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THE UPPER ST. GEORGE GROUP, WESTERN PORT AU PORT PENINSULA: LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS AND REGIONAL IMPLICATIONS

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ABSTRACT

Shallow-water carbonate rocks of the upper part of the Early Ordovician St. George Group outcrop in several roadside exposures at the west end of the Port au Port Peninsula, western Newfoundland. The succession contains a previously undocumented, fairly abundant and diverse shelly fauna that includes ostracodes, trilobites, articulate brachiopods, ?bryozoa, cephalopods, crinoids, gastropod shells and opercula, machaeridians, sponges and calcispheres. The fauna occurs within metre-scale parasequences of open-shelf, muddy carbonates overlain by grainy carbonates that are commonly rich in small oncolites, and which are assigned to the Costa Bay Member, Catoche Formation. Well-preserved graptolites occur in the upper 20 m of the member, an interval marked by a shoaling sequence of subtidal muddy carbonate to crossbedded, now dolomitized, grainstone.

In contrast, peritidal cyclic carbonates of the overlying Aguathuna Formation yield mainly a mixed molluscan fauna of cephalopods, gastropod shells and silicified gastropod opercula although grainstone beds contain as yet indeterminate articulate brachiopods and trilobites.

The abundant and diverse faunas in shoaling, subtidal, limestone parasequences of the Costa Bay Member support an open-shelf, marine environment, seaward of a major grainstone barrier complex. The presence of graptolites at the top of the Costa Bay Member suggests that a significant oceanic flooding event may have marked the shelf at the transition from the open-shelf Costa Bay Member to the broad development of peritidal flats preserved in the Aguathuna Formation.

Two trilobite faunas occur in the Costa Bay Member, western Port au Port Peninsula, a lower Gignopeltis rarus *fauna and an upper* Cybelopsis speciosa *fauna. The former is also known from the member at Burnt Island, Pistolet Bay but the upper fauna is newly discovered in western Newfoundland. It is correlated with a similar fauna in the Nunatami Formation of northern Greenland and with the* Pseudocybele nasuta *Zone (Zone J) of western Utah. The presence* of D. bifidus *zone graptolites in the upper* Cybelopsis speciosa *fauna, the Nunatami Formation and the Utah sections further strengthens this correlation. The trilobite and graptolite faunas, each support an older transition from Costa Bay Member to Aguathuna Formation in the north compared to the south of the western Newfoundland Arenig shelf. The* Goniotelina *and pliomerid trilobites in the subtidal muddy carbonates of the Costa Bay Member are tentatively assembled as a new biofacies, the* Goniotelina-Cybelopsis *biofacies.*

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INTRODUCTION

Recently exposed sections through the upper part of the Early Ordovician St. George Group outcrop in a number of roadcuts along Route 463 between Cape St. George and Mainland, at the west end of the Port au Port Peninsula, western Newfoundland (Figure 1). The roadcut sections preserve strata from the Costa Bay Member, Catoche Formation, and the overlying Aguathuna Formation (Knight and James, 1987, 1988). This upper St. George Group stratigraphy is repeated by high-angle reverse faults that strike northeast and dip to the west. Two logged sections separated by one of these faults are correlated bed by bed using lithology and fauna (Figures 2 and 3).

The succession preserved in the west Port au Port Peninsula area is unique in western Newfoundland in that there is an abundance of fossil-bearing, unaltered limestones through a stratigraphic interval that elsewhere in western Newfoundland is commonly extensively dolomitized and/or sparsely fossiliferous. A diverse and common shelly fauna in the Costa Bay Member includes ostracodes, trilobites, articulate brachiopods, ?bryozoa, cephalopods, crinoids, gastropod shells and opercula, machaeridians, sponges and calcispheres. Graptolites are present in a 2.5 m interval within 20 m of the top of the Costa Bay Member and are the focus of an accompanying short paper (Williams *et al., this volume*). Molluscan faunas, which are commonly silicified, dominate the overlying Aguathuna Formation.

The faunas described herein were collected by W.D. Boyce, D.M. Rohr and E.A. Measures in 1998 and 1999; I. Knight measured detailed sections to complement the systematic macrofossil sampling.

LITHOSTRATIGRAPHIC SETTING

The St. George Group is a succession of Early Ordovician to lower Middle Ordovician subtidal and peritidal carbonate rocks that are subdivided into the Watts Bight, Boat Harbour, Catoche and Aguathuna formations (Knight and James, 1987, 1988). This succession is recognized to preserve at least two unconformity-bounded sequences (James *et al.*, 1989), which consist of transgressive to regressive sedimentation, termed megacycles by Knight and James (1987). The upper megacycle includes rocks of the Barbace Cove Member of the Boat Harbour Formation, the Catoche Formation and the Aguathuna Formation. It is bounded below by the Boat Harbour disconformity ("pebble bed" of Knight, 1978; Boyce, 1978) and above by the St. George Unconformity (Knight *et al.*, 1991). Carbonate rocks from the lower part of the upper megacycle preserve strata of transgressive and highstand system tracts (i.e., Barbace Cove Member and lower to middle part of the Catoche Formation) and are well documented faunally and lithologically, especially on the Great Northern Peninsula (Fortey, 1979; Stouge, 1982; Boyce, 1989; Knight, 1991; Stait and Barnes, 1991; Ji and Barnes, 1994; Boyce and Stouge, 1997). The upper, essentially regressive part of the megacycle is poorly known faunally, except through conodonts and some scattered graptolites (Williams *et al.*, 1987; Stait, 1988; Stait and Barnes, 1991; Ji and Barnes, 1994), although it is well described lithologically on the Great Northern Peninsula (Knight, 1977, 1991; Knight and James, 1988; Stait, 1988; Knight and Cawood, 1991) and less so on the Port au Port Peninsula (Pratt, 1979; Pratt and James, 1986; Stait, 1988). This preliminary paper aims to address both the lithological and macrofaunal character of the upper part of the megacycle in a small area of the western end of Port au Port Peninsula and set this section within a regional Port au Port and western Newfoundland context.

The Catoche Formation on the Port au Port Peninsula consists of a lower limestone, a middle mound member and the Costa Bay Member. The lower limestone essentially consists of grey, bioturbated, peloidal and muddy, dolomitic limestone having thin storm beds and lenses of skeletal, intraclastic rudstone–grainstone. The middle mound member comprises stacked thrombolite mounds and grainstones and is pervasively dolomitized through much of the Peninsula (*see* Knight, 1996; Knight and Cawood, 1991). However, the mound member loses its massive character at the west end of the Peninsula (including the study area), so that mound beds are rather interbedded with bioturbated limestones like those of the lower member and the strata remains limestone.

The Costa Bay Member, which conformably overlies the mound member, is a well-bedded, white to cream, chemically pure limestone that predominantly comprises peloidal and intraclastic grainstone, and fenestral grainstone and grainy, fenestral microbial laminite. This apparently massive but well-bedded unit appears to lack cyclicity (Knight and James, 1988; I. Knight, unpublished data) although future detailed logging may change this impression. This grainy facies dominates the member from Aguathuna quarry west to the sections at Lower Cove limestone quarry in the centre of the Peninsula (Stride Consulting, 1988,1989) and White Hills limestone barrens (Tuach Geological Consultants, 1990) just 3.5 km east of the sections described in this paper (Figure 1).

The Costa Bay Member is conformably succeeded by the Aguathuna Formation, consisting of peritidal limestones and dolostones. Known from fairly detailed sections at the east end of the Peninsula, e.g., Aguathuna quarry and the East Bay coastal section (Pratt, 1979; Pratt and James, 1986; Knight and James, 1988; Stait, 1988), the Aguathuna For-

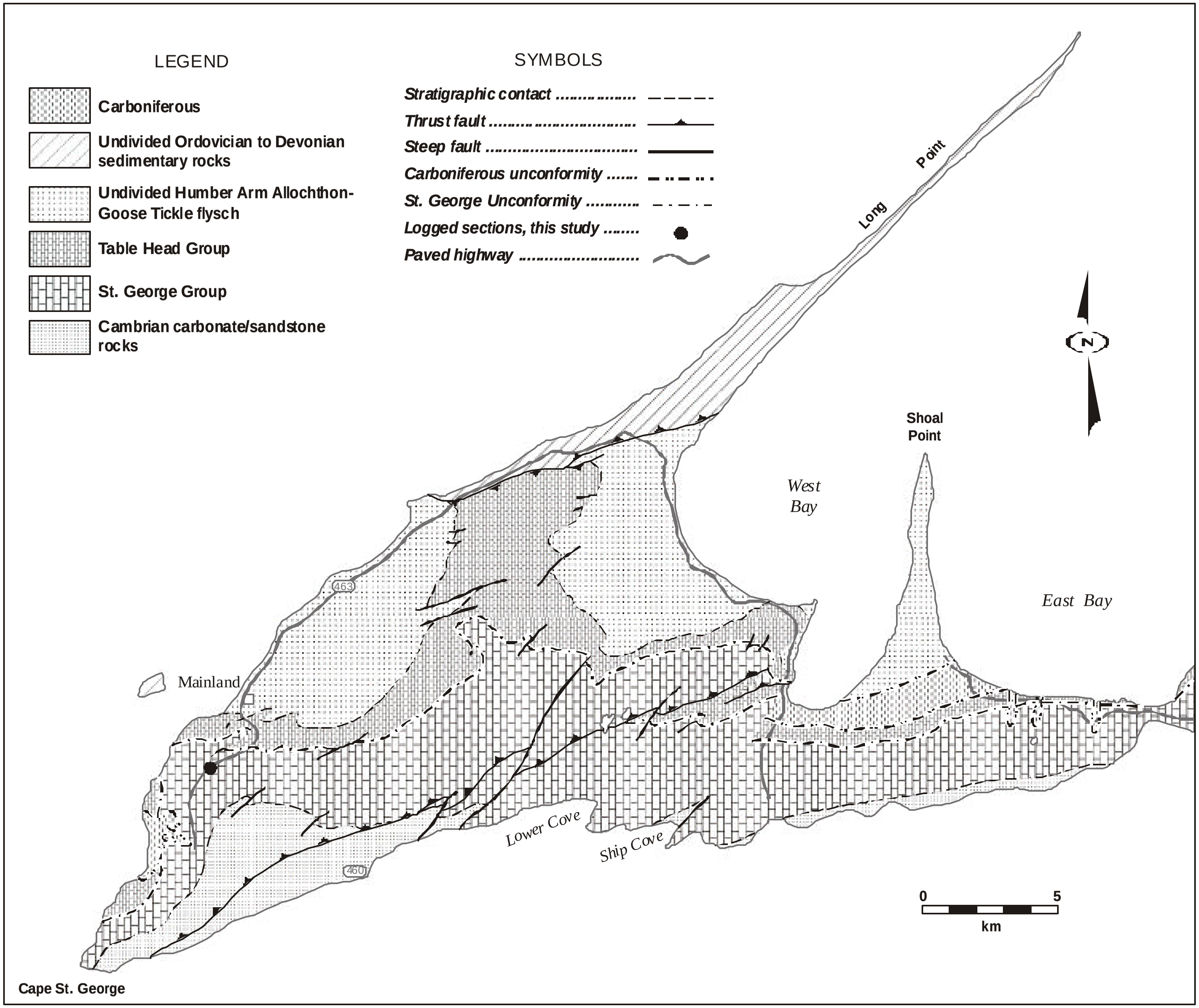


Figure 1. *Geological map of the Port au Port Peninsula showing the location of the new section at the western end of the Peninsula and other important sections through the Costa Bay Member, Catoche Formation. Map based on Stockmal and Waldron (1993).*

