Current Research (1992) Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 141-157

GEOLOGY OF MARMORIZED, LOWER PALEOZOIC, PLATFORMAL CARBONATE ROCKS, 'PYE'S RIDGE', DEER LAKE

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ABSTRACT

'Pye's ridge' is a northeast-trending hill, 300 m high, just to the north of Deer Lake. The hill, which is underlain by a succession of dolomitic and calcareous marble, has high potential as a source of dimension stone. The polydeformed succession features metamorphosed Middle Cambrian to Middle Ordovician carbonates similiar to those mapped in the adjacent areas of the Pasadena map sheet. The succession includes rocks correlated with the Hawke Bay Formation, Reluctant Head Formation, and the Port au Port, St George, Table Head and Goose Tickle groups. The marbles are juxtaposed structurally against psammitic and pelitic rocks of the Old Man Pond Allochthon to the northwest, and are overlain, unconformably, by flat-lying Carboniferous sediments in the south and, locally, elsewhere.

The rocks of 'Pye's ridge' are polydeformed and are probably part of a duplex. The three main phases of deformation include 1) northwest-verging thrusting, 2) northeast-trending, southeast-verging folding and 3) northwest-verging normal extension. These phases all predate the formation of Carboniferous cave deposits (red sediment and speleothems) along the northwestern terrain boundary and D_2 faults. Locally, reactivation of faults has deformed the speleothems; C−S fabrics indicate sinistral movement. Rare kink bands may correlate with this late or post-Carboniferous movement.

The marble of 'Pye's ridge' include several dimension-stone prospects. Varieties range from white (bianco) *to grey* (bardiglio) *to some pink and include a number of textures that range through* arabescato, venato, nuvolato, striato *and* scuro. *One variety of* bardiglio *resembles* b. imperial.

INTRODUCTION

'Pye's ridge' (informal name) (Figures 1 and 2) is a northeast-trending, forested ridge that occurs just to the northwest of the town of Deer Lake, and north of the lake of the same name. The ridge, which is 6 km long by 3 km wide rises to more than 330 m (950 feet). It is the location of an extensive and quite well-exposed succession of lower Paleozoic marble. The marble lies southeast of the Old Man Pond Allochthon, from which they are seperated by the 'Helen's brook' fault that follows a stream valley, informally named by Gillespie (1983) 'Helen's brook'. The marble is currently covered by a claim block operated by Len Pye. The claim block includes a number of interesting marble prospects that were recently evaluted for Technostone, an Italian engineering and dimension-stone company.

A mapping project was initiated by the Geological Survey Branch of the Department of Mines and Energy to delineate the prospective economic marble units and study the structure of the ridge. The ridge contains four known marble prospects, two white, one ivory and one grey. The white marble was originally thought to be unconnected stratigraphically but mapping indicated that the two prospects occur in the lower part of the stratigraphy, repeated by a thrust. The ivory and grey prospects occur stratigraphically higher. Several other marble targets are outlined in this report.

The rocks are deformed by at least three phases of deformation; an early phase of northwest thrusting, a phase of southeast-verging recumbent folding, possibly related to thrusting, and a phase of down-dip northwestward extension. The latter is related to normal-sense fault reactivation along the structural boundary betweeen the marble to the southeast and the Old Man Pond Allochthon to the northwest.

It is possible to define a stratigraphy within the marble that compares with that in rocks of the Goose Arm−Old Man Pond area to the west (Knight and Boyce, 1991) (Figure 3). The rocks are the equivalent of the Reluctant Head Formation, Port au Port Group (Late Cambrian Petit Jardin and Berry Head formations) and the Ordovician St. George and Table Head groups. The lower white marble prospects occur in the Berry Head formation; the stylolitic grey marble occupies a large area within the upper half of the Catoche Formation

This project is partially funded by the Canada−Newfoundland Cooperation Agreement on Mineral Development (1990-1994); project carried by Geological Survey Branch, Department of Mines and Energy, Government of Newfoundland and Labrador.

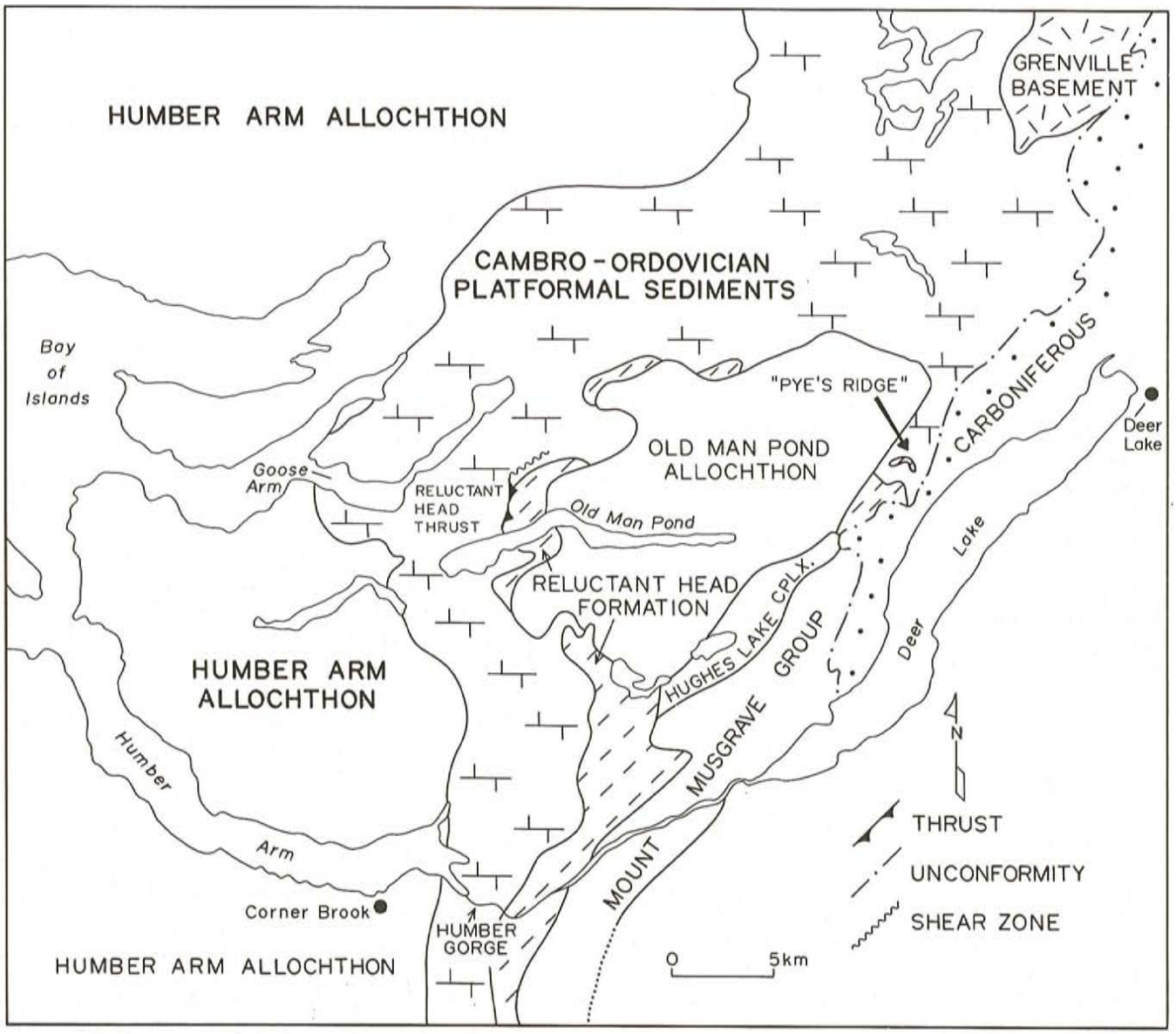

Figure 1. *Geology of the Humber Arm–Deer Lake area showing the main geological units and the location of 'Pye's ridge'. Modified from Williams and Cawood (1989).*

of the St. George Group; the ivory marble is the Costa Bay member of the Catoche Formation.

STRATIGRAPHY

CAMBRIAN

Unit 1: Pelite–Psammite

The structurally lowest and presumably oldest rocks exposed in the area consist of green pelites having thin leaves of quartz psammite (Plate 1). They occupy only a few small outcrops that include in two instances the cores of eye folds in lowland to the southwest of the ridge (Eighth Brook area). The unit is probably a distal siliciclastic shelf-facies equivalent of the Hawke Bay Formation and hence of late Early Cambrian to early Middle Cambrian age.

