

Communities and paleoecology of Eifelian (mid-Devonian) brachiopods from the Bird Fiord Formation of Arctic Canada

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Abstract: The carbonate–siliciclastic strata in the Bird Fiord Formation of Arctic Canada contain a diverse brachiopod-dominated biota. A collection of 46 381 brachiopods from 126 sites at 35 localities on Ellesmere Island, North Kent Island, Grinnell Peninsula (Devon Island), and Bathurst Island includes 22 species assigned to 21 genera. Many of these taxa are endemic to Arctic Canada. Each collection of brachiopods is typically dominated by only one or two taxa. Cluster analysis, based on binary data, shows that the brachiopods can be divided into an *Atrypa–Elythyna* community group and a *Spinatrypina–Desquamatia* community group. The former encompasses the *Atrypa–Elythyna* and *Atrypa–Elythyna–Perryspirifer* communities, and the latter includes the *Spinatrypina–Desquamatia* and *Spinatrypina–Desquamatia–Cranaena* communities. The distribution of these communities was primarily related to water depth. Thus, the *Atrypa–Elythyna* community group, which belongs to benthic assemblage 3, lived in a shallow, proximal-shelf environment. The *Spinatrypina–Desquamatia* community group, which belongs to benthic assemblage 4, lived in a deeper, distal-shelf environment.

Résumé : Les strates carbonatées-siliciclastiques de la Formation de Bird Fiord de l'Arctique canadien contiennent une biote diversifiée dominée par des brachiopodes. Une collection de 46 381 brachiopodes provenant de 126 sites à 35 localités de l'île d'Ellesmere, l'île de North Kent, la péninsule de Grinnell (île Devon) et l'île Bathurst comprennent 22 espèces attribuées à 21 genres. Plusieurs de ces taxons sont endémiques à l'Arctique canadien. Chaque collection de brachiopodes est typiquement dominée par seulement un ou deux taxons. Une analyse typologique basée sur des données binaires montre que les brachiopodes peuvent être divisés entre un groupe communautaire *Atrypa–Elythyna* et un groupe communautaire *Spinatrypina–Desquamatia*. Le premier englobe les communautés *Atrypa–Elythyna* et *Atrypa–Elythyna–Perryspirifer* alors que le second comprend les communautés *Spinatrypina–Desquamatia* et *Spinatrypina–Desquamatia–Cranaena*. La distribution de ces communautés est surtout fonction de la profondeur de l'eau. Ainsi, le groupe communautaire *Atrypa–Elythyna*, qui appartient à l'assemblage benthique 3, vivait dans un environnement peu profond de plate-forme proximale. Le groupe communautaire *Spinatrypina–Desquamatia*, qui appartient à l'assemblage benthique 4, vivait dans un environnement plus profond de plate-forme distale.

[Traduit par la Rédaction]

Introduction

The upper Lower to Middle Devonian Bird Fiord Formation of Arctic Canada (Embry and Klovan 1976; Goodbody 1989) is a carbonate–siliciclastic succession that outcrops widely on southwestern Ellesmere Island, North Kent Island, northwestern Devon Island, Bathurst Island, and parts of Cornwallis Island (Fig. 1). The formation, which ranges from 465 m thick on eastern Grinnell Peninsula to more than 900 m on western Bathurst Island, was initially divided into units A–F (Goodbody 1985). Later, Goodbody (1989) formally named these units the Cross Bay, Blubber Point, Baad Fiord, Norwegian Bay, Cardigan Strait, and Grise Fiord members (Fig. 2). On Bathurst Island, a 20 m thick unit of carbonates, named the “Blue Fiord” Formation by Goodbody (1989)

(also referred to as the Blue Fiord Formation by Kerr 1974; the limestone member of the Disappointment Bay Formation by Smith 1984; and the “Bird Fiord Formation carbonate equivalent” by Goodbody 1985), separates the Bird Fiord Formation from the underlying Eids Formation. The “Blue Fiord” Formation and the Baad Fiord Member, Blubber Point Member, Norwegian Bay Member, and Cardigan Strait Member of the Bird Fiord Formation contain an abundant, diverse fauna that is dominated by brachiopods along with fewer corals, mollusks, and trilobites.

Our brachiopod collection from the Bird Fiord Formation encompasses 22 species that belong to 21 genera (Appendix A, Table A1; Figs. 2–4). No taxon forms more than 20% of the total fauna. *Cupularostrum repititor*, *Spinatrypina borealis*, *Atrypa* sp. B, and *Desquamatia (Independatrypa) fortis* each

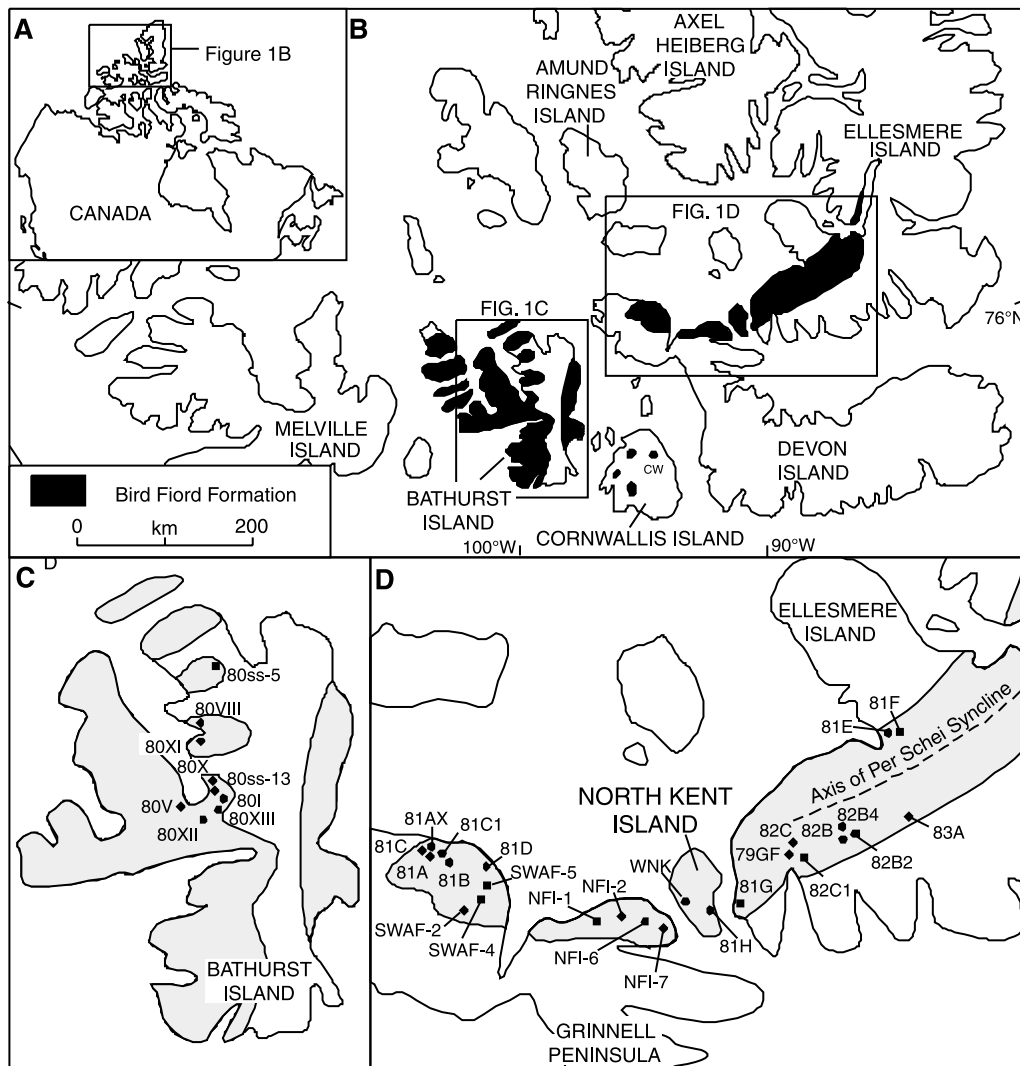
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Fig. 1. (A, B) Outcrops of Bird Fiord Formation in Arctic Canada. CW, Cornwallis Island locality. (C, D) Location of sections and spot localities from which brachiopods were collected from the Bird Fiord Formation.



form 15–20% of the total fauna (Table 1), whereas *Schizophoria sulcata* and *Elythyna sverdrupi* each form 5–10% of the total fauna (Table 1). Members of the other 16 taxa are scarce, with each taxon forming <5% of the total brachiopod fauna (Table 1). Individual collections are typically dominated by only one or two taxa. The collection of 4197 brachiopods from the sample at site 80XII-99m, for example, includes 4145 specimens (98.76% of fauna) of *C. repetitor*.

The brachiopods from the Bird Fiord Formation form distinct communities that are characterized by recurring associations of taxa (cf. Boucot 1975, 1981). Those communities that have taxa in common can be assigned to a community group (cf. Boucot 1975, 1981; Boucot and Perry 1981; Soja 1988a, 1988b; Wang et al. 1987). Communities and community groups can be defined according to qualitative and quantitative criteria. Qualitative definitions are usually based on a worker's experience with the faunas and generally lack a statistical basis (e.g., Johnson 1974, 1990; Feldman 1980; Boucot and Perry 1981; Wang et al. 1987; Rong and Li 1999; Jin and Zhan 2001). This subjective approach, however, may cause problems because "... some of the communities may be difficult

