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THE RELUCTANT HEAD FORMATION, GOOSE ARM THRUST STACK, NEWFOUNDLAND HUMBER ZONE: NEW OBSERVATIONS ON THE STRATIGRAPHY, BIOSTRATIGRAPHY AND IMPLICATIONS FOR THE EVOLUTION OF THE CAMBRIAN–ORDOVICIAN SHELF

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ABSTRACT

The Reluctant Head Formation is a regionally developed Middle Cambrian to Late Cambrian succession of shale (phyllite), ribbon limestone, grainstone, limestone conglomerate and minor boundstone, diachronouosly overlain by dolarenites and dol-boundstones of the Petit Jardin Formation. The Reluctant Head Formation, which can be traced over 350 km along the strike of western Newfoundland's Cambrian carbonate shelf sequence, was deposited in the deeper parts of a ramp shelf and shallowed up into a high-energy grainstone–boundstone belt. Trilobite faunas collected just below the top of the formation indicate that the formation and its upper contact become younger as they are traced through thrust slices of the Goose Arm Thrust Stack. The lithostratigraphy may reflect deposition of a prograding ramp shelf into a long-lived (late Delamaran to Skullrockian) intrashelf basin, or may mark the style of regional shelf margin from the St. Lawrence Promontory north into the Newfoundland Reentrant.

INTRODUCTION

The Humber (tectonostratigraphic) Zone of western Newfoundland is host to the northeastern end of Laurentia's Cambro-Ordovician shelf sequence in North America (Williams, 1978). The shelf terrain formed part of an once-contiguous, passive margin that swept sinuously along the southern margin of this ancient continent plate from Texas to eastern Greenland. In western Newfoundland, the shelf was deposited on the St. Lawrence Promontory (SLP), a paleo-continental promontory that projected into the Iapetus Ocean and was inherited from the irregular continental rupture of the ancient super continent Rhodinia.

In western Newfoundland, the shelf sequence is one of three principle geological terrains in the outer domain of the Humber Zone, where it is sandwiched between Proterozoic basement rocks below and, structurally overlying Taconian Allochthons, above. Proterozoic crystalline basement is now found in uplifted massifs, *e.g.*, Long Range Massif, and at the core of thick-skinned, fault-bounded structures (Figure 1) where it is overlain unconformably by the shelf sequence. The shelf sequence is hosted by an essentially undeformed foreland in the northwest, a series of basement-cored, thick-skinned structures in the south (TMS, PBA and NBA on Figure 1), and in a number of detached thin-skinned, thrust stacks along the east and southeast edge of the outer domain (BPTS, GATS and PBTS on Figure 1). The allochthons are host to a lower sedimentary package that includes deep-water, Cambro-Ordovician, peri-platformal carbonates and shales of the Cow Head and Northern Head groups (James and Stevens, 1986; Botsford, 1988). These groups are co-eval with the shelf sequence and are generally believed to have been emplaced above the ancient shelf during the Middle to Late Ordovician (Williams, 1995).

Recent studies of the Newfoundland shelf sequence support a broad, shallow carbonate shelf that dominated the passive margin from the late Middle Cambrian to the end of the Early Ordovician (James *et al.*, 1989). During the Middle to Late Cambrian, the shelf was host to both low- and high-energy shallow-water facies whose distribution varied as the shelf developed. A simple reconstruction of the Cambrian shelf proposed an inboard low-energy facies belt west of an intermediary high-energy facies belt, which in turn, passed outboard to deeper water successions of gravity-deposited and pelagic facies (James *et al.*, 1989). The shelf is thought to have developed as a generally narrow high-energy ramp that is preserved in rocks of the Port au Port Group. Rock sequences of the Cow Head Group formed in a toe-of-slope setting along a steep bypass margin (James and Stevens, 1986).

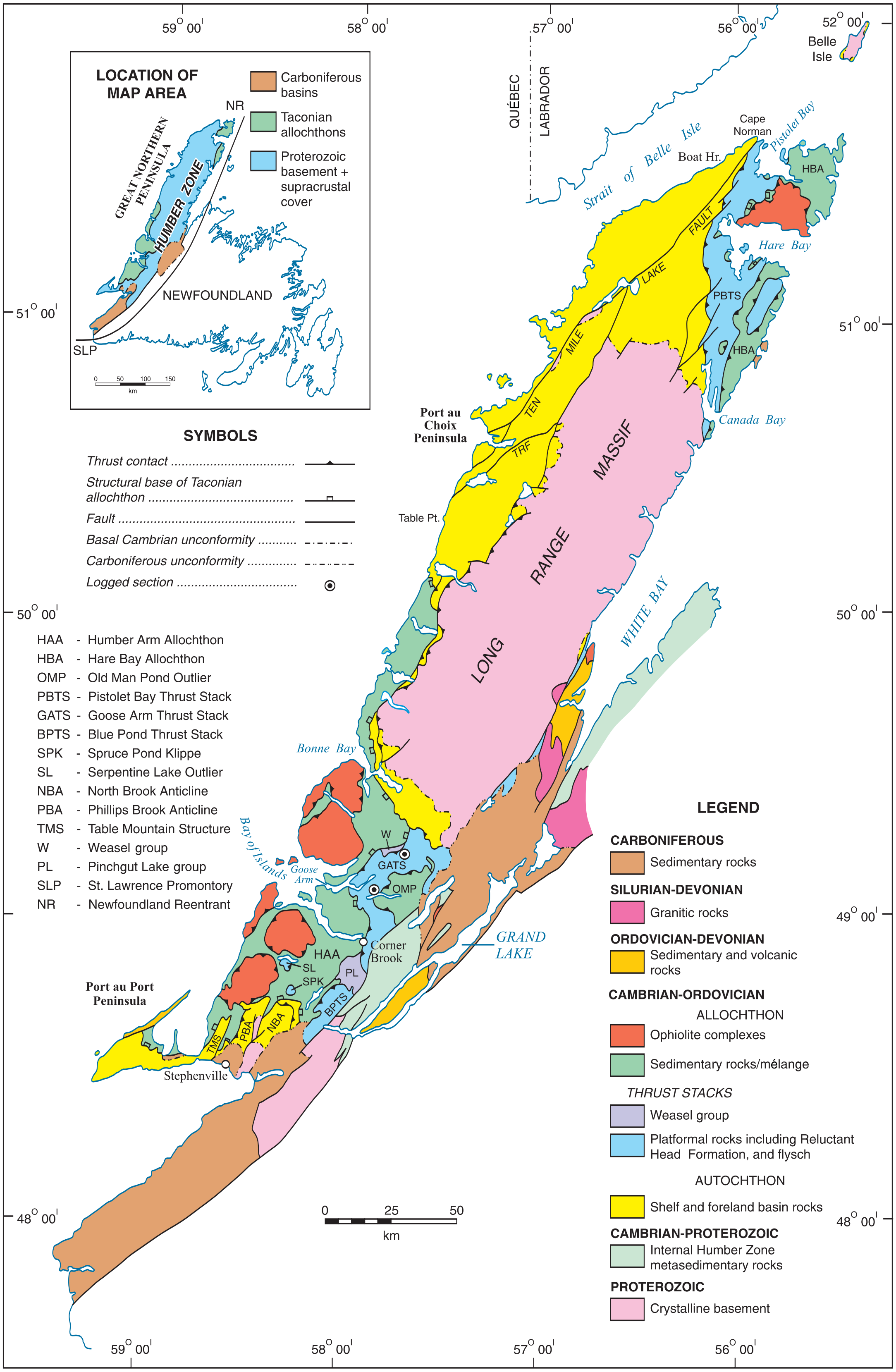

Figure 1. *Geological map showing the distribution of major geological terrains in western Newfoundland and the location of thrust stacks and the section locations.*

Deposition of the Port au Port Group began in the late Middle Cambrian (Delamaran) and continued, largely uninterrupted, until the earliest Ordovician Tremadoc (Missisquoia–Symphysurina trilobite zones; Boyce, 1977; Chow and James, 1987; Westrop, 1992; Knight and Boyce, 1991; Boyce *et al.,* 1992; Boyce and Knight, 2005). The group consists of three formations, *viz.*, the March Point, Petit Jardin and Berry Head formations which were interpreted to have been deposited in three Grand Cycles, A, B and C, of lower shaly half cycles and upper carbonate half cycles (Chow and James, 1987). The lower half cycles consisted mostly of shaly, nodular to parted, dolomitic limestone and shale and the upper half cycles of oolitic carbonates and laminites. Boundstone mounds feature in both half cycles. Chow and James (1987) interpreted all the carbonates as peritidal. The Grand Cycles were considered to be the sedimentary response to changing rates of long-term sea-level rise.