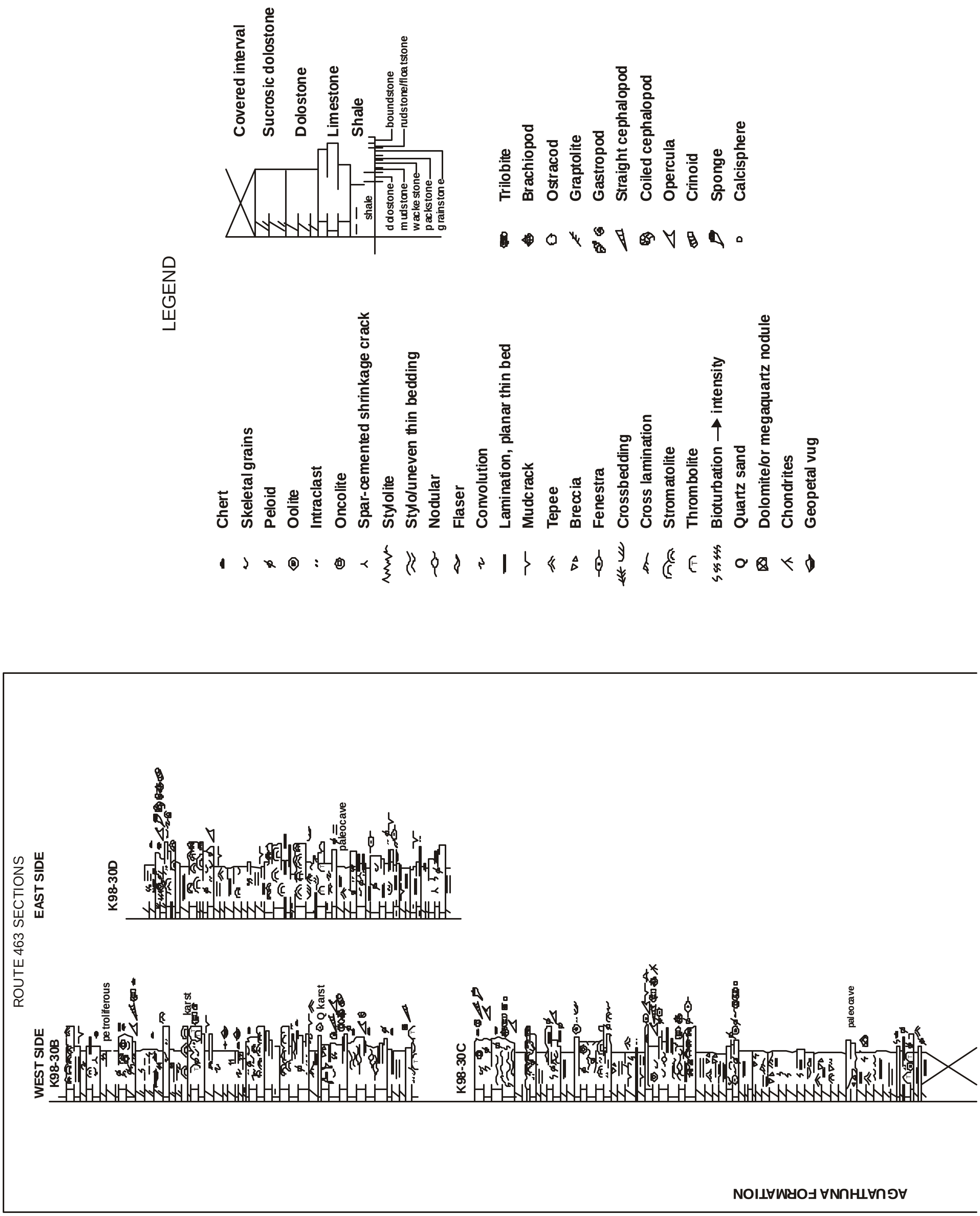
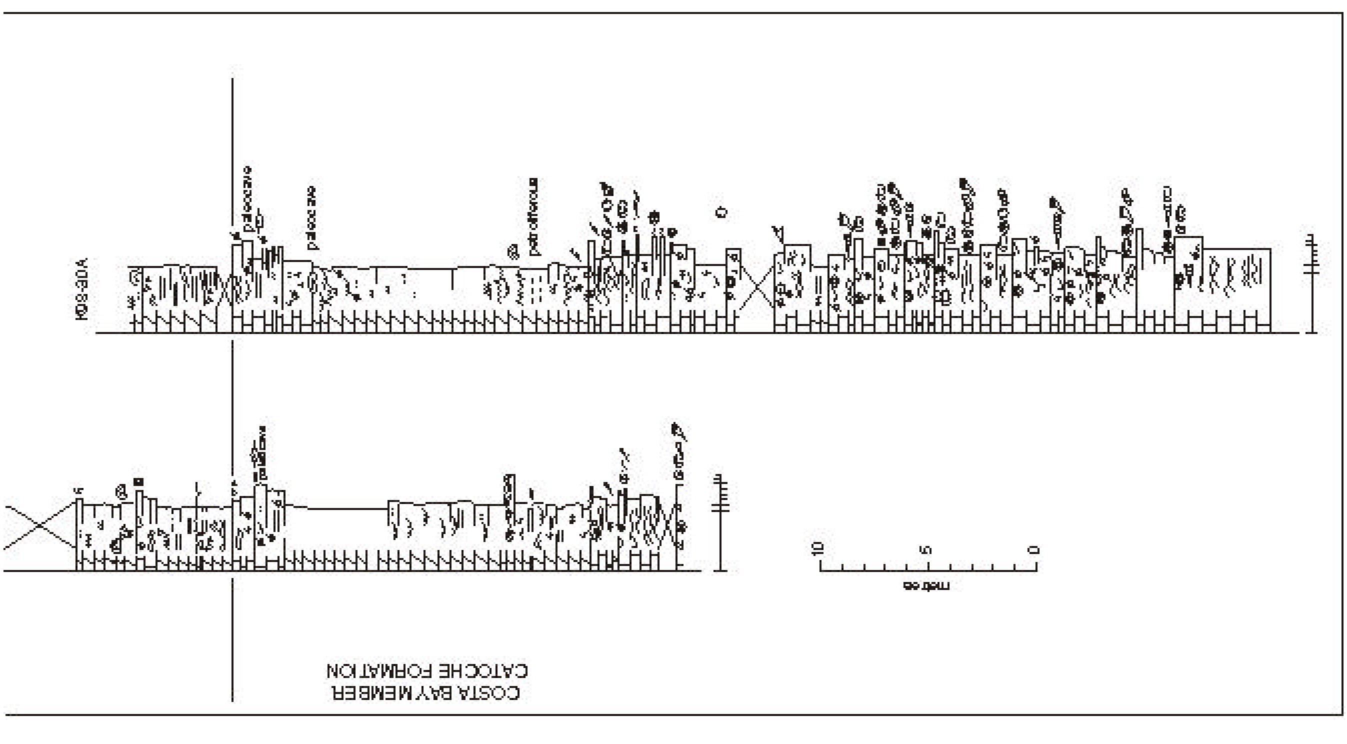

LEGEND
Covered interval
Sucrosic dolostone
Dolostone
Limestone
Shale
shale
dolostone
mudstone
wackestone
packstone
grainstone
boundstone
rudstone/floatstone
Trilobite
Brachiopod
Ostracod
Graptolite
Gastropod
Straight cephalopod
Coiled cephalopod
Opercula
Crinoid
Sponge
Calcisphere
Chert
Skeletal grains
Peloid
Oolite
Intraclast
Oncolite
Spar-cemented shrinkage crack
Stylolite
Stylo/uneven thin bedding
Nodular
Flaser
Convolution
Lamination, planar thin bed
Mudcrack
Tepee
Breccia
Fenestra
Crossbedding
Cross lamination
Stromatolite
Thrombolite
Bioturbation → intensity
Quartz sand
Dolomite/or megaquartz nodule
Chondrites
Geopetal vug
ROUTE 463 SECTIONS
EAST SIDE
K98-30D
paleocave
WEST SIDE
K98-30B
petroliferous
karst
karst
K98-30C
paleocave
AGUATHUNA FORMATION

Figure 2. *Detailed graphic logs of sections through the Costa Bay Member, Catoche Formation and the Aguathuna Formation, Route 463, western Port au Port Peninsula*



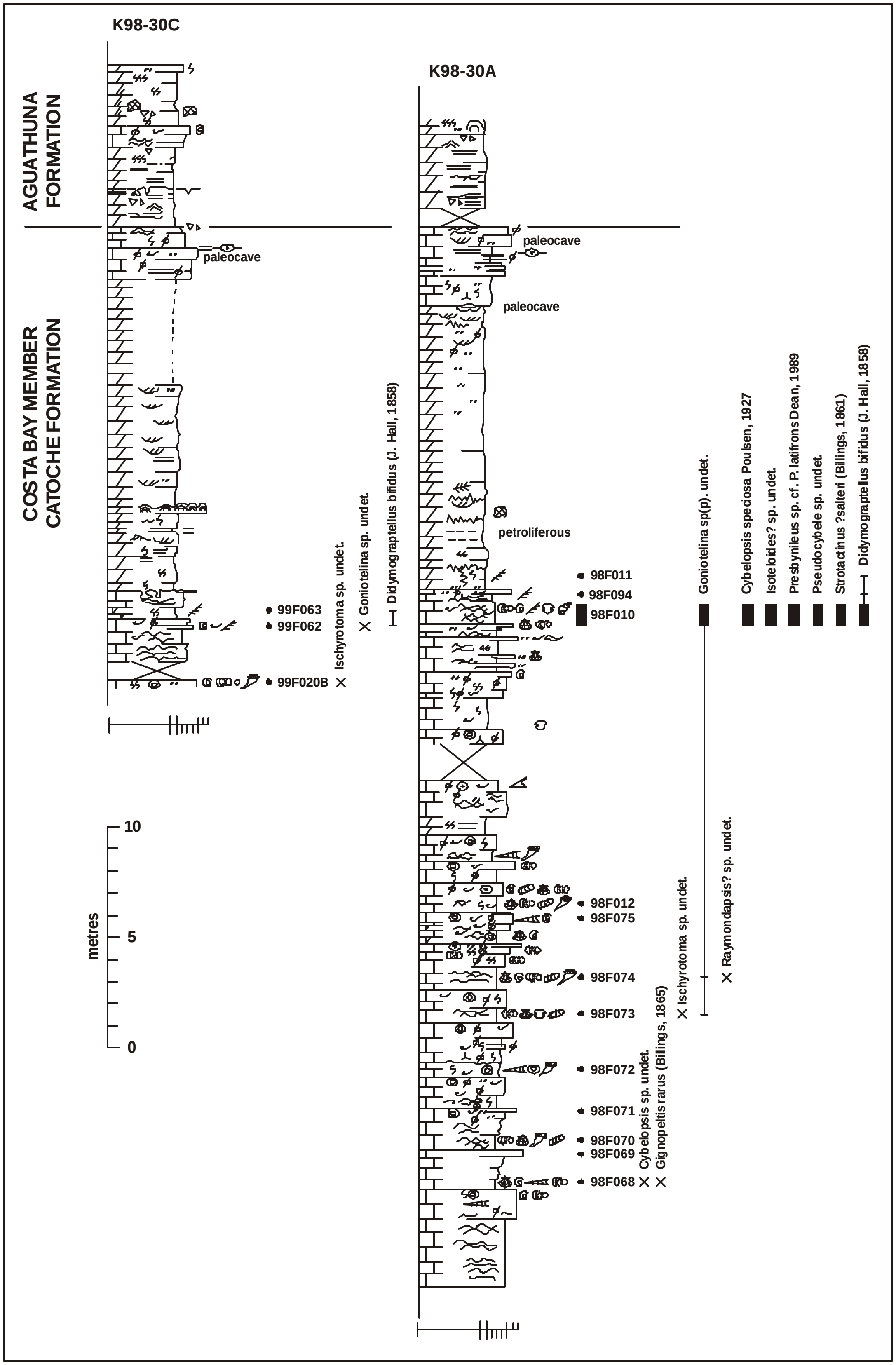


Figure 3. *Ranges of trilobite and graptolite taxa in the Costa Bay Member, Catoche Formation, section along Route 463, western Port au Port Peninsula.*

mation, at the west end of the Peninsula remained, until this study, very poorly known. The logging of the section however is still incomplete and must await further work.

