniana* (Safford) 1869.

GSC 103870, rubber cast, right valve interior, medial view (stereopair, left arrow — anterodorsal extension of pallial line onto hinge plate; right arrow — myophoric notch) and oblique view (stereopair, arrow — pedal protractor scar), x2.4, GSC loc. C-60924.

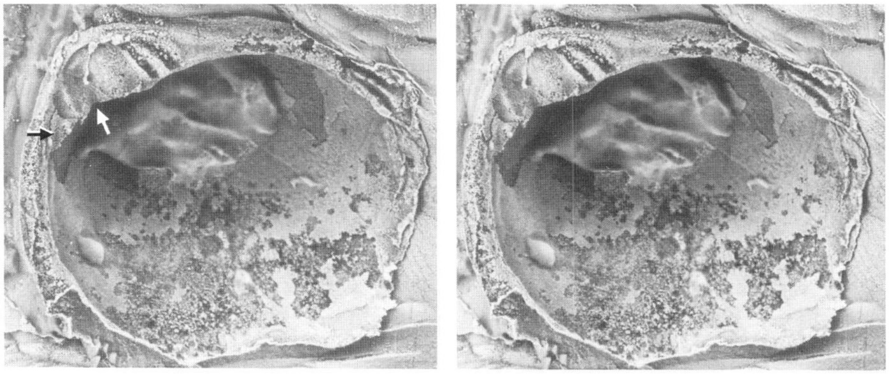
Figures 3–8. *Cyrtodonta* sp.

3–5. GSC 103872, silicified articulated shell, anterior, dorsal, and left lateral views, x9.1, GSC loc. C-60924.

6–8. GSC 103873, silicified articulated shell, anterior, right lateral, and dorsal views, x11.3, GSC loc. C-60924.

Figures 9–10. Ambonychiidae, genus and species indeterminate.

GSC 103876, silicified articulated shell, dorsal and right lateral views, x11.3, GSC loc. C-56101.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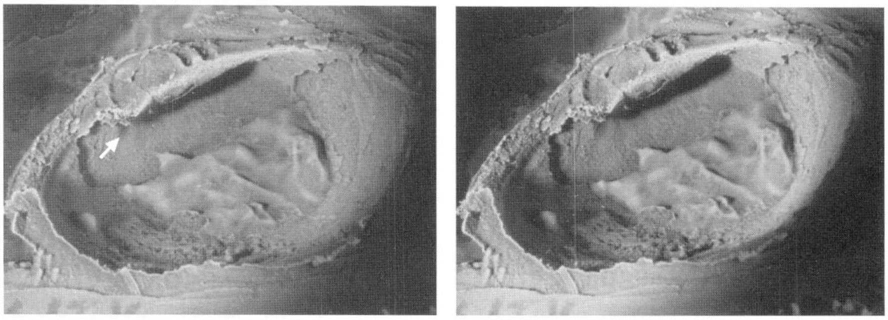
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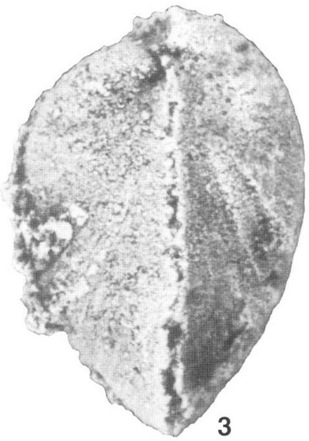
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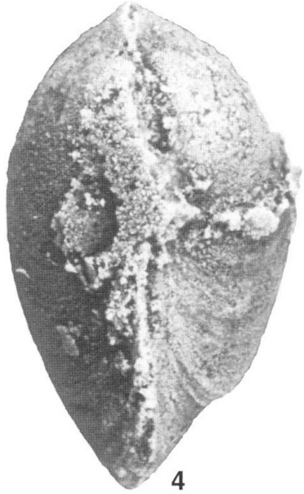
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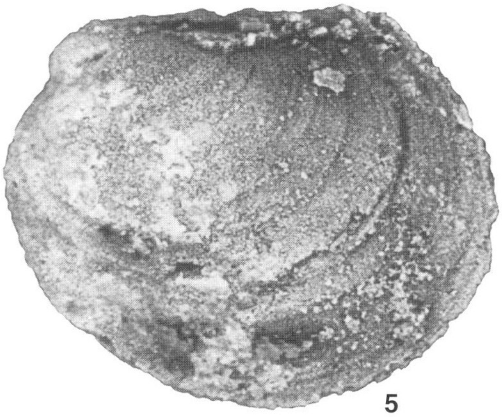
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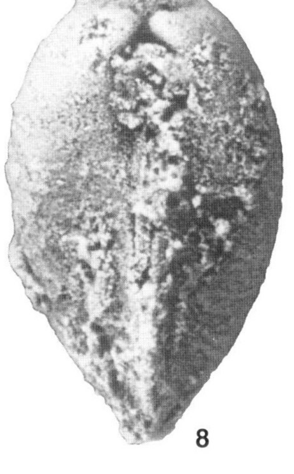
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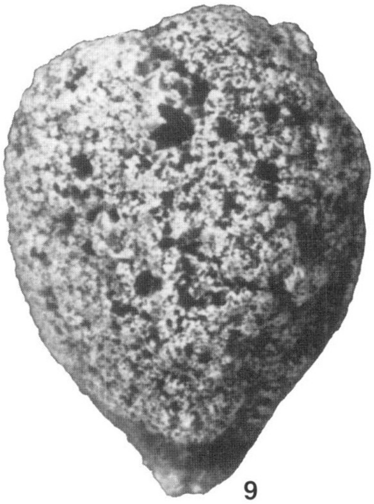
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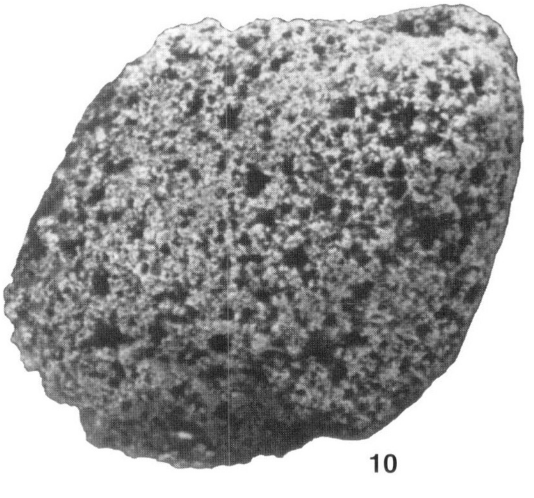
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PLATE 3