More recent studies (Cowan and James, 1993) redefined the Grand Cycles to consist of ribbon half cycles and oolitic half cycles separated by sequence boundaries composed of peritidal carbonates. Stacked oolitic carbonates were deposited in a low-stand system tract of shifting high-energy oolitic sand shoals and the fine-grained, often shaly, ribbon carbonates (ribbon rock) were deposited in open-shelf settings during high stand. Maximum progradation of peritidal carbonates across the shelf, marked regional shallowing of the shelf and formed the sequence boundary to the Grand Cycles. A eustatic sea-level fall, reflected in faunas and facies, was recognized essentially at the contact of Grand Cycles B and C (Chow and James, 1987; Westrop, 1992; *see* Cowan and James, 1993, for a different view of this stratigraphic interval).

As outlined above, the reconstruction of the paleogeography of the Cambrian shelf has been generally simple and assumed that most of the sequence is either autochthonous or near autochthonous. Recent mapping of the carbonate-shelf rocks, from southwest of Corner Brook to the southern edge of the Long Range Massif indicates, however, that the carbonates in this area are detached from basement, and are deformed in two thrust stacks, the Blue Pond and Goose Arm thrust stacks (Figure 1). These stacks are emplaced above Goose Tickle Group flysch, thrust slices of the Weasel group and, in some places, Taconic mélange along their leading edge (Knight, 1994a, b, 1997, 2006; and ongoing studies 2005 to present) and appear to sit in a structurally high position. At present, there is no estimate of how much transport and shortening is accommodated by the thrust stacks but it appears likely that these sequences may have lain much more outboard on the margin (*see* Waldron and Milne, 1991). A third stack, the Pistolet Bay Thrust Stack, occurs north of the Long Range Massif and carries similar stratigraphy to that discussed here.

Cambrian facies and stratigraphy show significant changes, from west to east, as they are traced across the different thrust slices of the thrust stacks (Figure 2; Knight, 1997). More westerly and lower structural foreland thrust slices are dominated by oolitic and stromatolitic limestones and thick-bedded dolostone intercalated with dololaminites and argillaceous dololaminites (Chow and James, 1987; Knight and Boyce, 1991; Knight and Cawood, 1991; Cowan and James, 1993). The higher structural thrust slices, to the east, are characterized by a lower succession of deeper water, ramp ribbon carbonates and phyllitic shales and slates, the Reluctant Head Formation, overlain by an upper succession of thick-bedded dolostones (Knight and Boyce, 1991; Knight and Cawood, 1991; Knight, 1994a).

The purpose of this article is to describe the stratigraphy and paleontology of the Reluctant Head Formation including a new section logged during recent mapping of the Goose Arm Thrust Stack (GATS), and to interpret the relationships with the immediately overlying Port au Port Group and the importance of these relationships in the broader context of buildup of the shelf during the Cambrian in western Newfoundland.

RELUCTANT HEAD FORMATION

The Reluctant Head Formation is a succession of shale, ribbon limestone, grainstone and carbonate conglomerate containing bioturbated and fossiliferous limestone, and a rare microbial lime boundstone near the top of the formation. The name Reluctant Head Formation was proposed by Lilly (1963)[1] for the unit in the area of the Humber River gorge. In this area, the unit, although strongly deformed and metamorphosed, still retains its ribbon-bedded character although some or much of this may be now transposed bedding (Knight and Boyce, 1991). Recent mapping indicates that the formation forms the basal part of easterly thrust slices in the three thrust stacks that occur close to the inner domain of the Humber (tectonostratigraphic) Zone (Knight and Boyce, 1991; Knight, 1994a, b, 1995a, b, 1997).

[1]Although the Reluctant Head Formation is defined as formal in Volume VI of the Lexicon of Canadian Stratigraphy (1985), Lilly's 1963 publication is an inhouse university document that includes no defined type section, as such the formation should be considered informal, according to rules of stratigraphic nomenclature.

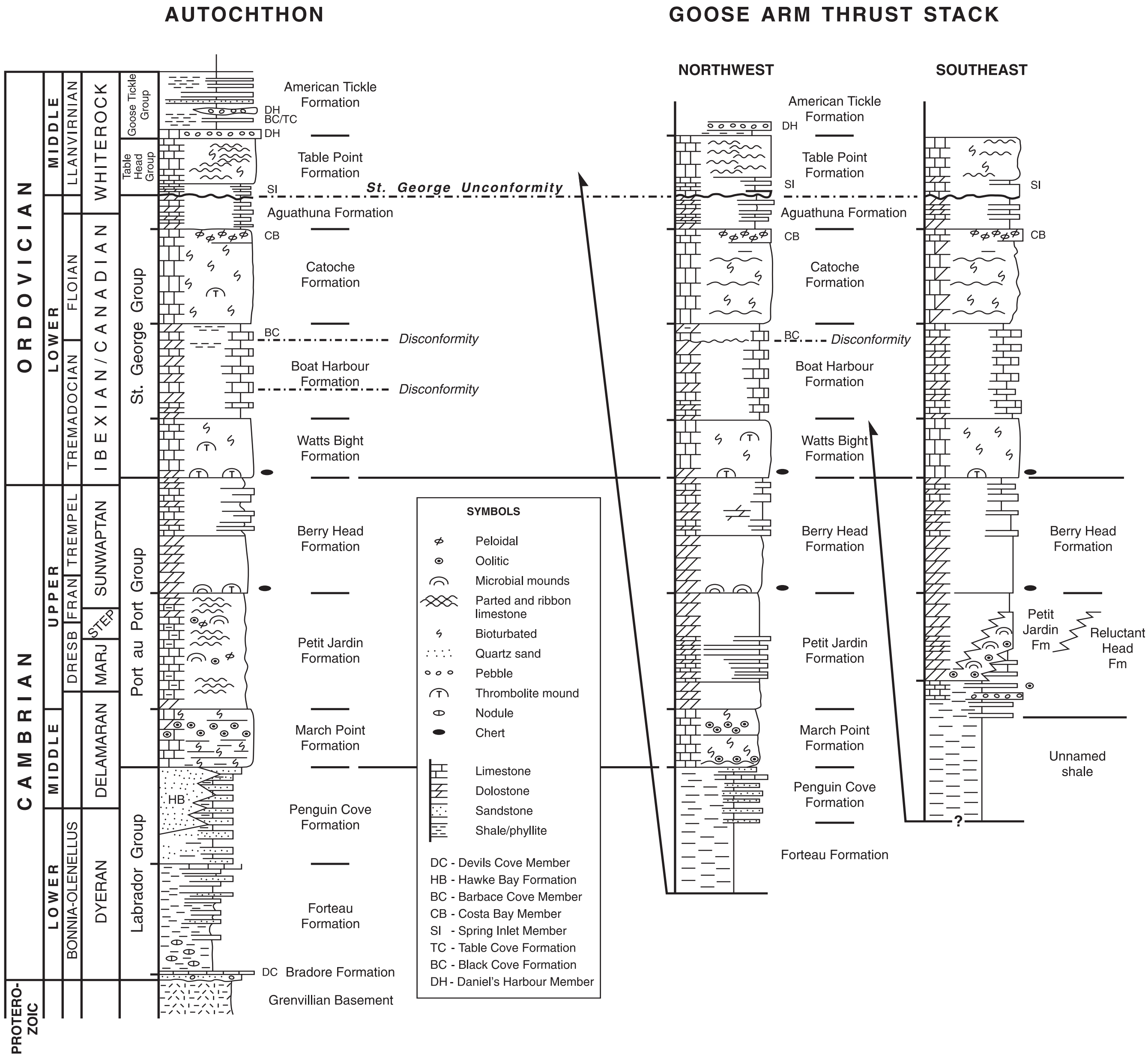

Figure 2. *Stratigraphy of the Goose Arm Thrust Stack and its correlation to the Cambro-Ordovician shelf sequence in western Newfoundland.*

The Reluctant Head Formation is deformed and inadequately exposed inland, resulting in very few sections through the formation having been measured in detail. The type area for the formation, (selected as the Reluctant Head thrust slice), occurs near Old Man Pond in the Pasadena map area (NTS 12H/4; Knight, 1994a, b). A broken and deformed section, shown in Figure 3, was measured in 1990 and 2000 by the first author. In this area, the formation is minimally metamorphosed and deformed away from the basal sole of the thrust and retains lithological features and sedimentary structures. In this area, the sequence has yielded a trilobite and inarticulate brachiopod fauna (Knight and Boyce, 1991; Boyce *et al.*, 1992).