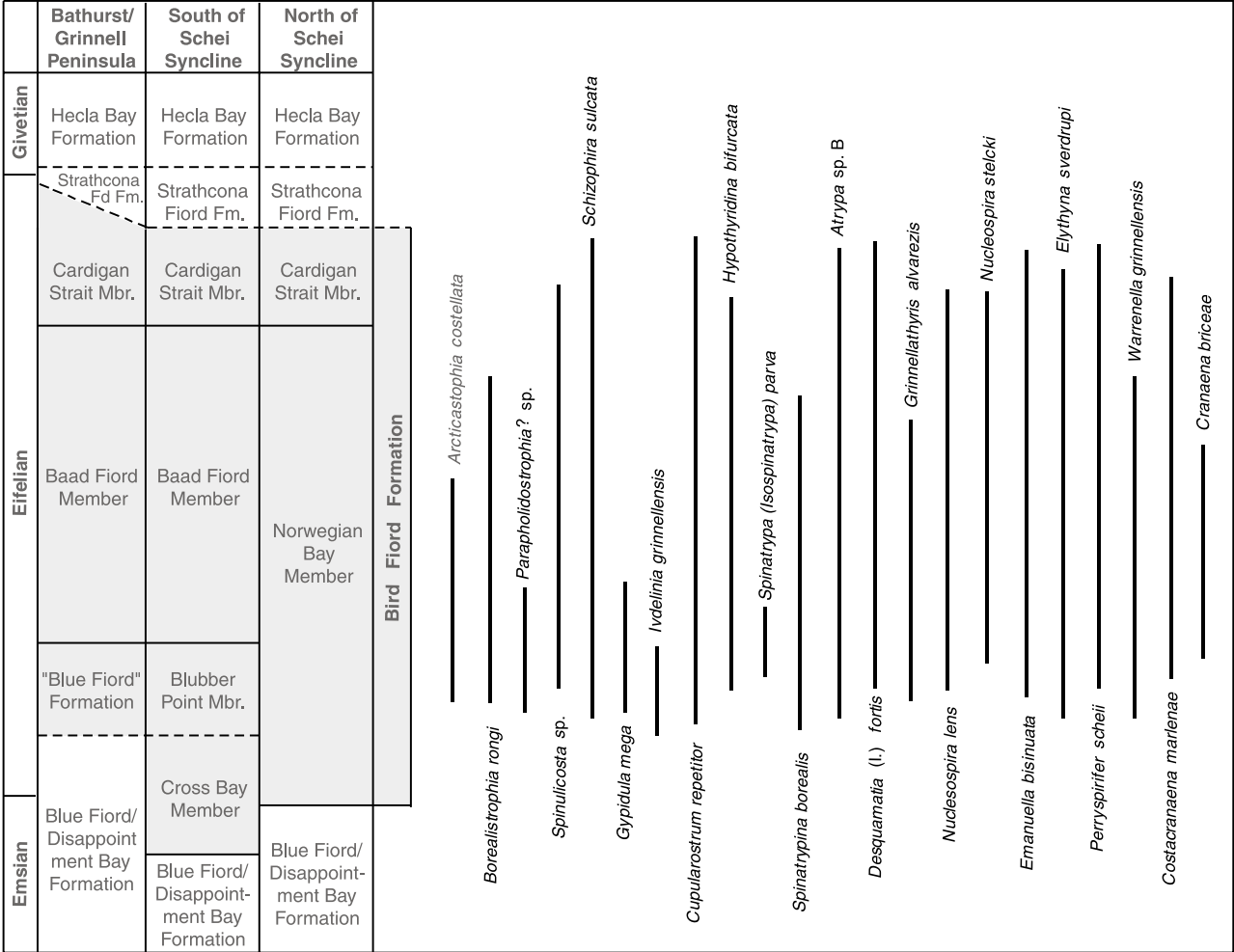
to understand for the workers unfamiliar with the examples" (Boucot and Perry 1981, p. 186). Accordingly, this study used quantitative methods (similarity index, cluster analysis) to define the brachiopod communities and community groups present in the Bird Fiord Formation.

The paleogeographic setting of the brachiopod communities and community groups is established by placing them in the sedimentological framework that was delineated by Goodbody (1985, 1989). These Eifelian brachiopods, which come from an outcrop belt of the Bird Fiord Formation that stretches for ~400 km, provide important insights into the factors that may have controlled their distribution. Potentially, these data are important for any future studies that consider the paleobiogeographic distribution of Eifelian brachiopods throughout North America and the rest of the world.

Methods

This study is based on 46 381 brachiopods collected from 126 sites at 35 localities throughout the outcrop belt of the Bird Fiord Formation (Fig. 1). Some collections came from

Fig. 2. Stratigraphic ranges of brachiopod taxa found in the Bird Fiord Formation of Arctic Canada (modified from Li and Jones 2003). Fd, Fiord; Fm., Formation; Mbr., Member.



different stratigraphic levels in continuous sections, and others came from isolated outcrops. Most of the brachiopods are articulated, and the lack of abrasion indicates that they underwent little or no transport after their death. Following Jones and Smith (1980, 1985) and Jones (1991), the total number of specimens of each species is calculated as the total number of articulated individuals and the larger number of either the dorsal or ventral valves.

Cluster analysis is commonly used to quantitatively delineate communities (e.g., Keyser 1977; Ludvigsen and Westrop 1983; Jones and Smith 1985; Lespérance and Sheehan 1988; Soja 1988a, 1988b; Jones 1988, 1991; Kovach 1989; Kovach and Batten 1994; Patzkowsky 1995; Budd et al. 1999; Etter 1999; Smith 1999; Watkins et al. 2000; Zhan et al. 2002). In this study, cluster analyses were done using ClustanGraphics 5.0 (Wishart 1999). Q-mode and R-mode analyses of the raw data (absolute numbers) produced chained clusters, whereas analyses based on percentages produced good clusters for the sample sites but chained clusters for the taxa. Such analyses were deemed unacceptable because of the chaining effect (cf. Jones 1988). Q-mode and R-mode cluster analysis based on binary data (i.e., presence or absence of a taxon), however, produced very good clusters that facilitated definition of the brachiopod communities. For these analyses, the Jaccard

coefficient of similarity and Ward's method (i.e., minimum variance or increase in sum of square) of clustering were used. The Jaccard coefficient (**Jd**) is expressed as

$$Jd = \frac{C}{N_A + N_B - C}$$

where *C* is the total joint occurrence of taxa A and B in the collections; and *N_A* and *N_B* are the total presence of taxa A and B, respectively, in the collections. The simple matching coefficient was not used because it is based on the mutual presence and absence of a taxon (cf. Keyser 1977, p. 188). With this index, there is the possibility that a high coefficient may be more reflective of mutual absences than mutual presences. The Jaccard coefficient avoids this problem and is one of the reasons why it has been widely used, in conjunction with Ward's method of clustering, for delineating communities (e.g., Keyser 1977; Jones and Smith 1985; Jones 1988, 1991; Lespérance and Sheehan 1988; Soja 1988a, 1988b).

Our samples should be statistically reliable, given the size of the total collection, the number of brachiopods in individual collections (up to 4197), and the manner in which the samples were collected. Two to four people collected as many

Fig. 3. Nominal taxa of brachiopod communities in Bird Fiord Formation of Arctic Canada. (**Figs. 3.1–3.5**) *Atrypa* sp. B Jones in dorsal (3.1), ventral (3.2), anterior (3.3), posterior (3.4), and lateral (3.5) views, from Norwegian Bay Member, locality 81F, P951, $\times 2.3$. (**Figs. 3.6–3.10**) *Elythyna sverdrupi* Brice in lateral (3.6), ventral (3.7), dorsal (3.8), anterior (3.9), and posterior (3.10) views, from Norwegian Bay Member, locality 81E, P952, $\times 2$. (**Figs. 3.11–3.14, 3.27**) *Perryspirifer scheii* (Meyer) in dorsal (3.11), ventral (3.12), posterior (3.13), anterior (3.14), and lateral (3.27) views, from boundary of Blubber Point and Baad Fiord members, locality NFI-1, P953, $\times 1.2$. (**Figs. 3.15, 3.16, 3.20, 3.21, 3.28**) *Spinatrypina borealis* (Warren) in dorsal (3.15), ventral (3.16), posterior (3.20), lateral (3.21), and anterior (3.28) views, Baad Fiord Member, locality 81A, UA12974, $\times 2.3$. (**Figs. 3.17–3.19, 3.25, 3.26**) *Desquamatia* (*Independatrypa*) *fortis* Li and Jones in lateral (3.17), anterior (3.18), posterior (3.19), ventral (3.25), and dorsal (3.26) views, Baad Fiord Member, locality 81A, UA12951, $\times 1.5$. (**Figs. 3.22–3.24**) *Cranaena briceae* Li and Jones in lateral (3.22), ventral (3.23), and dorsal (3.24) views, Baad Fiord Member, locality 81A, UA12976, $\times 3.3$. All the specimens are stored in the Paleontology Museum, Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta.

brachiopods as possible from each site with special attention being paid to the acquisition of specimens of all sizes. Small specimens are, for example, well represented throughout the collections. The collection from site 81AX-104m (Devon Island), for example, contains numerous *Grinnellathyris alvarezis* that are less than 5 mm wide (Li and Jones 2002, their table 3). Thus, we are confident that there is little or no size bias in these collections. The overall integrity of the samples is further supported by the fact that virtually almost all of the brachiopod taxa previously reported from the Bird Fiord Formation by Johnson and Perry (1976), Brice (1982), Jones (1982), and Jones and Boucot (1983) are present. Nevertheless, the rarefaction curve does not show the classic pattern of a progressively decreasing number of species with increasing sample size (Fig. 5). For this set of samples, the number of species does not always correlate with sample size. The 4197 brachiopods in the sample from site 80XII-99m, for example, only include six species, whereas the 1842 brachiopods in the sample from site 80I-659m include eight species. The poor correlation between sample size and species diversity probably reflects the fact that most of the collections are dominated by only one or two species.

Sedimentological regimes

The Bird Fiord Formation is part of the Devonian succession that accumulated in the Franklinian Mobile Belt (Goodbody 1989). During the Eifelian, a broad shelf stretched from northern Ellesmere Island, through Grinnell Peninsula (Devon Island), to Bathurst Island and Cornwallis Island (Fig. 6). This shelf was bound to the east and south by land and to the northwest by a deep oceanic basin (Fig. 6). The Bird Fiord Formation, which is transitional between an underlying carbonate shelf – argillaceous basin regime and an overlying siliciclastic regime, records the westerly advance of siliciclastic sediments, derived from the land masses to east and south, over a carbonate platform (Embry and Klovan 1976; Goodbody 1985, 1989). Goodbody (1985, 1989) showed that the Bird Fiord Formation encompasses a broad array of depositional regimes. The following summary, which provides an overview of the facies that are considered representative of each stratigraphic unit, is based on the descriptions given by Goodbody (1985, 1989).

Near Bird Fiord, Ellesmere Island, the Bird Fiord Formation is divided into the Norwegian Bay Member and the Cardigan Strait Member (Fig. 2). The Norwegian Bay Member (583 m thick), which is confined to the north axis of the Schei Syncline, encompasses a diverse array of facies. Goodbody

(1989) divided this member into units 1 (basal) to 5 (top): (1) interbedded bioclastic limestones – calcareous siltstone and shale (232 m); (2) interbedded shale and rubbly bedded siltstone or cryptalgal laminite, with scattered stromatolites (26 m); (3) coarsening-upward cycles that grade upward from shale into calcareous rubbly sandstone (90 m); (4) coarsening-upward cycles that grade from shale to argillaceous siltstone to cross-bedded, bioturbated, calcareous sandstones (115 m); and (5) interbedded bioclastic, calcareous sandstones and shale (120 m). The Norwegian Bay Member encompasses facies that formed in an intertidal to shallow-shelf setting (Goodbody 1985).