Figures 1–5. *Lyrodesma* sp.

1, 2. GSC 103874, silicified fragmentary right valve, internal view (arrow — anterior adductor scar) and ventral view (arrow — pedal elevator scar), x8.8, GSC loc. C-60924.

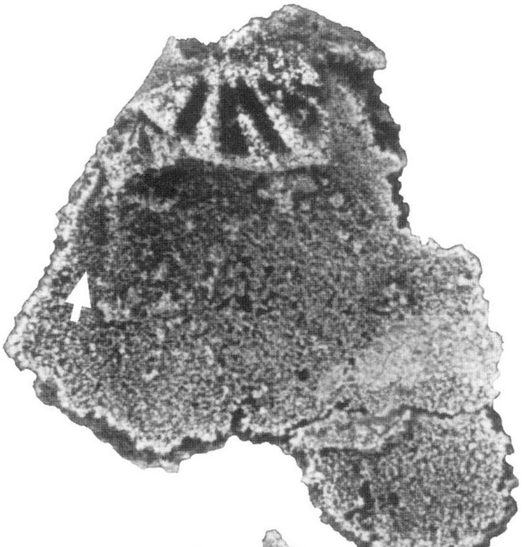
3–5. GSC 109380, silicified fragmentary left valve, internal, lateral and dorsal views (stereopair, arrow — nymph), x12, GSC loc. C-205923.

Figure 6. Modiomorphoida, genus and species indeterminate.

GSC 103877, internal mould, incomplete right valve, lateral view, x4.2, GSC loc. C-56101.

Figure 7. Malletiidae, genus and species indeterminate.