During 2006, a short section of the Reluctant Head Formation was located south of Weasel Ponds, in the Pasadena map area, along a series of fairly new, winter wood-harvesting roads (Plate 1). The section illustrated in Figure 4 yielded important new fossil collections. In the more easterly thrust slices, the formation is characterized by scattered inland exposures that display an increase in deformation and metamorphism.

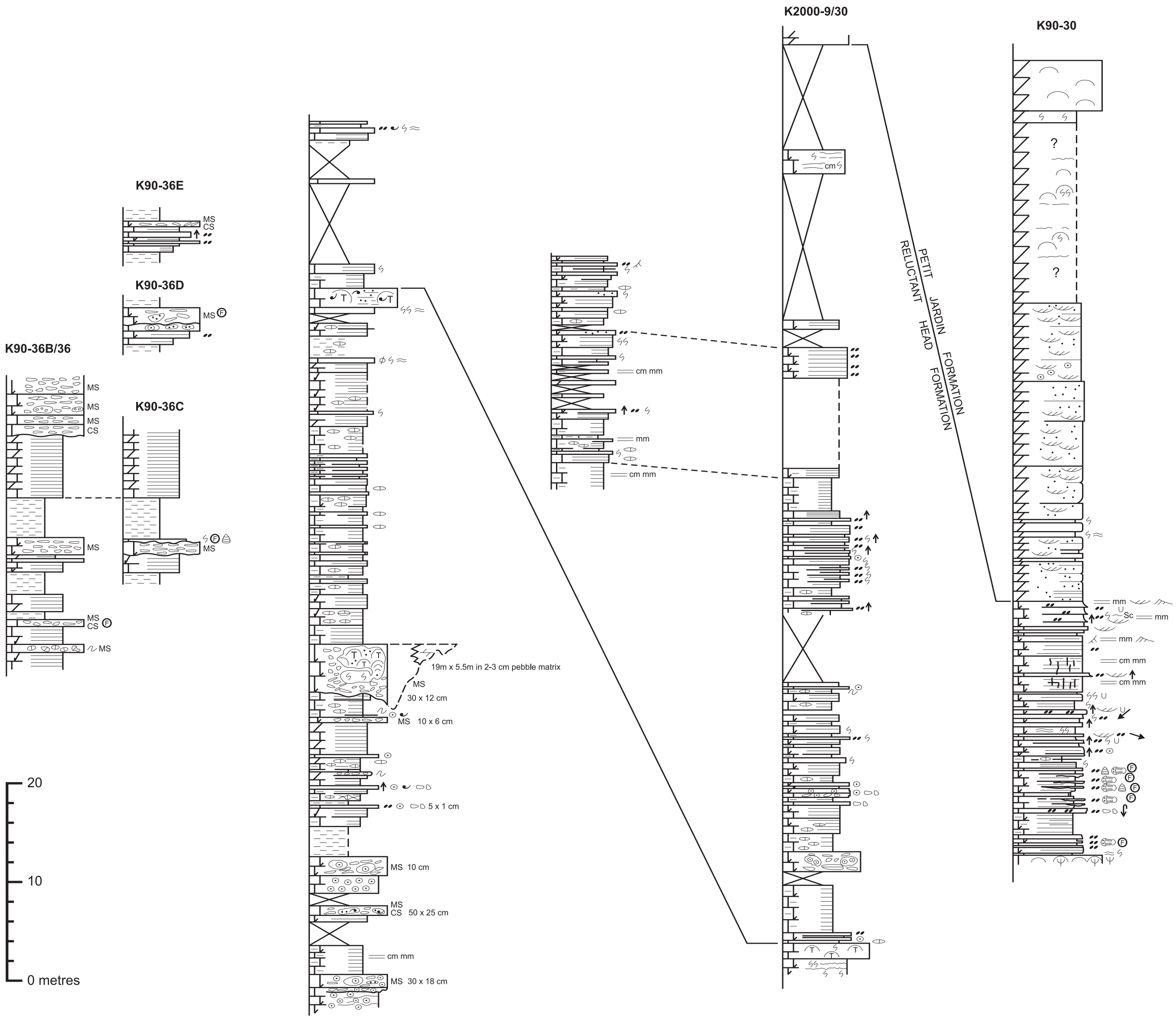

Figure 3. *A graphic log of the type section of the Reluctant Head Formation and immediately overlying Petit Jardin Formation in the type area. The section was compiled along the Goose Arm woods road just north of Old Man Pond by Knight in 1990 and 2000. See Figure 4 for legend.*

THICKNESS

The Reluctant Head Formation was estimated to be no more than 250 m thick by Gillespie (1983) and Knight (1992). However, as the unit is folded and intermittently covered in the type area, its true thickness is unknown.

CONTACTS

The upper contact of the Reluctant Head Formation is conformable but diachronous, and is placed at the base of the first thick sequence of dolarenite, dol-boundstone and other dolostones assigned to the Petit Jardin Formation.

For the most part, the base of the formation is not exposed and in several areas is marked by its carrying thrust. Shale and beds of grey sandstone underlie the formation in the type area. However, there is no exposed contact to indicate that these clastic rocks are in stratigraphic continuity with the Reluctant Head Formation. At 'Pye's Ridge', north of Deer Lake, a small area of polydeformed psammite and pelite occurs structurally below the formation (Knight, 1992, 1994a). Recent mapping south of Bonne Bay Big Pond, and west of the Viking Highway (Route 430), indicates that the formation overlies phyllites that include laminae of limestone and sandstone (Knight, 2007). This may indicate that the formation originally sat upon distal equiva-

Plate 1. *Upper part of the Reluctant Head Formation (section illustrated in Figure 4), on a winter woods road, south of Weasel Ponds. Arrow indicates dolostones of the Petit Jardin Formation.*

lents of the Penguin Cove Formation, known to be the distal equivalent of the Hawke Bay Formation (Knight and Boyce, 1991; Knight, 1994a; Knight and Cawood, 1991).

THE OVERLYING DOLOSTONES OF THE PETIT JARDIN FORMATION

The lower part of the Petit Jardin Formation comprises a variably thick sequence (up to 30 m) of crossbedded, intraclastic dolarenite intercalated with a few 60 cm beds of burrow-mottled dolostone (Plate 2). Locally, the dolarenite contains poorly preserved ooids but the general lack of ooid structure, in most grains, suggests that much of the lime sand was originally intraclastic or perhaps peloidal. Some skeletal grains and quartz sand are found locally. The dolarenite is succeeded by a 25-m-thick succession (Figure 3) of thick-bedded dolostones that, in the type area, display large boundstone mounds and dololaminites. Thick-bedded dolostone extends beyond the section, for many tens of metres more, up to the basal, cherty, stromatolitic dolboundstone marker of the lower member of the Berry Head Formation, which is succeeded by the upper member of limestone and dolostone (Cambrian–Ordovician transition; Knight and Boyce, 1991). The same stratigraphy is encountered at the new section south of Weasel Ponds.

The dolomitized grainstone is widely developed throughout the Bay of Islands area. It is mapped at the top of the Reluctant Head Formation in folded rocks of the Humber River Gorge (Knight, 1995a). The grainstone is markedly flattened into the plane of an early, bedding-parallel shear fabric suggesting some degree of detachment at this contact before folding of the strata in the area. The same grainstone is also found to the southwest at Pikes Brook in the Blue Pond Thrust Stack. There, the unit comprises well-stratified bioturbated limestone overlain by oolitic grainstone. In all, the unit can be traced for at least 75 km along strike of this part of the fold and thrust belt.

At 'Pye's Ridge', the top of the formation is marked by a transition from the ribbon limestone into the overlying Petit Jardin Formation dolostone (Knight, 1992). Metamorphism in this area makes identification of the dolostone facies difficult but it is generally thick bedded, suggesting it may be comparable to other sections.

In the Canada Bay area, rocks, now recognized as equivalent of the Reluctant Head Formation, are conformably and sharply overlain by dolostones of the Petit Jardin Formation (Knight and Saltman, 1980; Knight, 1987).

