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DEFORMED LOWER PALEOZOIC PLATFORM CARBONATES, GOOSE ARM–OLD MAN'S POND

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ABSTRACT

The Goose Arm–Old Man's Pond area embraces a sinuous terrane of polydeformed lower Paleozoic miogeoclinal rocks that lies between the Humber Arm and Old Man's Pond allochthons. Preliminary studies indicate the area possesses comparable lithostratigraphy, biostratigraphy and structural geology to other parautochthonous terranes of the Great Northern Peninsula. In particular, thrusts have juxtaposed distal shelf-facies, upon more proximal shallow shelf-facies.

Cambrian rocks in the section at Goose Arm include siliciclastic and carbonate rocks. At the base of the section, mixed siliciclastic and lesser carbonate strata of the Penguin Cove Formation are correlated with the Hawke Bay Formation (Bridge Cove Member) of Canada Bay. Trilobites from low in the formation indicate a possible Albertella *Zone age. The overlying Port au Port Group consists of limestone and dolostone. Thick oölitic and oncolitic limestone of the March Point Formation contain trilobites correlative with the late Middle Cambrian* Olenoides longispinus *and* Ehmaniella cloudensis *zones of Canada Bay; these are succeeded by cyclic, peritidal dolostone, argillaceous dolostone and limestone of the Petit Jardin Formation. Previously unrecorded* Cedaria *and* Crepicephalus *zone trilobite faunas from the Petit Jardin Formation indicate that most of it was deposited during the early Late Cambrian Dresbachian Stage. Peritidal dolostones dominate the Berry Head Formation but it also includes a massive basal sequence of cryptalgal mounds and an upper member of interbedded limestone and dolostone. The latter includes previously unknown trilobite faunas correlative with the* Saukia, Mississquoia *and* Symphysurina *zones, suggesting that the Cambrian–Ordovician boundary occurs in the upper 45 m of the formation.*

Ribbon limestone, phyllite and limestone conglomerate mark the allochthonous Reluctant Head Formation and are overlain by unnamed dolostones and the Berry Head Formation in the Reluctant Head Thrust. Trilobites from the top of the Reluctant Head Formation indicate a correlation with the lower part of the Petit Jardin Formation. This suggests that the shelf evolved through the Middle and early Late Cambrian as a prograding ramp, and was transformed to a platform in the latest Cambrian.

The miogeoclinal rocks are assembled in a number of thrusts that were transported westward and later deformed by northeast-trending folds. At lower structural levels, the folds are steepened to recumbent to the west. This is in contrast to folds in higher structural slices that are for the most part east-verging, associated with west-dipping cleavage and recumbent near the Old Man's Pond Allochthon. Polyphase deformation of the carbonates occurred during westward thrusting. It is marked by small-scale structures that include penetrative cleavage (transposed bedding), bedding co-planar foliation in limestone marbles, boudinaged dolostone interbeds, and recumbent folds that are refolded, locally into sheath folds. However, there are some large-scale, west-verging, recumbent folds in thrust footwalls. The main thrusts in the area are the Reluctant Head and Penguin Head thrusts. Others also occur and are locally linked to shear zones.

INTRODUCTION

Carbonate rocks of the Goose Arm–Old Man's Pond area, although mapped and described in several studies, have remained relatively poorly understood within the regional geological framework of western Newfoundland. Detailed lithobiostratigraphic studies and preliminary geological mapping in the area began in the summer of 1990. The highlights of this work indicate that the area contains rock sequences that fundamentally affect the geological picture of western Newfoundland during the lower Paleozoic. The highlights include:

a) the carbonates are probably allochthonous,

b) they are polyphased deformed in a number of thrust slices,

c) Middle to Upper Cambrian siliciclastics and carbonates were deposited upon a prograding ramp shelf,

d) common, low diversity trilobite faunas provide reasonably accurate biostratigraphic correlation, and

e) the faunas locate the Cambrian–Ordovician boundary within 45 metres.

Although the area is mentioned by Schuchert and Dunbar (1934), it was largely ignored until the 1950's when Brinex Limited began exploration in the area. A thesis study and subsequent work by Lilly (1961, 1963) in conjunction with one by McKillop (1963) near Corner Brook, provided the first subdivision of the rocks. Lilly (1961) subdivided the sequence at Goose Arm into the Penguin Cove, Hughes Brook and Corner Brook formations. Near Old Man's Pond, Lilly (1961) identified the Reluctant Head Formation, which he assigned to the Upper Cambrian. More recent studies were those of Levesque (1977) and Chow (1986). They subdivided the succession and placed it within its western Newfoundland context. However, because of the general lack of fossil control, correlations remained largely speculative. Structural study of the Old Man's Pond Allochthon (Gillespie, 1983) provided some description of the rocks of the Reluctant Head Formation. Later base-metal exploration (Wilkinson, 1983) relied heavily upon structural and stratigraphic mapping that showed a number of thrust slices occur in the Goose Arm area.

GEOLOGICAL SETTING

Lower Paleozoic miogeoclinal and foreland basin rocks, which are mainly carbonates, occupy a sinuous belt between the Humber Arm Allochthon in the west and the Old Man's Pond Allochthon in the east (Figure 1). Early Cambrian to Early Ordovician passive margin sedimentary sequences were succeeded by a Middle Ordovician carbonate to flysch sequence. This was deposited in a foredeep above the collapsed margin during initiation of Taconic orogenesis.

The miogeocline, unlike its counterpart throughout much of the Northern Peninsula, is folded and faulted. However, the lithostratigraphy is closely comparable with that of the parautochthonous thrust belt of Canada Bay to Pistolet Bay (Knight, 1986, 1987). This suggests that the exposed miogeocline in the area is indeed parautochthonous, as previously advocated by Waldron (1988) and Cowan and James (1989). The first deformation of the miogeocline accompanied westerly emplacement of the Taconic allochthons including westward-directed thrusting (Waldron, 1988). The area was then affected by Acadian deformation in the Late Silurian to Early Devonian (Cawood and Williams, 1988). Eastward-directed back thrusting placed the miogeocline over the Old Man's Pond Allochthon, although Waldron (1988) interprets the allochthon to be a structural window beneath tectonically duplicated carbonates.

STRATIGRAPHY

The autochthonous succession in the Goose arm area comprises units of the Labrador, Port au Port, St. George and Table Head groups. Taconic flysch of the Goose Tickle Group is preserved in the area but is largely dismembered as part of a unit of strongly deformed melange. Strata within the Reluctant Head Thrust do not conform to the standard Cambrian subdivisions of the platform but include the lithologically distinct Reluctant Head Formation, which is the time equivalent of the lower part of the Port au Port Group. It will remain outside the group structure. Only the Cambrian stratigraphy has been logged in any detail (Figure 2).