Plate 1. *A cycle of dolomitic stylonodular limestone overlain by peloidal and fossiliferous limestone, Costa Bay Member, Route 463 roadcut.*

Plate 2. *A large coiled cephalopod* Centrotarphyceras *sp. undet. mixed with oncolites and other shelly debris at the top of a metre-scale cycle in the Costa Bay Member, Route 463, Port au Port Peninsula.*

LITHOSTRATIGRAPHY OF THE STUDY AREA

The upper St. George Group succession is characterized by a metre-scale cyclicity in both the Costa Bay Member and the Aguathuna Formation (Figure 2). The Costa Bay Member is at least 50 m thick and consists of a lower sequence of limestone and an upper unit of crystalline dolostone and minor limestone. The lower limestone comprises lithologically distinct facies by comparison to the type section at Aguathuna quarry. The upper dolostone unit is possibly also unique to the western end of the Peninsula although this must be verified by additional studies.

The lower limestone consists of 33 m of at least nineteen repetitive metre-scale cycles ranging in thickness from 0.35 to 7.5 m. The cycles consist of a basal, rubbly weathering, stylonodular, fossiliferous, dolomitic and argillaceous mudstone–wackestone having minor thin lenses of packstone, gradationally overlain by variably bioturbated and dolomitic, fossiliferous, peloidal wackestone–packstone–grainstone that is capped by oncolitic, skeletal, intraclastic-peloidal floatstone–rudstone–grainstone at the top of the cycle (Figure 2; Plate 1). The peloidal and oncolitic packstone–grainstone–rudstone are characteristically pale grey reflecting their generally clean and undolomitized state, similar to the limestones in the type section at Aguathuna. Sedimentary structures are rarely visible in the upper coarser facies of the cycles but rather skeletal and oncolitic allochems are commonly seen floating in a finer grained matrix (Plates 2 and 3). The tops of the cycles are generally sharp and planar but lack evidence of erosional truncation surfaces discounting the likelihood of erosion of lithified carbonate sediment.

Preservation of the shelly faunas in the limestones is excellent, with abundant complete articulate brachiopod valves, large robust straight and coiled cephalopods (Plate 2) and trilobite parts and (locally) almost complete trilobite carapaces, especially in the more stylonodular, muddier carbonates. Disarticulated crinoid ossicles, stem lengths and spines are scattered ubiquitously throughout the cycles.

The oncolites in the coarser facies generally average about 1 cm in diameter. They are oval in shape, mostly structureless and micritic (Plates 2 and 3), but rarely oncoids comprise peloidal packstone (some displaying cortices of a single microbial laminae), *Girvanella* or fenestral laminated fabric. Centimetre-sized sponges (Plate 3) are common in the upper part of the cycles.

The uppermost parasequences of the lower limestone consist of four decametre-scale cycles of rubbly weathering, stylonodular, dolomitic lime mudstone–wackestone capped by centimetre-thick intraclastic rudstone (Plates 4, 5 and 6).

This interval, which is 2.2 m thick, is exceptionally rich in shelly fossils. Graptolites are hosted by the topmost parasequence in the lower limestone, a sequence 1.6 m thick (*see* Williams *et al., this volume*).

The upper dolostone of the Costa Bay Member follows directly the graptolitic limestones of the top of the lower limestone (Plate 6). It comprises very finely to finely crystalline, dark grey to grey, burrow-mottled dolostone and crossbedded dolarenite (Plate 7), the latter hosting porosity and a faint petroliferous odor. Vestiges of limestone in the dolostone suggest that the unit is still part of the Costa Bay Member rather than part of the overlying Aguathuna Formation. The burrowed dolostone, which is 3 m thick, hosts the uppermost graptolite horizon in the section, 47 cm above its base. It is overlain by 11 m of crossbedded dolostone and the member is completed by a limestone, 3.7 m thick, of grainy, laminated, burrowed and possibly thrombolitic limestone below the first dololaminite bed of the Aguathuna Formation. White cauliflower megaquartz nodules occur in the top of the lower burrowed dolostone and are present near the top of the dolarenite.

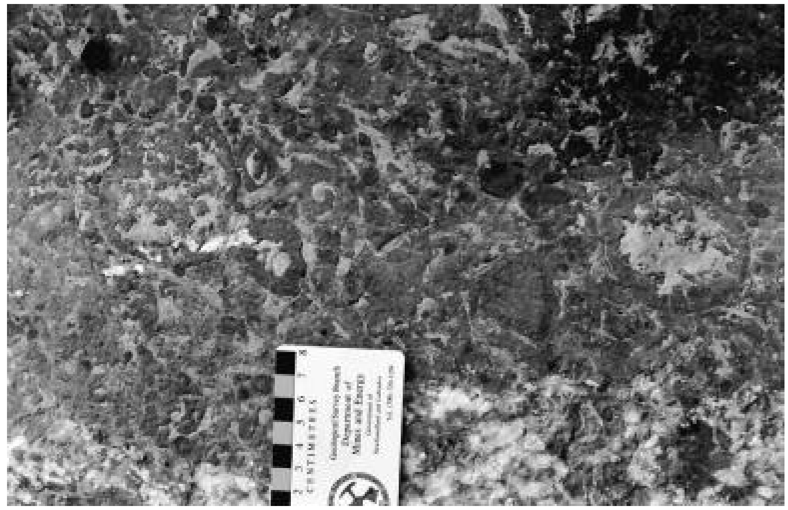


Plate 3. *Abundant sponges,* ?Zittelella *sp. undet., and small dark micritic oncolites in a dolomitic floatstone in the upper part of a metre-scale cycle in the Costa Bay Member, Route 463, Port au Port Peninsula.*

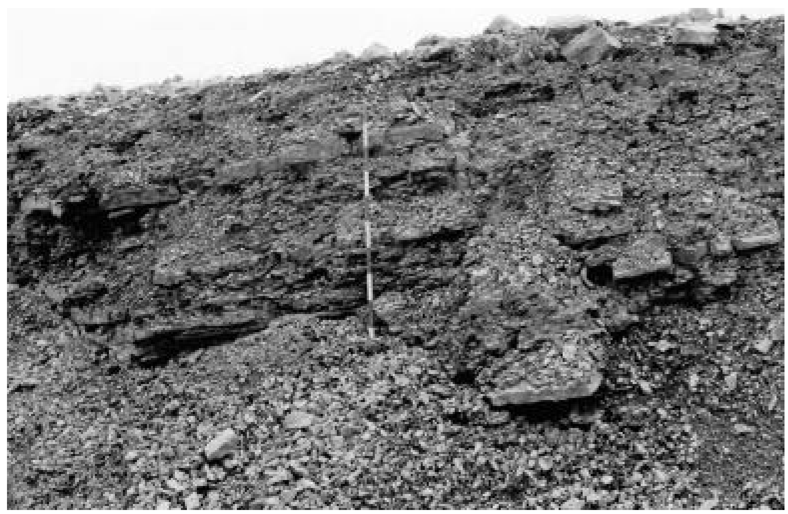


Plate 4. *Rubbly weathering, argillaceous and dolomitic stylonodular, skeletal wackestone with beds of intraclastic rudstone at the top of the lower limestone unit of the Costa Bay Member, Route 463, Port au Port Peninsula. This limestone hosts a particularly prolific skeletal fauna as well as scattered graptolites (Boyce 98F010).*

The Aguathuna Formation is characterized by limestone, dolostone and shale and its base is defined at the first thick dololaminite bed (*see* Knight and James, 1987, 1988). The section measured to date is incomplete at 39 m; it will be completed to the St. George Unconformity in future field studies. The formation consists of 0.5 to 2.5 m parasequences comprised essentially of dololaminites, many of which host mudcracks, fissure cracks, sheet cracks, *in situ* brecciation, tepees and crosslamination (Plates 8 and 9), interbedded with peloidal, micritic and stromatolitic limestones, some oncolitic–peloidal and oolitic grainstones and beds of laminated and fenestral limestone. Most of the stromatolites consist of biostromes of decametre-scale heads of laterally linked hemispheroidal laminated structure (Plate 10). Oncolites in contrast to those in the Costa Bay Member reach 2 to 3 cm in diameter, are beautifully laminated, display multiple asymmetrical growth stages and locally nucleate vertical digitate stromatolite suggesting that the oncoid had become immobilized in the rudstone–floatstone bed (Plate 11). Opercula form the nucleii of some of the oncolites.

Shales are intercalated with dololaminites higher in the formation but have yet to be logged in any significant thickness. However, shale forms the matrix to broken and brecciated carbonate at the top of one parasequence. Burrowed and crossbedded, very finely to finely crystalline, grey and dark grey mottled dolostones (Plate 12) commonly containing distinctive chert layers (Plate 13) and cauliflower chert nodules also occur. Cephalopods and silicified gastropod opercula are common in the oncolitic and dolomitic beds and cross sections of trilobites and brachiopods occur in some of the peloidal grainstones.

Paleocaves filled by oligomictic breccias and geopetal laminated dolomite siltstone occur associated with dissolution of select limestone beds within the section (Plate 14).

Their presence, plus fairly widespread development of angular and irregular hairline fractures, are probably related to karstification of the succession below the St. George Unconformity. They are cut by subvertical fractures filled by red Carboniferous mudstone and siltstone.