LITHOSTRATIGRAPHY OF THE RELUCTANT HEAD FORMATION

Type Area

The Reluctant Head Formation, in its type area (Figure 3), comprises decimetre-thick intervals of phyllite and shale (*see* below) with minor ribbon limestone and limestone nodules, shaly and dolomitic ribbon limestone, bioturbated wackestone to packstone, and intraclastic grainstone. A few beds of microbial lime boundstone are found near the top of the formation. Intraformational conglomerates and boulder conglomerates are interspersed within these fine-grained rocks, being more common in lower stratigraphic intervals than in the upper half of the section[2].

The phyllites (originally shale) are silver-grey, grey to dark grey and are polydeformed about more than one cleavage close to the sole of the thrust slices. Away from the thrust soles, thin bedding and lamination is locally discernable in cleaved shale. The ribbon limestone generally consists of thinly intercalated, grey lime mudstone and yellow-weathering dolomitic lime mudstone or dolostone (with or without shale partings and thin beds) that give the formation a banded appearance. However, some beds of dolomitic ribbon limestones are nodular. Rare slump folds are found locally in the lower parts of the section.

[2]Several conglomerates were logged in short disconnected sections (K90-36B, C, D and E, Figure 3) in folded strata along one of the older woods road in the south of the type area. The conglomerates lie east of and topographically lower than the main section logged along the Goose Arm woods road and based on the structure of the area they should sit lower in the section.

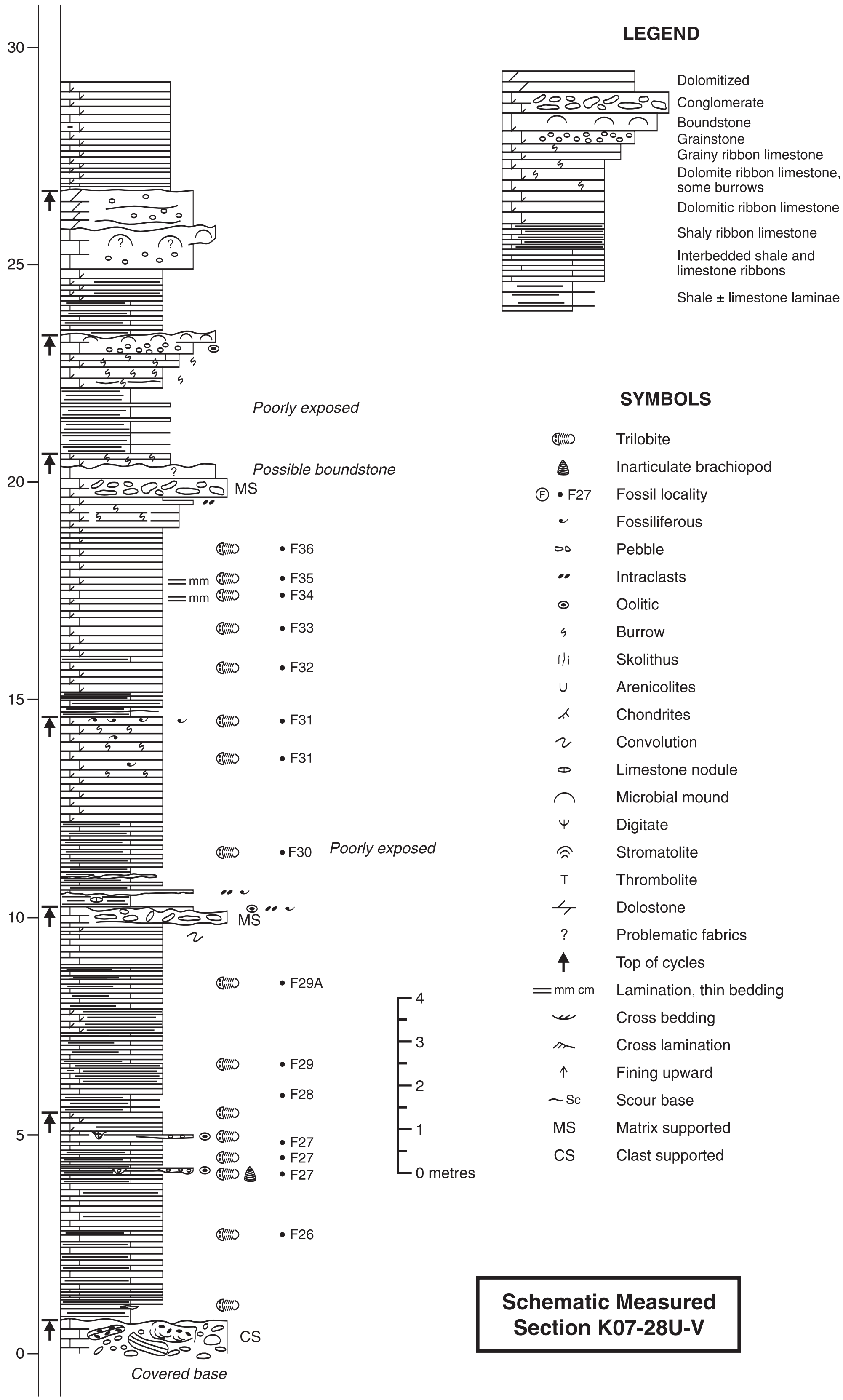

Figure 4. *Detailed graphic log of the short section (K07-28U-V) through the upper part of the Reluctant Head Formation, winter woods road, south of Weasel Ponds.*

Plate 2. *Crossbedded dolarenite, Petit Jardin Formation, immediately above Reluctant Head Formation, Goose Arm woods road. Hammer is 33.5 cm long.*

Grainstones generally form beds, a few tens of centimetres thick, composed of oolite and skeletal grains; the thickest bed is 1.8 m thick. The beds are generally without depositional structures but may enclose intraformational pebbles and some have quartz sand. One skeletal-rich grainstone bed rests upon the irregular top of a conglomerate.

In the upper half of the formation, the ribbon limestone is no longer only fine grained and planar bedded. Instead, units of thin-bedded, burrowed, mudstone–wackestone and skeletal-intraclastic (possibly peloidal) grainstone–packstone are common. U-shaped burrows and small-scale cross-stratification occur in this coarser, burrowed lithofacies.

Scour-based, carbonate conglomerate units are up to 2.8 m thick. They are matrix- to clast-supported, poorly sorted and carry pebble- to boulder-size clasts that have dimensions of 60 by 25 cm and are enclosed in a yellow-weathering, argillaceous, dolomitic limestone matrix. Grading has not been found, although clast-supported conglomerate overlain by matrix-supported conglomerate is not uncommon. Clasts are mostly tabular pebbles to slabs of ribbon limestone, and lumpy to nodular, thin-bedded, parted limestone. However, some conglomerates have a preponderance of intraclastic grainstone pebbles, as well as pebbles of skeletal-intraclastic grainstone, oolitic-intraclastic grainstone, graded granular lime rudstone to grainstone, and laminated dolostone. One, channelized conglomerate contains a broken block of lime boundstone and grainstone, 19 m long and 5.5 m thick. The block is upright, and consists of a basal interval of bioturbated limestone below boundstone mounds of stromatolite and thrombolite, the latter surrounded by intraclastic grainstone. The conglomerate pinches out laterally above an irregular channel scour. The pinchout is accompanied by dolomitization. Pebble-filled, extensional fractures cut down into the block.

In addition to the microbial mound block, two beds of boundstone, about 1 to 2 m thick, occur in the sequence. One consists of thrombolitic boundstone mounds enclosed by grainstone, the other of mounds of columnar and digitate stromatolite.

The rock types are arranged in upward-coarsening packages, 2 to 5 m thick. They consist of phyllite ± limestone nodules and laminae, ribbon limestone that is shaly near its base and becomes cleaner upward, and a bed of grainstone at the top. Conglomerate beds sit on top of grainstone in some packages and in others rest on, or within, sequences of ribbon carbonate.

Beds of burrowed, ribbon carbonate top some of the packages in the middle of the section, particularly below the lower bed of thrombolitic boundstone. In the upper third of the formation, however, the burrowed ribbon carbonates beds are more abundant in the packages at the expense of ribbon limestone and rare grainstone caps. Ribbon limestone is overlain by burrowed mudstone to wackestone and skeletal-intraclastic (possibly peloidal) packstone beds in these uppermost sequences (Plate 3B). Many U-shaped burrows, *Skolithus* and small-scale, cross-stratification are also present.