The Cardigan Strait Member, which overlies the Norwegian Bay Member in the Bird Fiord area, is 230 m thick (Goodbody 1989). This member is formed of planar and cross-bedded noncalcareous sandstone that commonly contains crinoids, brachiopods, bivalves, and plant fragments (Fig. 7). These successions formed as deltas advanced onto the shelf.

The Grise Fiord Formation, which is only found in the easternmost part of the outcrop belt, underlies the upper tongue of the Strathcona Formation (Goodbody 1989). This succession (~100 m thick), formed of orange-brown noncalcareous, fine- to medium-grained, mica-rich subarkosic sandstones with lesser amounts of argillaceous siltstone, shale, and calcareous shale, formed in a nonmarine, delta-plain setting (Goodbody 1985).

On the south limb of the Schei Syncline, the Bird Fiord Formation is divided into the Cross Bay Member, the Blubber Point Member, the Baad Fiord Member, and the Cardigan Strait Member (Fig. 2). The upper part of the Cross Bay, Blubber Point, and Baad Fiord members is equivalent to the Norwegian Bay Member (Fig. 2).

The Cross Bay Member, ~300 m thick, is formed of interbedded dolostones, limestones, siltstone, shale, and evaporites. The succession encompasses 2–6 m thick cycles that grade up from basal shale into silty dolostone and, in some areas, gypsum. Planar laminations, wrinkly laminations, stromatolitic laminae, fenestrae, mudcracks, scours, vugs, and intraclastic layers are common (Fig. 7). Few fossils are found in this member. The lithologies and sedimentary structures are indicative of sediments that accumulated in a sabkha setting.

The Blubber Point Member on southwest Ellesmere Island (south of Schei Syncline axis), North Kent Island, and northern Devon Island (excluding Grinnell Peninsula), typically ~60 m thick, is formed of resistant, cliff-forming limestone and calcareous sandstone and some shale. Cycles consist of dark grey–green shale that grades upwards into argillaceous siltstone – fine-grained sandstone, to grey–green rubbly

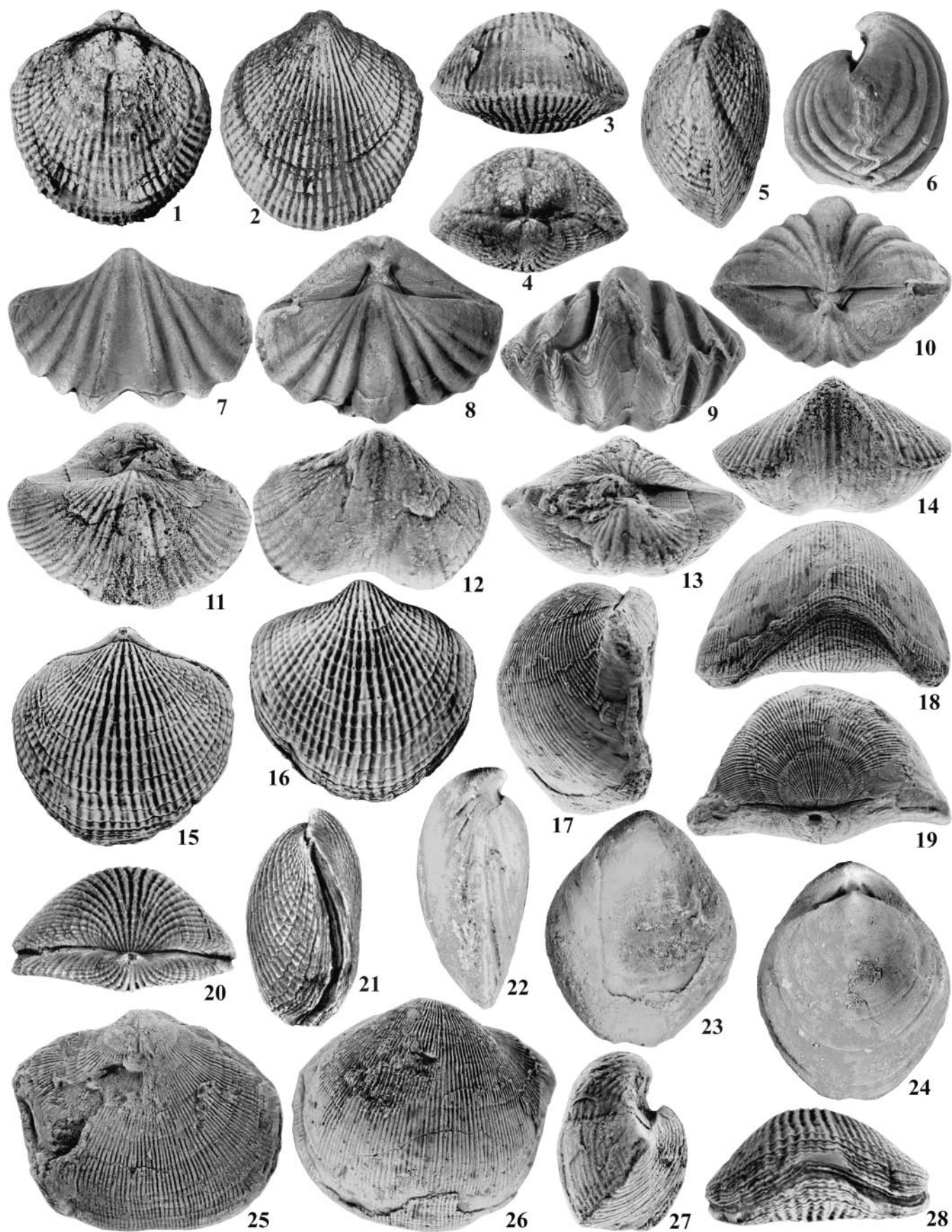


Fig. 4. Common taxa in brachiopod communities from Bird Fiord Formation of Arctic Canada. (Figs. 4.1–4.5, 4.9, 4.14) *Schizophoria sulcata* Johnson and Perry in ventral (4.1), dorsal (4.2), anterior (4.3), posterior (4.4), and lateral (4.14) views, from Baad Fiord Member, locality 80XII, P954, $\times 1.5$; and in ventral exterior (4.5) and interior (4.9) views, Blue Fiord Formation, locality 80VIII, P955, $\times 2$. (Figs. 4.6–4.8, 4.10, 4.11) *Ivdelinia grinnellensis* Brice in ventral (4.6), dorsal (4.7), lateral (4.8), anterior (4.10), and posterior (4.11) views, Blue Fiord Formation, locality SWAF2, P956, $\times 1.6$. (Figs. 4.12, 4.13, 4.15–4.17) *Cupularostrum repetitor* Johnson and Perry in lateral (4.12), ventral (4.13), posterior (4.15), anterior (4.16), and dorsal (4.17) views, Norwegian Bay Member, locality 81F, P957, $\times 3.3$. (Figs. 4.18–4.21) *Hypothyridina bifurcata* Brice in ventral (4.18), anterior (4.19), lateral (4.20), and dorsal (4.21) views, “Blue Fiord” Formation, locality 81B, P958, $\times 2.3$. (Figs. 4.22–4.26, 4.31) *Emanuella bisinuata* Brice in ventral view (4.22) showing part of spiralia, Baad Fiord Member, locality SWAF5, P959, $\times 4.2$; and in lateral (4.23), posterior (4.24), anterior (4.25), dorsal (4.26), and ventral (4.31) views, Baad Fiord Member, locality 82B, P960, $\times 4.2$. (Figs. 4.27–4.30, 4.32) *Costacranaena marlenae* Johnson and Perry in lateral (4.27), ventral (4.28), dorsal (4.29), and anterior (4.30) views, Cornwallis Island (locality CW), P961, $\times 2$; and in dorsal view (4.32) showing part of loop, Baad Fiord Member, locality 80XII, P962, $\times 3$.

Table 1. Brachiopods from the Bird Fiord Formation, Arctic Canada, source for their description, and total number of specimens collected from localities shown in Fig. 1.

Species	Description	Total no. of specimens	% of fauna
<i>Arcticastrophia costellata</i>	Li and Jones 2002	87	0.19
<i>Borealistrophia rongi</i>	Li and Jones 2002	179	0.39
<i>Parapholidostrophia?</i> sp.	Li and Jones 2003	32	0.07
<i>Spinulicosta</i> sp.	Li and Jones 2003	1 392	3.00
<i>Schizophoria sulcata</i>	Johnson and Perry 1976	3 520	7.60
<i>Gypidula mega</i>	Li and Jones 2003	42	0.09
<i>Ivdelinia grinnellensis</i>	Brice 1982	218	0.47
<i>Cupularostrum repetitor</i>	Johnson and Perry 1976; Brice 1982	9 114	19.60
<i>Hypothyridina bifurcata</i>	Brice 1982	420	0.90
<i>Spinatrypa (Isospinatrypa) parva</i>	Li and Jones 2003	106	0.23
<i>Spinatrypina borealis</i>	Li and Jones 2003	8 178	17.63
<i>Atrypa</i> sp. B	Jones 1982	7 264	15.66
<i>Desquamatia (Independatrypa) fortis</i>	Li and Jones 2003	8 538	18.40
<i>Grinnellathyris alvarezis</i>	Li and Jones 2002	100	0.22
<i>Nucleospira lens</i>	Li and Jones 2003	645	1.39
<i>Nucleospira stelcki</i>	Li and Jones 2003	103	0.22
<i>Emanuella bisinuata</i>	Brice 1982	1 099	2.37
<i>Elythyna sverdrupi</i>	Brice 1982	2 426	5.23
<i>Perryspirifer scheii</i>	Jones and Boucot 1983	647	1.39
<i>Warrenella grinnellensis</i>	Li and Jones 2003	1 610	3.47
<i>Costacranaena marlenae</i>	Johnson and Perry 1976	303	0.65
<i>Cranaena briceae</i>	Li and Jones 2003	355	0.77
Total		46 381	100.00

bedded sandy, fossiliferous micrite, and (or) calcareous sandstone (Fig. 7). Horizontal trace fossils are common in the micrite. The sandstone is characterized by current lineations, planar laminations, cross-laminations, and, in some areas, large channels. Fossils include brachiopods, crinoid ossicles, corals and sponges, tentaculites, gastropods, and fish bones. Goodbody (1985, fig. 5.21) suggested that these facies represent sediments that were deposited in a shallow, proximal-shelf setting.