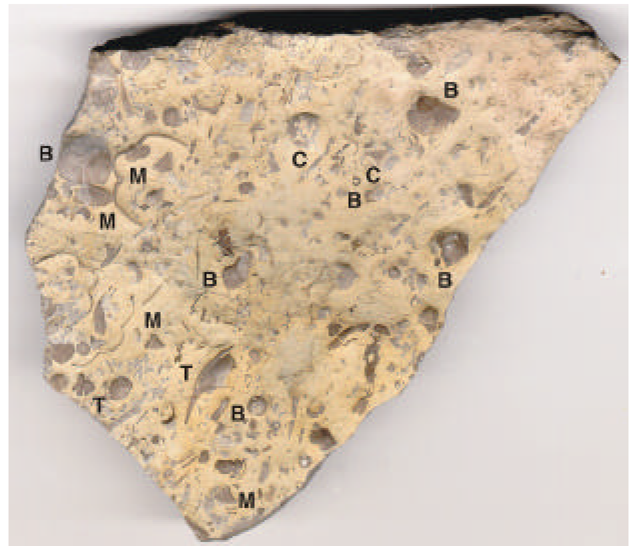


Plate 5. *Abundant skeletal parts litter a bedding plane of a thin peloidal to skeletal packstone bed from the interval shown in Plate 4. T-trilobite, B-brachiopod, C-crinoid, M-machaeridian. The upper edge of the sample is 7 cm long. The fossils are upstanding through a yellow-weathering dolostone drape.*

Plate 6. *The thick interval of stylonodular dolomitic and argillaceous lime mudstone (Plate 4) rich in shelly fossils and graptolites at the top of the lower limestone unit of the Costa Bay Member, Catoche Formation, overlain by bioturbated and crossbedded dolostones that mark the upper unit of the member, Route 463 between Cape St. George and Mainland on the Port au Port Peninsula. The location of the main graptolitic horizons in the section are shown by the arrow.*

BIOSTRATIGRAPHY

The preservation of a diverse and abundant shelly fauna in unaltered limestones of the Costa Bay Member in the west Port au Port Peninsula area is unique in western Newfoundland. The fauna includes ostracodes, trilobites, articulate brachiopods, ?bryozoa, cephalopods, crinoids, gastropod shells and opercula, machaeridians, sponges and calcispheres. Brachiopods and trilobites dominate the lower muddy strata of the Costa Bay parasequences where they may also be mixed with orthocones, ostracodes and crinoid ossicles. These faunas are also associated with robust coiled and straight cephalopods, gastropods and sponges in the grainier upper strata of the parasequences. A monospecific *Didymograptellus bifidus* (J. Hall, 1858) graptolite fauna occurs at a number of levels over a 2.5 m interval within 20 m of the top of the Costa Bay Member. The graptolites are preserved in predominantly burrowed muddy to grainy limestone and are concentrated just below the rudstone at the top of the lower limestone unit. They also occur in burrow-mottled dolostone 35 cm above the base of the upper dolostone unit (*see* Williams *et al., this volume*).

Two trilobite faunas are recognized in the limestones of the Costa Bay Member in the Route 463 sections at the west end of Port au Port Peninsula. The faunas include a lower *Gignopeltis rarus* fauna and an upper *Cybelopsis speciosa* fauna, which is partially illustrated in Plate 15.

The lower *Gignopeltis rarus* fauna (98F068) includes:

Arthropoda-Trilobita
- *Cybelopsis* sp. undet.
- *Gignopeltis rarus* (Billings, 1865) - pygidium (+)

Brachiopoda-Articulata
- *Hesperonomia?* sp. undet.
- Gen. et spp. undet. - at least two (2) species

?Bryozoa?
- Gen. et sp. undet.

Echinodermata-Crinoidea
- Gen. et sp(p). undet.

Mollusca-Cephalopoda
- Gen. et sp. undet. - straight form

Mollusca-Gastropoda
- *Maclurites* sp(p). undet.

The higher *Cybelopsis speciosa* fauna (98F069 to 98F011) includes:

Arthropoda-Ostracoda
- *Bivia?* sp. undet. - "wings" extend outward from shell (Plate 15D)

Arthropoda-Trilobita
asaphid? gen. et sp. undet.
Cybelopsis speciosa Poulsen, 1927 (Plate 15C)
Gen. et sp. undet.
Goniotelina sp(p). undet. (Plate 15A)
Ischyrotoma sp. undet.
Isoteloides? sp. undet.
Presbynileus sp. cf. *P. latifrons* Dean, 1989 (Plate 15E)
Pseudocybele sp. undet. (Plate 15B)
Raymondaspis? sp. undet. - cranidium (+, -)
Strotactinus ?salteri (Billings, 1865) (Plate 15G)
Brachiopoda-Articulata
Hesperonomia? sp. undet. (Plate 15H)
Gen. et spp. undet. - at least two (2) species
Pomatotrema sp. cf. *P. semiconvexum* (Poulsen, 1927)
Echinodermata-Crinoidea
Gen. et sp(p). undet.
Hemichordata-Graptolithina
Didymograptellus bifidus (J. Hall, 1858) (*see* Williams *et al., this volume*)
Machaeridia
Plumulites sp. undet. (Plate 15F)
Mollusca-Cephalopoda
Buttsoceras? sp. undet.
Centrotarphyceras sp. undet. (Plate 2)
Gen. et sp. undet. - straight form
Mollusca-Gastropoda
Maclurites sp(p). undet.
Ophileta? sp. undet.
Porifera
Zittelella? sp. undet.

Plate 7. *Crossbeds, planar scours and lamination in the finely crystalline dolostone that forms the upper unit of the Costa Bay Member, Catoche Formation, Route 463, Port au Port Peninsula. The dolostone hosts good porosity and has a petroliferous odour.*

Plate 8. *A dololaminite exhibiting good lamination and some dessication structures, Aguathuna Formation, Route 463, Port au Port Peninsula.*

Subtidal shelf limestones and boundstone mound limestones of the lower part of the Catoche Formation of neighbouring areas to the road sections have yielded a fauna characteristic of the lower Catoche Formation elsewhere in western Newfoundland (Boyce, 1989; Boyce and Stouge, 1997). The lower Catoche fauna collected from Route 463 roadside outcrops and from the limestone barrens overlooking the road includes:

Arthropoda-Trilobita
?Benthamaspis sp. undet.
Bolbocephalus convexus (Billings, 1865)
Ischryotoma anataphra Fortey, 1979
Jeffersonia angustimarginata Boyce, 1989
Jeffersonia sp. undet.
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)
Petigurus sp. nov. A of Boyce (1989, pages 53-54; Plate 29, figure 7)
Strigigenalis caudata (Billings, 1865)
Brachiopoda-Articulata
Gen. et sp(p). undet.
Echinodermata-Crinoidea
Gen. et sp(p). undet.
Mollusca-Cephalopoda
Cassinoceras wortheni (Billings, 1865)
Centrotarphyceras sp. undet.
Gen. et sp . undet. - straight form
Protocycloceras lamarcki (Billings, 1859)
Mollusca-Gastropoda
Gen. et sp(p). undet.

Maclurites oceanus (Billings, 1865)
Maclurites sp(p). undet.
operculum illustrated by Billings (1865, page 243; Figure 229)
Pleurotomaria normani Billings, 1865
Pleurotomaria numeria Billings, 1865

Mollusca-Rostroconchia
Euchasma blumenbachii (Billings, 1859)

Porifera
Archaeoscyphia ?minganensis Billings, 1865
Calathium? sp. undet.

The above species are indicative of the late Canadian (Cassinian) *Strigigenalis caudata* to *Benthamaspis gibberula* zones of Boyce (1989, 1997a) and Boyce and Stouge (1997) and compare closely with faunas recovered from the bulk of the formation in sections on the Great Northern Peninsula.

The presence of *Gignopeltis rarus* (Billings, 1865) in the Costa Bay Member at Port au Port Peninsula indicates that the lower fauna correlates with the Late Canadian (Cassinian) *Gignopeltis rarus* Zone of Boyce (1997a). The fauna is also developed in the upper part of white limestones of the Costa Bay Member on Burnt Island, Pistolet Bay (Boyce *et al.*, 1988). There *G. rarus* is part of a fairly diverse trilobite fauna that includes species recovered from a lower interval of grainy and bioturbated limestone and those recovered from an upper interval of dominantly thrombolitic mounds. The fauna includes the following trilobites:

Bathyurellus platypus Fortey, 1979****
Benthamaspis gibberula (Billings, 1865)**
Jeffersonia spp undet.***
Illaenus sp. nov.**
Strotactinus insularis (Billings, 1865)
Isoteloides canalis Whitfield, 1886****[1]
Peltabellia glandicephalus (Whitfield, 1890)****
Catochia glabra Fortey, 1979****
?Raymondaspis sp. undet.****
Bolbocephalus convexus (Billings, 1865)*
Uromystrum affine (Poulsen, 1937)*
Bolbocephalus kindlei Boyce, 1989*

Plate 9. *A crosslaminated dolostone bed, Aguathuna Formation, Route 463, Port au Port Peninsula.*

Plate 10. *Dololaminite overlain by an intraclastic rudstone that is capped by stromatolitic limestone. Aguathuna Formation, Route 463, Port au Port Peninsula.*

Ischyrotoma sp. undet.*
?Goniotelina sp.undet.*
Bathurellus/Punka sp.undet.*
Kawina sp. undet.*
Benthamaspis sp. nov.?*
Gignopeltus rarus (Billings, 1865)*

* trilobites found only in the upper thrombolitic mound interval
** trilobites found predominantly in the upper mounds but also in the underlying bioturbated and grainy limestone interval
*** trilobites found only rarely in the mounds but common in other rock types
**** trilobites found only in the lower bioturbated and grainy limestone interval
[1] formerly identified as *I. latimarginatus* Fortey, 1979

The trilobite fauna on Burnt Island therefore appears to be divisible into a lower assemblage that is compatible with a late faunal assemblage of the upper part of Zone I (Boyce *et al.*, 1988; Boyce and Stouge, 1997). The mound-hosted fauna in the upper part of the section, which includes the zone fossil *G. rarus*, however, may mark the lower part of Zone J in western Newfoundland, since it also carries the Zone J (to later) trilobite genus *Kawina.*

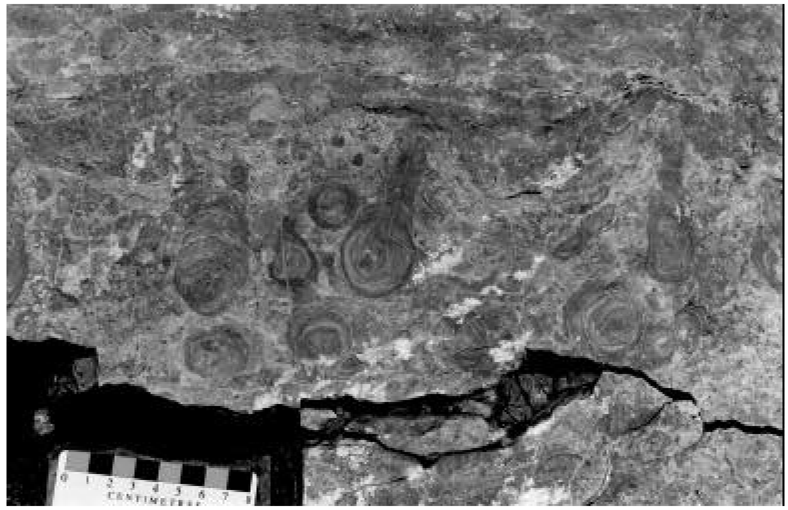


Plate 11. *Spectacular oncolites in a floatstone bed within the Aguathuna Formation, Route 463, Port au Port Peninsula. The oncoids show multiple phases of growth punctuated by internal discontinuities suggesting episodic movement on the sea floor. Once stablized in the grainy substrate, some oncolites acted as the nucleus for stromatolitic growth. Note some broken oncolites.*

Plate 12. *Burrow-mottled sucrosic dolostone overlying a dolarenite bed, Aguathuna Formation, Route 463, Port au Port Peninsula. The dolostone is petroliferous.*

The upper *Cybelopsis speciosa* fauna has not been identified in abundance anywhere else in western Newfoundland, although isolated elements of the fauna (i.e., *Bivia?* sp. nov.) have been recovered from undolomitized vestiges of upper Catoche limestone at Freshwater Cove near Table Point, Great Northern Peninsula (Boyce, 1985).