New Section Near Weasel Ponds

The section near Weasel Ponds (Figure 4; Plate 1) is only 30 m thick and occurs on the eastern limb of a doubly plunging, hanging-wall anticline above the Goose Arm Thrust Stack (Knight, 1994a, b). The section includes units of shale with limestone laminae and rare limestone nodules, interbedded thin-bedded shale and fine-grained limestone, dolomitic ribbon limestone, burrowed ribbon limestone, intraclastic and minor, oolitic grainstone, and clast- and matrix-supported, unsorted, carbonate conglomerate (Plates 3A and 3C). The internal features of the few boundstone beds near the top of the section are difficult to distinguish. Small, lenses of grainstone and grainstone-filled gutter casts are found locally in the ribbon beds, near the base of the section. The ribbon limestones are uncommonly rich in trilobites and inarticulate brachiopods (Plates 4 and 6).

In the Weasel Ponds section, metre-scale facies packages generally shallow and coarsen upward. They include a basal shale, thin-bedded shale and limestone, ribbon limestone and burrowed ribbon limestone. Grainstone and boundstone mark the tops of some of the upper packages. Carbonate conglomerates occupy the top of packages in the lower sequences. The facies, therefore, match those that occur in the type area. The top of the section is covered but lies about 10 m or more below the Petit Jardin Formation dolostones which, like their counterparts at Old Man Pond

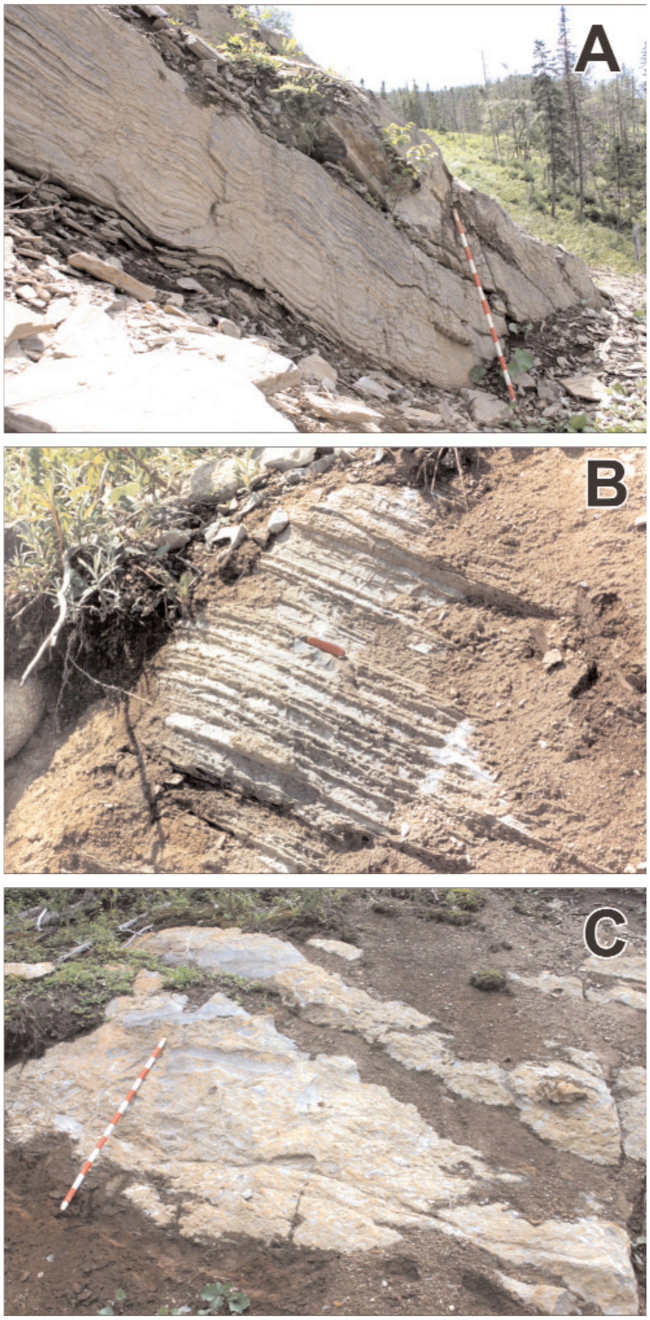

Plate 3. *Common lithofacies of the Reluctant Head Formation: A) Dolomitic ribbon limestone overlying a unit of grey shale with lenses and nodules of limestone, Reluctant Head Formation, winter woods road, south of Weasel Ponds. Graduated staff 1.5 m long, 10 cm divisions; B) Thin-bedded, burrowed, grainy, dolomitic limestone at the top of the Reluctant Head Formation, Goose Arm woods road just below top of the formation.* Skolithus *and other burrows are replaced by dolostone as are partings between grainy beds. Knife is 9 cm long; C) Matrix supported limestone conglomerate, Reluctant Head Formation, winter woods road, south of Weasel Ponds. Graduated staff 1.5 m long, 10 cm divisions.*

Plate 4. *Plentiful trilobite fragments (circled) scattered randomly across a fine grained dolostone parting in ribbon limestone, Weasel Pond woods road. Finger 5 cm.*

and other places, consists of doloarenite and thick-bedded dol-boundstone.

Other Sections of Reluctant Head Formation in Western Newfoundland

Metamorphosed Reluctant Head Formation is exposed at 'Pye's Ridge', at Humber River Gorge, in the Pikes Brook and Gullet Pond thrust slices of the Blue Pond Thrust Stack, southwest of Corner Brook, and in the East Pond and Englee Head thrust slices, in the Canada Bay area (Knight, 1987, 1992, 1994a, 1995b, 1997). The unit is also present along Route 420 in a narrow, fault-bounded sliver in the Doucers Fault zone southwest of White Bay (Knight, reconnaissance survey, unpublished data, 2003).

'Pye's Ridge' Area

The Reluctant Head Formation, at 'Pye's Ridge', consists of silver-grey to dark-grey phyllite and blue-grey, thin-bedded, dolomitic ribbon limestone that underlie the low ground and the foot-of-slope at the southwest end of the ridge. The formation is also found in a narrow zone that trends eastward across the middle of the ridge where it forms the hanging-wall sole of the 'Pye's Ridge' thrust. Although displaying strong internal deformation, the unit has an overall upward trend from phyllite-dominated to carbonate-dominated rocks. Silver-grey and dark-grey phyllites form beds up to 1 m thick, in the lower parts of the formation, and are intercalated with beds, up to 40 cm thick, of thin-bedded phyllite and limestone. Locally, some limestone beds are grainy and others are intraformational limestone conglomerate. In the middle of the formation, the phyllite and limestone occur in roughly equal proportions, forming units commonly up to 1 m thick. Beds of thinly stratified grainstone, intraformational lime conglomerate and dolostone, reaching 40 cm in thickness are also found. Some grainstone beds are graded with crosslamination at the top. Toward the top of the formation, phyllite is restricted mostly to partings within very compact, dolomitic, ribbon limestone and some limestone beds possess a nodular texture. The transition into the overlying Petit Jardin Formation is marked by interbeds of ribbon limestone and argillaceous dolostone, dolostone and intraformational limestone conglomerate. In the upper thrust slice, ribbon limestone is dolomitized between thick dolostone beds, suggesting a transition in this area between the ribbon facies and the thick-bedded facies of the Petit Jardin Formation.

Humber River Gorge

At Humber River Gorge, the Reluctant Head Formation occurs in the core of the Bear Head anticline and at the eastern end of the gorge, near the Marble Mountain ski resort, where it forms the lowest strata in a belt of vertical strata that form the eastern limb of a syncline (Knight, 1995a, b, 1997). The strata are characteristically ribbon-banded, fine-grained grey limestone and dark-grey phyllite. Much of this bedding-like fabric is interpreted to be transposed bedding because rootless closures of brown-weathering, thin-bedded, argillaceous limestone, dolomitic limestone and phyllite are found in the vertical zones of ribbon-banded limestone and phyllite. In addition, bioturbated and grainy limestone intercalated with phyllite and brown-weathering, planar thin-bedded, massive to laminated, calcareous argillites occur in the Bear Head anticline. Carbonate conglomerates are not present in the gorge but they do occur in the formation near Rubber Lake, on the mountain ridge to the north of the gorge, where they are host to lead-zinc mineralization (Wilkinson, 1983, 1984).