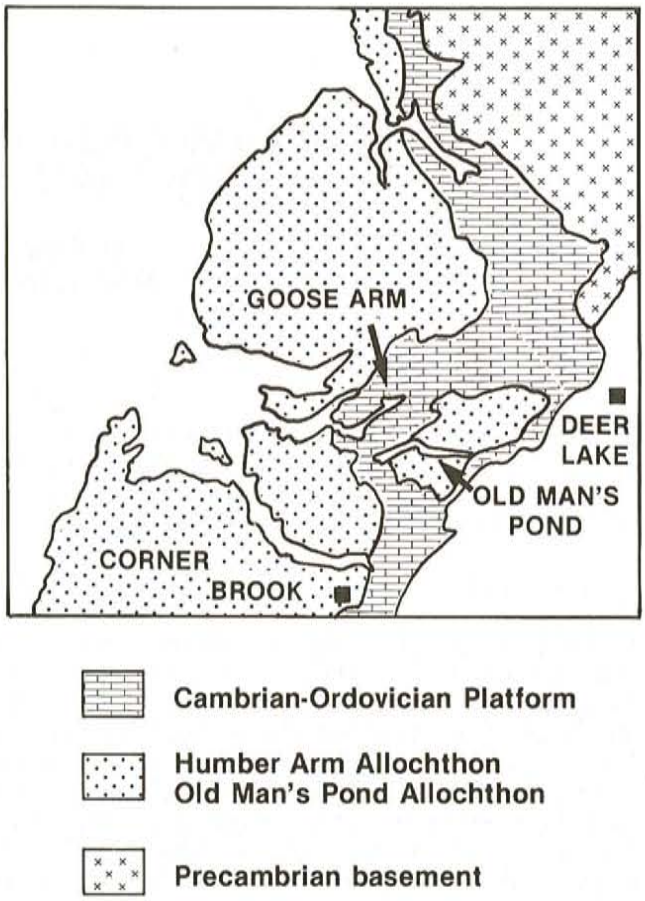


Figure 1. *Location map of the Goose Arm–Old Man's Pond study area showing the main geological terrains.*

PENGUIN COVE FORMATION, LABRADOR GROUP

The Penguin Cove Formation occupies the core of the Goose Arm Anticline. It comprises a mixed siliciclastic–carbonate succession of shallow subtidal to possibly intertidal origin. The succession consists of a lower member, 108 m thick, of intercalated siliciclastics and metre-thick oncolitic limestone units. This is separated by a covered interval that possibly obscures 110 m of strata from an upper member, 87 m thick, comprising mostly siliciclastic rocks. The latter are rusty weathered and have become significantly, increasingly dolomitic upward. The lower member contains a moderately abundant, low-diversity fauna of problematic ptychopariid trilobites. The upper member contains only hyolithids and a few inarticulate brachiopods, as yet unidentified.

The siliciclastic rocks consist of well-bedded, generally thinly interstratified, very fine-grained sandstone, siltstone and cleaved shale. Sedimentary structures are generally crosslamination and lamination. The rocks are arranged in numerous, 1- to 5-m-thick coarsening-upward (CU) sequences. Quartz arenite, which displays crossbedding and undulose to planar lamination, occurs as isolated thick beds and lenses at the top of several of these sequences, especially within the upper part of the unit. Locally, scour-based arenites lie at the base of fining-upward sequences within the CU

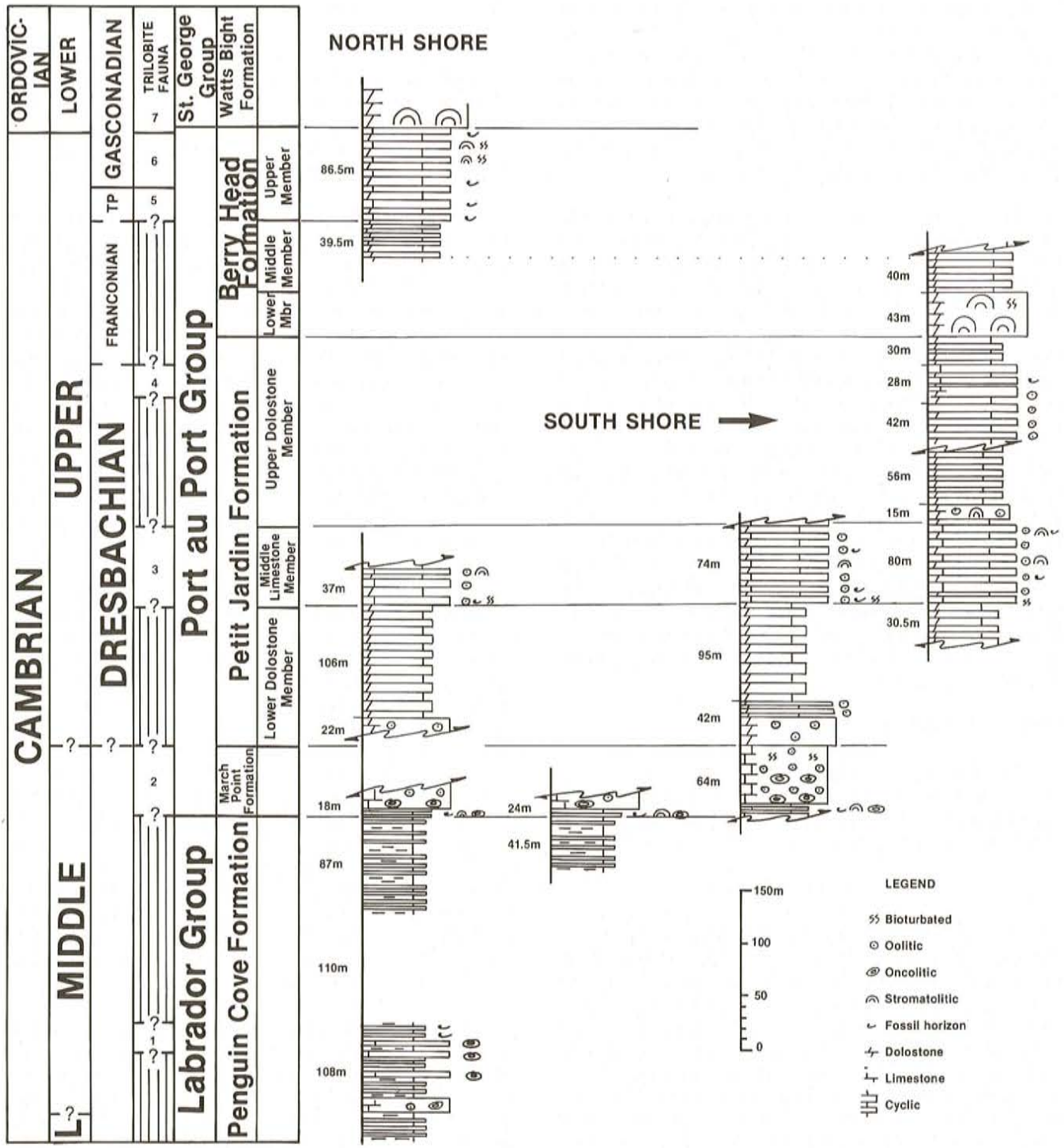


Figure 2. *Schematic stratigraphic sections of Cambrian rocks of Goose Arm including range of trilobite faunas. 1*–'Proliostracus / Glossopleura / Polypleuraspis' *fauna. 2*–'Olenoides longispinus / Ehmaniella cloudensis' *fauna. 3*–'Cedaria' *fauna. 4*–'Crepicephalus' *fauna. 5*–'Saukia' *fauna. 6*–'Mississiquoia' *fauna. 7*–'Symphysurina' *fauna.*