Unit 2: Ribbon Limestone–Phyllite

Silvery-grey to dark-grey phyllites and blue-grey, thin-bedded, dolomitic ribbon limestones overlie the green pelitic unit (Plate 2). It is widely developed and occupies the foot of the slope at the southwest end of 'Pye's ridge' and much of the land around Eighth Brook. It also occurs in a narrow zone trending east-west across the middle of 'Pye's ridge' where it forms the hanging wall sole of the 'Pye's ridge' thrust. The unit is lithologically comparable to the Middle Cambrian Reluctant Head Formation that occurs extensively in the Reluctant Head Thrust at the west end of Old Man Pond (Knight and Boyce, 1991).

Although the unit is strongly deformed internally, the overall upward trend appears to be one of phyllite to

carbonate. Silvery-grey and dark-grey phyllites form beds up to 1 m thick in lower parts of the formation and are intercalated with phyllite beds up to 40 cm thick that include thin beds and ?laminations of limestone. Locally, some limestone beds are grainy and others comprise intraformational rudstone. Quartz–calcite–siderite veins are common. In the middle of the formation, the phyllite and limestone occur in roughly equal proportions to each other, forming units up to 1 m or more of interbedded thin beds of ribbon limestone and phyllite. Beds of thinly stratified grainstone, intraformational lime conglomerate and dolostone, reaching 30 to 40 cm thickness also occur. Some grainstone beds are graded with crosslamination at the top. Toward the top of the formation, phyllite is mostly restricted to partings within very compact, thin-bedded limestone. Some of the limestone beds possess a nodular texture. A transition into the overlying dolomite unit is marked by interbeds of ribbon limestone and argillaceous dolostone having limestone lumps, dolostone and intraformational limestone conglomerate. At the same contact within the upper thrust slice, ribbon limestone is dolomitized between thick dolostone beds.

The true thickness of the formation cannot be estimated although structural cross-sections indicate a thickness of approximately 250 to 350 m.

Unit 3: Dolomite Marble

The lower dolostone unit generally comprises thick beds of pale, buff- to yellow-weathering, finely crystalline, structureless, sparcely stylolitic, pale-grey dolostone. Locally, crossbeds and crosslamination are discernable with carbonate grains (now recrystallized) visible. Some beds exhibit thin stratification and locally, some brown-weathering, thinly stratified argillaceous dolostone occurs. Rounded, coarse-grained quartz sand occurs in the middle part of the dolostone, and the upper part of the dolostone unit (subunit 3a) is marked by abundant white to black chert nodules and irregular to folded quartz veins. Toward the top, the dolostones are cleaner and include brown-weathering, massive, cream dolomite marble of fine, massive texture. These characteristics suggest that the dolostone consists of strata equivalent of both the Petit Jardin and Berry Head formations. The latter comprises the cherty dolostones which, in sections at Goose Arm and in the Reluctant Head thrust slice, occupy the lower two-thirds of the formation.

The thickness of the dolomite marble is estimated structurally to range between 250 and 500 m.

Unit 4: Lower Limestone–Dolomite Marble

This unit is characterized by white, ivory, very pale blue-grey, very pale-grey to blotchy off-white and pale-grey limestone marble, yellow-weathering dolostone and carbonate conglomerate or breccia; pink colouration is also locally developed. The unit is extensively developed at the top of the lower thrust slice and is repeated in the upper thrust slice.

The succession from the base upward is as follows–1) interbedded white marble and dolostone; the marble frequently passes laterally into a pure, creamy, massive dolomite marble; 2) limestone conglomerate–breccia (Plate 3) comprising both marble and lesser dolostone blocks in a fine-grained, phyllitic carbonate matrix (1 and 2 combine to form subunit 4a); 3) dominantly white to ivory marble with thin dolostone beds; and 4) off-white, pale blue-grey, pale-grey and some dark-grey marble and interbedded dolostones.

Within this succession, the sedimentary fabrics still preserved include stromatolite mounds, crossbedding, burrow fabrics, parted carbonate, stylolitic bedding, thin stratification and lamination including mudcracks in dolostone beds. White stylolitic marble having phyllitic partings are probably recrystallized peloidal grainstones, which are commonly pale-coloured in less-deformed thrust slices in the Goose Arm area to the west. These characterisistics indicate that the succession is upright. Blotchy grey and off-white marble are probably recrystallized crypt-microbial mounds. Some thicker dolostone beds include interstratification of lamination and intraclastic grainstone–rudstone. These sedimentary features and the interbedded nature of the marble and dolostone, plus the stratigraphic position of the unit above massive dolostones, suggest that the unit is equivalent to the transition at the top of the Berry Head formation mapped at Goose Arm (Knight and Boyce, 1991). The unit attains a thickness of about 200 m.

The limestone conglomerate–breccia (Plate 3) (part of subunit 4a) comprises white marble and yellow-weathering, cream dolomite marble blocks that are mostly massive but also include stylolites and thin stratification. The matrix is dolomitic containing minor white and green micas. Although subunit 4a reaches a thickness of 30 to 50 m, the conglomerate is less extensive and perhaps no thicker than 5 to 10 m. Also, it is not always developed, and locally, in the upper thrust slice, as in the 330 m hill, it is associated with only very thin white marble, and appears instead to be associated with grey and some off-white marble interbedded with dolostone. The explanation for this variation may reflect the origin of the conglomerates. Although they may be channelized resedimented gravity or waterlain deposits, the poor sorting, uneven distribution and varied stratigraphic association suggest that they are metamorphosed interstratal collapse breccias, like those that are common in the autochthonous sections of western Newfoundland (Knight, 1978; Knight and Cawood, 1991).

ORDOVICIAN

Ordovician strata are typified by a thick succession of dominantly dark-grey to light-grey lime marbles having various proportions of dolomite marble overlain by a unit of slate and carbonate. Six rock units are delineated: lower dark-grey marble; varicoloured marble; middle dark-grey marble; ivory marble; upper dark-grey marble, and dark-grey phyllite with marble. This succession is correlated with the carbonates of the St. George and Table Head groups and the flysch of the Goose Tickle Group.