Blue Pond Thrust Stack

Southwest of Corner Brook, the Reluctant Head Formation occurs as a narrow outcrop along the sole of the Pikes Brook thrust and the Gullet Pond thrust (Knight, 1995b, 1997). The formation consists of dolomitic and argillaceous, dark-grey ribbon limestone, thin-bedded grey and silver-grey phyllite, calcareous and dolomitic phyllite, minor limestone conglomerate, and bioturbated, thinly stratified limestone. Phyllite and ribbon limestone characterize most of the formation. However, the top of the formation is marked by well-stratified bioturbated limestone, and is capped by a unit of mostly dolomitized, oolitic(?) grainstone.

Canada Bay

In the Canada Bay area, the formation comprises thin-bedded, blue-grey ribbon limestone, dolomitic limestone and dark-grey, phyllitic shales interbedded locally with carbonate conglomerates (containing platy limestone pebbles) and oolitic grainstone containing some skeletal material. The formation is sharply overlain by oolitic and laminated dolostones of the Petit Jardin Formation. The formation occupies the basal part of the East Pond and Englee thrust slices. In the East Pond thrust slice, it is interpreted to overlie a succession of dark grey, pyritiferous shales interbedded with thin, black limestones and calcareous siltstones containing intercalated units of oolitic and oncolitic grainstone and rudstone, typical of the Bridge Cove Member, Hawke Bay Formation, and the Penguin Cove Formation (Knight and Boyce, 1987, 1991; Knight and Saltman, 1980).

FAUNA, AGE AND CORRELATION

Reluctant Head Formation Type Area

A trilobite and inarticulate brachiopod fauna from the top of the Reluctant Head Formation at the type area includes the following trilobite species (Boyce *et al.*, 1992):

Asaphiscus sp. cf. *A. wheeleri* Meek, 1873
Hemirhodon convexifrons Rasetti, 1948
Kormagnostus seclusus (Walcott, 1884)

The fauna is dominated by pygidia of *Hemirhodon convexifrons* Rasetti, 1948, ranging in size from 2 mm to at least 5 cm (Plate 5).

Asaphiscus wheeleri Meek, 1873 occurs in the *Bathyuriscus fimbriatus* Subzone of the *Bolaspidella* Zone in Utah (Robison, 1964). *Hemirhodon convexifrons* Rasetti, 1948 was originally described from latest Middle Cambrian boulders in the Levis Formation conglomerates of Quebec (Rasetti, 1948) and a possibly related species, *Hemirhodon amplipyge* Robison, 1964, occurs in the *Bolaspidella contracta* Subzone of the *Bolaspidella* Zone in Utah (Robison, 1964). Other species of *Hemirhodon* such as *Hemirhodon sp.* of Kindle (1982) and *Hemirhodon spp.* of Palmer (1968) occur in *Bolaspidella* Zone-correlative rocks. Other *Hemirhodon* species occur in (early Dresbachian) Cedaria Zone-correlative strata.

Plate 5. *Dorsal view of the pygidium (cast) of Trilobite* Hemirhodon convexifrons *Rasetti,1948 from Boyce 1991F011 = 1990F054 in the Reluctant Head Formation type area, Goose Arm woods road (NFM F-764). One-cent coin (18 mm in diameter) for scale.*

Kormagnostus seclusus (Walcott, 1884) ranges from the lower *Lejopyge laevigata* Zone (*Bolaspidella* Zone-correlative) to the *Glyptagnostus stolidotus* Zone (*Crepicephalus* Zone-correlative) (Robison, 1988, page 45).

The above taxa suggest that the top of the Reluctant Head Formation, in the type area, was deposited entirely within the late Middle Cambrian *Bolaspidella* Zone or in the early Late Cambrian *Cedaria* zone (in North American terms) at the latest. Consequently, it is probably a lateral equivalent of the upper part of the March Point Formation and the lower dolostone member of the Petit Jardin Formation exposed in the Penguin Head Thrust Slice at Goose Arm. It also suggests that the top of the Reluctant Head Formation correlates with the top of the March Point Formation and the Cape Ann Member of the Petit Jardin Formation, on the Port au Port Peninsula (Chow and James, 1987; Westrop, 1992; Cowan and James, 1993; Boyce and Knight, 2005).

Trilobite Faunas of the Weasel Ponds Section (Figure 4, Appendix)

The trilobites, *Crepicephalus*, *Terranovella*, *Tricrepicephalus*, *Talbotina* and ?*Kormagnostus* were collected from the section (*see* Plate 6 and Appendix). *Crepicephalus*, *Terranovella* and *Tricrepicephalus* indicate a late Dresbachian/Marjuman age for the section. This correlates with horizons 1990F080 to F083 of the upper dolostone member of the Petit Jardin Formation, on the south shore of Goose Arm, where the formation is carried in the Penguin Head Thrust Slice at the leading edge of the Goose Arm Thrust Stack (Knight and Boyce, 1991; Knight, 1994a). The fauna is also a time equivalent of the lowest conglomeratic interval in the lower member of the Weasel group in its type section exposed in the footwall to the Goose Arm Thrust Stack (Boyce *et al.*, 1992; I. Knight and D. Boyce, unpublished data). The fauna also correlates with the lower part of the Felix Member, Petit Jardin Formation on the Port au Port Peninsula (*see* Westrop, 1992).

The combined faunas of the two sections imply that the Reluctant Head Formation, in the eastern thrust stacks, is likely equivalent of much of the March Point Formation, and Grand Cycles A and B of the Petit Jardin Formation. Most importantly, it indicates that the top of the formation is younger in the Weasel Ponds area than in the type area, on the Goose Arm Road, implying that the upper contact with the overlying Petit Jardin Formation dolostones is diachronous.

DISCUSSION

The lithofacies in the Reluctant Head Formation are likely re-sedimented, gravity- and suspension-deposited carbonates and siliciclastic mudstones of a distally steepened ramp (Knight and Boyce, 1991; Boyce *et al.*, 1992; *see* Tucker and Wright, 1990). The shale and lime-mud, ribbon beds that dominate the sequence imply a generally quiet, sub-wave-base, depositional setting for the unit. Phyllites and ribbon limestones associated with some slump beds and rare, thin lenticular limestone conglomerate form the lowest beds in the section. The very fine grain size, planar lamination and thin bedding suggest quiet, dominantly suspension deposition, below wave base, and only minor gravity-induced instability and re-sedimentation. The carbonate mud was probably placed in suspension by storms stirring the bottom in the shallower parts of the ramp and shelf (*see* Markello and Read, 1981).

The scour-based, carbonate conglomerates are characterized by their unsorted, clast- to matrix-supported, and locally lensoid features. The conglomerates are deposits of debris flows generated by slope failure high on the ramp and close to a fringing belt of high-energy, oolitic and intraclastic, lime-sand shoals that were host to stromatolitic and thrombolitic, mound complexes. This is indicated by the dominance of platy fine-grained limestone clasts derived from the slope, the presence of pebbles and boulders of intraclastic, oolitic and skeletal grainstone, and the large block of upright, burrowed limestone overlain by stromatolitic and thrombolitic boundstone mounds. Storms periodically likely swept oolitic and intraclastic grainstone sediment off the shoals and down the slope where they were redeposited as essentially structureless beds.