sequences. Commonly, arenites are also associated with thick beds of massive mudstone to intraclastic mudstone (slurry deposits) and mudstone enclosing impressive sandstone ball and pillow structure. Shrinkage cracks occur in many of the shale interbeds. Synsedimentary sandstone dykes intrude mudstone and interstratified rocks.

The limestone of the lower member occurs as 1- to 20-m-thick oncolitic and oölitic rudstone–grainstone units, which are commonly penetratively cleaved, obscuring structures other than thin dolostone partings and intercalation of oncolitic grainstones with non-oncolitic ones. Toward the top and bottom of the lower member, centimetre-thick, commonly

lenticular, skeletal, intraclastic and oncolitic grainstone beds are intercalated within the interstratified siliciclastics. One oncolitic rudstone bed is capped by a stromatolitic mound bed. Dolomitic siltstones and very fine sandstone grade laterally into thinly bedded dolostone in the upper member. The gradation is suggested by their very similar gross appearance, dark grey phyllitic interbeds and partings as well as undulose lamination and crosslamination.

The Penguin Cove Formation is comparable to the rocks of the Hawke Bay Formation at Canada Bay (Knight and Boyce, 1987). The formation may be completely equivalent to the early Middle Cambrian Bridge Cove Member. Alternatively, only the upper member at Goose Arm is equivalent, whereas the lower member is mainly equivalent to the lower siliciclastic member at Canada Bay; this cannot be confirmed by the trilobite fauna. However, if the correlation with the lower siliciclastic member is valid, it would suggest that carbonate grainstone generation occurred in a narrow outer belt that stepped basinward as the shelf prograded during the late Early to early Middle Cambrian eustatic sea-level fall i.e., the Hawke Bay Event of Palmer and James (1980). However, if the Penguin Cove Formation correlates exclusively with the Bridge Cove Member, it suggests that the grainstone belt was only intermittently developed along the margin at that time confirming that sea level was rising throughout the time allotted to the event (see Knight and Boyce, 1987). Furthermore, the section preserved in the area is significantly thicker than the Bridge Cove Member at Canada Bay.

PORT AU PORT GROUP

The Port au Port Group in the area consists of a succession of interbedded limestone, dolostone, argillaceous shale and argillite. It can be subdivided into the March Point, Petit Jardin and Berry Head formations.

March Point Formation

The formation, which is approximately 64 m thick, is characterized by oölitic and oncolitic lime grainstones, which are dolomitized in the upper part of the formation. Beds of shale, stromatolitic lime boundstone, fossiliferous, oncolitic grainstone–packstone–rudstone and parted dolomitic limestone occur in a lower shaly member that is up to 11 m thick. Several beds of bioturbated dolomitic lime wackestone intercalate with the oölitic grainstone in the upper part of the formation. The oölitic grainstone is generally crossbedded to unevenly thinly stratified, probably indicative of small-scale crossbedding and crosslamination. In contrast, oncolitic beds are commonly structureless with some grading.

A low-diversity fauna of abundant trilobites, inarticulate brachiopods and hyolithids occurs in the lower member of the formation. Robust articulate brachiopods occur in oncolite beds in the overlying oölitic limestone. High-energy oölitic lime sand–shoal conditions prevailed in the area, in contrast to time equivalent rocks of the formation on the Northern Peninsula, where dominantly quiet water, subtidal lagoonal carbonate characterizes the formation.

Petit Jardin Formation

The Petit Jardin Formation is a thick sequence of interbedded dolostone, argillaceous dolostone, argillite and limestone arranged in repetitive centimetre- to metre- scale shallowing-upward sequences. The formation in the area comprises three members, a lower dolostone, middle limestone and upper dolostone.

The lower dolostone and upper dolostone members are quite similar. They consist of white, yellow to buff weathering, grey to pale grey, massive, microcrystalline dolostone intercalated with lesser rusty weathering, argillaceous dolostone and olive-grey to grey argillite. Both members begin with thick dolostone units of oölitic grainstone. Robust domal to slender digitate stromatolites occur with the grainstones. However, the grainstones are separated by metre-thick beds of dololaminites that, as elsewhere in the formation, comprise thin stratification and planar to crinkly lamination, which is broken in discrete layers in association with tepee structures and desiccation cracks. Lenses and thin beds of crosslamination, intraclastic grainstone and pebble beds, and frequent, shallow scour and fill structures also occur in the dololaminites.

Above these thick oölitic grainstone sequences, the members are composed of smaller cycles 0.55 to 3.0 m thick. Massive dolostone at the base of the cycles is generally featureless, but locally is clearly oölitic (especially in the lower member) and stromatolitic; however burrow-mottle fabrics do occur rarely. Dololaminites that cap most cycles are generally easily identified, but, in some cycles, the dololaminite is underlain or capped by argillite or argillaceous dolostone. Dolostone lamination and thin beds are interstratified in various proportions in both lithofacies. Where the argillite underlies a dololaminite, it has generally smooth, unbroken bedding. Dolomitic argillites that overlie the dololaminites are invariably mudcracked. The argillaceous lithofacies are commonly 20 to 90 cm thick. In the upper members, a few fossiliferous limestone beds occur in the small-scale cycles. Rocks resemble those of the middle member. A potential karst surface displaying kamenitza and irregular relief also occurs in the member.

The middle limestone member is a conspicuously cyclic unit comprising dark grey to black oölitic limestone, grey peloidal limestone, grey stromatolitic limestone and dolostone overlain by pale grey dololaminite, intraformational lime- and dolo-rudstone, and rusty weathering argillaceous dolostone to dolomitic argillite and argillite. Rare beds of parted dolomitic lime mudstone occur in the member, which in all sections begins with a burrow-mottled limestone. Erosional truncation surfaces are common, frequently cutting off stromatolite mounds. Argillaceous dolostones are common in the member, unlike the other members, and are frequently thick (up to 1.7 m). They display abundant desiccation features including deep, downward-tapering, dolostone- and carbonate sand-filled fissure cracks.