GSC 103875, internal mould, right valve, lateral view, x8.8, GSC loc. C-56101.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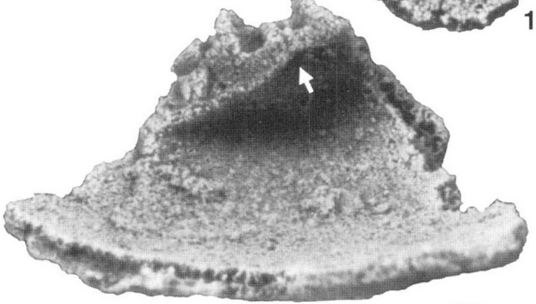
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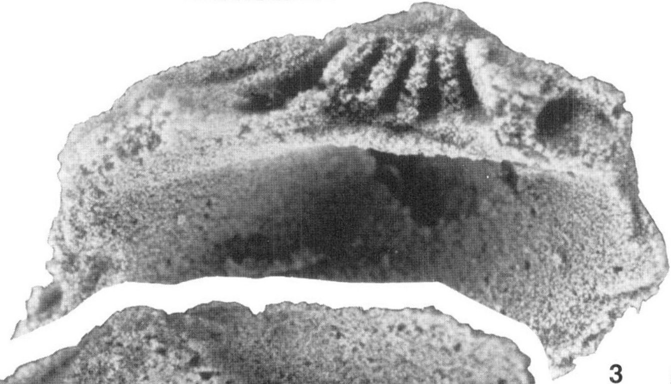
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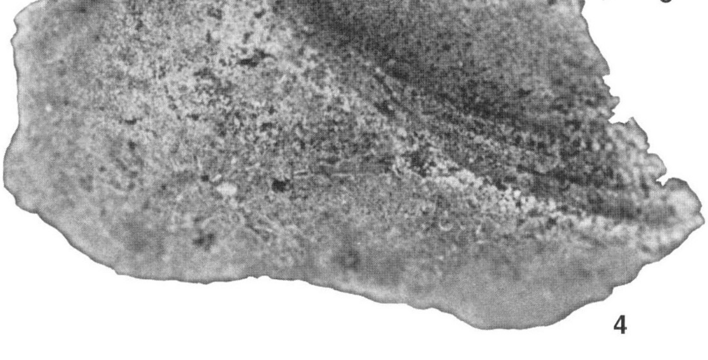
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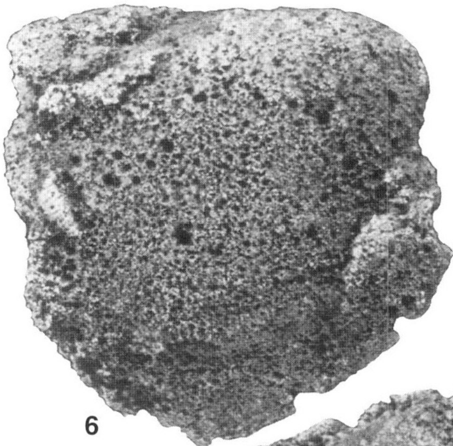
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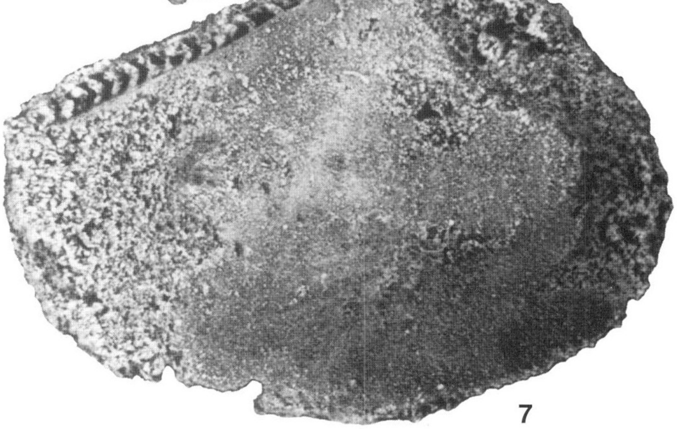
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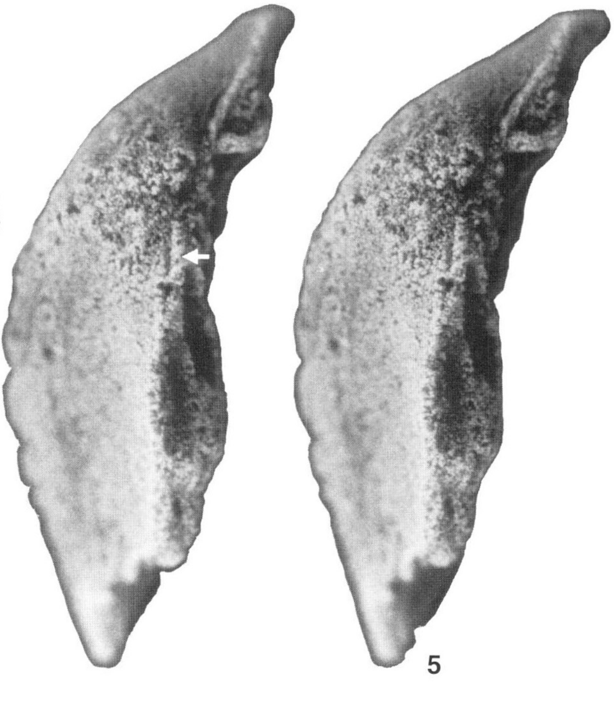
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