The grainstone and boundstone clasts in the conglomerates are comparable to shallow-water, shelf lithofacies preserved in the coeval Port au Port Group, mapped throughout

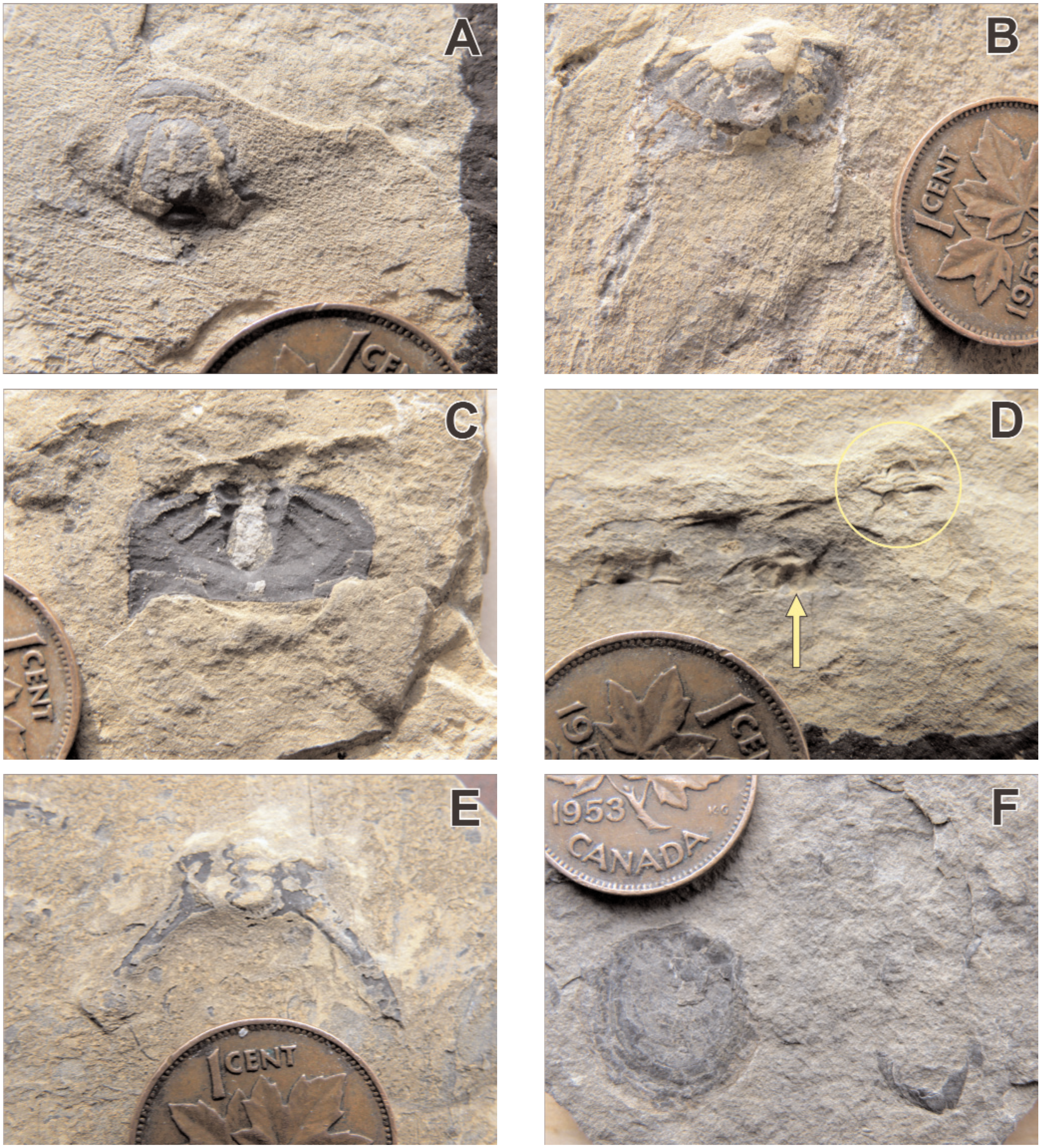

Plate 6. *Fossils of the Reluctant Head Formation, Weasel Ponds section, Pasadena Map Sheet. One-cent coin (18 mm in diameter) for scale. A) Trilobite* Crepicephalus *sp. from 2007F030 (NFM F-765). Dorsal view of cranidium (cast). B) Trilobite* Crepicephalus *sp. from K-2007-028U, presumably = 2007F030 (NFM F-766). Dorsal view of pygidium (cast). C) Trilobite* Crepicephalus *sp. from 2007F030 (NFM F-766). Dorsal view of pygidium (mold). D) Trilobite* Terranovella *sp. from 2007F030 (NFM F-767). Dorsal views of cranidium (arrow) and two pygidia (circled) (molds). E) Trilobite* Tricrepicephalus *sp. from 2007F035 (NFM F-769). Dorsal view of pygidium (cast). F) Inarticulate brachiopod ?Dicellomus sp. from 2007F030 (NFM F-768). Dorsal view.*

the Goose Arm and other thrust stacks. This comparison suggests that a belt of high-energy, shallow-water carbonate-sand shoals associated with boundstone mound complexes occurred at the rim of the shelf and above the ramp slope. This model is supported by, 1) the suite of clast types in the conglomerate, 2) the presence of a variety of grainstone beds associated with the debris flows, 3) the local capping of some sequences by thrombolitic boundstone and grainstone, and 4) the consistent stratigraphy throughout the various thrust stacks of Reluctant Head Formation being overlain by crossbedded dolarenites and thick-bedded dolboundstones of the Petit Jardin Formation. The changing faunal ranges of the youngest beds, in two of the sections through the Reluctant Head Formation, also suggests that this style of shelf architecture was long lived throughout the late Delamaran and Marjuman (Dresbachian) of the mid to late Cambrian and suggests that the shelf prograded consistently with time (*see* below and Knight and Boyce, 1991; Boyce *et al.*, 1992).

The geographical distribution of the Reluctant Head Formation facies association, from southwest of Corner Brook in the south to Canada Bay in the north, and along a strike distance of 350 km, confirms that this is a regional ramp slope facies belt, lying east of predominantly peritidal carbonates of the Port au Port Group. The deeper ramp facies is consistently overlain by dolarenites (both oolitic and intraclastic) and thick-bedded, dolomitized boundstone mounds suggesting that the ramp shallowed into a high-energy, sand shoal and boundstone-mound complex. This shallowing-upward motif couples with younging of the top of the formation, as it is traced from section to section, suggesting that the margin consistently prograded through the Middle to Late Cambrian. This progradation began in the late Delamaran *Ehmaniella* and *Bolaspidella* zones and continued throughout the Marjuman (Dresbachian) into the *Crepicephalus* zone. This indicates that the prograding ramp/shoal couple was established during the deposition of the March Point Formation (*Ehmaniella* and *Bolaspidella* zones) and continued to thrive throughout the deposition of Grand Cycles A and B of the Petit Jardin Formation. However, recent studies of the fossiliferous Weasel group, an allochthonous sequence, whose lower member is identical lithologically to the Reluctant Head Formation, indicate that the ramp/shoal couplet survived until at least the *Dunderbergia* zone *i.e.*, middle Steptoan, as the uppermost conglomerate of the lower member contains a *Dunderbergia* fauna (Boyce *et al.*, 1992; Knight and Boyce, in preparation). The progradation of the shelf was halted by sea-level rise, which drowned the ramp margin in the late *Elvinia* zone and allowed the deposition of dark shale and minor *Elvinia*-rich limestones to onlap up the ramp and abruptly overlie the uppermost *"Dunderbergia"* conglomerates of the lower member of the group (*see* Saltzman *et al.*, 2004 for contemporary events throughout Laurentia).

The conglomerates and the depositional setting of the Reluctant Head Formation and the lower member of the Weasel group are quite different from those described for time-equivalent, allochthonous sequences of the Cow Head Group and, to a lesser degree, Northern Head group (James and Stevens, 1986; Botsford, 1988). In the Cow Head Group, a toe-of-slope succession formed an apron of welded conglomerates, *i.e.*, Downes Point Member, Shallow Bay Formation of James and Stevens (1986). The conglomerates are host to exotic clasts dominated by calcified and marine-cemented, microbial boundstones and oolitic grainstones, which suggest a platform rim of oolitic shoals and robust, microbial buildups associated with a steep-profile bypass margin. Combining the evidence of depositional setting and margin types from the Reluctant Head Formation-Weasel group conglomerate facies and the Cow Head Group suggests that these two time equivalent facies associations did not lie along a common or adjacent part of the ancient margin.