The oölitic and peloidal grainstones that commonly form the bases of cycles are characteristically crossbedded at

different scales reflecting shifting dune and ripple sets; herring-bone structure occurs. Many grainstone units have reverse grading of oöid grainsize. Stromatolite mounds are mostly solid domal to upward expanding pedestal forms that rest in or upon the grainstone. Digitate structures are rare, but in some mounds they, or laminar sheet structures, form a peculiar rim around the mound core. Intraclastic lime and dolomite grainstone are thinly interstratified with dolomitic lime mudstone–dololaminite in some cycles. Intraclastic flaky grainstones derived by erosion of stromatolite, filling in one example a metre-wide channel, are a striking although not common facies in the section. They are associated with dololaminite and argillaceous dolostone facies.

The three measured sections through the member in Goose Arm indicate that correlation of cycles is difficult because there are complex lateral changes in lithofacies from section to section. Overall, the succession within the middle member is characterized by two sequences 36 and 43 m thick, each comprising a shift from subtidal to intertidal, oölitic grainstone–stromatolite-dominated cycles upward to those dominated by intertidal and supratidal dololaminite–argillaceous dolostone facies.

Berry Head Formation

The Berry Head Formation comprises three members in the area. The basal unit consists of thickly bedded, dark tan-grey, stromatolitic dolostones with chert-capped mounds. This 43-m-thick unit is succeeded by a middle member, approximately 100 m thick, that resembles the characteristic peritidal, cyclic dolostones of the Cambrian. The upper member, 87 m thick, consists of limestone with an Ordovician aspect interbedded with dololaminites characteristic of the Cambrian. This transition contains sparse trilobite faunas that indicate that the Cambro-Ordovician boundary in the autochthon lies 5 to 45 m below the base of the overlying St. George Group (Figure 3).

The thickly bedded, cherty stromatolitic dolostone of the lower member is comparable to those at the base of the formation throughout the Northern Peninsula. Although the middle member consists dominantly of pale grey dolostones, which contain abundant typical Cambrian dololaminite units (see above), it is distinguished by the cherty stromatolitic dolostone beds and by distinctive beds of crossbedded, crosslaminated and laminated pebbly dolarenite that contain frequent shallow scours and thin sheets and lenses of dololutite and in some instances reach 1.5 m in thickness.

The limestones of the upper member are characteristically dark grey, burrow-mottled, skeletal wackestone–packstone, stromatolitic boundstone, oölitic and intraclastic, skeletal grainstone–rudstone, pale grey peloidal grainstone and wavy, thinly bedded, dolomitic parted lime mudstone and dolostone. Gastropods, scattered trilobite remains and inarticulate brachiopods occur in some of these limestone beds that reach up to 2.5 m in thickness. Intercalated dololaminites can attain up to 3 m in thickness. The rocks are arranged in shallowing-upward, metre-scale cycles (Figure 3).

RELUCTANT HEAD FORMATION AND OVERLYING CAMBRIAN UNITS

The Reluctant Head Formation is an enigmatic unit comprising thin to very thinly stratified, ribbon limestone, shale, intraformational limestone conglomerate, bioturbated wackestone, intraclastic grainstone and rare microbial lime boundstone. It may be as thick as 250 m but is of limited areal extent (Gillespie, 1983).

The Reluctant Head Formation is dominated by ribbon limestone and phyllites, in which a number of intraformational conglomerates and boulder conglomerates are interspersed. The ribbon limestone generally consists of thinly intercalated grey lime mudstone and yellow-weathering dolomitic lime mudstone or dolostone. The phyllites are silvery grey, grey to dark grey. The lime conglomerates, which are interspersed in the fine-grained rocks are up to 2.8 m thick. They are matrix- to locally clast-supported, with clasts that locally reach 60 by 25 cm in size enclosed in a yellow-weathering, argillaceous dolomitic limestone matrix. Clasts are mostly slabs of ribbon limestone–phyllite, and slabs to individual lumps derived from lumpy to nodular, thin-bedded parted limestone and phyllite. However, some conglomerates have a preponderance of intraclastic grainstone clasts, as well as clasts of oölitic–intraclastic lime grainstone, graded granular lime rudstone to grainstone, and some laminated dolostone. The latter assemblage indicates the tapping of shallow-water sediments by the resedimenting gravity deposits.

In the upper 25 m of the formation, the ribbon limestone is arranged in coarsening-upward sequences 2 to 5 m thick. Ribbon limestone in these sequences is overlain by burrowed mudstone–wackestone and skeletal–intraclastic (possibly peloidal) grainstone–packstone beds. U-shaped burrows and small-scale cross stratification occur in these upper lithofacies. A digitate stromatolite-mound bed occurs at the top of one of the sequences.

The Reluctant Head Formation is conformably overlain by an unnamed unit, 42 m thick, of crossbedded dolarenites intercalated with a couple of 60 cm beds of thinly stratified, bioturbated dolostone. The allochems are probably intraclast or peloidal grains. The unit is then succeeded by further unnamed dolostones that include thick-bedded stromatolitic dolostone and dololaminites. This is succeeded by the Berry Head Formation and includes the basal cherty stromatolite marker and the upper Cambrian–Ordovician transition member of limestone and dolostone.

ST. GEORGE GROUP

Although no detailed stratigraphic work has yet been undertaken on the St. George Group in the Goose Arm–Old Man's Pond area, the four-fold stratigraphic subdivision observed elsewhere in western Newfoundland (Knight and James, 1987) is applicable in the study area. Preliminary observations suggest that the rocks resemble those of the parautochthonous successions of Canada Bay, Hare Bay and Pistolet Bay (Knight, 1986, 1987). This is marked by much

