

# THRUSTING OF THE LONG RANGE MASSIF ABOVE CAMBRIAN ROCKS OF THE 'JACK LADDER TRIANGLE', LOMOND AND CORMACK MAP AREAS, WESTERN NEWFOUNDLAND: STRATIGRAPHIC AND STRUCTURAL EVIDENCE

I. Knight

Regional Geology Section

## ABSTRACT

The informally named 'Jack Ladder triangle' is a triangular-shaped area on the eastern edge of the Lomond (NTS 12H/5) and the adjoining Cormack map sheets (NTS 12H/6), which hosts the most easterly hinterland of the Goose Arm thrust stack. Platformal metasedimentary rocks of Lower to Middle Cambrian Labrador and Middle to Upper Cambrian Port au Port groups, form a triangular window surrounded by uplands of Long Range Proterozoic basement. This relationship is interpreted to reflect thrusting of Proterozoic granite-dominated basement of the Long Range Massif over the metasediments. Locally, the basement rocks unconformably carry basal Labrador Group rocks. The Smelt Pond thrust at the sole of the massif is a mylonite with a strong northwestward-trending lineation carried on the foliation. Locally, the mylonite is also seen as a series of hill-capping outliers south of the main thrust. The Smelt Pond thrust is believed to be folded on a map scale around a large  $D_2$  buckle fold that involves steep inversion of the thrust along the southeastern edge of the 'triangle'.

Slate, phyllite, minor thin limestone, and ribbon metasandstones intercalated with a few metre-thick units of white meta quartz arenites of the Forteau and Penguin Cove formations of the Labrador Group dominate the Jack Ladder triangle. Locally, the basal Bradore Formation, a thin, magnetic, purple pebbly sandstone rests unconformably upon basement above the Smelt Pond thrust but has also been mapped locally beneath the thrust in one of the outliers. Limestone of the Devils Cove Member, Forteau Formation, also occurs locally in the footwall and possibly adjacent to the informally named Underground Brook shear zone. Oolitic and oncolitic limestone of the March Point Formation is widely distributed along the western edge of the triangle, where it is overlain by dolostones of the Petit Jardin Formation. Both units occur in a narrow, tightly folded and strongly deformed sliver in the immediate vicinity of the footwall to the Smelt Pond thrust, at Smelt Pond.

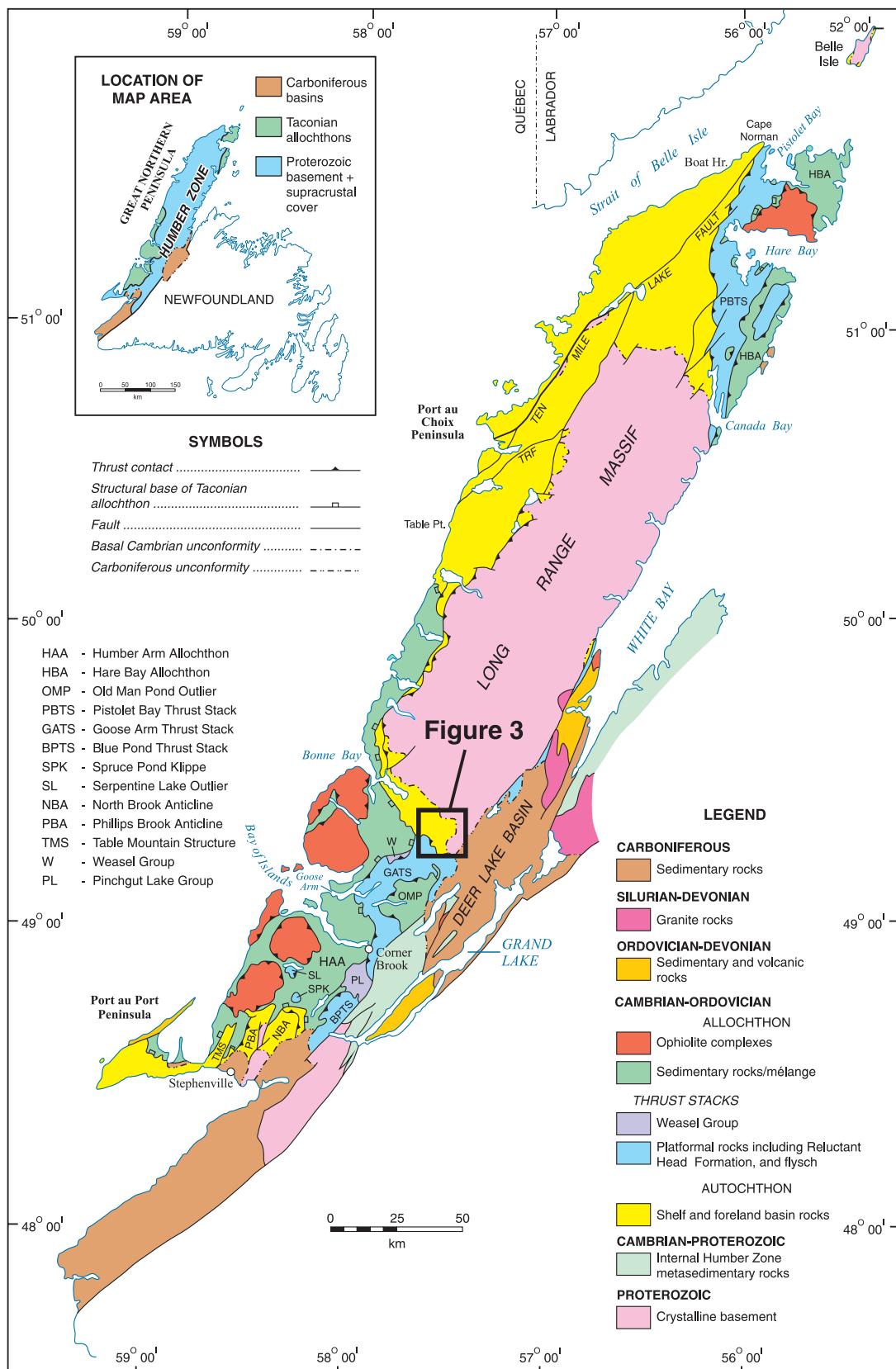
The metasediments are deformed by at least three deformations, the first, likely related to thrust emplacement to the northwest, whilst the dominant  $D_2$  structures trend northeast and verge southeast and reflect the second deformation. Strong transposition and foliation fabrics occur in the metasediments and locally can be linked to  $D_1$  as they are folded by  $D_2$  structures. Nonetheless, some zones of strong transposition and shearing may also reflect  $D_2$  events. The third deformation is marked by a faint to locally strong, crenulation lineation on  $D_2$  cleavage. This lineation is formed by a south-dipping crenulation cleavage.