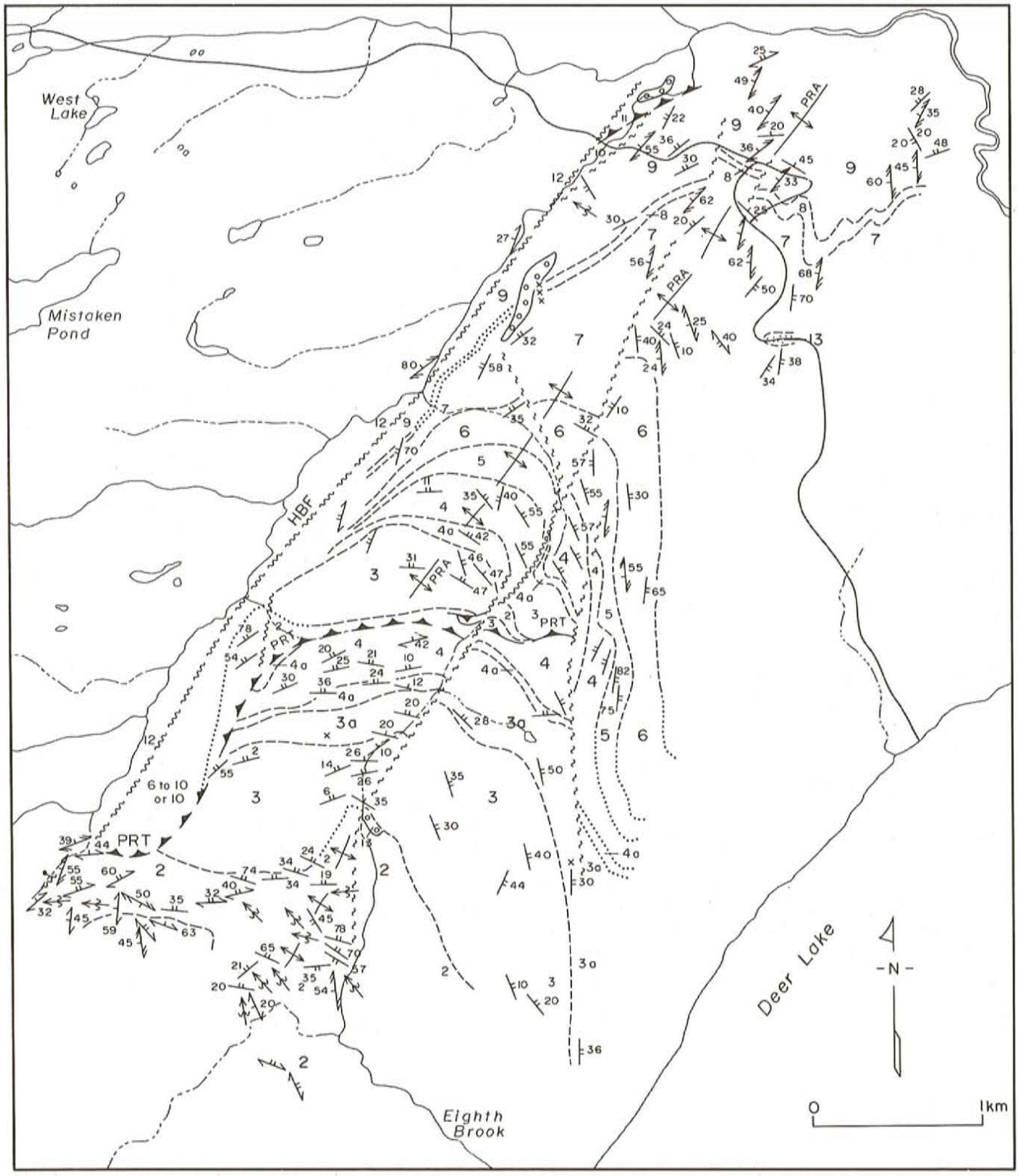

Figure 2. *Geological map of 'Pye's ridge' and adjoining areas.*

LEGEND (for Figure 2)

CARBONIFEROUS

13 *Grey conglomerate–breccia, red conglomerate, sandstone and siltstone*

?PRECAMBRIAN–CAMBRIAN

OLD MAN POND ALLOCHTHON

12 *Psammite and pelite*

?ORDOVICIAN

11 Melange

MIDDLE ORDOVICIAN

GOOSE TICKLE GROUP

10 *Dark-grey phyllite with marble; grey phyllite, thin-bedded and conglomeratic limestone and dolostone*

TABLE HEAD GROUP

9 UPPER DARK GREY MARBLE *Thick-bedded, massive dark-grey to grey limestone; cyclic with fenestral fabrics and rare dolostone at the base*

LOWER ORDOVICIAN

ST. GEORGE GROUP

8 IVORY MARBLE *Ivory- to white-coloured, thinly bedded marbles having green, dark-grey and dolomitic, stylolitic partings; minor dolostone beds at the base*

7 MIDDLE DARK GREY MARBLE *Burrow-dolomite-mottled, thick bedded and stylolitic*

6 VARICOLOURED MARBLE *Vari-grey to white, burrow-mottled, mounds, dololaminite*

5 LOWER DARK-GREY MARBLE *Thick-bedded, burrow-mottled, mounds*

CAMBRIAN

PORT AU PORT GROUP

4 LOWER LIMESTONE–DOLOMITE MARBLE *White, blue to light-grey marble, dololaminite, mounds, crossbedded;* **4a,** *conglomeratic*

3 DOLOMITE MARBLE *Light-grey to cream, massive, thick bedded;* **3a,** *cherty in upper part*

2 RIBBON LIMESTONE–PHYLLITE *Blue-grey, thin-bedded marble having phyllite and dolomitic beds and partings; some grainy and conglomeratic beds*

LABRADOR GROUP?

1 PELITE AND PSAMMITE *Green-grey to grey pelite having white psammite laminae*

SYMBOLS

Bedding, tops known, unknown

Co-planar bedding-cleavage; schistosity

Cleavage, D_1, D_2

Thrust fault

High-angle fault, dip, downthrow

Fold axes, anticline, syncline

Minor folds, plunge, upright to inclined axis, recumbent to reclined

30 *Lineation, plunge*

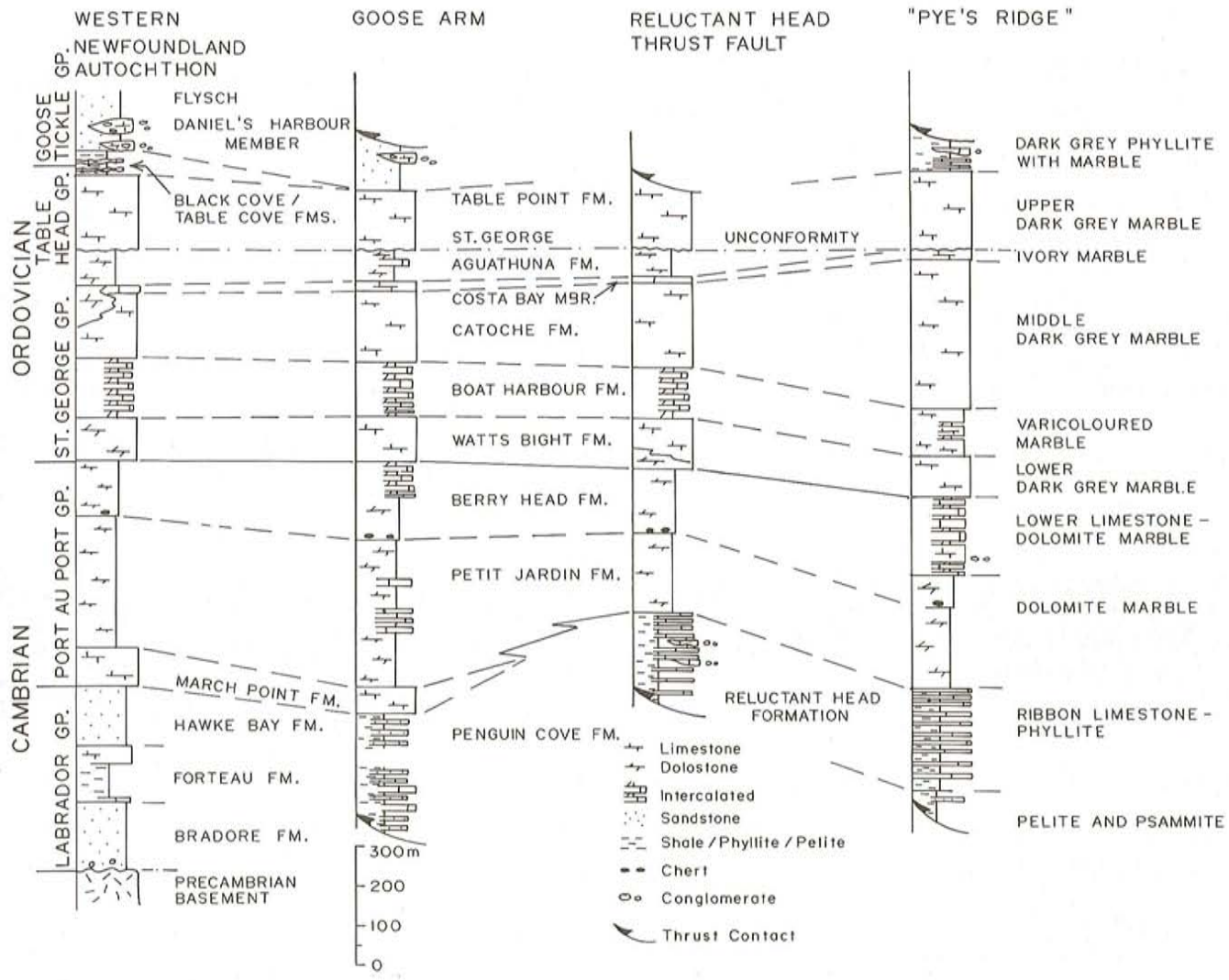

Figure 3. *Comparative stratigraphy of 'Pye's ridge' with that of western Newfoundland autochthon, and the parautochthonous successions of the Goose Arm area and Reluctant Head thrust, Old Man Pond. Based upon Knight (1991),* this report, *unpublished data and Knight and Boyce, (1991).*