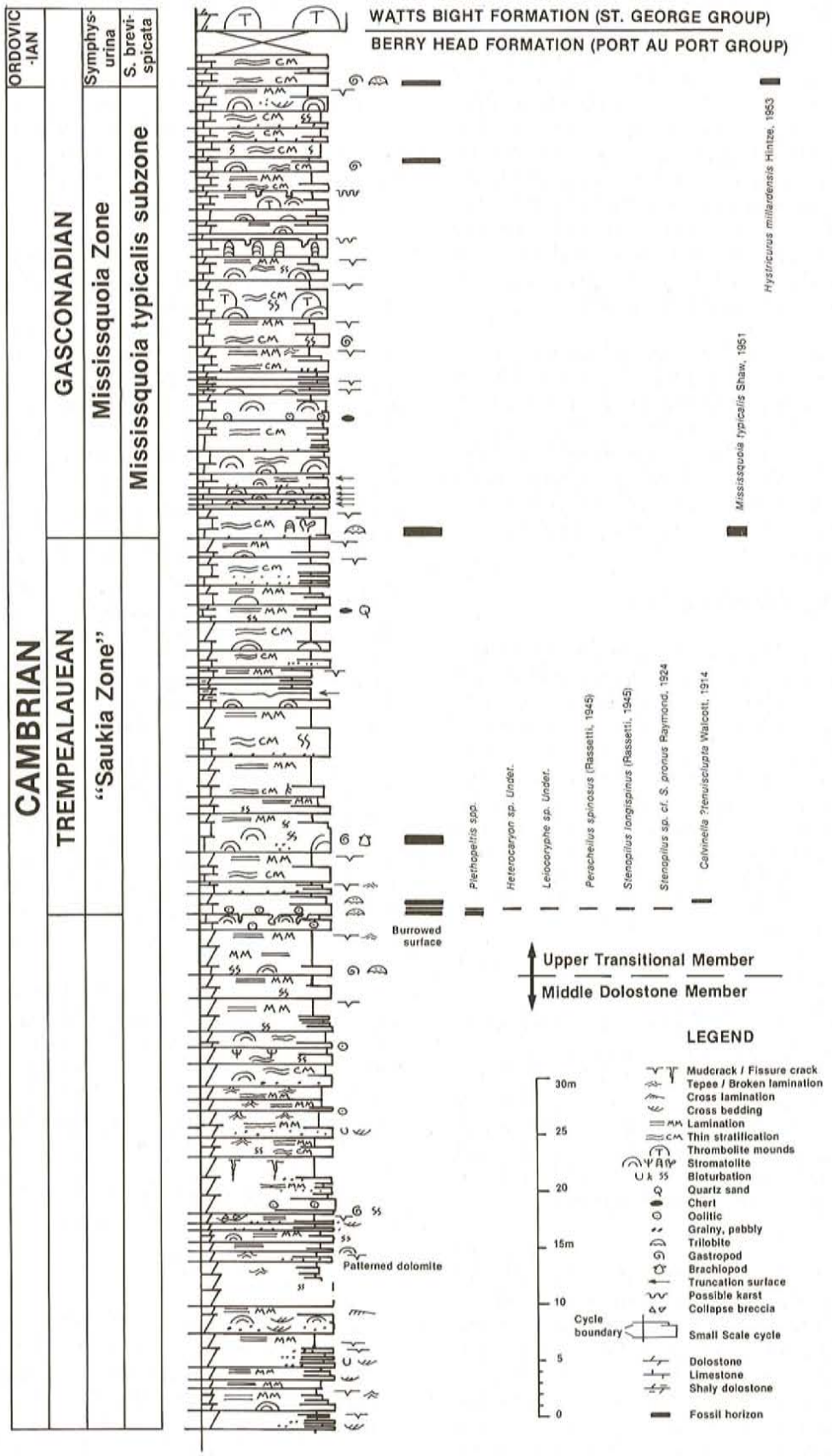


Figure 3. *Biostratigraphy and lithostratigraphy of the Berry Head Formation, north shore, Goose Arm.*

less dolomitization of the Watts Bight and Catoche formations, large metazoan–microbial mounds in the Watts Bight and Catoche formations, the white peloidal limestone of the Costa Bay Member and the presence of intercalated limestone and dolostone in the Aguathuna Formation.

MIDDLE ORDOVICIAN STRATA

Preliminary observations indicate that massive, blue-grey limestone of the Table Point Formation rests upon the St. George Group; the St. George Unconformity has yet to be located. The base of the unit (Spring Inlet Member) is marked by intercalated limestone and dolostone including beds of oncolitic, skeletal-intraclastic lime grainstone and rudstone. Younger rocks of the Goose Tickle Group have only been seen in structural contact with the carbonate succession in the area. For the most part, it seems to be incorporated in a strongly deformed melange, together with black shales and thin black limestone beds of the Table Cove and Black Cove formations (Stenzel *et al.*, 1990) along the western edge of the carbonate terrane.

BIOSTRATIGRAPHY OF THE PENGUIN COVE FORMATION, RELUCTANT HEAD FORMATION AND PORT AU PORT GROUP

Although the geology of the Hughes Brook–Goose Arm area was first outlined by Lilly (1961, 1963), paleontological information from the Cambrian–Ordovician rocks has been distinctly lacking. Levesque (1977, page 79) reported unidentified early Middle Cambrian ptychopariid trilobite and inarticulate brachiopod fragments from the base of his Wolf Brook Formation (March Point Formation, *this report*) on the north and south shores of Goose Arm. Later, Boyce *in* Gillespie (1983, page 22, Plate 1) illustrated the late Middle Cambrian trilobite *Kootenia cloudensis* Howell, 1943, collected by Gillespie from an inland oncolitic limestone exposure of the March Point Formation (our usage) between Goose Arm and Old Man's Pond.

In 1983, at the request of Westfield Minerals, the authors rendered stratigraphic assistance in Goose Arm. As a result, seven previously unreported fossiliferous localities were sampled (Glover *in* Wilkinson, 1983, Appendix A, page 13, Figure 8); Boyce discovered faunas indicative of the early Late Cambrian Dresbachian Stage *(Cedaria–Crepicephalus* zones) and the late Late Cambrian Trempealeauan Stage *(Saukia* Zone). In 1990, more assiduous biostratigraphic sampling resulted in the discovery of many additional macrofossil localities. This work was done in concert with detailed lithostratigraphic sectioning. Fifty-seven horizons yielded macrofossils, principally trilobites and inarticulate brachiopods. Twenty-two collections were obtained from the north shore of Goose Arm, thirty-five from the south shore. In addition, fourteen macrofossil collections were obtained from the upper part of the Reluctant Head Formation exposed on the Hughes Brook–Goose Arm logging road system south of Old Man's Pond.

PENGUIN COVE FORMATION

The lower member of the Penguin Cove Formation is characterized by a low diversity fauna of moderately abundant, (problematic) ptychopariid trilobites, including a possible new species of *Yohoaspis* (an early Middle Cambrian *Albertella* Zone genus). The fauna of the lower member is probably correlative with that of the *Proliostracus* Zone in the Hawke Bay Formation (Bridge Cove member) of Canada Bay (Knight and Boyce, 1987).

The upper member of the Penguin Cove Formation contains only hyolithids and a few inarticulate brachiopods, as yet unidentified. It may correlate with the strata of the *Glossopleura* and *Polypleuraspis* zones in the Hawke Bay Formation (Bridge Cove member) of Canada Bay (Knight and Boyce, 1987).

RELUCTANT HEAD FORMATION

The newly discovered trilobite and inarticulate brachiopod fauna from the top of the Reluctant Head Formation includes the agnostid species *Kormagnostus seclusus* (Walcott, 1884). According to Robison (1988, page 45), this species ranges from the late Middle Cambrian *Lejopyge laevigata* Zone (i.e., latest *Bolaspidella* Zone) to the early late Cambrian *Glyptagnostus stolidotis* Zone (i.e., *Crepicephalus* Zone).