Based on the presence of *Cybelopsis speciosa* Poulsen, 1927, *Pomatotrema* sp. cf. *P. semiconvexum* (Poulsen, 1927) and *Didymograptellus bifidus* (J. Hall, 1858), the *Cybelopsis speciosa* fauna is correlated with the fauna of the Nunatami Formation of western North Greenland (*see* Appendix 1), and by extension with the *Pseudocybele nasuta* Zone (Zone J) of western Utah. The Nunatami Formation contains light grey, clean limestones that resemble the limestones of the section described in western Port au Port Peninsula (*see* Poulsen, 1927; W.D. Boyce, observation of samples and faunas of the Nunatami Formation housed at the Geological Museum, Copenhagen). The Zone J *P. nasuta* fauna of Utah is hosted by argillaceous and silty, fine-grained and grainy carbonates of the Wah Wah Formation (Jensen, 1967; Ethington *et al.*, 1995) and the upper cherty member of the Garden City Formation (Ross, 1951). Yellow-weathering, thin-bedded, quartzose silty calcisiltites and tan-coloured calcareous shales intercalated with ledges of massive calcarenite characterize the Wah Wah Formation (Jensen, 1967; Ethington *et al.*, 1995). The cherty member of the Garden City is similarly argillaceous and silty, cryptocrystalline limestones that have a stylonodular aspect (interpreted from Ross's description) (Ross, 1951).

Isoteloides polaris Poulsen, 1927 is common to the Nunatami Formation of western North Greenland and the *Pseudocybele nasuta* Zone (Zone J) of western Utah (*see* Appendix 2). Consequently, the *Cybelopsis speciosa* fauna of the Costa Bay Member readily correlates with the *Pseudocybele nasuta* Zone (Zone J). The correlation of the Route 463 Costa Bay sequence with Utah is strengthened by the presence of *Didymograptellus bifidus* (J. Hall, 1858) in Zone J correlative sections in Utah and Nevada (Ross and Berry, 1963).

This suggests that the Zone J fauna is hosted by lithofacies similar to those of the Costa Bay Member of western Port au Port Peninsula. The common association of *Goniotelina* and *Cybelopsis* in similar rocks of these three geographically distant areas, further suggests a common trilobite biofacies, tentatively designated here as the

Goniotelina-Cybelopsis biofacies. This *Goniotelina-Cybelopsis* biofacies marks it as a subfacies within the broader Bathyurid biofacies of Fortey (1975).

DISCUSSION

DEPOSITIONAL SETTING OF THE UPPER ST. GEORGE GROUP, PORT AU PORT PENINSULA

The diverse fauna, the repetitive upward-coarsening cycles consisting of stylonodular and bioturbated, peloidal, muddy carbonate overlain by clean fossiliferous, peloidal, oncolitic and intraclastic grainy limestones suggest that the Costa Bay Member, at the western extreme of the Port au Port Peninsula,was deposited in an open-shelf setting. Here, the shelf was characterized by high carbonate production rates and moderate to low energy conditions that favoured proliferation of abundant calcareous organisms. Argillaceous and dolomitic stylonodular mudstone and wackestone are lithologically similar to fine-grained stylonodular carbonates described widely in the Middle Ordovician Table Point Formation (Stenzel, 1992; Stenzel *et al.*, 1990) and were probably deposited below wave base, where they hosted mostly trilobites and brachiopods, crinoids and ostracodes. The carbonate mudrocks became cleaner as the shelf shallowed and the somewhat coarser and more mixed peloidal carbonates becoming extensively burrowed as the macrofauna became more diverse to include abundant crinoids, molluscs and sponges. The tops of the parasequences are marked by a mixture of floatstones, rudstones and packstone–grainstones. The general unsorted and featureless floatstones and rudstones, many with oncolites floating in a finer grained matrix along with robust molluscs and sponges, suggest storm deposits with little reworking by later bottom currents and/or an organic gravel-strewn sea floor, the preferred environment for prolific growth of sponges, molluscs and algal oncolites. The better sorted grainstones and very locally rudstones, still importantly devoid of observable current structures however, suggest sorting and reworking by bottom currents as the sea floor prograded toward wave base.

Plate 13. *Bioturbated, tan-grey, sucrosic dolostone containing distinctive layers of chert nodules that form a marker in the Aguathuna Formation along Route 463, Port au Port Peninsula. The bed is overlain by a grey limestone rich in silicified opercula and cephalopods.*

The coarsening-upward muddy to grainy, metre-scale parasequences characterize a zone of unknown width where repetitive sedimentation was controlled by repeated progradation of the leading edge of carbonate sand shoals over a muddy shelf bottom. However, the zone may be as wide as 10 km allowing for its extension south to Cape St. George. The lack of interbedded laminites, stromatolites, crossbedding or truncation surfaces at the cycle tops suggests the prograding lime sand shoals were never emergent, subject to tidal currents or extensively lithified in this area although the sharp planar tops to the cycles suggest that bottom currents scoured the top of the grainy shoals before the shelf was again drowned.

These characteristics, plus regional lithostratigraphic relationships, suggest that the area lay seaward of a broad peloidal carbonate barrier sand body (represented by the type Costa Bay lithofacies of the Aguathuna quarry to White Hills sections) that supplied much of the sand-sized detritus to the shelf. The generally consistent thickness and facies architecture of the metre-scale cyclicity throughout the lower limestone suggests that the major facies belts remained essentially stable in this area throughout the Costa Bay Member although influenced by 5th order sea-level fluctuations. The barrier complex geographically occupied the centre and eastern part of the Port au Port Peninsula. It consists of stacked bodies of clean, peloidal and intraclastic, fenestral grainstones that characterize the high-purity limestone of the member quarried at Lower Cove and Aguathuna and which is last seen in the area of White Hills, 3.5 to 5 km to the east of the study area.

The graptolite-rich interval, 20 m from the top of the Costa Bay Member is part of a thick prograding sequence that began at its deepest in muddy, fossiliferous and burrowed, low-energy carbonates and was completed by a high-energy, crossbedded grainstone barrier complex. At least 75 percent of this thick sequence was later dolomitized. At its simplest, this sequence marks a transition from the open-shelf setting of the lower Costa Bay Member to the more restricted peritidal flat complex of the Aguathuna Formation. The unusually plentiful and diverse shelly fauna that includes deeper water shelf trilobites, the presence of didymograptids, and the predominance of deeper shelf carbonates in the lower half of the interval with little evidence of cyclicity may indicate a marine flooding event onto the shelf at this time.

Plate 14. *A limestone bed of skeletal and peloidal wackestone–packstone wedging out between two dolostone beds in the Aguathuna Formation, Route 463, Port au Port Peninsula. A dolostone breccia (Br) formed by collapse of the overlying dolostone bed occurs where the limestone terminates indicating the limestone was removed by dissolution. A sheet-like paleo-cave partially filled by geopetal dolostone occurs in the middle of the limestone bed (arrow). Since the breccia is cut by Carboniferous fractures bearing laminated speleothemic flowstone, the dissolution of the limestone is believed to be Ordovician in age and genetically linked to the St. George Unconformity that occurs some 50 m above stratigraphically.*

The abundance of graptolites at the top of the Costa Bay Member may also, however, signal the stressful confluence of normal marine and saline shoal conditions along the seaward front of the barrier. It is probable that the briny waters of the shallow, hypersaline lagoon and tidal flat in the lee of the Costa Bay barrier complex were periodically flushed seaward by storms through tidal channels and storm-generated breaches across the barrier. The evacuation of the brines into the normal marine setting offshore of the barrier poisoned the pelagic graptolites and effected mass extinctions such as the graptolitic laminae described by Williams *et al.* (*this volume*). Turbulence, which would have been greatest in front of the barrier, possibly also lead to significant mortality in itself as well as perhaps sorting the pelagos into some of the graptolite beds (*see* Williams *et al., this volume*).

The extensive dolomitization that marks this interval may also be a reflection of the transitional position of a carbonate barrier complex between an open-shelf having normal marine salinity and carbonate chemistry and a very extensive, very shallow-water back-barrier tidal-flat complex with accompanying heightened salinity. The fine-grained crystallinity of the dolomite, the preservation of sedimentary textures (burrows, crossbedding, allochems) as well as some fossils and cauliflower chert nodules in the dolostone suggest that early shallow burial dolomitization, possibly the product of mixing zone diagenesis, marked the barrier complex as it was buried (compare to Haywick, 1984).

The Aguathuna Formation, characterized largely by metre-scale cyclicity and rocks that support peritidal deposition of carbonates, preserves a mix of tidal flats, shallow lagoons, oolitic and peloidal lime sand shoals and stromatolitic mound banks adjacent to tidal flats. Importance of mudcracked, broken and tepeed dololaminites, restricted faunas and of dolomitized burrowed carbonate, some with nodular chert layers possibly after evaporites, suggest a more restricted hypersaline setting for the much of the formation with zones of early dolomitization. Karstification at the top of one cycle supports local subaerial exposure of the tidal-flat complex. Apart from the obvious molluscan fauna, only the clean grainier limestones in the Aguathuna Formation contain some trilobites and brachiopods, suggesting short-lived open marine flooding at the margins of the flats.