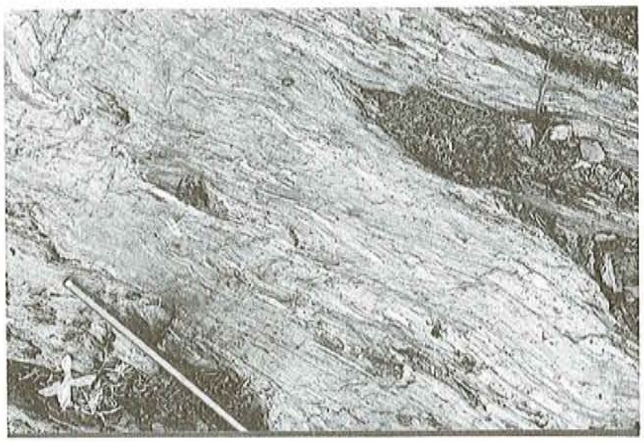

Plate 1. *Intensely deformed pelite and psammite (Unit 1) with rootless psammite folia flattened and folded parallel to the schistosity. Southwest end of 'Pye's ridge'.*

Unit 5: Lower Dark-Grey Marble

Unit 5 consists of approximately 125 m of thick-bedded dark-grey and grey marble interbedded with thin dolomite beds. The marble is characterized by mottle fabrics accentuated by dolomite. These indicate that the original rocks were bioturbated limestone (Plate 4) and microbial mounds. This unit is correlated with the Watts Bight Formation of the St. George Group.

Unit 6: Varicoloured Marble

This is a poorly exposed, 150-m-thick unit of varicoloured lime marble and rare dolomite. Most of the unit is medium to light-grey having whitish streaks and dolomite partings. Original fabrics are obliterated by metamorphism. The unit is correlated with the Boat Harbour Formation of the St. George Group.

Plate 2. *Banded limestone of Unit 2 with phyllitic and dolomitic bands. A thicker limestone layer is boudinaged and the trace of S_2 cleavage can be seen dipping steeply to the left. Hanging wall of the 'Pye's ridge' thrust near location 7 (Figure 4).*

Plate 3. *Limestone conglomerate* (arabescato) *in the lower part of Unit 4, lower thrust slice, location 1 (Figure 4).*

Plate 4. *Dark-grey marble showing inhomogeneous deformation. Dolomitized burrows are present in the less-deformed bed (upper right), which structurally overlies a strongly flattened marble (lower dark-grey marble, upper thrust slice).*

Plate 5. *Grey to off-white, stylolitic marble from the middle dark-grey marble unit on the south side of 'Pye's ridge'. Location 5, Figure 4; photograph courtesy of Jamie Meyer.*

Unit 7: Middle Dark-Grey Marble

This extensively developed unit underlies most of the middle part of the ridge. The marble has dolomitized burrow fabrics and bedding-parallel dolomite seams. Nodular, dolomitic blue-grey marble and blotchy grey to light-grey marble, originally microbial mounds possibly, are also common. Black chert nodules are also present, locally, in the middle part of the formation. Stylolitic grey marble (Plate 5) that occurs in the upper part of the unit underlies an extensive part of the southern slope of the ridge. The stylolites are dark-grey to black. The unit attains a thickness of at least 375 m. This is at least twice as thick as the equivalent unit elsewhere in western Newfoundland.

Unit 8: Ivory Marble

This unit, approximately 20 m thick, is ivory to white with green stylolitic seams and partings reflecting the presence of micas. Off-white to white marble having a dark-grey to black stylolitic seam marks the unit as it is traced to the east. Colour locally varies through pinkish to yellowish white. One locality, in a cutover exposing the unit on the northeast limb of the anticline, displays salmon pink and black nodular marble. Dolomite beds up to 20 cm thick occur in lower part of the unit. Angular, centimetre-thick dykes filled by rusty-weathering dolostone cut the ivory marble in some outcrop.

The middle dark-grey marble and the ivory marble are correlated with the Catoche Formation, St. George Group. The ivory marble is stratigraphically and lithologically identical to the Costa Bay member of the formation. The presence of abundant stylolites and its thick, uniform development below the Costa Bay member suggest that the original lithology at the top of the dark-grey marble was a grey peloidal or skeletal grainstone similiar to that described in the Catoche Formation in the Pistolet Bay area throughout the Northern Peninsula (Knight, 1977, 1991; Lane, 1984). The lack of an overlying unit of dolostone suggests that the Aguathuna Formation correlatives were either not deposited

or were eroded before the deposition of the overlying carbonate units. Regional stratigraphic evidence such as the thick development of the Aguathuna Formation in the nearby Goose Arm–Old Man Pond area and the presence of dolostone-filled fissures cutting the ivory marble in the map area suggest that there is a marked erosional disconformity at the top of the unit. This sequence boundary is known throughout Newfoundland as the St. George Unconformity (Knight *et al.*, 1991).

Unit 9: Upper Dark-Grey Marble

The uppermost marble unit, which attains about 200 m in thickness, underlies the northeastern-most part of 'Pye's ridge'. Uniform in colour, they consist mostly of dark-grey to grey-cleaved limestone marble having few distinctive features. Cliffs of the marble indicate that bedding is massive and thick but for the most part the marble is intensely veined and sheared especially in its upper part.

Cyclic carbonates mark the basal part of the formation. They outcrop in cutovers just east of the main track across the northeast termination of 'Pye's ridge'. They consist of thick beds of thin stylo-bedded grey limestone marble, overlain by light-grey marble, characterized by white calcite-cemented tubular burrows, in turn overlain by light-grey limestone having white laminar fenestral fabrics. These rocks are also associated with nodular, dolomitic blue-grey marble. Such rocks are characteristic of the Spring's Inlet member of the Table Point Formation (Ross and James, 1987; Knight, 1991) and help to confirm that the upper dark-grey marble is equivalent of the Middle Ordovician Table Point Formation, Table Head Group.

Unit 10: Dark-Grey Phyllite and Marble

At the foot of the northwest slope of the ridge close to 'Helen's brook', a few outcrops of grey phyllite having a well-developed slaty cleavage occupies a structural wedge between the upper dark-grey marble to the south and the faulted boundary with the Old Man Allochthon to the northwest. A single band of recrystallized, dark-grey limestone, dolostone and phyllitic dolostone is intercalated with the phyllites. Each carbonate lithofacies forms units 2 to 5 m thick. The limestone is massive containing folded stylolitic seams. The dolostone is rusty-yellow-weathering, and cut by numerous white quartz veins and quartz–salmon-pink feldspar veins. The phyllitic dolostone is thinly planar stratified and picks up a well-developed cleavage in more phyllitic stratum.

The actual age and correlation of this unit is problematic, but based upon comparisons with rocks outcropping just beneath the Humber Arm Allochthon west of Old Man Pond, it belongs to the Goose Tickle Group. The phyllites were originally shaly flysch of the American Tickle Formation and the carbonates may belong to the Daniel's Harbour member of the same formation (Stenzel *et al.*, 1990).

MELANGE

Unit 11 occurs along 'Helen's brook' in one small area at the north end of the ridge where it overlies structurally, sheared marbles of Unit 9. It consists of polydeformed green-grey and blue-black phyllites with carbonate lenses, disarticulated green-grey, very fine-grained psammite and quartz–carbonate veins.

OLD MAN POND ALLOCHTHON

Unit 12: Old Man Pond Group

Chlorite grade metasedimentary rocks of the Old Man Pond Group outcrop to the northwest of the 'Helen's brook' fault. They include polydeformed pelites and psammites of Cambrian age and older and are not discussed here further.

CARBONIFEROUS

Unit 13: North Brook Formation, Deer Lake Group

Carboniferous sediments occur in two settings: 1) as conglomerate, breccia, sandstone and siltstone overlying unconformably both Paleozoic carbonates and the Old Man Pond Group; and 2) as cave sediments and precipitates principly developed along faults. The presence of these sediments scattered around 'Pye's ridge' indicate that the present topography is essentially an exhumed Carboniferous landscape.