MARCH POINT FORMATION

The March Point Formation in the Goose Arm–Hughes Brook area has, so far, yielded only two trilobite taxa, along with inarticulate brachiopods and some hyolithids. As stated above, Gillespie (1983) obtained *Kootenia cloudensis* Howell, 1943 from an inland exposure. Along Goose Arm itself, *Spencella proavita* (Howell, 1943) is the only trilobite thus far identified from the March Point Formation. These two species indicate a correlation with the late Middle Cambrian *Olenoides longispinus* and *Ehmaniella cloudensis* zones of the March Point Formation in the Canada Bay area (Knight and Boyce, 1987).

PETIT JARDIN FORMATION

Trilobite faunas correlative with the Dresbachian (early Late Cambrian) *Cedaria* Zone were recovered from the middle limestone member of the Petit Jardin Formation on the north and south shores of Goose Arm. Species recovered include:

Blountiella? johnsoni Troelsen, 1947
Kingstonia ara (Walcott, 1924)
Komaspidella sp. undet.
Lonchocephalus? sp. undet.
Talbotina degrasensis Lochman, 1938
Welleraspis newfoundlandensis Lochman, 1938

Lochman (1938) described and illustrated *Kingstonia ara* (Walcott, 1924), *Talbotina degrasensis* Lochman, 1938 and

Welleraspis newfoundlandensis Lochman, 1938 from the Petit Jardin Formation on the Port au Port Peninsula, western Newfoundland. *Welleraspis newfoundlandensis* Lochman, 1938 also occurs in *Cedaria* Zone age strata of the Holm Dal Formation in central North Greenland (Robison, 1988). *Blountiella? johnsoni* Troelsen, 1947 was originally described from Bonne Bay, western Newfoundland (Troelsen, 1947).

Definitive Dresbachian *Crepicephalus* Zone trilobites were collected from one horizon only, on the south shore of Goose Arm in the upper dolostone member of the Petit Jardin Formation. Pygidia of the following species were recovered from a white limestone:

Crepicephalus rivus Kindle, 1948
Kingstonia sp. undet.
Tricrepicephalus texanus (Shumard, 1861)

Crepicephalus rivus Kindle, 1948 and *Tricrepicephalus texanus* (Shumard, 1861) also occur in the Murphy Creek Formation of Quebec (Kindle, 1948). *Tricrepicephalus texanus* (Shumard, 1861) is a particularly widespread species, which ranges from the late *Cedaria* Zone to the *Crepicephalus* Zone.

Late Dresbachian and Franconian (medial Late Cambrian) trilobites have yet to be recorded from the Goose Arm area.

BERRY HEAD FORMATION

The most significant result of the investigations in Goose Arm may be the discovery of a fossiliferous Cambrian–Ordovician boundary interval in the Berry Head Formation. Elsewhere in western Newfoundland, this interval generally comprises unfossiliferous dolostone.

Three distinct trilobite faunas (indicative of the *Saukia, Mississquoia* and *Symphysurina* zones) are present in limestone beds on the north shore of Goose Arm; unidentified gastropods and less common inarticulate brachiopods also occur with the trilobites.

The oldest fauna is correlative with the Trempealeauan (latest Cambrian) *Saukia* Zone (*Saukiella junia* and *Saukiella serotina* subzones) and is chartacterized by the following trilobites:

Calvinella sp. cf. *C. tenuisculpta* Walcott, 1914
Heterocaryon sp. undet.
Leiocoryphe sp. undet.
Peracheilus spinosus (Rasetti, 1945)
Plethopeltis spp.
Stenopilus longispinus (Rasetti, 1963)
Stenopilus sp. cf. *S. pronus* Raymond, 1924

Peracheilus spinosus (Rasetti, 1945) and *Stenopilus longispinus* (Rasetti, 1963) occur in the *Keithia schucherti* faunas of the Levis Formation of Quebec and the Cow Head Group of western Newfoundland (Rasetti, 1944, 1945, 1963; Ludvigsen *et al.*, 1989).

The middle fauna contains *Mississquoia typicalis* Shaw, 1951. This widespread taxon generally[1] characterizes the *Mississquoia typicalis* Subzone of the *Mississquoia Zone* of Vermont (Shaw, 1951), Texas (Winston and Nicholls, 1967), Oklahoma (Stitt, 1971, 1977, 1983), Utah and Nevada (Taylor, 1971), South Dakota (Hu, 1973), New York (Taylor and Halley, 1974), Alberta and British Columbia (Dean, 1977; Westrop, 1986).

The youngest fauna of the Berry Head Formation contains *Hystricurus millardensis* Hintze, 1953. This widespread species generally[2] characterizes the *Symphysurina brevispicata* Subzone of the *Symphysurina* Zone of Utah (Hintze, 1953), Texas (Winston and Nicholls, 1967), Oklahoma (Stitt, 1971, 1977, 1983), South Dakota (Hu, 1973), New York (Taylor and Halley, 1974) and Idaho (Taylor and Landing, 1982).

THE CAMBRIAN–ORDOVICIAN BOUNDARY IN GOOSE ARM

In western Newfoundland, *Mississquoia typicalis* Shaw, 1951 and *Hystricurus millardensis* Hintze, 1953 also occur in the allochthonous Cow Head Group at the Broom Point South section (Fortey and Skevington, 1980; Fortey *et al.*, 1982; Fortey, 1983; Barnes, 1988). The currently favoured Cambrian–Ordovician global Boundary 'point' is the base of the *Cordylodus lindstromi* (conodont) Zone (Barnes, 1988, page 408, Figure 12). At the Broom Point South section, this lies between the occurrences of the two trilobite species (Barnes, 1988, page 393, Figure 6). Consequently, at Goose Arm, the Cambrian–Ordovician Boundary 'point' may also lie anywhere between the occurrences of *Mississquoia typicalis* Shaw, 1951 and *Hystricurus millardensis* Hintze, 1953. This represents a problematic interval of about 40 m (a distance of 5 to 45 m below the base of the Watts Bight Formation). Further trilobite (and conodont) sampling and analysis is required to test this hypothesis.

PALEOGEOGRAPHY OF THE CAMBRIAN SHELF

The combination of well-dated sequences at Goose Arm adjacent to the dated facies-distinct sequence in the Reluctant Head Thrust slice provides a unique opportunity to model part of the ancient Cambrian shelf in western Newfoundland. The shelf evolved essentially from a siliciclastic to a carbonate ramp. The evolution to a rimmed platform may have only occurred by the late Cambrian.

[1] In Oklahoma and Texas, *Mississquoia typicalis* Shaw, 1951 also ranges up into the *Symphysurina brevispicata* Subzone of the *Symphysurina* Zone (Stitt, 1977, Figures 9 and 10).

[2] In Oklahoma, *Hystricurus millardensis* Hintz, 1953 also ranges into the overlying *Symphysurina bulbosa* and *Symphysurina woosteri* subzones (Stitt, 1983, Figure 7).