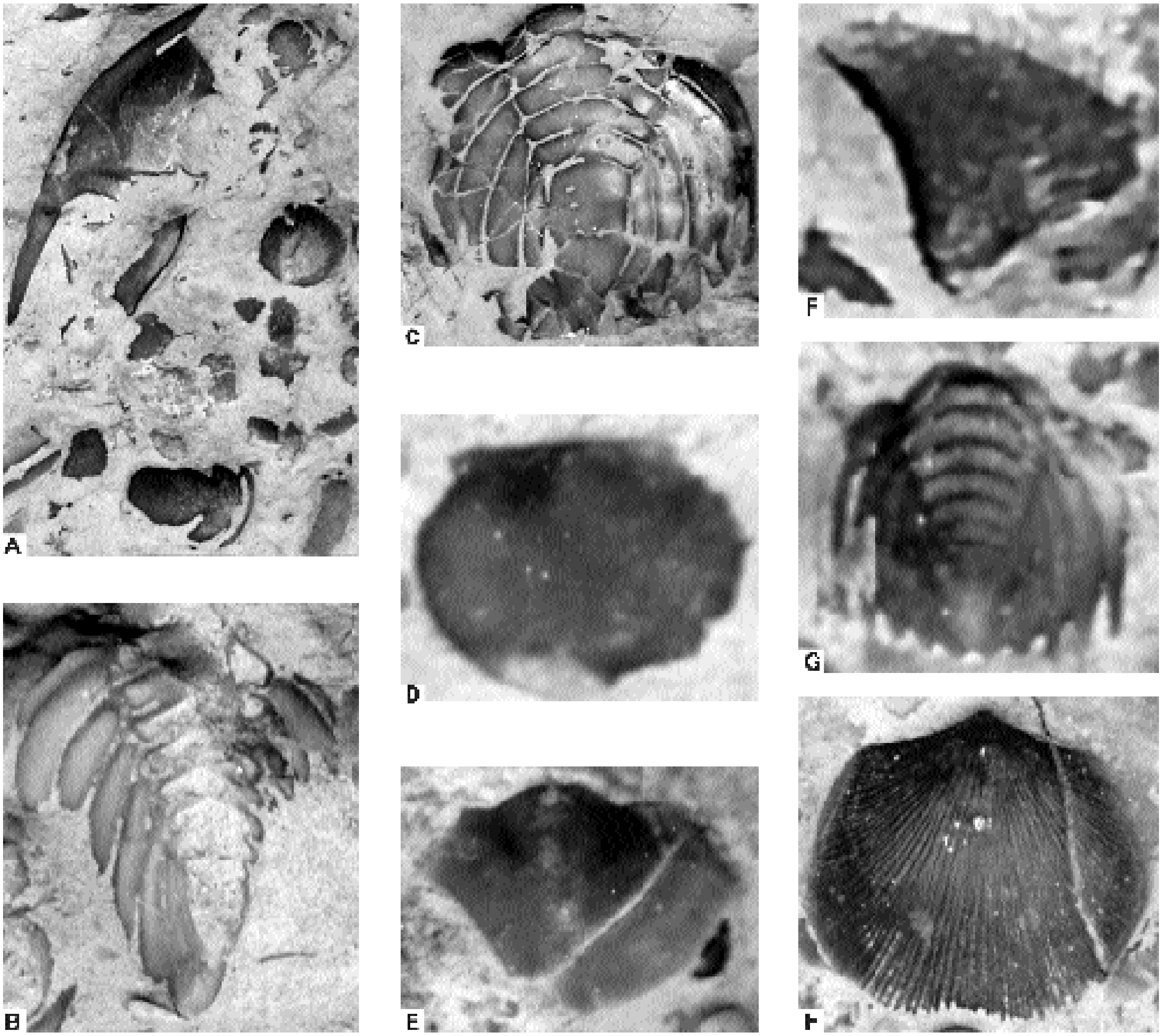


Plate 15. *Selected shelly fossils of the upper* Cybelopsis speciosa *fauna of the Costa Bay Member, Route 463, western Port au Port Peninsula.*

A. Goniotelina *sp. undet. Free cheek (top left) and hypostome (bottom centre). 12 mm from front to back tips of free cheek. Small pliomerid cranidium immediately to right of free cheek. Specimens from 98F095, (equivalent to 98F010, but on opposite side of Route 463) in same piece of rock as "F".*

B. Pseudocybele *sp. undet. Pygidium, 8 mm long. Specimen from 98F095 (equivalent to 98F010, but on opposite side of Route 463).*

C. Cybelopsis speciosa *Poulsen, 1927. Large, flattened and broken pygidium, 18 mm long. Specimen from 98F010.*

D. Bivia? *sp. nov., 4 mm horizontal length. Specimen from 98F010, in same piece of rock as "E".*

E. Presbynileus *sp. cf.* P. latifrons *Dean, 1989. Pygidium, 7 mm wide. Specimen from 98F010, in same piece of rock as "D".*

F. Plumulites *sp. undet. 2.3 mm long. Specimen from 98F095 (equivalent to 98010, but on opposite side of Route 463) in same piece of rock as "A".*

G. Strotactinus ?salteri *Billings, 1861. Pygidium, 2.4 mm long. Specimen from 98F010, in same piece of rock as "H".*

H. Hesperonomia? *sp. undet., 6.5 mm long. Specimen from 98F010, in same piece of rock as "G".*

THE COSTA BAY TRILOBITE FAUNAS – THEIR SIGNIFICANCE AND BIOFACIES

Ordovican trilobite asssemblages have been subdivided into four broad biofacies, the inshore Bathyurid biofacies, the mound-hosted Illaenid-Cheirurid biofacies, the slope-hosted Nileid biofacies and the deep-water Olenid biofacies (Fortey, 1975; Fortey and Droser, 1996). The Lower Ordovician carbonate shelf of western Newfoundland hosts only faunal assemblages of the *Bathyurid* and *Illaenid-Cheirurid* biofacies (Boyce, 1986, 1989, 1997b). The trilobites of these biofacies are illustrated by Boyce (1989) in the rocks of the Barbace Cove Member, Boat Harbour Formation and the overlying lower limestone and mound sequence of the Catoche Formation. In particular, Boyce (1997b) was able to subdivide the Bathyurid biofacies into two biofacies, the nearshore *Isoteloides-Strigigenalis* biofacies hosted mostly by ripple-marked grainstones, and the *Jeffersonia* biofacies that dominated much of the Catoche succession of bioturbated lime wackestones and packstones. The mound-hosted *Illaenid-Cheirurid* biofacies was refined to better reflect the Newfoundland mound fauna and was called the *Illaenus-Bolbocephalus* biofacies.

The biofacies model of Fortey (1975) is ideally suited to the the characteristics of the Ordovician carbonate shelf during the deposition of the lower limestone and mound member of the Catoche Formation (Figure 4, section A). The trilobite faunas of this sequence correlate with Utah Zones G2, H and perhaps I, and belong to the *Strigigenalis caudata* and *Benthamaspis gibberula* Zones of Boyce (1989, 1997a; Boyce and Stouge, 1997). The lower *Strigenalis caudata* Zone assemblages are essentially hosted by rocks that mark the transgressive system tract of the Arenig megacycle of Knight and James (1987) and comprise the *Isoteloides-Strigigenalis* and *Jeffersonia* biofacies. Individual mound beds in this part of the 3rd order sequence contain *Bolbocephalus* but lack illaenid trilobites (Boyce, 1989, 1997b).

Carbonates of the highstand system tract which is marked by a stable subtidal shelf of outer barrier and inner subtidal shelf seaway (Figure 4, Section A) occurred in the higher *B. gibberula* Zone. A thrombolite-sponge mound barrier complex developed from Cape Norman in the north over 400 km to the Port au Port Peninsula in the south (Knight and Cawood, 1991) and dominated the outer parts of the exposed Newfoundland shelf during trilobite Zones H to I. The barrier hosts trilobites of the *Illaenus-Bolbocephalus* biofacies (Boyce, 1986, 1997b; Boyce *et al.*, 1988). Inboard of this barrier complex (i.e., to the west and north), the Early Arenig–Late Canadian shelf was characterized by a broad subtidal lagoon/seaway dotted with a patchwork of isolated thrombolite mounds (Knight, 1991; Knight and Cawood, 1991). The wide inboard lagoon/seaway was the depository of subtidal shelf bioturbated muddy carbonates that host the *Bathyurid–Jeffersonia* biofacies while the *Illaenus–Bolbocephalus* biofacies trilobites inhabited the patch reef-like thrombolite mounds that studded the seaway (Boyce, 1986, 1997b; Knight, 1991; Knight and Cawood, 1991).

The distribution of the trilobite biofacies in the upper part of Zone I and in Zone J of the upper St. George Group is, however, in marked contrast to the distribution of biofacies during trilobite Zones H to I in the lower part of the Catoche Formation (Figure 4). The *Gignopeltis rarus* and *Cybelopsis speciosa* faunas in the Costa Bay limestones of the west end of Port au Port Peninsula are viewed as new and important facies-controlled faunas that probably inhabited the more open-shelf setting seaward of a shoreline-hugging barrier on the late Canadian (Arenig) Newfoundand shelf (Figure 4, Section B and C).

Trilobites of the time-equivalent and lithologically comparable Utah sections, however, have been characterized as inshore shelf Bathyurid biofacies (Fortey and Droser, 1996). The association of common *Goniotelina* and pliomerid trilobites in the Costa Bay Member as in the lithologically similar Nunatami Formation, Greenland and the Utah sections, together with the *D. bifidus* graptolites, strongly suggest an open-marine influence dominated the western Port au Port shelf and suggest that no outer barrier complex occurred during Zone J of this late Canadian stage in the development of the shelf. Rather in the Port au Port area, a shoreline barrier complex of high-energy carbonate sands marks the shoreline edge of this open shelf, protecting a very broad back barrier zone of peritidal flats (Aguathuna Formation).

At Burnt Island, Northern Peninsula, the nearshore barrier separating offshore shelf from back barrier peritidal flats is not a grainstone complex but a thrombolitic reef complex. The fauna and succession in the Costa Bay Member at Burnt Island is interesting for several reasons. First, it includes elements of both the *Illaenus-Bolbocephalus* biofacies that is predicted to dominate mound sequences in Newfoundland and elsewhere, and elements of the inshore shelf *Bathyurid* biofacies (Boyce *et al.*, 1988; Boyce and Stouge, 1997; Fortey, 1975; Fortey and Droser, 1996). The presence of the deeper water trilobite *Kawina* sp. undet. in the mound sequence however, appears to predict that the Burnt Island section lies just inboard of an open shelf (Figure 4, Section B). Second, the fauna appears to straddle Zones I to J. Lastly, the sequence occurs immediately below the contact with the Aguathuna Formation because the Costa Bay Member is overlain by a few metres of dololaminites of the Aguathuna Formation below the St. George Unconformity at the top of the Burnt Island section (*see* Knight *et al.*, 1991).