1) Sedimentary Rocks

Remnants of grey, calcareous carbonate breccia and conglomerate occur at several places fringing Pye's ridge. In the south of the ridge flanking Eighth Brook, breccias (Plate 6) comprising locally derived dolomite and lesser marble set in a slightly arenaceous, calcareous matrix lie against an angular Carboniferous paleo-hillside carved out of Unit 3 dolomite. Of special significance in the breccia are the presence of white, fine-grained rhizoliths (Plate 6) (Esteban and Klappa, 1983). The rhizoliths include rhizoconcretions and root petrification and combinations of both. The best examples are stout elongate concretions with root and rootlet tubules well preserved in the circular cross-sections. However, they also occur in the matrix as fine tubules, thin sheets or irregular clots locally attached to the underside of carbonate clasts.

The breccias appear to be a metre or so in thickness and are onlapped by red, friable, small-pebble conglomerate and sandstone that is seen throughout the Eighth Brook area as blocks and weathered rubble as high as 150 m up the present hillside.

Grey calcareous conglomerate also occurs at the bottom of and high on the upper-valley slopes (150 m) of 'Helen's brook'. The conglomerates are several metres thick and consists of locally derived marble clasts 10 to 40 cm in diameter. Almost flat-lying, red-brown, micaceous siltstone and some friable, crossbedded and crudely stratified sandstone occur in pockets along the south slopes of 'Pye's ridge'. These sediments belong to the North Brook Formation of the Deer Lake Group (Hyde, 1979).

Plate 6. *A grey carbonate breccia of Carboniferous age containing angular dolomite marble clasts set in a green-grey calcareous matrix. A long white rhizolith is indicated by an arrow; beside wood road climbing Eighth Brook to the crest of 'Pye's ridge'.*

2) Cave Deposits

Small cave deposits are located along 'Helen's brook' fault and the western, northeast-trending fault that traverses the crest of 'Pye's ridge' (Plates 7, 8 and 9). At 'Helen's brook', several caves (Plate 9) occur at the contact of marble and phyllite and along minor faults that splay off the 'Helen's brook' fault. The caves are up to 30 cm wide and 1.5 m long and are filled by red argillaceous limestone that is either massive or has discordant, stratification. Cave walls are smooth to solution sculptured.

Plate 7. *Botryoidal calcite flowstone with brown, ?dolomitic, banded crust lining the walls of a Carboniferous cave developed along a northeast-trending fault at the crest of 'Pye's ridge'.*

Several cave deposits occur along a 2 km length of the western fault that strikes across 'Pye's ridge'. The caves are narrow, generally less than 30 cm wide and locally can be followed for several metres along the fault zone. Unlike the 'Helen's brook' caves, these caves contain well-developed calcite speleothems that include globular botroyidal forms (Plate 7) having a distinct internal banding, sheeted flowstone

Plate 8. *Fragments of flowstone (short arrow) incorporated in green to red cave sediment. The Carboniferous cave sediment is faulted (long arrow) and deformed by sinistral shear.*

Plate 9. *Red Carboniferous cave fills (arrows) along small faults and fractures that occur in the footwall carbonates of the 'Helen's Brook' fault (location 11, Figure 4).*

that is commonly brecciated and locally incorporated in later cave sediments (Plate 8), and cave pisolites or pearls. In some instances where the cave has dolomite walls, the precipitates are buff-weathered, suggesting a magnesium and possibly ferruginous composition. Cave sediment includes buff- to red-coloured, fine-grained carbonate silt locally enclosing speleothem fragments and carbonate gravel. The latter is locally sheared in one cave (Plate 8). Wall rock is commonly reddened for several metres from the faults and caves.

STRUCTURE

The carbonates underlying 'Pye's ridge' are polydeformed (Figure 2). The main structures are the 'Pye's ridge' thrust (PRT), the 'Pye's ridge' anticline (PRA) and the 'Helen's brook' fault (HBF). The PRT outcrops midway along the ridge, repeating the Cambrian part of the succession. The PRA is a northeast-trending and plunging fold that disposes the broad structure of the ridge and folds the PRT. The HBF is a high-angle normal fault that forms the northwest contact of the carbonate sequence with metasedimentary rocks of the

Old Man Pond Allochthon to the northwest. A number of northeast-trending faults, with complex displacement history, traverse the length of the crest of the ridge.

THRUST FAULTS

'Pye's Ridge' Thrust

The PRT carries ribbon limestone and phyllite of Unit 2 over locally recumbently folded and foliated marbles of the interbedded limestone-dolomite marble (Unit 4). At the crest of the PRA, the thrust is gently dipping to the north (attitude based upon foliated footwall marbles just below the thrust plane). The thrust, however, seems to cut up section as it is traced north and south across the ridge. To the north, it swings southwest and steepens to 60°, juxtaposing hanging wall and footwall dolomites (both Unit 3) against one another. Its dip shallows as it swings west to intersect with the northeast-trending HBF. In this westernmost area, the footwall is Unit 2 ribbon limestone and phyllite whereas the hanging wall, although concealed in low boggy ground with no outcrop, is surmized as marbles of Unit 6 and younger, or may be Unit 10 grey phyllite and marble. Unit 3 dolomite forms the hanging wall above footwall rocks of Unit 4 as the PRT is traced southward over the crest of the ridge before it is truncated by a northeast-trending reverse fault.

Thrust zones are characterized by complex structural relationships. The sole of PRT's hanging wall is marked by a well-developed phyllite–limestone marble banding. It is uncertain whether this banding is original bedding or tectonic in origin. This is because in the Goose Arm area such banding is frequently related to transposition of bedding that is almost indistinquishable from the original bedding (Knight and Boyce, 1991). Small-scale folds having a westward and locally eastward sense of vergence and axial planes co-planar with the banding suggest a tectonic origin. Recumbent folds having a west sense of vergence, bedding co-planar S_1 foliation, and a stretching lineation occur in footwall marbles. Locally, the lineation pitches 36° northwest at 320 to 330°.

Evidence of Other Thrusts

Intensely deformed ribbon limestone and phyllite (Unit 2) and pelite–psammite (Unit 1) at the southwest end of 'Pye's ridge' suggest a subcropping thrust below the ridge. In this area, a west-trending, northward-dipping mylonitic foliation occurs in Unit 1 where psammitic folia are deformed as rootless intrafolia folds (Plate 1). Folded psammite and pelite in low-strain zones in the mylonite indicates west-verging compressive stress. Unit 1 also cores small, outcrop-sized, boomerang-shaped interference fold patterns within Unit 2 west of Eighth Brook. Complex folding of banded phyllite and ribbon limestone occurs in the same area. Small-scale, tight, isoclinal, recumbent folds folded by D_2 folds are common. The banding folded by these isoclinal structures, however, may not be bedding but transposition bedding, suggesting that at least multiple phases of deformation produced the D_1 fabric. The presence of associated sheath folds supports this hypothesis. Decametre-scale recumbent folds are also common (Plate 10).

Plate 10. *Polydeformed limestone and phyllite of Unit 2 at the southwest end of 'Pye's ridge'. A recumbent fold closure containing the j-shaped eye of an earlier fold occurs to the left of the hammer. The hammer is parallel to a foliation that is axial planar to the second-phase recumbent fold. S_2 and F_2 folds are deformed by a F_3 fold associated with a cleavage (arrow) that dips into the hill and to the right and has a right-handed sense of shear.*

A third thrust is likely at the northeast end of the ridge in the vicinity of North Brook. Dark-grey marbles of the upper part of Unit 9 in this area carry a prominent, generally shallowly dipping shear fabric, which is folded by D_2 folds and offset by D_3 fractures. Reconnaisance of this area and the ridge to the northeast of 'Pye's ridge' suggests that stratigraphy, including at least the ivory marble (Unit 8) and above, is repeated in the hanging wall of the thrust. Structural wedges of Unit 11 melange structurally overlie the marble in the footwall of the postulated thrust.

Although the sense of vergence and direction of lineations suggest west- to northwest-directed thrusting, the complexity of structure in the thrust zones makes this conclusion tentative. However, it is supported by a small-scale horse structure (Plate 11) recognized in thin-bedded marble of Unit 4 in the hanging wall of the PRT that clearly indicates a northwestward sense of shortening.

FOLDS

The 'Pye's ridge' anticline is one of two folds that deform the sequence as a whole. Both are northeast-trending and plunging folds associated with moderately northwest-dipping cleavage. Locally, the southeast limb of the PRA is overturned. A related syncline occurs in the northeast corner of the map area. It is mostly truncated and obscured by Carboniferous and recent sediment cover as it is traced southwest along the southern side of the ridge.