The Baad Fiord Member, usually ~60 m thick, is formed of intercalated dark grey shale, dark grey–brown argillaceous siltstone, and variable fossiliferous mica-rich, subarkosic sandstones. Coral–sponge biostromes are scattered throughout the member. Like the Blubber Point and Cross Bay members, most of the Baad Fiord Member is characterized by repetitive, coarsening-upward cycles (shale to sandstone) that are typically ~3 m thick (Fig. 7). There are, however, variations in the cycles from area to area. Thus, in some areas the upper sandstones are characterized by planar laminae and

cross-bedding (Fig. 7). Elsewhere, the upper parts of the cycles are characterized by variable amounts of bioclastic material, with coral–sponge biostromes being present in some areas (Fig. 7). Goodbody (1985, figs. 5.21, 9.8) suggested that this sequence of facies represents deposition on a shallow, proximal shelf. The dominance of clastic material over coral-bearing limestone in the Baad Fiord Member suggests that these sediments may have accumulated in a shallower, more landward setting than the sediments in the Blubber Point Member.

On Grinnell Peninsula (Devon Island) and Bathurst Island, the Bird Fiord Formation is divided into the Baad Fiord Member and the Cardigan Strait Member (Fig. 2). In those areas, the Baad Fiord Member is underlain by the “Blue Fiord” Formation, which probably represents deposition on a carbonate platform.

The Baad Fiord Member on Grinnell Peninsula and Bathurst Island is divided into unit 1, which is dominated by cycles that grade from a basal silty shale into very silty limestones,

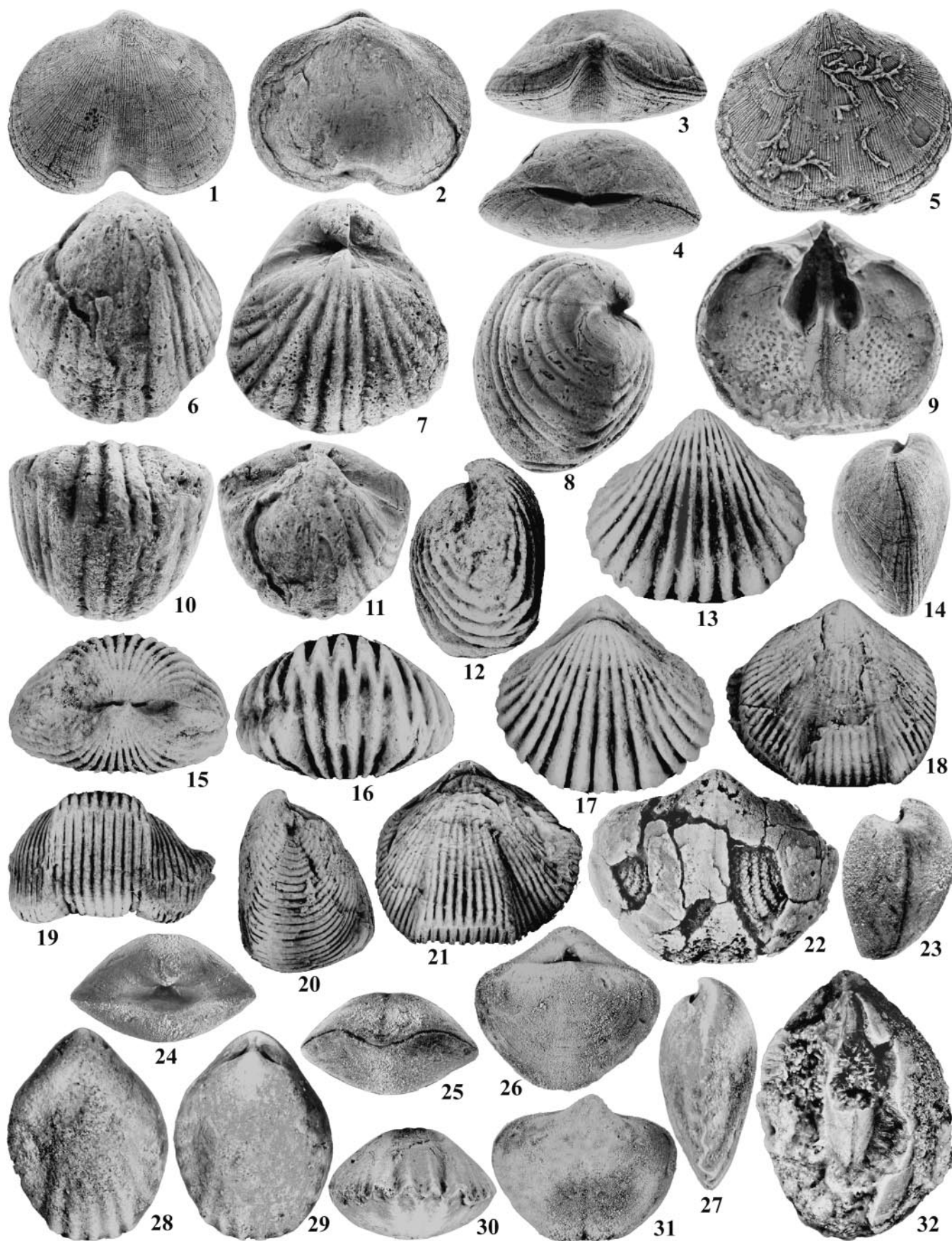
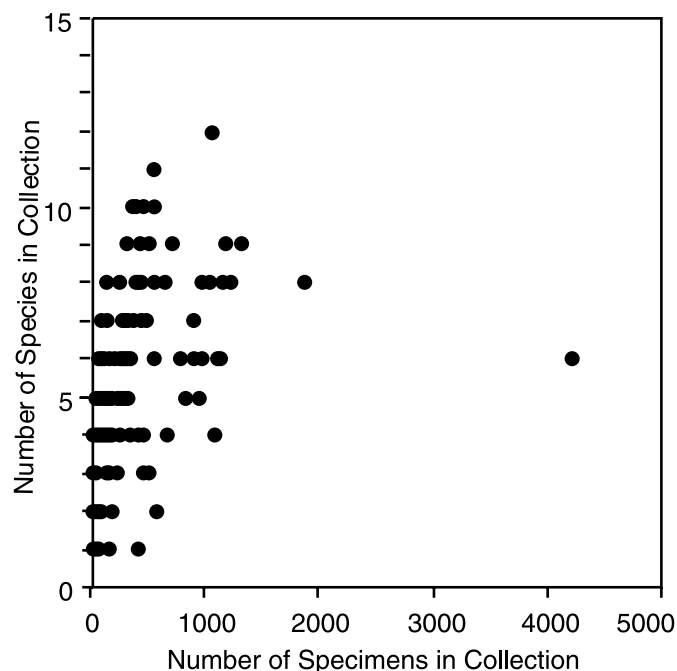


Fig. 5. Rarefaction plot comparing number of species and number of specimens in individual brachiopod collections from the Bird Fiord Formation.



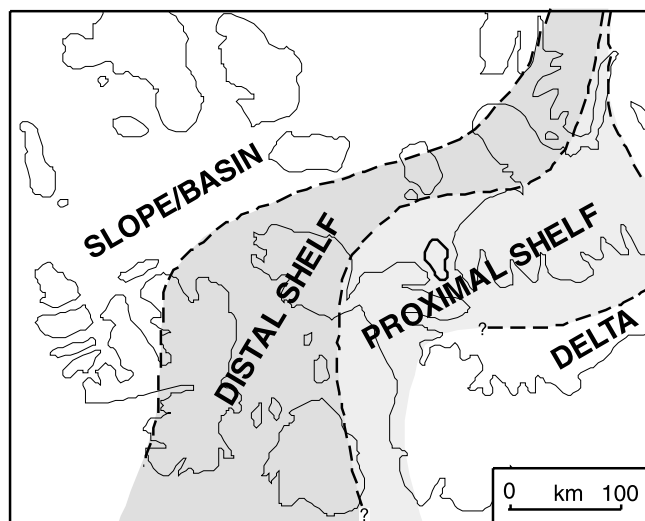
and unit 2, which is formed of cycles that grade upward from shale to argillaceous siltstone to silty sandstone to fine-grained sandstone. The argillaceous content of these rocks decreases upsection. Goodbody (1985, fig. 9.8) suggested that these successions developed in distal-shelf (unit 1) and mid-shelf (unit 2) settings. The higher shale and argillaceous content in the Baad Fiord Member on Grinnell Peninsula and Bathurst Island indicates that the water in this area was deeper than that in the southwest Ellesmere Island – North Kent Island – northern Devon Island area.

Sedimentological analysis indicates that the southwest Ellesmere Island – North Kent Island – northern Devon Island (excluding Grinnell Peninsula) region was the site of deposition on a shallow, proximal shelf, whereas the Grinnell Peninsula – Bathurst Island region was characterized by deeper water sedimentation in a more offshore position.

Brachiopod communities

Cluster analysis divides the collection sites into groups A and B, which are characterized by significantly different brachiopod faunas (Fig. 8). *Spinatrypina* and *Desquamatia* are present at virtually every site in group A, whereas *Atrypa* and *Elythyra* are usually present at each site in group B (Fig. 8). Other common genera present in group A include *Spinulicosta*, *Schizophoria*, and *Cupularostrum*, whereas *Spinulicosta*, *Schizophoria*, and *Borealistrophia* are found in group B (Fig. 8). *Spinatrypina* and *Desquamatia* are generally present at each site in group A but are rarely present at sites in group B. Conversely, *Atrypa* and *Elythyra* are generally present at each site in group B but are rarely found at sites in group A (Fig. 8). Collectively, these comparisons define the *Spinatrypina–Desquamatia* community group (group A) and the *Atrypa–Elythyra* community group (group B) (Fig. 8).

Fig. 6. Middle Devonian paleogeography of Arctic Canada (modified from Goodbody 1985).



Primarily on the basis of the presence or absence of *Cranaena* and (or) *Arcticastrophia*, the *Spinatrypina–Desquamatia* community group is divided into the *Spinatrypina–Desquamatia* (A1, Fig. 8) and *Spinatrypina–Desquamatia–Cranaena* (A2, Fig. 8) communities. *Emanuella* and *Costacranaena* are less common in the *Spinatrypina–Desquamatia* community than in the *Spinatrypina–Desquamatia–Cranaena* community (Fig. 8). The diversity of the former (~7) is slightly lower than that of the latter (~9).