Two solutions to this dilemma appear immediately to be possible, although these may prove inadequate with further analysis. The rocks of the Reluctant Head Formation contain facies similar to those of the Conasauga Group and equivalents, in southwest Virginia and eastern Tennessee that were deposited within, and along, the edge of an intrashelf basin (Markello and Read, 1981; Read, 1989; Glumac and Walker, 2000). If a similar basin occurred on the St. Lawrence Promontory, it suggests that the Cow Head Group margin lay outboard of an outer shelf/platform that would have, in turn, lain outboard of the intrashelf basin. The shelf-to-basin polarity of the Conasauga intrashelf basin is, in a general sense, towards the craton *i.e.*, from southeast to northwest and northeast to southwest, the polarity depending on the location around the edge of the Conasauga basin. Applying the same rules of polarity in western Newfoundland implies that the carbonate succession in the Goose Arm and Blue Pond Thrust stacks should form the western margin of the outer platform. Based on the present mapping and understanding of the lower Paleozoic shelf in western Newfoundland (James *et al.*, 1989), however, the polarity of the shelf to intrashelf basin in western Newfoundland appears to be from west to east or there abouts. This would mean that the intrashelf basin lay to the east of the shelf sequences of the thrust stacks and that much of the basin is now destroyed or hidden by collisional tectonics that affected the Newfoundland margin in the Paleozoic. Lastly, if the rocks of the Weasel group are correctly included in this model of a shelf marginal to an intrashelf basin, it suggests that the basin has a protracted history that spans the late Middle Cambrian

Delamaran until the Early Ordovician Skullrockian[3]. This implies that the basin was a significant paleo-morphological feature on the Newfoundland margin even as the carbonate shelf was first established in the late Middle Cambrian and that it continued to influence sedimentation even as a broad low energy platform is thought to have prevailed in the Early Ordovician (James *et al.*, 1989).

Three further observations may be important in this debate. First, the top of the Reluctant Head Formation appears to young in a more northerly direction, based on the two fossil-rich sections of the Pasadena map area because the younger section lies northwest and forward of the section in the older Reluctant Head Formation type area. This hints that the polarity of the shelf-intrashelf basin may be other than suggested to date by our interpretation of the thrust stacks. Second, because the Goose Arm and Blue Pond Thrust stacks appear to be structurally high and thrust northwestward over foreland-basin flysch, mélange and the Weasel group slice, all of which sit east of and not necessarily below the classic Humber Arm Allochthon (ongoing mapping, Knight, 2005 to present day; *see* also Waldron and Milne (1991) for their innovative interpretation of the structure of the same area which presents similar ideas), it is possible that the carbonate-shelf sequence, preserved in the stacks, are part of an outer peritidal shelf platform, which may have lain southeast of the intrashelf basin. Moreover, the northward-younging of the Reluctant Head Formation may hint that the intrashelf basin coincided with, or is linked to, the Bonne Bay cross-strike discontinuity proposed by Cawood and Botsford (1991) to have influenced sedimentation and shelf style along the margin in the Bonne Bay area. If this line of argument has merit, it means that the Middle to Late Cambrian platform may not be a relatively narrow one as suggested in earlier studies (James *et al.,* 1989). Rather it was broad, and had a complex, non-linear paleogeography that included a major intrashelf basin of unknown shape. The latter was surrounded by a mosaic of carbonate shelfs, that locally may have been narrow, and include a major outer bank whose oceanward margin was the site of Cow Head Group deposition.

The second possible solution is that the differing margin styles, *i.e.*, Cow Head-rimmed shelf versus Port au Port-ramp shelf, reflects deposition along different parts of the same margin whose geomorphology was fundamentally structurally controlled as a result of rifting. A relatively narrow shelf having a steep-rimmed Cow Head-style margin might be expected to form along a transform margin. The westward swing of the margin across the Gulf of St. Lawrence to Gaspé, Québec, may reflect such a feature (Stockmal *et al.*, 1987; Knight *et al.*, 1991; *see* inset map, Williams and Cawood, 1989). However, along long, ocean-parallel segments of the margin, such as would have characterized the margin from the apex of the St Lawrence Promontory north into the Newfoundland Reentrant (*see* inset map of Williams and Cawood, 1989), a broad foundation of continental basement would have supported the accretion of shallow-water, predominantly peritidal, warm-water carbonates across a broad shelf in response to thermal subsidence, local tectonism, the efficiency of the carbonate factory, and the rate of long-term, sea-level rise. This margin favoured the development of a prograding, distally steepened ramp during the early stages of shelf growth, in the Mid to Late Cambrian (Delamaran to Steptoan), before supporting a broader, low-energy platform in later Cambrian (Sunwaptan) and Early Ordovician times.

This margin configuration would require re-evaluating the distribution of facies and position of the shelf to slope break around the apex of the promontory and may imply northward emplacement of Cow Head Group rocks rather than from the east as is currently accepted (Cawood and Botsford, 1991).

SUMMARY

The Reluctant Head Formation is a regionally developed Middle Cambrian to Late Cambrian succession of shale (phyllite), ribbon limestone, grainstone, limestone conglomerate and minor boundstone preserved exclusively in a series of thin-skinned thrust stacks in western Newfoundland. The best preserved and only fossiliferous sections occur in the Goose Arm Thrust Stack including a newly discovered fossiliferous section on winter woods roads south of Weasel Ponds. There, the Reluctant Head Formation is diachronouosly overlain by dolarenites and dol-boundstones of the Petit Jardin Formation. The Reluctant Head Formation, which can be traced over 350 km along the strike of western Newfoundland's Cambrian carbonate shelf sequence, was deposited in the deeper parts of a ramp shelf and shallowed up into a high-energy grainstone–boundstone belt that formed the rim of the adjacent shallow shelf. Trilobite faunas collected just below the top of the formation indicate that the formation and its upper contact ranges from *Bolaspidella* to *Crepicephalus* zone (*i.e.*, Delamaran to Marjuman (Dresbachian)) and that the top of the formation becomes younger as it is traced through thrust slices of the Goose Arm Thrust Stack. This indicates a diachronous contact which, coupled with the consistent

[3]Recent conodonts recovered from the upper conglomerate unit of the Weasel group suggest an early Ordovician age, time equivalent of the Watts Bight Formation of the St. George Group.

stratigraphic superposition of facies across the contact of the Reluctant Head and Petit Jardin formations indicates that a prograding ramp margin prevailed from the late Delamaran through the Marjuman and, based on the Weasel group, until the middle Steptoan. The stratigraphy of the Weasel group as a whole, however, suggests that the basin with its adjacent shelf continued as a major morphological feature on the Newfoundland shelf until at least the early Ordovician. The lithostratigraphy may reflect deposition of a prograding ramp shelf into an intrashelf basin or may mark the style of regional shelf margin from the St. Lawrence Promontory north into the Newfoundland Reentrant.

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

APPENDIX

Fossil Horizons in the Reluctant Head Formation, Weasel Ponds area, NTS 12H/04 (Pasadena)

The datum for the fossil sites is NAD 27 and the UTM Zone is 21. "2007F" = samples collected by W.D. Boyce. "K-2007" = samples collected by I. Knight. The collections are placed in stratigraphic order from the top down. UTM coordinates and altitude obtained by GPS. (+) = casts (-) = molds

2007F035 – 442105E, 5453279N, 266 m
Arthropoda–Trilobita
?*Kormagnostus* sp. undet.
Talbotina sp.undet.. – pygidium (+)
Tricrepicephalus sp. undet. – pygidium (+)

2007F034 –. 442109E, 5453279N, 265 m.
Arthropoda–Trilobita
Crepicephalus sp.undet. – pygidium (+)
Talbotina sp.undet. – pygidium (-)

2007F033 – 442109E, 5453284N, 266 m
Arthropoda–Trilobita
Tricrepicephalus sp. undet. – cranidium (+)

2007F032 – 442110E, 5453291N, 263 m
Arthropoda–Trilobita
Tricrepicephalus sp. undet. – cranidium (+), pygidium (+)

2007F031 – 442113E, 5453290N, 266 m
Arthropoda–Trilobita
Crepicephalus sp. undet. – cranidium (+)

2007F030 = K-2007-028U – 442121E, 5453292N, 262 m
Arthropoda–Trilobita
Crepicephalus sp. undet. – cranidia (+), thorax (+, -), pygidia (+, -)
Terranovella sp.undet. – cranidium (-), pygidia (-)
Brachiopoda–Inarticulata
Dicellomus sp. undet.

2007F029A – 442126E, 5453300N, 267 m
Brachiopoda–narticulata
Dicellomus sp. undet.

2007F029 – 442126E, 5453300N, 267 m
Arthropoda–Trilobita
Crepicephalus sp. undet. – cranidia (+), pygidium (+)
Terranovella sp.undet. – cranidium (+)

2007F02 – 442129E, 5453302N, 270 m
Arthropoda–Trilobita
Crepicephalus sp. undet. – pygidia (+)

2007F027 – 442132E, 5453301N, 259 m
Arthropoda–Trilobita
Gen. et sp. undet.

2007F026 = TRIL-1 – 442132E, 5453304N, 259 m
Arthropoda–Trilobita
Gen. et sp. undet.