FAULTS

Two northeast-trending faults that dip at 55 to 71° northwest, traverse the crestal area of the anticline. The

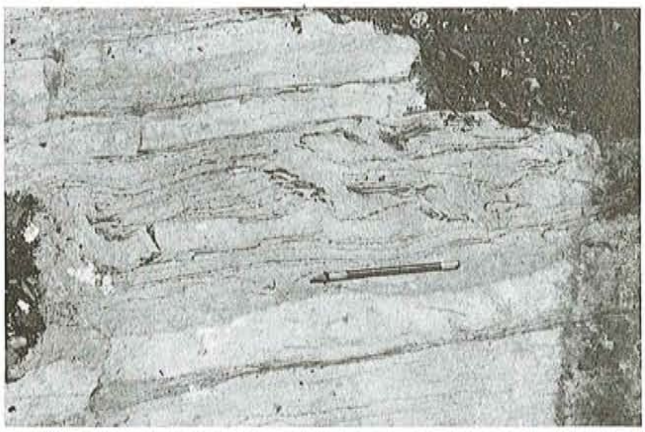

Plate 11. *Small-scale horse structure developed in sheared off-white marble of Unit 4. The sense of thrusting is to the northwest (left of photograph); near location 3 of Figure 4.*

Plate 12. *Mylonitic shear zone developed in the hanging wall of a northeast-trending fault cutting the crest of the 'Pye's ridge' anticline. The fault plane is in the lower part of the plate. En-echelon and irregular calcite veins cut the foliation; Near location 13, Figure 4.*

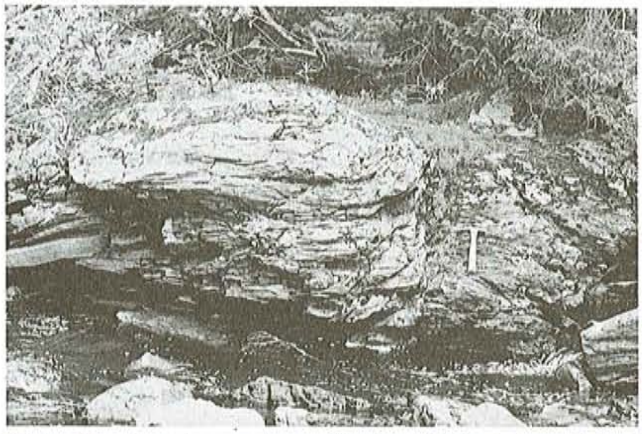

Plate 13. *Steeply northwest-dipping 'Helen's brook' fault (left of hammer), 'Helen's brook'. Psammites and pelites of the Old Man Group have a flat-lying schistosity deformed by normal-sense drag folds and C–S fabrics. The footwall consists of Unit 10 phyllites.*

western fault is characterized by a hanging wall shear zone several metres wide (Plate 12). Footwall dolomites are strongly shattered. To the southwest, the shear zone passes into a brecciated zone that is overprinted by red colouration and postdated by Carboniferous cave deposits that are locally deformed by sinistral displacement (Plate 8). Drag folds on this fault indicate reverse motion but present disposition of units across the fault is more compatable with normal displacement. This is reflected in the numerous small-scale indicators such as small folds, C–S-like fabrics and rotated boudins indicate that the main sense of movement across the shear zone is dextral, or down dip. Locally, some small folds and C–S fabrics also give a sinistral sense of shear. The order of movement is not presently understood. Several sets of dilation fractures occluded by calcite cut the shear foliation. Some of these structures give a sinistral sense of movement. The eastern fault has a narrow 40-cm shear zone and dextral sense of shear.

'Helen's Brook' Fault Zone

The 'Helen's brook' fault strikes 225° and dips 70° northwest (Plate 13). It seperates Old Man Pond Group from sheared upper dark-gray marble and phyllite of Unit 10. The psammites and pelites of the Old Man Pond Group have an early schistosity that is axial planar to recumbent folds. They are also cut by a later crenulation cleavage and are folded about north- to northwest-trending axes. Close to the fault, S_1 schistosity is cut by fault-related fractures striking 210° and dipping 35° west. They displace the schistosity and indicate a normal sense of shear.

Footwall rocks also suffered several deformations. Marbles have a steeply dipping foliation that locally, in the southern part of the fault zone, strikes 214 to 245° and dips west at 31 to 52°. The variation in strike is attributed to faults that splay off the HBF at 250 to 255° strike and dip 54 to 60° northwest. They repeat the contact of the foliated marble and the overlying Unit 10 phyllite with marble. Sense of displacement on these splay faults is reverse. Fabrics in the foliated marble and the overlying phyllites are discordant to each other by 90°, suggesting that their pre-faulting relationship is structural not stratigraphic. The marble foliation is associated with a steeply dipping stretching lineation that plunges at 51° and trends 326°. Late fractures cutting the phyllite and marble trend 230°, dip west at 51° and have a sense of shear compatable with normal displacement on the HBF. Similiar structural relationships occur in a number of outcrops of upper dark-grey marble and Unit 10 phyllites in the north of the fault zone.

OTHER STRUCTURES

Kink bands trending 232° and dipping at 42° northwest are rare in the marble of Unit 4. Numerous small calcite- and quartz-filled dilation fractures occur throughout the succession but are not described here.

INTERPRETATION OF THE STRUCTURAL HISTORY OF 'PYE'S RIDGE'

Three main phases of deformation effect the sequence. The first is related to thrusting with zones of high-ductile strain, developed particularly in Units 1 and 2. Complexity of structures and fabrics in these zones indicate that they hide multiple deformation themselves. Stratigraphic relationships associated with the PRT suggest that it structurally transgresses stratigraphy and was probably a ramp.

Although only the PRT is mapped, a lower thrust is postulated to occur below the ridge. In addition, reconnaisance of the northeastern end of 'Pye's ridge' and the adjoining ridge to the northeast suggests that there is another thrust between the ridges. This thrust duplicates the upper part of the carbonate sequence and overlying flysch by overthrusting the Ordovician rocks and melange of the northeast end of 'Pye's ridge'. A widely developed early foliation and mylonitic fabric deformed by later structures in the top of Unit 9, and in Unit 10 along the northwest side and northern end of the ridge, indicate that a thrust or thrusts occur above the upper thrust slice of the ridge. In one case, melange structurally overlies sheared, upper dark-grey marble in the north of the ridge suggesting that this relationship may in part be related to emplacement of the allochthons above the platform sequence. Discordant structural relationships between phyllite (originally flysch) of Unit 10 and Unit 9 marbles also indicate décollement between the platform and overlying flysch.

These structural relationships imply an imbricated thrust stack assembled during or after the emplacement of the allochthons. The structural fabrics of the polydeformed metasedimentary rocks of the lower thrust slice indicate polydeformation during thrusting but whether this relates to Taconian allochthon emplacement or to later Acadian shortening of an already assembled package is yet to be resolved. If the allochthon is the hanging-wall plate, the underlying disrupted autochthonous sequence may be imbricated as part of a duplex structure. In this situation the 'Pye's ridge' anticline could have formed as a hanging-wall anticline to a ramp below the lower thrust.

However, southeast-verging, northeast-trending folding and cleavage is thought to be a second phase of deformation. This is suggested by the folding of the PRT and by the presence of several scales of interference fold patterns that appear to postdate the thrustal shortening. Northeast-trending high-angle faults having evidence of reverse displacement are probably related to this event.

The third deformation is associated with the vertical juxtaposition of the Old Man Pond Allochthon against the carbonate sequence across the HBF. It is characterized by deformation of earlier fabrics by downdip extension along fractures parallel to the fault in both hanging wall and footwall rocks. Steepening of dips in the northwest limb of the 'Pye's ridge' anticline may be related to this. Similiar down-dip extensional fabrics associated with northeast-trending faults that traverse the crest of the 'Pye's ridge' anticline are probably related to reactivation of these D_2 faults during this phase.

Minor deformation of Carboniferous cave deposits along the northeast-trending faults indicates minor brittle deformation of the sequence in Late or post-Carboniferous times. Rare kink bands may be related to these events

The three main deformations are interpreted to reflect: 1) westward-verging shortening during or following the westward emplacement of the Old Man Pond Allochthon; 2) southeast-verging backthrusting; and 3) normal sense juxtaposition of the Old Man Pond Allochthon adjacent to the Paleozoic marbles. These three phases all predate the Carboniferous.