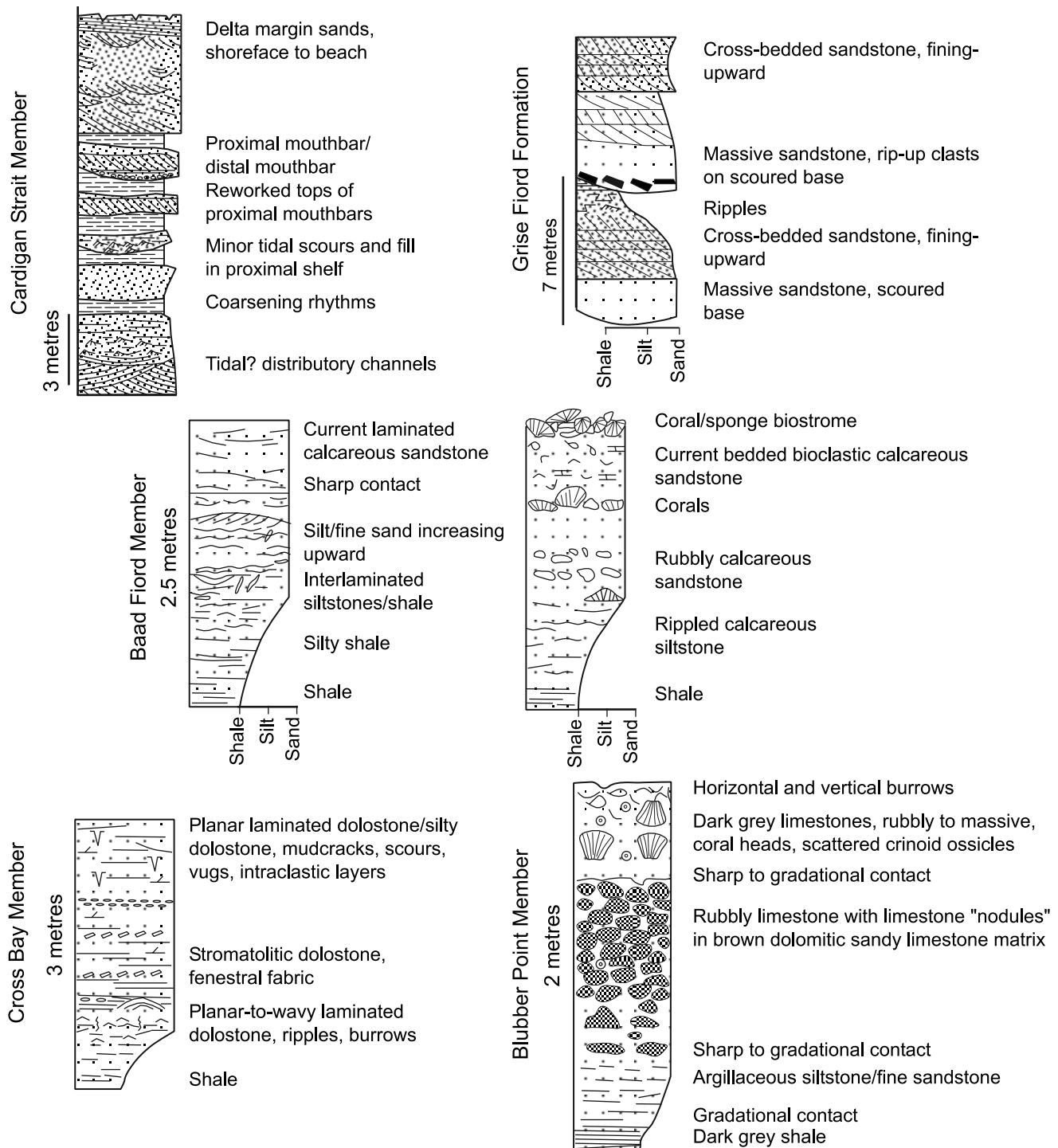
The presence or absence of *Perryspirifer* is the main basis for dividing the *Atrypa–Elythyra* community group into the *Atrypa–Elythyra–Perryspirifer* (B1, Fig. 8) and *Atrypa–Elythyra* (B2, Fig. 8; Table 2) communities. *Nucleospira stelcki* and *Cupularostrum* are present in the *Atrypa–Elythyra–Perryspirifer* community but generally are absent in the *Atrypa–Elythyra* community (Fig. 8). The diversity of the *Atrypa–Elythyra–Perryspirifer* community (~9) is higher than that of the *Atrypa–Elythyra* community (~5). In the *Atrypa–Elythyra–Perryspirifer* community, the percentage of *Atrypa* is typically higher than that of *Elythyra*. Conversely, the percentage of *Elythyra* tends to be higher than that of *Atrypa* in the *Atrypa–Elythyra* community (Table 2).

Potentially, each of the four communities can be divided into smaller units according to the hierarchical structure of the dendrogram (Fig. 8). The smaller divisions, however, would primarily reflect differences in the taxa that are relatively minor components of each fauna. For example, the *Spinatrypina–Desquamatia* community could be divided according to the presence or absence of *Warrenella* (Fig. 8). In most cases, however, the further division of the four communities is not warranted and serves to confuse rather than clarify the paleoecological framework.

Distribution of brachiopod communities

The *Atrypa–Elythyra* community group is found on the northern part of Devon Island (excluding Grinnell Peninsula), North Kent Island, and Ellesmere Island (Fig. 9). Conversely, the *Spinatrypina–Desquamatia* community group is found

Fig. 7. Schematic diagrams showing facies succession and characteristics of typical cycles in the Cardigan Strait Member, Griese Fiord Member, Baad Fiord Member, Cross Bay Member, and Blubber Point Member. All diagrams modified from Goodbody (1989, figs. 8, 13, 15, and 18).



on Grinnell Peninsula, Bathurst Island, and Cornwallis Island (Fig. 10).

From a stratigraphic perspective, the *Atrypa–Elythyna* community is generally restricted to the Blubber Point Member, whereas the *Atrypa–Elythyna–Perryspirifer* community is typically found in the Baad Fiord Member (Fig. 9). The *Spinatrypina–Desquamatia* community is found in the Blue

Fiord Formation and unit 2 of the Baad Fiord Member, whereas the *Spinatrypina–Desquamatia–Cranaena* community is largely restricted to unit 1 of the Baad Fiord Member (Fig. 10).

The high degree of organization in the geographic and stratigraphic distribution of the four communities clearly indicates that environmental conditions must have exerted a

Fig. 8. Delineation of brachiopod community groups and communities based on distribution of brachiopod species (black indicates presence) throughout the Bird Fiord Formation of Arctic Canada. The dendrograms, which dictate the ordering of the localities and species, are based on the Jaccard similarity coefficient and Ward’s method of clustering.

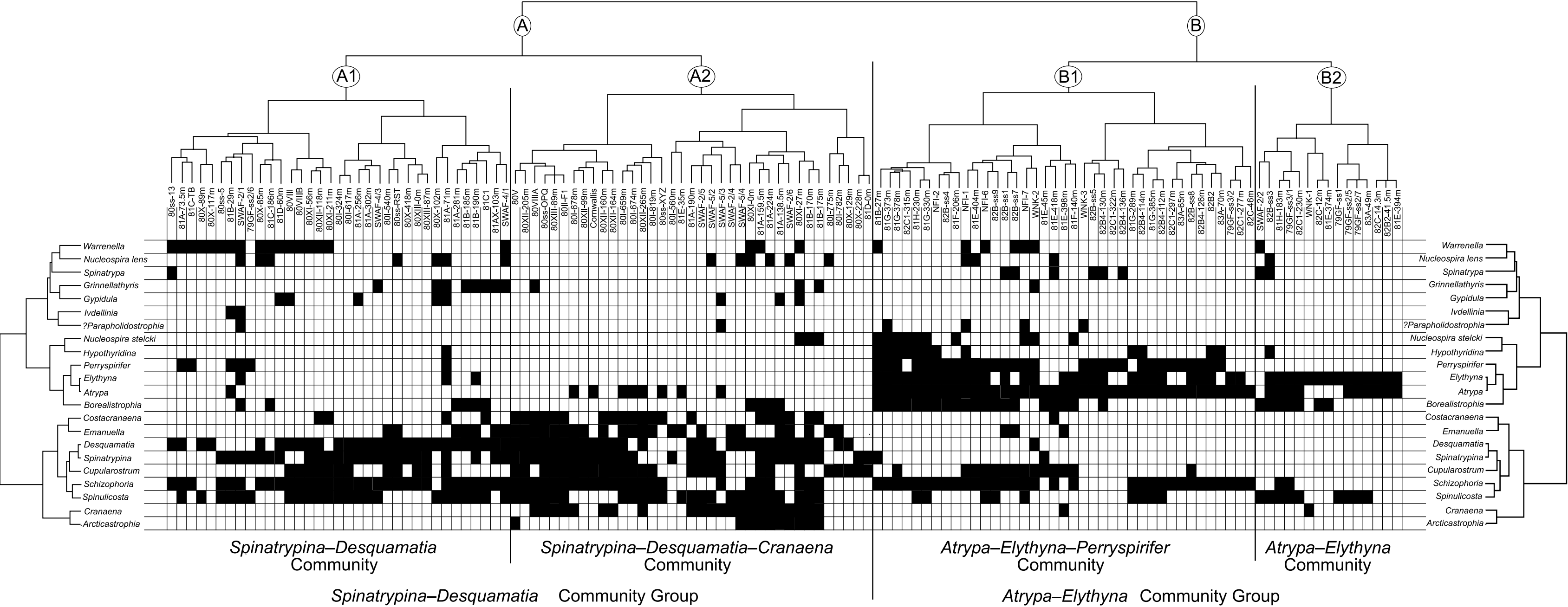


Table 2. Distribution of brachiopod species in the brachiopod communities of the Bird Fiord Formation, Arctic Canada.