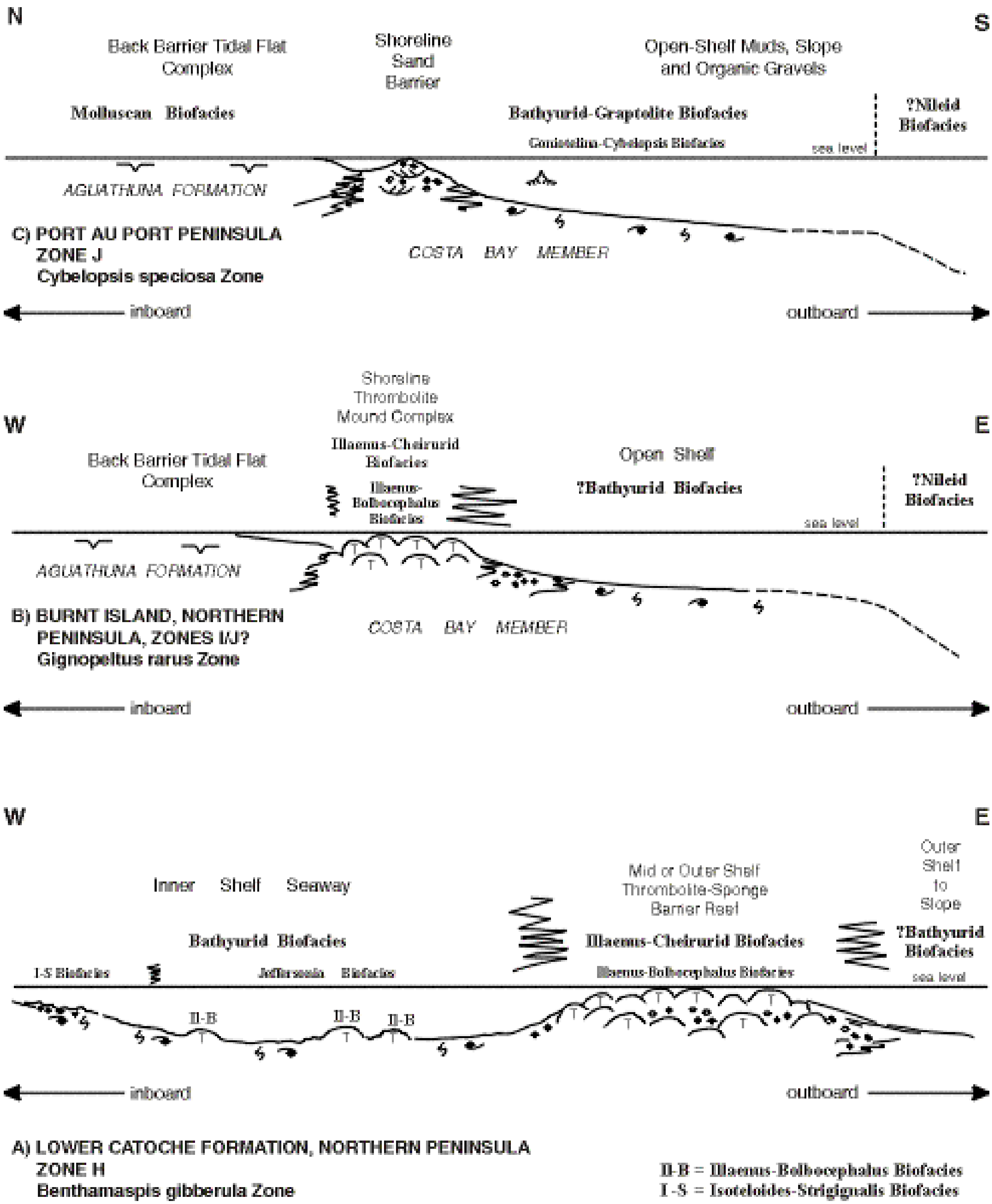


Figure 4. *Early Ordovician biozones related to lithofacies in the lower and upper parts of the late Canadian (Arenig) shelf in western Newfoundland. Based on Fortey, 1975; Fortey and Droser, 1996 and modified to include Newfoundland faunal zones and biozones of Boyce (1997a and b), Boyce and Stouge, 1997.*

This indicates that the development of Aguathuna Formation peritidal flat complexes that marks the top of the St. George Group occurred sooner on the Northern Peninsula than to the south on Port au Port Peninsula. The transition in the south occurs after the proliferation of the later Zone J *Cybelopsis speciosa* fauna in the open shelf limestones of the upper part of the Costa Bay Member. A similar conclusion was reached for this Costa Bay–Aguathuna transition based on graptolite distribution on the Northern and Port au Port Peninsulas (*see* Williams *et al., this volume*). Nonetheless, regardless of timing or geographical areas, the widely separated sections (400 km apart) each illustrate a common theme of inboard tidal flat that mostly hosts a molluscan biofacies, a shoreline barrier complex that may host locally in mounds the *Illaenus-Bolbocephalus* biofacies and then offshore an open shelf of unknown width that was host to a specialized Bathyurid biofacies trilobite fauna, the *Goniotelina-Cybelopsis* biofacies.

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REFERENCES

Billings, E.

1859: Fossils of the Chazy Limestone with the description of new species. Canadian Naturalist and Geologist (Ottawa), Volume 4, pages 426-470.

1861: On some of the rocks and fossils occurring near Phillipsburg, Canada east. Canadian Naturalist and Geologist (Ottawa), Volume 6, pages 310-328.

1865: Palaeozoic fossils. Volume 1. Containing descriptions and figures of new or little known species of organic remains from the Silurian rocks. 1861-1865. Geological Survey of Canada, separate report, 426 pages.

Boyce, W.D.

1978: Recent developments in western Newfoundland Cambro-Ordovician trilobite biostratigraphy. *In* Report of Activities for 1977. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 80-84.

1985: Cambrian-Ordovician biostratigraphic investigations, Great Northern Peninsula, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 161-168.

1986: Ordovician biostratigraphic investigations, Great Northern Peninsula, western Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 161-168.

1989: Early Ordovician trilobite faunas of the Boat Harbour and Catoche formations (St. George Group) in the Boat Harbour - Cape Norman area, Great Northern Peninsula, western Newfoundland. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-2, 175 pages.

1997a: Early to Middle Ordovician trilobite-based biostratigraphic zonation of the Autochthon and Parautochthon, western Newfoundland, Canada. Second International Trilobite Conference, Brock University, St. Catharines, Ontario, August 22-25, 1997, Abstracts with Program, page 10.

1997b: Late Canadian (Latest Jeffersonian to Cassinian) trilobite biofacies of the St. George Group, western Newfoundland, Canada. Second International Trilobite Conference, Brock University, St. Catharines, Ontario, August 22-25, 1997, Abstracts with Program, pages 11-12.

Boyce, W.D. and Stouge, S.

1997: Trilobite and conodont biostratigraphy of the St. George Group at Eddies Cove West, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 97-1, pages 183-200.

Boyce, W.D., Ash, J.S. and Knight, I.

1988: Biostratigraphic studies of Ordovician carbonate rocks in western Newfoundland, 1987. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 75-83.

Braithwaite, L.F.
1976: Graptolites from the Lower Ordovician Pogonip Group of Western Utah. Geological Society of America, Special Paper 166, 106 pages.

Dean, W.T.
1989: Trilobites from the Survey Peak, Outram and Skoki Formations (Upper Cambrian – Lower Ordovician) at Wilcox Pass, Jasper National Park, Alberta. Geological Survey of Canada, Bulletin 389, 141 pages.

Ethington, R.L., Finney, S.C., Miller, J.F., Ross, R.J., Jr. and Valdes-Camin, C.
1995: Pre-meeting trip – central Great Basin transect. *In* Ordovician of the Great Basin: Field Trip Guidebook and Volume for the Seventh International Symposium on the Ordovician System. *Edited by* J.D. Cooper. The Pacific Section Society for Sedimentary Geology (SEPM), pages 1-50.

Fortey, R.A.
1975: Early Ordovician trilobite communities. *In* Evolution and Morphology of the Trilobita, Trilobitoidea and Merostomata. *Edited by* A. Martinsson. Fossils and Strata, Number 4, pages 331-352.

1979: Lower Ordovician trilobites from the Catoche Formation (St. George Group), western Newfoundland. Geological Survey of Canada, Bulletin 321, pages 61-114.

Fortey, R.A. and Droser, M.L.
1996: Trilobites at the base of the Middle Ordovician, western United States. Journal of Paleontology, Volume 70, pages 73-99.

Hall, J.
1858: Descriptions of Canadian graptolites. Geological Survey of Canada, Report of Progress for 1857, pages 111-145.

1865: Graptolites of the Quebec Group. Geological Survey of Canada, Figures and Descriptions of Canadian Organic Remains, Decade II, 151 pages.

Haywick, D.W.
1984: Dolomite within the St. George Group (Lower Ordovician), western Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St John's, Newfoundland, 281 pages.

Hintze, L.F.
1952: Lower Ordovician trilobites from western Utah and eastern Nevada. Utah Geological and Mineralogical Survey, Bulletin 48, 249 pages.

James, N.P., Stevens, R.K., Barnes, C.R. and Knight, I.
1989: Evolution of a Lower Paleozoic continental margin carbonate platform, northern Canadian Appalachians. *In* Controls on Carbonate Platforms and Basin Development. *Edited by* P.D. Crevello, J.L. Wilson, J.F. Sarg and J.F. Read. Society of Economic Paleontologists and Mineralogists, Special Publication 44, pages 123-146.

Jensen, R.G.
1967: Ordovician brachiopods from the Pogonip Group of Millard County, western Utah. Brigham Young University Geology Studies, Volume 14, pages 67-100.

Ji, Z. and Barnes, C.R.
1994: Lower Ordovician conodonts of the St. George Group, Port au Port Peninsula, western Newfoundland, Canada. Palaeontographica Canadiana, Number 11, 149 pages.

Knight, I.
1977: Cambro-Ordovician platformal rocks of the Northern Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-6, 27 pages.

1978: Platformal sediments on the Great Northern Peninsula: stratigraphic studies and geological mapping of the North St. Barbe District. *In* Report of Activities for 1977. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 140-150.

1991: Geology of Cambro-Ordovician rocks in the Port Saunders (NTS 12I/11), Castors River (NTS 12I/15), St. John Island (NTS 12I/14) and Torrent River (NTS 12I/10) map areas. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-4, 138 pages.

1996: Stratigraphic logs of carbonate rocks of western Newfoundland. Based on mineral exploration drill hole logs. Government of Newfoundland and Labrador, Department of Mines and Energy, Energy Resource Development Division, Open File Release 1996-PRD-1, 91 pages.

Knight, I. and Cawood, P.A.
1991: Paleozoic geology of western Newfoundland: an exploration of a deformed Cambro-Ordovician passive margin and foreland basin, and Carboniferous successor basin. Centre for Earth Resources Research, Memorial University of Newfoundland, St. John's, Newfoundland, Geologic setting and field guide, 403 pages.

Knight, I. and James, N.P.
1987: Stratigraphy of the Lower Ordovician St. George Group, western Newfoundland: the interaction between eustasy and tectonics. Canadian Journal of Earth Sciences, Volume 24, pages 1927-1951.

1988: Stratigraphy of the Lower to lower Middle Ordovician St. George Group, western Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Report 88-4, 48 pages.

Knight, I., James, N.P. and Lane, T.E.
1991: The Ordovician St. George Unconformity, northern Appalachians: the relationship of plate convergence at the St. Lawrence Promontory to the Sauk/Tippecanoe sequence boundary. Geological Society of America Bulletin, Volume 103, pages 1200-1225.

Poulsen, C.
1927: The Cambrian, Ozarkian and Canadian faunas of northwest Greenland. Meddelelser om Grønland, Volume 70, Number 2, pages 233-243.

1937: On the Lower Ordovician faunas of east Greenland. Meddelelser om Gronland, Volume 119, Number 3, pages 1-72.

Pratt, B.R.
1979: The St. George Group (Lower Ordovician), western Newfoundland: sedimentology, diagenesis and cryptalgal structures. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 254 pages. [NFLD/1248]

Pratt, B.R. and James, N.P.
1986: The St. George Group (Lower Ordovican) of western Newfoundland: tidal flat island model for carbonate sedimentation in shallow epeiric seas. Sedimentology, Volume 33, pages 313-343.

Ross, R.J., Jr.
1951: Stratigraphy of the Garden City Formation in northeastern Utah and its trilobite faunas. Yale University, Peabody Museum of Natural History, Bulletin 6, 161 pages.

Ross, R.J., Jr. and Berry, W.B.N.
1963: Ordovician graptolites of the Basin Ranges in California, Nevada, Utah and Idaho. United States Geological Survey, Bulletin 1134, 177 pages.

Ross, R.J., Jr., Hintze, L.F., Ethington, R.L., Miller, J.E., Taylor, M.F. and Repetski, J.E.
1993: The Ibexian Series (lower Ordovician) a replacement for "Canadian Series" in North American chronostratigraphy. United States Geological Survey, Open-File Report 93-598, 47 pages.

Ruedemann, R.
1947: Graptolites of North America. Geological Society of America, Memoir 19, 527 pages.

Stait, K.A.
1988: Upper Canadian to Whiterockian (Ordovician) conodont biostratigraphy of the upper St. George Group, western Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 493 pages.

Stait, K.A. and Barnes, C.R.
1991: Conodont biostratigraphy of the upper St. George Group (Canadian to Whiterockian), western Newfoundland. *In* Advances in Ordovician Geology. *Edited by* C.R. Barnes and S.H. Williams. Geological Survey of Canada, Paper 90-9, pages 125-134.