The three deformations are comparable to the structural chronology described in the Old Man Pond area by Waldron and Milne (1991). They suggested that the structural relationships at the west end of the Old Man Pond Allochthon indicate the emplacement of Reluctant Head Formation and overlying carbonate platform above the allochthon. From the work at 'Pye's ridge', it is clear that the carbonate facies are very similiar to those described at Old Man Pond west (Knight and Boyce, 1991) and that the structural relationships in the area of the ridge show the allochthon was downdropped to occupy its present position. Knight and Boyce (1991), and reconnaisence mapping by Knight in 1991 in the Old Man Pond west area, also suggest that the Reluctant Head thrust slice is emplaced upon lower thrust slices of platform carbonates. The thrusts first verged to the west, and then were folded by east-verging structures. This is similiar to the chronology described for D_1 and D_2 structures at 'Pye's ridge'. In addition, to the south of the western end of Old Man Pond, the carbonates of the Table Head Group and overlying Goose Tickle flysch lie structurally beneath the allochthon. This indicates that the structural relationships at the west end of Old Man Pond are the result of east-verging back thrusting as suggested by Knight and Boyce (1991).

MARBLE DEPOSITS

The metacarbonates that underlie 'Pye's ridge' have a number of prospective deposits of dimension stone, some of which are currently being evaluated for commercial exploitation. Two stratigraphic intervals that provide very contrasting styles of marble are presently the main exploration targets. Unit 4 is dominated by several white varieties of marble that include a number of bodies of arabescato (Plate 3). The stratigraphic interval, which always immediately succeeds Unit 3 dolomite, is repeated by the PRT and potential dimension-stone deposits are present in both thrust slices. The other stratigraphic target is marked by grey marbles having a distinctive stylolitic pattern (Plate 5). They occur in the upper part of Unit 7 and underlie a large area along the southeastern slope of the ridge. Other attractive marbles occur in Units 2 (Plate 2), 8 and 9 and these are discussed along with marbles that have been effected by faulting and Carboniferous diagenesis to give distinctive qualities.

In general, the marbles of 'Pye's ridge' are fine to medium grained, having good crystallinity and are compact and massive. Natural structures to exploit the marbles include bedding and cleavage planes. Comparison of the 'Pye's ridge' marbles with those of Italy is based upon a recent visit to the quarries of Carrarra, the marbles exhibited at the Museo del Marmo at Carrarra and the Italian Marble–Technical Guide (Italian Institute for Foreign Trade, 1982).

WHITE MARBLE OF UNIT 4

White, ivory, pale blue-grey, light-grey and locally pink marbles occur in the unit (locations 1 to 4, Figure 4). The white varieties *(bianco)* are rarely truly brilliant white but several outcrops indicate a number of varieties are likely from white alone to white having a faint grey veining *(bianco venato)* to dappled off-white and grey, which appears to reflect the metamorphism of microbial mounds. Strongly foliated white marble (Plate 14) usually has streaky colour variation that can include folds and resembles the variety *nuvolato.* Most spectacular amongst these marbles are several bodies of *arabescato* (Plate 3). This is a marmorized limestone conglomerate and breccia, several metres thick, that is fairly consistently mapped within a few metres of the base of Unit 4. White marble and some dolostone clasts are set in a dolomitic to calcareous matrix that has sericitic seams. Inhomogenous strain throughout the area means bodies range from almost undeformed conglomerate to conglomerates having strongly flattened clasts. The latter are common in the upper thrust slice (location 3) and also occur in the lower thrust slice where the conglomerate is recumbently folded below the PRT (location 4).

Other varieties in Unit 4 that appear attractive are the off-white marbles that retain crossbeds and a number of beds of a fine-grained, smooth pale blue-grey marble. At the base of the Unit 4, just below the *arabescato* interval, pure ivory to cream marble pass laterally into creamy dolomite marble. The latter has an uniformly fine-grain size and is very massive and hard.

GREY MARBLE OF UNIT 7

Grey marble (location 5) commonly refered to in Italian quarries as *bardiglio* is both thick (many tens of metres) and extensive along the southern slope of 'Pye's ridge'. The variety is characterized by the presence of a dark-grey to black stylolite (Plate 5) that essentially picks out bedding in the rock. The stylolites are folded at different scales and this combined with the original (pre-deformation) intersecting nature of these solution structures makes this a very attractive rock, not significantly different from *bardiglio imperial* of the Massa area, Italy. The outcrops in the area indicate metre-thick bedding and good consistency of material.

MARBLE OF UNIT 2

Marble in the upper part of Unit 2 (locations 6 and 7) is banded. They consist of blue-grey calcareous bands having thin phyllitic partings and seams. The banding varies from planar to folded with small offsets as well as fine calcite veinlets common. The unit is well developed extensively in both lower and main thrust slice and the quarryable interval is likely to exceed tens of metres.

IVORY MARBLE OF UNIT 8

This 20-m-thick stratigraphic unit is consistently developed around the PRA in the upper part of the main thrust slice. The gently to moderately dipping unit is characterized by ivory to white colouration and green, sericitic to buff, dolomitic stylolite seams parallel to bedding. Based on comparison with the equivalent unit elsewhere in western Newfoundland, the unit is likely to be quite pure especially in the middle and upper parts. A conjugate set of joints is developed in the unit around the PRA. The most interesting marble in this unit occurs in the vicinity of the synclinal closure (location 8). There the marbles are off-white, white and light-grey with a very attractive dark-grey to black stylolite, not unlike the Italian variety *uliano venato* and *calda 'D'.*

MARBLE OF UNIT 9

Although Unit 9 comprises a dark-grey marble of probable little decorative interest, modification of the unit by intense deformation has added some attractive variants. At locations 9 and 10 in the northeast of the area, several phases of shear superimposed upon black to buff, argillaceous and dolomitic stylo-bedding and burrow fabrics have created an impressive *bardiglio scuro* (Plate 15). To the imaginative eye, the textures are reminisant of dense leafy foliage blown by a gale. Retention of light-grey to white burrow and fenestral fabrics in grey marbles in the basal cyclic part of Unit 9 are similiar to *bardiglio nuvolato* from Carrarra, Italy and will require additional assessment.

OTHER MARBLE

Marbles preserved close to the HBF along the northwestern side of 'Pye's ridge' are commonly characterized by a strong foliation that verges on a mylonitic fabric. The resulting varieties of marble vary in colour from off-white to dark-grey but all have the resemblence of the Italian variety *striato* (locations 11 and 12). Strongly sheared grey marble cut by an abundance of white calcite veins is common along stretches of the hanging wall associated with the northeast-trending fault that strikes along the crest of 'Pye's ridge'.

PINK MARBLES, VEIN AND BRECCIA MARBLES ASSOCIATED WITH CARBONIFEROUS OVERPRINT OF FAULTS

These marbles are best developed close to the western northeast-trending fault that intersects the marbles at the crest of 'Pye's ridge' (location 13). Hanging-wall rocks in the area are commonly red to pink in colour and vary from intensely foliated and veined varieties to those that are brecciated. The