Community	Nominal taxa ^a	Associated taxa
<i>Atrypa</i> – <i>Elythyna</i> – <i>Perryspirifer</i>	<i>Atrypa</i> (50–70%); <i>Elythyna</i> (5–20%); <i>Perryspirifer</i> (5–20%)	<i>Spinulicosta</i> , <i>Schizophoria</i> , <i>Cupularostrum</i> , <i>Emanuella</i> , <i>Borealistrophia</i> , <i>Hypothyridina</i> , <i>?Parapholidostrophia</i> , <i>Nucleospira lens</i> , <i>Nucleospira stelcki</i> , <i>Spinatrypa</i> , <i>Warrenella</i>
<i>Atrypa</i> – <i>Elythyna</i> <i>Spinatrypa</i> – <i>Desquamatia</i>	<i>Atrypa</i> (5–45%); <i>Elythyna</i> (50–95%) <i>Spinatrypa</i> (5–55%); <i>Desquamatia</i> (5–85%)	<i>Spinulicosta</i> , <i>Schizophoria</i> , <i>Borealistrophia</i> , <i>Spinatrypa</i> <i>Spinulicosta</i> , <i>Schizophoria</i> , <i>Cupularostrum</i> , <i>Emanuella</i> , <i>Costacranaena</i> , <i>Borealistrophia</i> , <i>Ivdelinia</i> , <i>Gypidula</i> , <i>Grinnellathyris</i> , <i>Nucleospira lens</i> , <i>Warrenella</i>
<i>Spinatrypa</i> – <i>Desquamatia</i> – <i>Cranaena</i>	<i>Spinatrypa</i> (5–55%); <i>Desquamatia</i> (10–55%); <i>Cranaena</i> (1–15%)	<i>Spinulicosta</i> , <i>Schizophoria</i> , <i>Cupularostrum</i> , <i>Arcticastrophia</i> , <i>Emanuella</i> , <i>Costacranaena</i> , <i>Borealistrophia</i> , <i>Gypidula</i> , <i>Grinnellathyris</i> , <i>Atrypa</i> , <i>Nucleospira lens</i> , <i>Nucleospira stelcki</i> , <i>Warrenella</i>

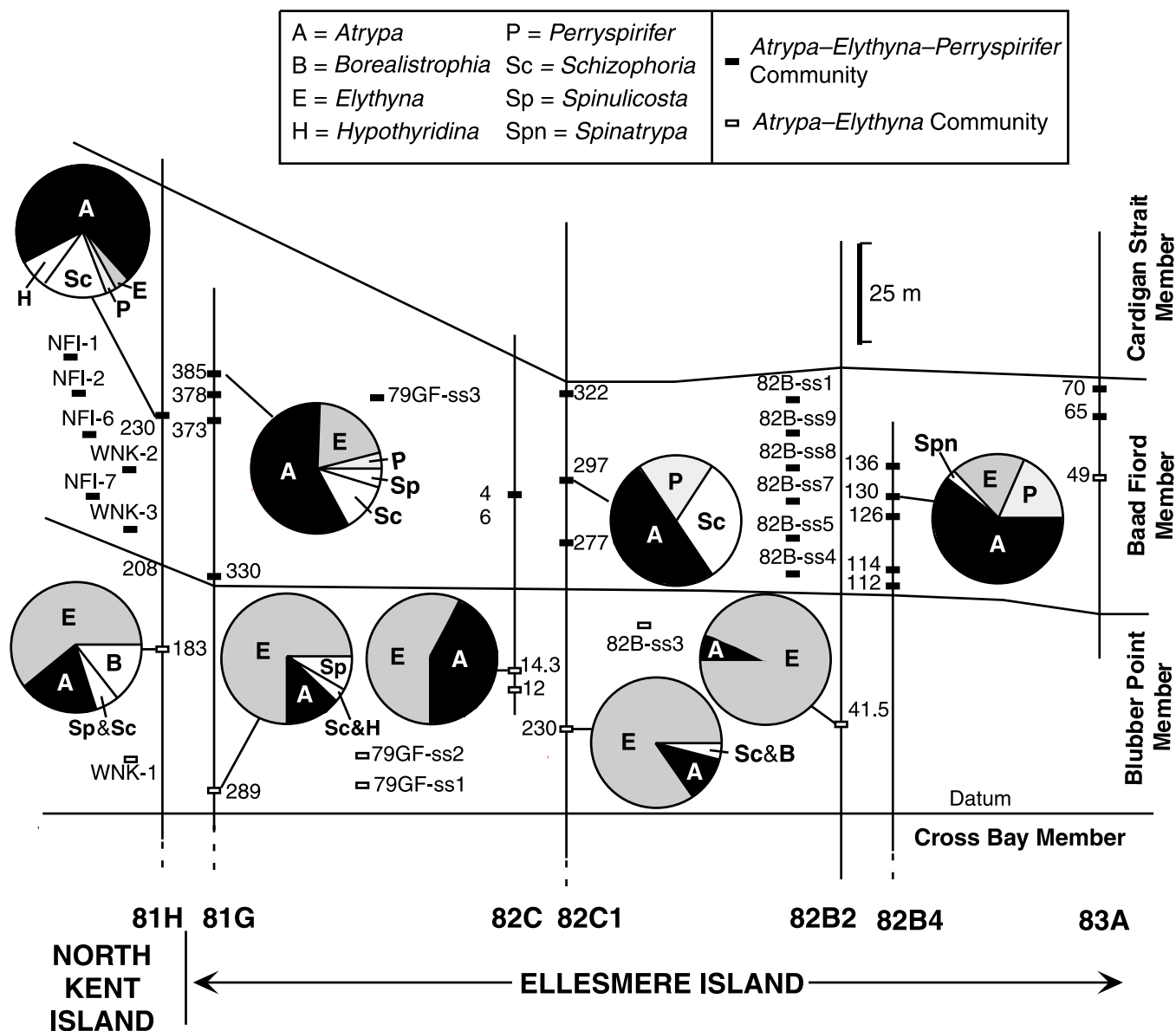
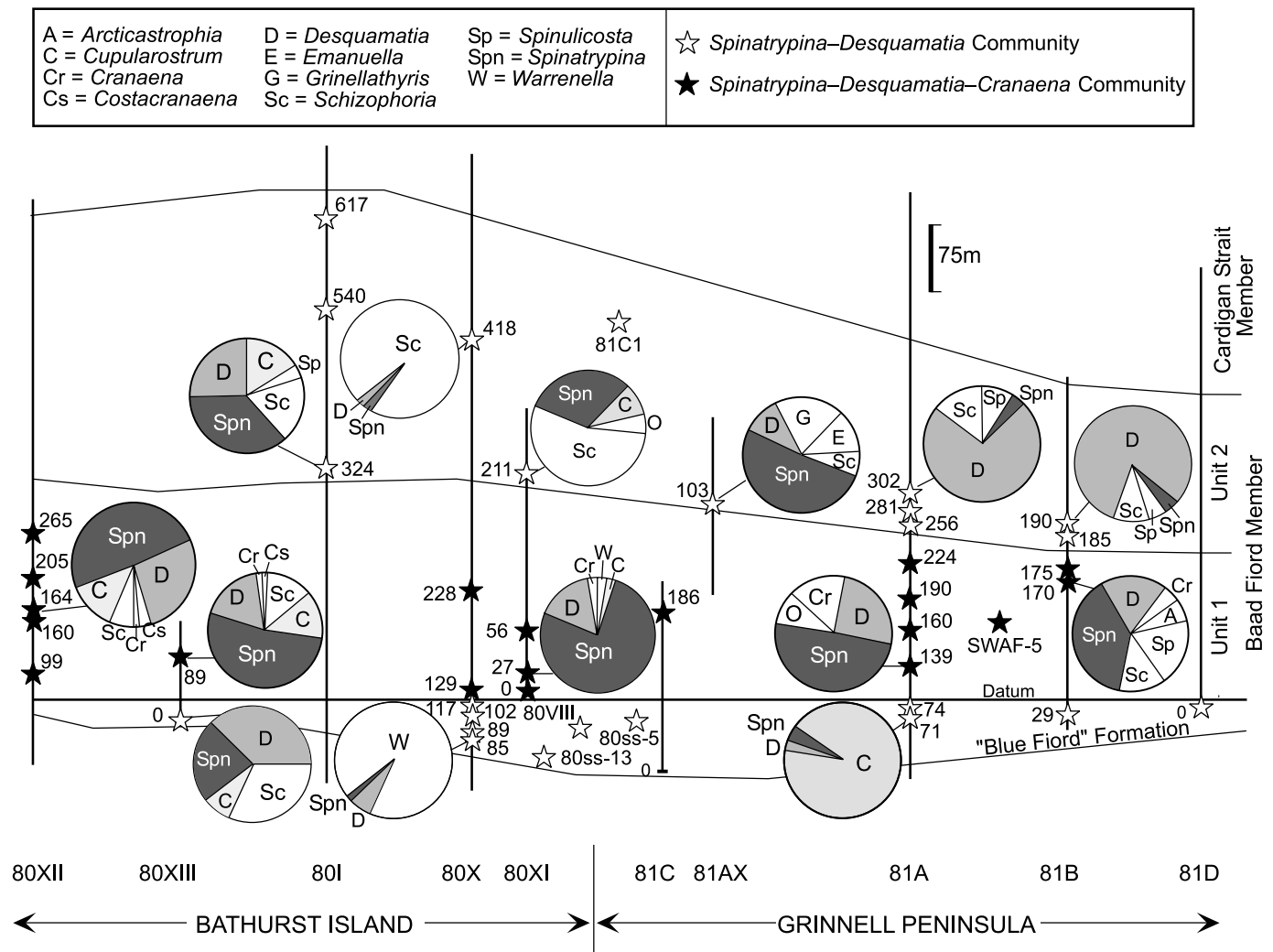
^aPercent of fauna in parentheses.**Fig. 9.** Distribution of the *Atrypa*–*Elythyna*–*Perryspirifer* community and the *Atrypa*–*Elythyna* community in the Bird Fiord Formation on Ellesmere Island and North Kent Island. Selected pie diagrams are included to illustrate the percentage of brachiopod fauna formed by constituent taxa. Numbers on section indicate metres above base of measured section. Correlation modified from Goodbody (1985).

Fig. 10. Distribution of the *Spinatrypina*–*Desquamatia* community and the *Spinatrypina*–*Desquamatia*–*Cranaena* community in the Bird Fiord Formation on Grinnell Peninsula and Bathurst Island. Selected pie diagrams are included to illustrate the percentage of brachiopod fauna formed by constituent taxa. Numbers on section indicate metres above base of measured section. Correlation modified from Goodbody (1985).



significant control over their distribution. Among the collections examined, there are only a few that are exceptions to these well-defined geographic (e.g., sites 81B-27m, 81E-35m, SWAF-2/2, and 79GF-ss2/6) and stratigraphic (e.g., sites 83A-49m, 81C-186m, 80XI-56m, 80I-560m, and 80XII-118m) distribution patterns.

Benthic assemblages

Boucot (1975) suggested that the Silurian and Devonian benthic biota can be divided into five benthic assemblages (BA) that were fundamentally related to water depth. Thus, BA1 developed in nearshore, shallow-water settings, whereas BA5 was present in distal, deep-water settings. Each benthic assemblages encompassed many different communities that developed in response to local environmental conditions.