1) EARLY MIDDLE CAMBRIAN SILICICLASTIC SHELF

The thinly but well-stratified, fine-grained siliciclastic sediments of the Penguin Cove Formation were probably supplied by low density, decelerating traction currents across a gentle slope. The presence of isolated thick beds of quartz arenite, several oncolitic grainstone beds and metre-thick units, regularly punctuating the lower member of the formation suggests that the shelf was not deep. This conclusion is also supported by the stromatolite bed lying upon one oncolite bed.

Regular carbonate deposition within a dominantly siliciclastic system hints that they may reflect small-scale eustatic sea-level fluctuations superimposed upon a longer term eustatic sea-level cycle. This would suggest that the oncolite–oölite sands formed during sea-level rise that would have drowned shorelines and dampened terrigenous input. In the oldest beds of the member, the grainstone beds may have been storm beds swept from a shoal complex on to the siliciclastic ramp. The problem with this is the presence of the stromatolite, which, unless considered as subtidal, would mean that the carbonates represent shallowing events, when an outer oncolitic–oölitic carbonate shoal belt shifted in board upon the ramp to displace siliciclastic facies.

On a regional scale, the repetitive presence of carbonate grainstone in the Goose Arm section, coupled to those that are interspersed in co-eval successions at Canada Bay, indicate that sea-level rise continued regionally in western Newfoundland throughout the early Middle Cambrian. Its effect was muted by the volume of terrigenous input, suggesting that the latter was primarily controlled by tectonically induced source area uplift.

2) LATE MIDDLE CAMBRIAN TO LATE CAMBRIAN CARBONATE RAMP

Transgression during the late Middle Cambrian preceded widespread carbonate sedimentation. In the Goose Arm area, the shallow shelf facies comprised two end members. Thick, generally non-cyclic oölitic grainstone shoal complexes dominated the March Point Formation and occupy the lower parts of the lower and upper dolostone members of the Petit Jardin Formation. The rest of the Petit Jardin Formation comprises shallowing-upward, metre-scale peritidal sequences. The cycles comprise tidal-dominated oölite sands and stromatolite biostromes (probably subtidal to lower intertidal). They accreted to tidal flats consisting of intertidal dololaminites and argillaceous dolostones, the latter possibly verging on a supratidal setting or forming on the inner, landward side of the tidal flat. The significance within the dolostone-dominated succession of the Petit Jardin Formation of the limestone plus trilobite fauna in the middle limestone member may suggest that there was a change on the shelf from restricted to less restricted conditions, perhaps linked to relative sea-level rise.

The sediments of the Reluctant Head Formation are typical of a ramp slope setting that shallowed into a dolomitized carbonate sand complex and then with time into typical peritidal shelf dolostones. Resedimented limestone conglomerates in the ribbon limestone and shale indicate some reworking of slope sediments, but at least one of the conglomerates contains clasts derived by reworking of oölitic grainstone and dolostone, indicating a peritidal source. The dolomitized lime sands at the base of the unnamed dolostone above the Reluctant Head Formation are not oölitic, however, but intraclastic and peloidal. The ribbon bedding, lack of slump folds and beds and the general shallowing-upward trend suggest that the Reluctant Head Formation was deposited upon a prograding ramp shelf. The Dresbachian trilobites recovered from the top of the formation indicate that the formation is at least partly equivalent to the Petit Jardin Formation. The exact position is not certain however, but the fauna plus stratigraphic reasons suggest that the formation probably straddles the lower members of the formation and that the carbonate sand shoal may correlate with the lower part of the upper dolostone member. This is supported by the position of the shoal facies at the base of the unnamed peritidal dolostone sequence that is capped by the Berry Head Formation, because the cherty stromatolite member at the base of the latter is a regional marker from autochthon to parautochthon. This must indicate that the evolution to a platform occurred late in the Cambrian (i.e., post Dresbachian).

STRUCTURE OF THE GOOSE ARM AREA

Preliminary mapping of the Goose Arm–Old Man's Pond area indicates that deformation of the carbonate sequence occurred during and following the emplacement of several thrust slices into the area. The two most obvious thrusts are the Reluctant Head Thrust (RHT) in the east and the Penguin Head Thrust (PHT) at the western margin of the autochthon (Figure 4). Binocular viewing of recumbently folded strata at Raglan Head and mapping in the Old Man's Pond area suggest that several other thrusts occur in the area (see also Glover, in Wilkinson, 1983).

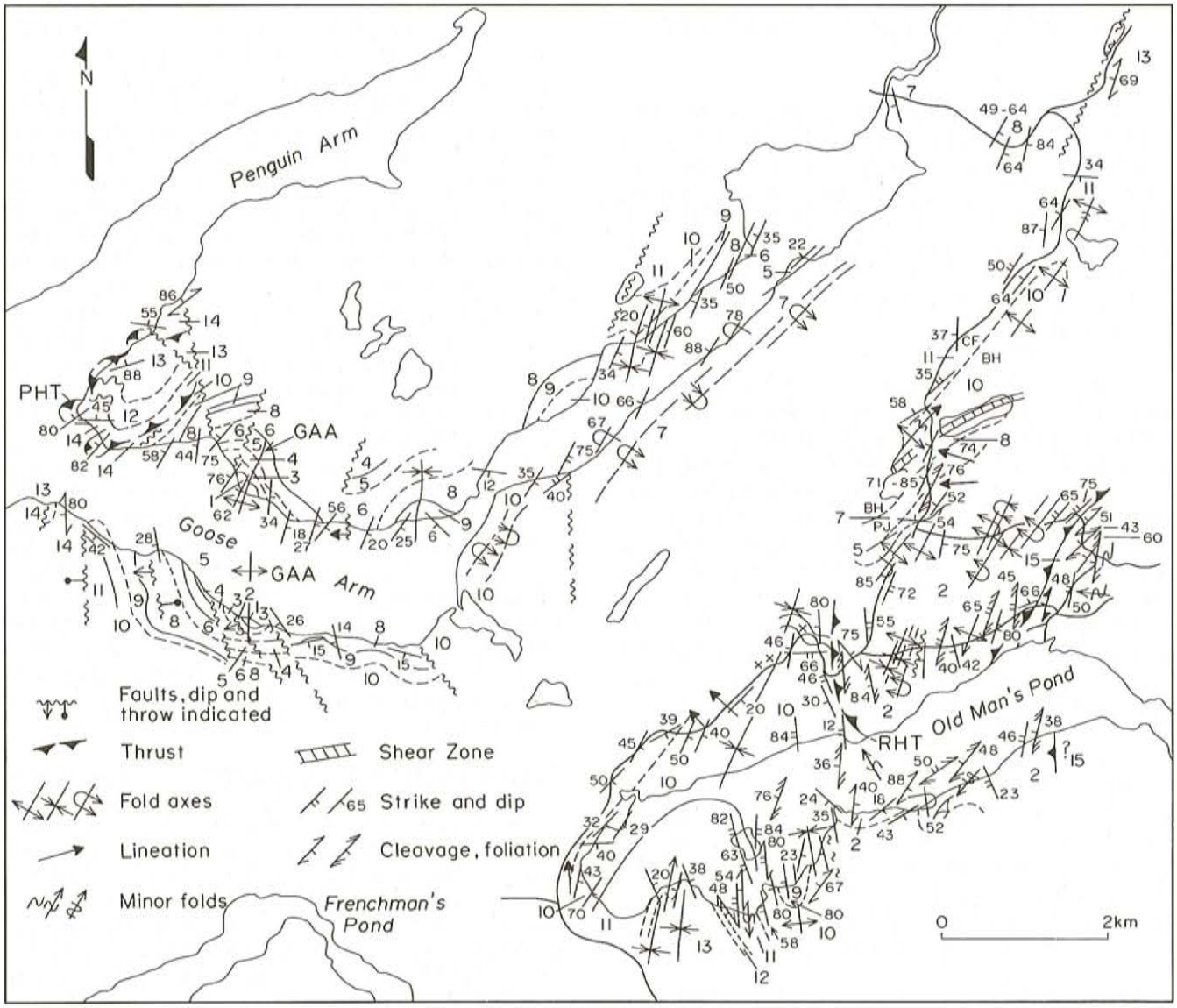
The Goose Arm carbonate succession has undergone polyphase deformation. This includes:

PHASE 1

Phase 1 (P1) structures include the west-directed thrusts and the associated development of bedding co-planar foliation in intercalated limestone marble and dolostone of the Port au Port, St. George and Table Head groups, penetrative cleavage (transposed bedding) in the Reluctant Head Formation and small-scale recumbent folds. Dolostone beds were boudinaged to dismembered and locally intensely flattened in the plane of the marble foliation.

PHASE 2

Phase 2 (P2) consists of deformation only within the Reluctant Head Thrust zone. The early foliation is folded by



LEGEND

15 Old Man's Pond Allochthon

MIDDLE ORDOVICIAN

14 Undivided Table Cove Formation/Goose Tickle Group

TABLE HEAD GROUP

13 Table Point Formation

LOWER ORDOVICIAN

ST. GEORGE GROUP

12 Aguathuna Formation

11 Catoche Formation

10 Boat Harbour Formation

9 Watts Bight Formation

MIDDLE TO UPPER CAMBRIAN

PORT AU PORT GROUP

8 Berry Head Formation

Petit Jardin Formation

7 *undivided*

6 *Upper dolostone*

5 *Middle limestone*

4 *Lower dolostone*

3 March Point Formation

2 Reluctant Head Formation

LABRADOR GROUP

1 Penguin Cove Formation

Figure 4. *Preliminary geological map of Goose Arm and Old Man's Pond area.*

small-scale west-directed recumbent folds. Earlier folds were refolded and sheath folds generated at the sole of the Reluctant Head Thrust.

PHASE 3

Phase 3 (P3) consists of folding of earlier P1 structures by east-verging, northeast-trending folds associated with a spaced, axial-planar cleavage. The folds are markedly recumbent adjacent to the Old Man's Pond Allochthon. Crenulation of the P1 cleavage has occurred.

Phase 1 westward-directed thrusting superimposed Reluctant Head Formation over St. George Group limestones (Reluctant Head Thrust) and transported middle St. George Group to Table Point Formation limestone above Taconic flysch and deepwater shales and carbonates (Table Cove Formation) along the PHT. At Penguin Head and the south shore of Goose Arm, the intensely deformed Middle Ordovician flyschoid rocks of the footwall have a dismembered aspect that suggests they were incorporated in a melange before or during the emplacement of PHT thrust. However, it is improbable that the PHT is a large melange block as suggested by Waldron (1985).

At Old Man's Pond, intense deformation within the Reluctant Head Formation at the sole of the RHT developed a penetrative, phyllitic cleavage (transposed bedding, S1) and small-scale recumbent structures that were subsequently refolded, and locally as sheath folds. Polyphase deformation is also present in the Petit Jardin Formation and the St. George Group along the south shore of Old Man's Pond. An early foliation (S1), which is well developed in limestones interbedded with dolostones in these rocks, is interpreted to have formed during P1 thrusting. It is roughly co-planar with bedding and locally is folded by small-scale recumbent, west-facing folds (F2). Dolostone beds are locally pinched by rows of articulated boudins during extension. The bedding and early foliation is folded about P3 upright to overturned, northeast-trending structures. These folds steepened the F2/?F3 folds in the thrust sole and P3 cleavage, which dips to the west, crenulates the earlier penetrative east-dipping cleavage. Strengthening of the east-verging domain occurs eastward in the RHT as the latest folds gradually become recumbent adjacent to the Old Man's Pond Allochthon.

Northeast-trending, east-verging folds deform the PHT and its hanging- and footwalls. Hanging-wall bedding and thrust attitudes are basically co-planar in the east, and small-scale structures suggest some eastward-directed shear along the thrust contact. The key to understanding the relationship at Penguin Head however, occurs along the shore of Penguin Arm. There, the footwall melange and Taconic flysch structurally overlies to abuts vertically against stratigraphically, northward-younging St. George and Table Head group rocks. This relationship, plus some anomalous fold trends in the Aguathuna Formation of the hanging-wall, is best explained by folding the thrust and a west-verging hanging-wall rollover about the northeast-trending folds.

The structural relationship between the RHT and the Old Man's Pond Allochthon north of the pond is obscured by overburden. However, it appears that the RHT may lie structurally upon the allochthon, unless a steep fault separates the two terranes. Likewise, the trace of the RHT south of the pond is uncertain. North toward Goose Arm, the RHT appears to intersect a shear zone that trends 210° and dips at 82° northwest. Kinematic indicators in the shear zone suggest steep oblique slip associated with dolomite augen and folded boudins, indicating the north hanging wall has been upthrust. The shear zone appears to cut out all of the Watts Bight Formation and the lower part of the overlying Boat Harbour Formation, perhaps totalling 200 m. However, bedding trends in the carbonates on either side of the shear zone do not diverge.

Not all northeast-trending folds in the area verge eastward. The Goose Arm Anticline (GAA) has a steeply dipping west limb and east-dipping, axial-planar cleavage. West-verging recumbent folds occur in the St. George Group at Raglan Head and in Cambrian strata on the east side of inner Goose Arm. These folds probably formed in the footwall of two thrusts including the Window Pond Thrust of Glover (in Wilkinson, 1983). If this is so, it suggests that the GAA is a related structure.

Most high-angle faults trend northwest and dip southwest between 66 and 80°. They are reverse faults marked by generally sharp fault planes, very little fault breccia only in the hanging wall, and drag folding in the footwall. They offset folds and thrusts.

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