Stenzel, S.R.
1992: Carbonate sedimentation in an evolving Middle Ordovician foreland basin, western Newfoundland. Unpublished Ph.D. thesis, Memorial University of Newfoundland, St John's, Newfoundland, 494 pages.

Stenzel, S.R., Knight, I. and James, N.P.
1990: Carbonate platform to foreland basin: revised stratigraphy of the Table Head Group (Middle Ordovician), western Newfoundland. Canadian Journal of Earth Sciences, Volume 27, pages 14-26.

Stockmal, C.S. and Waldron, J.W.F.
1993: Structural and tectonic evolution of the Humber Zone, western Newfoundland: Implications of balanced cross-sections through the Appalachian structural front, Port au Port Peninsula. Tectonics, Volume 12, pages 1056-1075.

Stouge, S.
1982: Preliminary conodont biostratigraphy and correlation of Lower to Middle Ordovician carbonates of the St. George Group, Great Northern Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-3, 63 pages.

Stride Consulting
1988: Report on geological, geochemical, geotechnical and engineering feasibility investigations conducted in the Lower Cove area of the Port au Port Peninsula, October 1985 – February, 1988, Licence No. 2785 and

3005, prepared for Newfoundland Resource and Mining Company Ltd., July 1988. Newfoundland Department of Mines and Energy File No. 12B 297.

1989: Report on the high-purity limestone of the Port au Port Peninsula at Lower Cove, Newfoundland, Canada. Prepared for Newfoundland Resource and Mining Company Ltd., July 1988. Newfoundland Department of Mines and Energy File No. 12B 331.

Troelsen, J.P.
1950: Contributions to the geology of Northwest Greenland, Ellesmere Island and Axel Heiberg Island. Meddelelser om Grønland, Volume 149, Number 7, 86 pages.

Tuach Geological Consultants
1990: Report on diamond drilling of the Port au Port limestone deposit, western Newfoundland, by P. Saunders, NTS 12B/11, licence 3971 for Western Canadian Mining Corporation.

Ulrich, E.O. and Cooper, G.A.
1936: New genera and species of Ozarkian and Canadian brachiopods. Journal of Paleontology, Volume 10, pages 616-631.

1938: Ozarkian and Canadian Brachiopods. Geological Society of America, Special Paper 13, 253 pages.

Whitfield, R.P.
1886: Notice of geological investigations along the eastern shore of Lake Champlain, conducted by Prof. H.M. Seely and Prest. Ezra Brainerd of Middlebury College, with descriptions of the new fossils discovered. American Museum of Natural History Bulletin, Volume 1, pages 293-345.

1890: Observations on the fauna of the rocks at Fort Cassin, Vermont, with descriptions of a few new species. American Museum of Natural History Bulletin, Volume 3, pages 25-39.

Whittington, H.B.
1948: A new Lower Ordovician trilobite. Journal of Palaeontology, Volume 22, pages 567-572.

Williams, S.H., Boyce, W.D. and James, N.P.
1987: Graptolites from the Lower-Middle Ordovician St. George and Table Head groups, western Newfoundland, and their correlation with trilobite, graptolite, brachiopod and conodont zones. Canadian Journal of Earth Sciences, Volume 24, pages 456-470.

Williams, S.H., Boyce, W.D., Knight, I., Measures, E.A. and Rohr, D.M.
This volume: Early Ordovician (Arenig) graptolites from the Upper St. George Group, Port au Port Peninsula: Preservation, correlation, and paleo-environmental and stratigraphic implications.

Note: Geological Survey file numbers are included in square brackets.

APPENDIX 1

Faunas of the Nunatami Formation of western North Greenland

Poulsen (1927) subdivided the Nunatami Formation into four members; in ascending order, these are:

Bifidus shale
Angustifolius limestone
Gastropod limestone
Ostracod limestone

The faunas of the members are listed below.

***Bifidus* Shale**
Hemichordata-Graptolithina
dichograptid? genus et sp. ind. Poulsen, 1927
Didymograptus (Didymograptellus) bifidus (J. Hall, 1858)[1]

***Angustifolius* Limestone**
Arthropoda-Trilobita
Goniotelina? sp. ind. (Poulsen,1927; Plate XX, figure 3)
Isoteloides polaris Poulsen, 1927
Hemichordata-Graptolithina
Phyllograptus angustifolius Hall, 1858
Mollusca-Cephalopoda
Genus et sp. ind. Poulsen, 1927
Mollusca-Gastropoda
Raphistomina latiumbilicata Poulsen, 1927

Associated brachiopod. Associated low spired gastropod.

Gastropod Limestone
Arthropoda-Trilobita
Psephosthenaspis sp. ind.
Brachiopoda-Articulata
Deltorthis sp. Poulsen, 1927
Mollusca-Gastropoda
Hormotoma sp. ind.
Turritoma sp. ind. I. Poulsen, 1927
Turritoma sp. ind. II. Poulsen, 1927

Troelsen (1950, page 53) suggested that the Gastropod limestone merely occurs as lenses or thin layers within the Nunatami Formation.

Ostracod Limestone
Arthropoda-Ostracoda
Isochilina arctica Poulsen, 1927
Isochilina egressa Poulsen, 1927
Isochilina perporosa Poulsen, 1927
Isochilina suavis Poulsen, 1927

[1] *Didymograptus bifidus* (Hall, 1858)

Arthropoda-Trilobita
- *Bathyurellus tenuis* Poulsen, 1927
- *Bolbocephalus angustisulcatus* Poulsen, 1927
- *Cybelopsis speciosa* Poulsen, 1927
- *Goniotelina boggildi* (Poulsen, 1927)
- *Goniotelina crassicornis* (Poulsen, 1927)
- *Illaenus/Presbynileus glaber* (Poulsen, 1927)
- *?Isoteloides* sp. Poulsen, 1927
- *Jeffersonia exterminata* Poulsen, 1927
- *Kanoshia insolita* (Poulsen, 1927)[2]
- *Pseudomera dactylifera* (Poulsen, 1927)[3]
- *Psephosthenaspis?* sp. ind.

Brachiopoda-Articulata
- *Clitambonites trivialis* Poulsen, 1927
- *Pomatotrema semiconvexum* (Poulsen, 1927)
- *Syntrophia rhombica* Poulsen, 1927

Mollusca-Cephalopoda
- *Buttsoceras? modestum* (Poulsen, 1927)

This unit also contains crinoids.

[2] *Pliomera insolita* Poulsen, 1927
[3] *Pliomera dactylifera* Poulsen, 1927

APPENDIX 2

Taxa of the *Pseudocybele nasuta* Zone (Zone J) of Utah and Nevada, U.S.A.

Ross (1951, pages 27-28) listed the following from the Garden City Formation of northeastern Utah:

Arthropoda-Trilobita
- *Carolinites genacinaca* Ross, 1951
- *Goniotelina williamsi* (Ross, 1951)[4]
- *Ischyrotoma caudanodosa* (Ross, 1951)[5]
- *Isoteloides?* sp.
- *Kawina sexapugia* Ross, 1951
- *Lachnostoma latucelsum* Ross, 1951
- *Pseudocybele nasuta* Ross, 1951
- *Ptyocephalus declevita* (Ross, 1951)[6]

Brachiopoda-Articulata
- *Diparelasma* sp.
- *Hesperonomia dinorthoides* Ulrich and Cooper, 1938
- *Syntrophopsis* sp. cf. *S.polita* Ulrich and Cooper, 1938
- *Tritoechia* sp. nov.

Hintze (1952, page 18, Table 10), Jensen (1967), Braithwaite (1976), Ross *et al.* (1993), and Ethington *et al*. (1995, pages 16-17) listed the following from the Wah Wah Formation (Pogonip Group) of western Utah and eastern Nevada:

Arthropoda-Trilobita
- *Benthamaspis diminutiva* Hintze, 1952
- *Carolinites genacinaca* Ross, 1951
- *Cybelopsis* sp. cf. *C. speciosa* Poulsen, 1927
- *Goniotelina brighti* (Hintze, 1952)[7]
- *Goniotelina brevus* (Hintze, 1952)[8]
- *Goniotelina* sp. D (Hintze, 1952)[9]
- *Goniotelina wahwahensis* (Hintze, 1952)[10]
- *Ischyrotoma caudanodosa* (Ross, 1951)[11]
- *Isoteloides polaris* Poulsen, 1927
- *Kanoshia* sp. cf. *K. insolita* (Poulsen, 1927)
- *Kawina sexapugia* Ross, 1951
- *Kawina webbi* Hintze, 1952
- *Lachnostoma latucelsum* Ross, 1951
- *Presbynileus* sp.[12]
- *Presbynileus utahensis* (Hintze, 1952)[13]

[4] *Eleutherocentrus williamsi* Ross, 1951
[5] *Dimeropygiella caudanodosa* Ross, 1951
[6] *Kirkella declevita* Ross, 1951
[7] *Goniotelus brighti* Hintze, 1952
[8] *Goniotelus brevus* Hintze, 1952
[9] *Goniotelus* sp. D. Hintze, 1952
[10] *Goniotelus wahwahensis* Hintze, 1952
[11] *Dimeropygiella caudanodosa* Ross, 1951
[12] *Paranileus* sp.
[13] *Paranileus utahensis* Hintze, 1952

Psephosthenaspis? sp.[14]
Pseudocybele nasuta Ross, 1951
Ptyocephalus declevita (Ross, 1951)[15]
Ptyocephalus sp. cf. *P. vigilans* Whittington, 1948[16]
Stenorhachis genalticurvatus (Hintze, 1952)[17]
Theamataspis sp.[18]
Trigonocercella acuta Hintze, 1952

Brachiopoda-Articulata
Diparelasma sp. cf. *D. transversa* Ulrich and Cooper, 1938
Diparelasma typicum Ulrich and Cooper, 1936
Hesperonomia dinorthoides Ulrich and Cooper, 1938
Hesperonomia fontinalis (White)
Hesperonomia subtransversa Ulrich and Cooper, 1938
Syntrophopsis sp. cf. *S.polita* Ulrich and Cooper, 1938
Tritoechia sinuata Ulrich and Cooper, 1938

Bryozoa?

Echinodermata-Cystoidea
cystid plates

Hemichordata-Graptolithina
Callograptus sp.
Desmograptus sp.
Dichograptus octobrachiatus (J. Hall, 1858)
Didymograptus extensus (J. Hall, 1858)
Phyllograptus anna J. Hall, 1865
Phyllograptus anna longus (Ruedemann, 1947)
Phyllograptus griggsi Ross and Berry, 1963
Phyllograptus ilicifoliusmajor Ruedemann, 1947
Phyllograptus loringi White
Tetragraptus agilis Braithwaite, 1976
Tetragraptus ibexensis Braithwaite, 1976
Tetragraptus pogonipensis Braithwaite, 1976

Mollusca-Cephalopoda
Campbelloceras? sp.
Catoraphiceras sp.
Endoceras sp.

Mollusca-Gastropoda
Bellerophon-like sp.
Lesuerilla? sp.
Raphistomina sp.

Porifera
Zittelella sp. cf. *Z. clarae* Howell

[14] Unassigned pygidium of Hintze (1952, page 18; Plate XV, figure 19)
[15] *Kirkella declevita* Ross, 1951
[16] *Kirkella* sp. cf. *K. vigilans* (Whittington, 1948)
[17] *Isoteloides genalticurvatus* Hintze, 1952
[18] *"Barrandia?* sp." Walcott