Previous studies of *Elythyna*- and *Atrypa*-dominated communities have shown that they are part of BA3 that developed in a shallow, moderately quiet marine environment (e.g., Boucot and Perry 1981; Wang et al. 1987).

Boucot and Perry (1981), for example, assigned a BA3 position to the Early Devonian *Elythyna* community that had originally been defined by Johnson and Kendall (1976). *Atrypa*, which is the dominant element in many *Atrypa*-bearing communities, usually appears in BA3. Such communities include the *Atrypa* community of Boucot (1975) which spans BA3–BA5, the *Carinagypa*–*Atrypa* and *Brachyspirifer*–*Atrypa* communities of Johnson (1977) and Niebuhr (1977) which are part of BA3 (Boucot and Perry 1981), and the Emsian *Acrospirifer*–*Atrypa* and Eifelian *Atrypa*–*Xystostrophia* communities that were placed in BA3 by Wang et al. (1987). Comparisons with communities like these indicate that the *Atrypa*–*Elythyna*–*Perryspirifer* and *Atrypa*–*Elythyna* communities in the Bird Fiord Formation should also be considered part of BA3 (Fig. 11).

The Middle Devonian *Spinatrypina asymmetrica* community of Johnson (1990) (formerly named the *Spinatrypina*–*Thamnopora* community by Johnson and Flory 1972) probably inhabited a quiet-water biotope landward of the shelf edge (Johnson and Flory 1972). Boucot and Perry (1981) assigned

this community to BA3 or BA4. With similar diversity and dominant taxa, a BA4 position is proposed for the *Spinatrypina-Desquamatia* and *Spinatrypina-Desquamatia-Cranaena* communities that are found in the Bird Fiord Formation (Fig. 11).

Correlation between brachiopod communities and sedimentological regimes

There is a strong correlation between the distribution of the brachiopod communities and the depositional framework, as determined by sedimentological analysis (Fig. 11). Brachiopods are absent from the Cross Bay Member, which is formed of sediments that accumulated in a sabkha setting, and from the Grise Bay Member, which represents deposition on a delta plain. Brachiopods are found throughout the members that include sediments that accumulated on a shelf in open marine conditions.

The *Atrypa-Elythyna* community, which is common in the Blubber Point Member (Fig. 9), lived in a proximal-shelf setting. The *Atrypa-Elythyna-Perryspirifer* community, found in the Baad Fiord Member (Fig. 9), also lived in a proximal-shelf setting but in a slightly shallower setting than that of the *Atrypa-Elythyna* community (Fig. 11).

The *Spinatrypina-Desquamatia-Cranaena* community, found in unit 1 of the Baad Fiord Member (Fig. 10), lived in a distal-shelf environment (Fig. 11). The *Spinatrypina-Desquamatia* community, found in unit 2 of the Baad Fiord Member (Fig. 10), probably lived in a mid-shelf environment (Fig. 11).

The distribution patterns indicate that parameters related to water depth exerted a primary control over the distribution of the brachiopod communities. The fact that the same brachiopod community is found in limestone, shale, siltstone, and sandstone indicates that the substrate did not play a major role in the distribution of these communities. The paleogeographic boundary between proximal and distal shelf, established on sedimentological criteria (Fig. 6), also separates the *Atrypa-Elythyna* community group on Ellesmere Island, North Kent Island, and north Devon Island from the *Spinatrypina-Desquamatia* community group on Grinnell Peninsula, Cornwallis Island, and Bathurst Island (Fig. 12). This spatial correlation supports the notion that environmental parameters related to water depth were responsible for their distribution (Fig. 11).

On southwest Ellesmere Island, North Kent Island, and north Devon Island, the sedimentological change from the Blubber Point Member to the Baad Fiord Member has been attributed to a regressive cycle (Goodbody 1985). The change in the lithologies between these members is matched by a change from the *Atrypa-Elythyna* community in the Blubber Point Member to the *Atrypa-Elythyna-Perryspirifer* community in the Baad Fiord Member. This correlation supports the notion that parameters related to water depth exerted a primary control over the distribution of the brachiopod communities. In this case, the *Atrypa-Elythyna-Perryspirifer* community lived in shallower water than the *Atrypa-Elythyna* community (Fig. 11). A parallel situation is also found in the Baad Fiord Member on Grinnell Peninsula, Cornwallis Island, and Bathurst Island. At those localities, the change from unit 1 to unit 2, which resulted from a regressive cycle, is matched

Fig. 11. Positions of brachiopod communities in the Bird Fiord Formation of Arctic Canada relative to sea level and benthic assemblages (BA1–BA5) as defined by Boucot (1975).

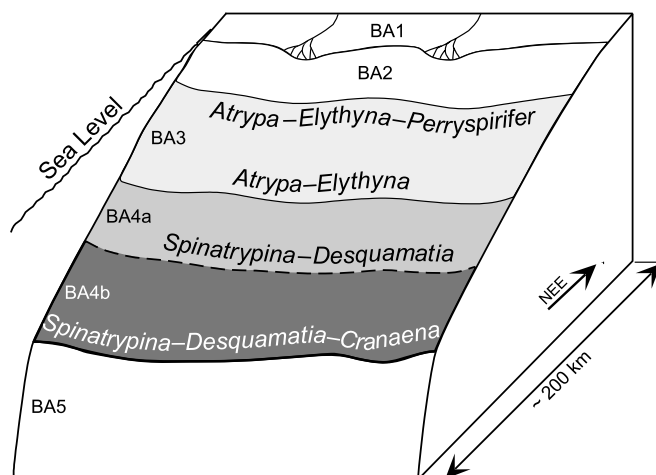
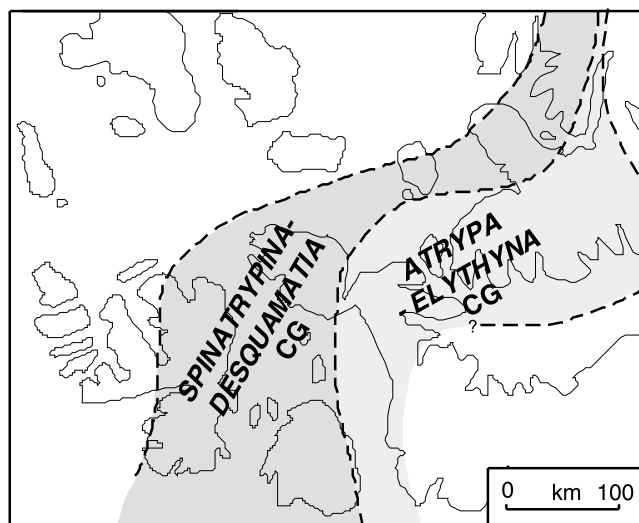


Fig. 12. Distribution of the *Atrypa-Elythyna* and *Spinatrypina-Desquamatia* community groups (CG) relative to paleogeographic framework (from Fig. 6).



by a change from the *Spinatrypina-Desquamatia-Cranaena* community in unit 1 to the *Spinatrypina-Desquamatia* community in unit 2. The change in brachiopod communities appears to have been related to depth-related environmental parameters (Fig. 11).

The change from the *Spinatrypina-Desquamatia* community in the "Blue Fiord" Formation to the *Spinatrypina-Desquamatia-Cranaena* community in the overlying Baad Fiord Member (unit 1) probably resulted from a short-lived transgression.

Discussion

The composition and paleoecology of Early Devonian brachiopod communities are relatively well known from studies such as those by Johnson (1974, 1977, 1990), Boucot (1975), Johnson and Kendall (1976), Niebuhr (1977), Boucot and Perry (1981), Jones and Smith (1985), Wang et

al. (1987), Jones (1991), Hiller and Theron (1988), Soja (1988a, 1988b), and Lespérance and Sheehan (1988). Although Middle Devonian brachiopod communities have been described from various parts of the world (e.g., Johnson and Flory 1972; Savage and Boucot 1978; Feldman 1980; Wang et al. 1987; Brower et al. 1988; Johnson 1990; Brower and Nye 1991; McCollum 1991), they are generally not as well known as the Early Devonian communities.

The *Atrypa–Elythyna–Perryspirifer* community in the Bird Fiord Formation is similar to the Early Devonian *Atrypa–Schizophoria–Perryspirifer* community from southwest Ellesmere Island, as defined by Jones and Smith (1985). *Atrypa* dominates both, *Perryspirifer scheii* is common to both, and *Schizophoria*, *Nucleospira*, and *Warrenella* are present in both. The two communities differ because the *Atrypa–Schizophoria–Perryspirifer* community lacks *Elythyna*, *Spinulicosta*, *Cupularostrum*, *Hypothyridina*, and *Borealistrophia*. Conversely, *Cymostrophia*, *Carinagypa*, *Cortezorthis*, and *Parapholidostrophia* are present in the *Atrypa–Schizophoria–Perryspirifer* community but absent from the *Atrypa–Elythyna–Perryspirifer* community. The similarities between these two communities may indicate that the Middle Devonian *Atrypa–Elythyna–Perryspirifer* community may have replaced the Early Devonian *Atrypa–Schizophoria–Perryspirifer* community. This suggestion is realistic given that both communities had similar geographic and environmental constraints. The *Atrypa–Schizophoria–Perryspirifer* community can therefore be assigned to the *Atrypa–Elythyna* community group.

Communities belonging to BA1 or BA2 have not been recognized among the brachiopod collections from the Bird Fiord Formation. The absence of such communities may reflect the fact that they (i) were not recognized, (ii) are not present in the Bird Fiord Formation but may be present in time-equivalent formations that were not examined in this study, or (iii) were in strata that are not exposed or have been removed by erosion.

The brachiopod communities found in the Middle Devonian strata of Arctic Canada are taxonomically different from Middle Devonian communities found in New York (Feldman 1980; Brower et al. 1988; Brower and Nye 1991; McCollum 1991), Nevada (Johnson and Flory 1972; Johnson 1990), northern California (Savage and Boucot 1978), and south China (Wang et al. 1987). Biogeographically, the Middle Devonian fauna from New York belongs to the Eastern Americas Realm, whereas the Arctic Canada fauna falls into the Old World Realm (Johnson and Boucot 1973; Boucot 1988). The lack of similarity between the brachiopod faunas of Arctic Canada and other areas is perhaps not surprising given that some elements of the Arctic brachiopod fauna are endemic (cf. Brice 1982; Li and Jones 2002, 2003). The endemism of these genera–species probably explains, at least in part, why the brachiopod communities are not comparable to those found in Nevada, northern California, and south China, even though they were all part of the Old World Realm during the Middle Devonian (Wang et al. 1987; Boucot 1988; Johnson 1990).