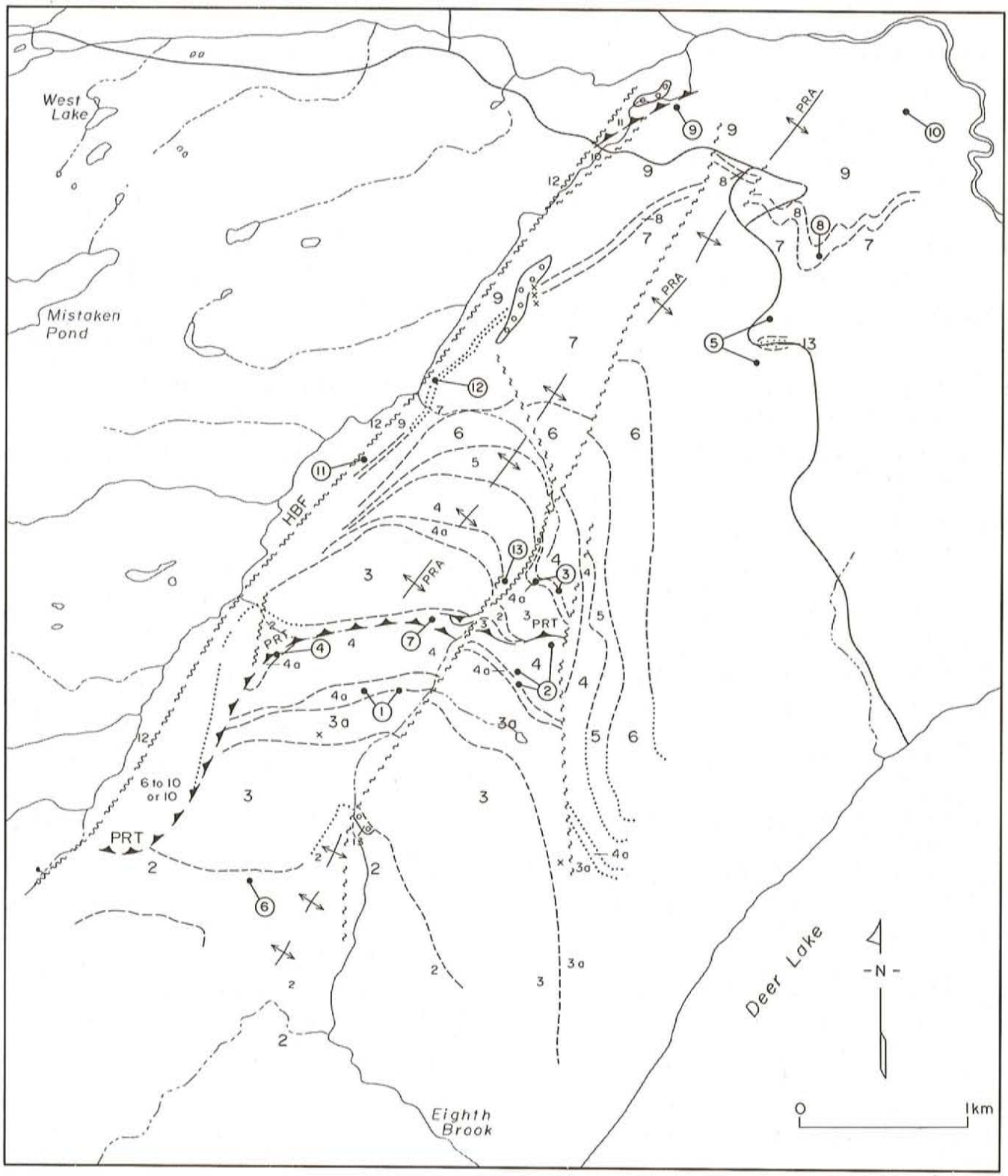

Figure 4. *Location map of marbles described in the text.* • *location of marble deposit.*

LEGEND (for Figure 4)

CARBONIFEROUS

13 *Grey conglomerate–breccia, red conglomerate, sandstone and siltstone*

?PRECAMBRIAN–CAMBRIAN

OLD MAN POND ALLOCHTHON

12 *Psammite and pelite*

?ORDOVICIAN

11 Melange

MIDDLE ORDOVICIAN

GOOSE TICKLE GROUP

10 *Dark-grey phyllite with marble; grey phyllite, thin-bedded and conglomeratic limestone and dolostone*

TABLE HEAD GROUP

9 UPPER DARK GREY MARBLE *Thick-bedded, massive dark-grey to grey limestone; cyclic with fenestral fabrics and rare dolostone at the base*

LOWER ORDOVICIAN

ST. GEORGE GROUP

8 IVORY MARBLE *Ivory- to white-coloured, thinly bedded marbles having green, dark-grey and dolomitic, stylolitic partings; minor dolostone beds at the base*

7 MIDDLE DARK GREY MARBLE *Burrow-dolomite-mottled, thick bedded and stylolitic*

6 VARICOLOURED MARBLE *Vari-grey to white, burrow-mottled, mounds, dololaminite*

5 LOWER DARK-GREY MARBLE *Thick-bedded, burrow-mottled, mounds*

CAMBRIAN

PORT AU PORT GROUP

4 LOWER LIMESTONE–DOLOMITE MARBLE *White, blue to light-grey marble, dololaminite, mounds, crossbedded;* **4a,** *conglomeratic*

3 DOLOMITE MARBLE *Light-grey to cream, massive, thick bedded;* **3a,** *cherty in upper part*

2 RIBBON LIMESTONE–PHYLLITE *Blue-grey, thin-bedded marble having phyllite and dolomitic beds and partings; some grainy and conglomeratic beds*

LABRADOR GROUP?

1 PELITE AND PSAMMITE *Green-grey to grey pelite having white psammite laminae*

SYMBOLS

Bedding, tops known, unknown

Co-planar bedding-cleavage; schistosity

Cleavage, D_1, D_2

Thrust fault

High-angle fault, dip, downthrow

Fold axes, anticline, syncline

Minor folds, plunge, upright to inclined axis, recumbent to reclined

30 *Lineation, plunge*

Plate 14. *White marble showing a crenulated, yellow stylolitic fabric cut by a transposition fabric axial planar to the crenulation. Pure marble is developed in the zones of transposition. Upper thrust slice, 'Pye's ridge' near location 3, Figure 4.*

Plate 15. *A dark-grey marble (Unit 9) with well-developed shear fabric gently crenulated by obliquely dipping fractures (arrows) with a normal sense (left-handed) of shear; 'Helen's brook', north end of 'Pye's ridge'.*

latter are characterized by foliated, often off-white marble fragments cemented by a red to yellow calcite. The colouration and possibly the brecciation is Carboniferous in age. The zone attains several metres in thickness.

MARBLE DIMENSION-STONE PROSPECTS ELSEWHERE IN WESTERN NEWFOUNDLAND

LOWER PALEOZOIC MARBLES

Marbles in the Deer Lake area form part of a narrow belt that extends from Canada Bay in the north to Humber gorge near Corner Brook. This belt occupies the most easterly edge of the lower Paleozoic platform sequence. The marble belt abuts structurally against psammite and pelitic rocks of the inner domain of the Humber Tectonostratigraphic Zone of Williams (1978) in the south and the Hare Bay Allochthon in the north.

Several marble deposits occur in the Canada Bay–Coles Pond area on the Northern Peninsula (Howse, 1986, 1989) where they have been assessed for both dimension stone and industrial filler. Unlike the 'Pye's ridge' marble, those of Canada Bay are finer grained and commonly display buff to green phyllitic seams parallel to bedding. The ivory to white marbles are believed to occupy the same stratigraphic interval as those in the Deer Lake area. Zones of strongly foliated marble are also common giving a good *'striato'*-like stone. Southwest of Deer Lake, the belt should continue southwestward from the Humber gorge adjacent to the Corner Brook Lake Thrust. The stratigraphy of this area is similiar to that on 'Pye's ridge' suggesting good ground for prospecting.

CARBONIFEROUS DEPOSITS

The presence of Carboniferous cave fills along faults is likely in the southern part of the marble belt. That these deposits can be spectacular is shown by the deposit recently destroyed during construction of the Trans-Canada Highway through the Humber gorge. The deposit, which occurred along the south side and the west-central part of the gorge trended parallel to the west-flowing river, and is hosted by massive Paleozoic metacarbonate that structurally lies just east of banded phyllitic marbles of the Reluctant Head Formation. The cave fill was several metres wide and thick and was traced for tens of metres. It was characterized by a dyke of breccia (the cave fill) flanked by a zone of extensively fractured wall rock (cave wall). Breccia clasts and wall rocks are both reddened and the clasts and fractures surrounded and occluded respectively by bright white calcite cements that commonly display faint red colour banding. Well-cemented red sediment infilling open spaces also adds to the attractiveness of the stone in some cave fills of the Deer Lake area. Dimension stone quarried from similiar cave deposits figured prominently at the 1991 Marmomachine Trade Fair for dimension stone at Verona, Italy, suggesting that these types of deposits should not be overlooked and dismissed casually in the future.

ACKNOWLEDGMENTS

Frederico Bradley showed the author the marbles of the Carrerra–Massa area of Italy and he and his wife Sandra are thanked for their hospitality while visiting their fair and wonderful country.

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