The distribution of the brachiopod communities in the Bird Fiord Formation of Arctic Canada was primarily determined by ecological controls that were related to water depth (Figs. 11, 12). This is the fundamental reason for the

differences between the brachiopod faunas found in the Ellesmere Island – North Kent Island and Grinnell Peninsula – Bathurst Island regions. Clearly, this ecological control will have to be factored into any biostratigraphic zonation scheme that is based on the brachiopods. Furthermore, biogeographic comparisons between Arctic Canada and other parts of the world must be based on comparisons of faunas from similar water depths. Such comparisons, for example, will be invalid if they are based on comparison of a brachiopod community that belonged to BA1–BA2 with a brachiopod community that belonged to BA3–BA4.

Conclusions

The analysis of the brachiopod faunas from the Bird Fiord Formation has demonstrated the following points: (i) two community groups and four brachiopod communities are present in the fauna; (ii) the *Atrypa–Elythyna–Perryspirifer* and *Atrypa–Elythyna* communities, which belong to benthic assemblage BA3, probably lived in a shallow, proximal-shelf environment; (iii) the *Atrypa–Elythyna–Perryspirifer* community lived in shallower water than the *Atrypa–Elythyna* community; (iv) the *Spinatrypina–Desquamatia* and *Spinatrypina–Desquamatia–Cranaena* communities, which belong to benthic assemblage BA4, probably lived in a deeper, distal-shelf environment; (v) the *Spinatrypina–Desquamatia* community lived in shallower water than the *Spinatrypina–Desquamatia–Cranaena* community; (vi) the *Atrypa–Elythyna–Perryspirifer* community may have developed from the Early Devonian *Atrypa–Schizophoria–Perryspirifer* community of Jones and Smith (1985) from southwest Ellesmere Island; and (vii) the distribution of the brachiopod communities appears to have been primarily related to water depth or factors that were controlled by water depth.

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See Appendix on next page

Appendix A. Brachiopod data from the Bird Fiord Formation

Table A1. Numbers of brachiopods of the 22 species collected from 126 sites at 35 localities in the Bird Fiord Formation.

Site No.	Species ^a														
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
80SS-13					3						2		2		
80SS-5				16	7							3			
80V	1			14	58			54				476	317		
80I-324m				2	10			11				22	15		
80I-540m					2			6				2	1		
80I-560m												1			
80I-617m				3	206			1				11	17		
80I-659m				31	303			479		5		279	602		
80I-674m				1	21			315		21		26			
80I-678m					9			27		1		8	30		
80I-775m								1							150
80I-782m								49					7		
80I-819m				14	83			49							
80X-85m					1							1	23		1
80X-89m				38									438		
80X-102m				1		31							2	1	1
80X-117m													13		
80X-129m								42					1		
80X-228m								18				3			
80X-418m					118							2	2		
80VIII				1	7	3		128					77		
80VIII A				4	105							185	32	2	
80VIII B				4	3			1					63		
80XI-0m	11	1		5								293	17		17
80XI-27m	1			6	7	1		11				411	83	1	
80XI-56m				11	5			7				3	21		
80XI-211m				1	38			5				25			
80XII-99m					30			4145				3	3		
80XII-118m				1	11			1				16	80		
80XII-160m					54			84				141	69		
80XII-164m					50			99				374	215		
80XII-205m				1	68			364				342	107		
80XII-265m				2	56			653		56			372		
80SS-XYZ				1	54					5					
80SS-OPQ				3	87			65				255	99		
80SS-RST					85			436				428	135		1
80XIII-0m					32			8				23	38		
80XIII-87m					69			66				471	457		
80XIII-89m				4	158			144				602	206		
80II-F1				33	158			135				502	143		
81A-71m				8	10	1		950	1			15	8	2	8
81A-73.5m				1	15								1		
81A-138m	10	3		132		2						629	294		
81A-159m	2	1		56	17			1				125	233		
81A-190m				4				3				331	525		
81A-224m	8	1		19	60			7				293	115		12
81A-256m				19	34	1						1	155		
81A-281m		1		33	69								710		
81A-302m				32	51							5	317		
81C1		6		39	148								896	12	
81AX-103m					6							70	13	26	
81B-27m		11			131				100	414		496			
81B-29m				9	46		79			51		10			
81B-170m	21			94	60							189	94		
81B-175m	7			117	33							199	49	2	
81B-185m		1		10	9								211	1	
81B-190m		3		12	29							1	314	1	
81C-TB					1										
81C-186m		2			9							20			336
81D-0m								8				3			
81D-60m					1	3						4	3		
SWAF-2/1		2	1	6	64		139					54			8
SWAF-2/2		1		8											5

Species ^a							Total
T16	T17	T18	T19	T20	T21	T22	
				2			9
				112			138
	4				15		939
							60
	200						211
	160						161
							238
	120				23		1 842
	33				2		419
	2				2		79
	300						451
	69						125
	8				12		166
				233			259
				4			480
							36
				42			55
							43
							21
							122
				30			246
	12				8	16	364
				8			79
				48		2	394
2				10		1	534
				8			55
				3	1		73
	15				1		4 197
				1	1		111
	8				6	2	364
					23	9	770
	1				1		884
	15				38	17	1 209
					6		66
	9				19	5	542
	2						1 087
							101
							1 063
	1				13	7	1 135
	27				14	4	1 016
		1	1		28		1 033
			1	11			29
	3				25	190	1 288
				1	6	5	447
					2	8	873
					7	17	539
							210
	1						814
							405
					8		1 109
	17						132
1		6	1	6			1 166
			22	33			250
2	1				6	19	486
1					4	11	423
	4						236
	7	1					368
			1	15			17
				563			930
							11
				2			13
		8	2	59			343
				318			332

Table A1 (*concluded*).

Site No.	Species ^a														
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
SWAF-2/4				69									86		
SWAF-2/5				24				35				6	107		
SWAF-2/6	7											230	25		1
SWAF-4/1				10	52							4	324	17	1
SWAF-4/3				5	81							3	146	33	
SWAF-5/2				3				527				1	2		2
SWAF-5/3			2	283				2		3		48		1	
SWAF-5/4	19			86									202		5
NFI-1		1	2		42			1	5	243					2
NFI-2		8			33				28	105					
NFI-6		23		3	60			2		116					
NFI-7			6	1	94			1		488					
WNK-1															
WNK-2					96			3		186			3	1	
WNK-3			12							68					
81H-183m		24		9	1					34					
81H-230m		5		3	49				20	270					
81G-289m				10	2				1	15					
81G-330m		3		12	10				4	76					
81G-373m		1	9		88				31	981					
81G-378m		2			21			13	223	344					
81G-385m				5	13					63					
82GF-SS1				5											
82GF-SS2/5				4						6					
82GF-SS2/6				1								1			
82GF-SS2/7				1						22					
82GF-SS3/1		5		8	21					244					
82GF-SS3/2					5					32					
82C-12m		5													
82C-14.3m										24					
82C-46m					5					70					
82C1-230m		2		7						26					
82C1-277m					11					198					
82C1-297m					3					5					
82C1-315m		1			16				3	70					
82C1-322m										42					
82B2-41m										3					
82B-SS1		1			5			6		35	35				
82B-SS3		7		2					1	18	21				1
82B-SS4		1			30					27					
82B-SS5										18	5				
82B-SS7		1			2			4		73	40				
82B-SS8					32			2		192					
82B-SS9		2		3	4			4		280					
82B2					2				1	48					
82B4-112m				1	1					38					
82B4-114m				1	7				1	70					
82B4-126m					10					62					
82B4-130m		1								53	2				
82B4-136m										13	1				
83A-49m				1						16					
83A-65m					3					136					
83A-70m					10				1	360					
81E-35m				39						35					
81E-45m		9						31		588		20			
81E-374m		12													
81E-394m										1					
81E-398m		7						15		6					
81E-404m		2			1			4		152					1
81E-418.3m		13			4			21		3		330			93
81F-140m		4			3			10		40					
81F-206m		6			3					703					
Cornwallis					12			60		10		182	18		
Total	87	179	32	1392	3520	42	218	9114	420	7264	106	8178	8538	100	645

Species ^d							
T16	T17	T18	T19	T20	T21	T22	Total
	6					4	165
	1					1	174
	2				12	23	300
	2			16			426
							268
						1	536
						1	340
	11					12	335
		22	32	28			378
		4	3				181
		28	1	4			237
4		8	47	48			697
		566			1		567
3		4	8	4			308
		10	17				107
		104					172
3		14	9				373
		87					115
4		9	6				124
2		24	62				1 198
16		7	1				627
		22	4				107
		33					38
		10					20
			1				3
		87					110
		34					312
		1					38
		26					31
		32					56
							75
		189					224
		4					213
			2				10
1		2					93
			17				59
		58					61
	2	9	14				107
		68					118
		1	66				125
		1	1				25
	1		5	1			127
		3	4				233
			5				298
		17	6				74
		80	8				128
		40	27				146
		2	21				95
		16	16				88
			1				15
		51					68
			11				150
			69				440
	53						127
							648
		67					79
		127					128
	2	200			2		232
		116	2				278
					2		466
44		171					272
20		56	153				941
					15		297
103	1099	2426	647	1610	303	355	46 381

^aT1, *Arcticastrophia costella* Li and Jones 2002; T2, *Borealistrophia rongi* Li and Jones 2002; T3, *?Parapholidostrophia* sp.; T4, *Spinulicosta* sp.; T5, *Schizophoria sulcata* Johnson and Perry 1976; T6, *Gypidula mega* Li and Jones 2003; T7, *Ivdelinia grinnellensis* Brice 1982; T8, *Cupularostrum repetitor* Johnson and Perry 1976; T9, *Hypothyridina bifurcata* Brice 1982; T10, *Atrypa* sp. B Jones, 1982; T11, *Spinatrypa (Isospinatrypa) parva* Li and Jones 2003; T12, *Spinatrypa borealis* (Warren 1944); T13, *Desquamatia (Independatrypa) fortis* Li and Jones 2003; T14, *Grinnellathyris alvarezi* Li and Jones 2002; T15, *Nucleospira lens* (Schnur, 1851); T16, *Nucleospira stelcki* Li and Jones 2003; T17, *Emanuella bisinuata* Brice 1982; T18, *Elythyna sverdrupi* Brice 1982; T19, *Perryspirifer scheii* (Meyer 1913); T20, *Warrenella grinnellensis* Li and Jones 2003; T21, *Costacranaena marlenae* Johnson & Perry 1976; T22, *Cranaena briceae* Li and Jones 2003.