A zone of intense flattening, transposition and shearing, the Underground Brook shear zone, separates highly deformed and more recrystallized rocks of the 'triangle' to the east from less-deformed and altered rocks of the lower Paleozoic shelf sequence to the west. This shear zone has yet to be interpreted.

## INTRODUCTION

The informally named 'Jack Ladder triangle' is a triangular-shaped area 20 km northwest of Deer Lake and east of the Viking Highway (Route 430). Located within the eastern edge of the 1: 50 000-scale Lomond map area (NTS 12H/5)

and the adjoining Cormack map area (NTS 12H/6) (Figure 1), the area is accessible from the highway using ATVs along old, narrow woods trails and the main Newfoundland Power transmission line and then by foot traverse. There, Lower to Middle Cambrian platformal metasediments of the Labrador and Lower Port au Port groups are surrounded by



**Figure 1.** Regional geology map of western Newfoundland showing the study area.

uplands of Long Range Proterozoic basement. The area hosts the most easterly hinterland of the Goose Arm thrust stack, a complex, polydeformed, tectonic assemblage of lower Paleozoic platform rocks that lie east of the main elements of the Humber Arm Allochthon and the Old Man Pond Allochthon and west of the Long Range (Proterozoic) Massif (Figure 1). The assembled terranes are erosionaly truncated and onlapped by Carboniferous sedimentary rocks of the Deer Lake Basin in the south. Although the northwest-verging stack comprises several thrust slices and northeast-trending folds, it is deformed by a later southeast-verging deformation that also involves northeast-trending folds, back thrusts and strongly developed, penetrative cleavage. Consequently, some of the early thrusts and their co-eval structures are inverted and folded. Only the basement rocks and Cambrian shelf metasediments within the 'Jack Ladder triangle' are discussed here.

The Jack Ladder triangle has received no detailed geological mapping since the western edge of the area was included on a 1:50 000-scale map by Williams *et al.* (1984). In the southeast along the White Hills Brook valley, the area is a mix of pond-strewn, bog and low (200 to 300 m) wooded topography underlain by phyllites. The low terrane rises northwestward from the valley up onto a northeast-trending ridge of polydeformed quartz-rich metasandstones and phyllite up to 400 m high across the middle of the area. Northwest of the ridge, a steep topography of more rounded, wooded hills cut by deeply incised valleys rise to over 250 m elevation from Bonne Bay Big Pond (164 m asl). These hills of metasediments are in turn dominated by the southern edge of the rugged, glacially sculpted Long Range Mountains, which rise to more than 600 m in the space of a kilometre. The granitic highlands are wide expanses of rock barren and low shrub separated by wooded fault-controlled valleys. Likewise, the granite basement upland southeast of the Jack Ladder triangle, here informally named the 'Long Pond finger', is a rugged, southwestward-projecting, rock barren upland terrain rising abruptly from the valley of White Hill Brook along a west- to northwest-facing fault scarp of 150 to 200 m. This jutting basement finger projects into the hinterland of the Goose Arm thrust stack where it is onlapped unconformably along its southeastern margin by the Carboniferous of the Deer Lake Basin.

## STRATIGRAPHY OF THE 'JACK LADDER TRIANGLE'

The Jack Ladder triangle is underlain mostly by slate to low greenschist-grade metasediments of the Labrador Group. Also present, though restricted mostly to the area northwest of Underground Brook, are carbonate rocks of the Port au Port Group. The stratigraphy is that used elsewhere in the area and illustrated in Figure 2 (see Knight, 2007).

## LABRADOR GROUP

The Labrador Group in the map area consists of the Bradore, Forteau and Penguin Cove formations, the latter being equivalent of the Hawke Bay Formation (see Knight, 2007).

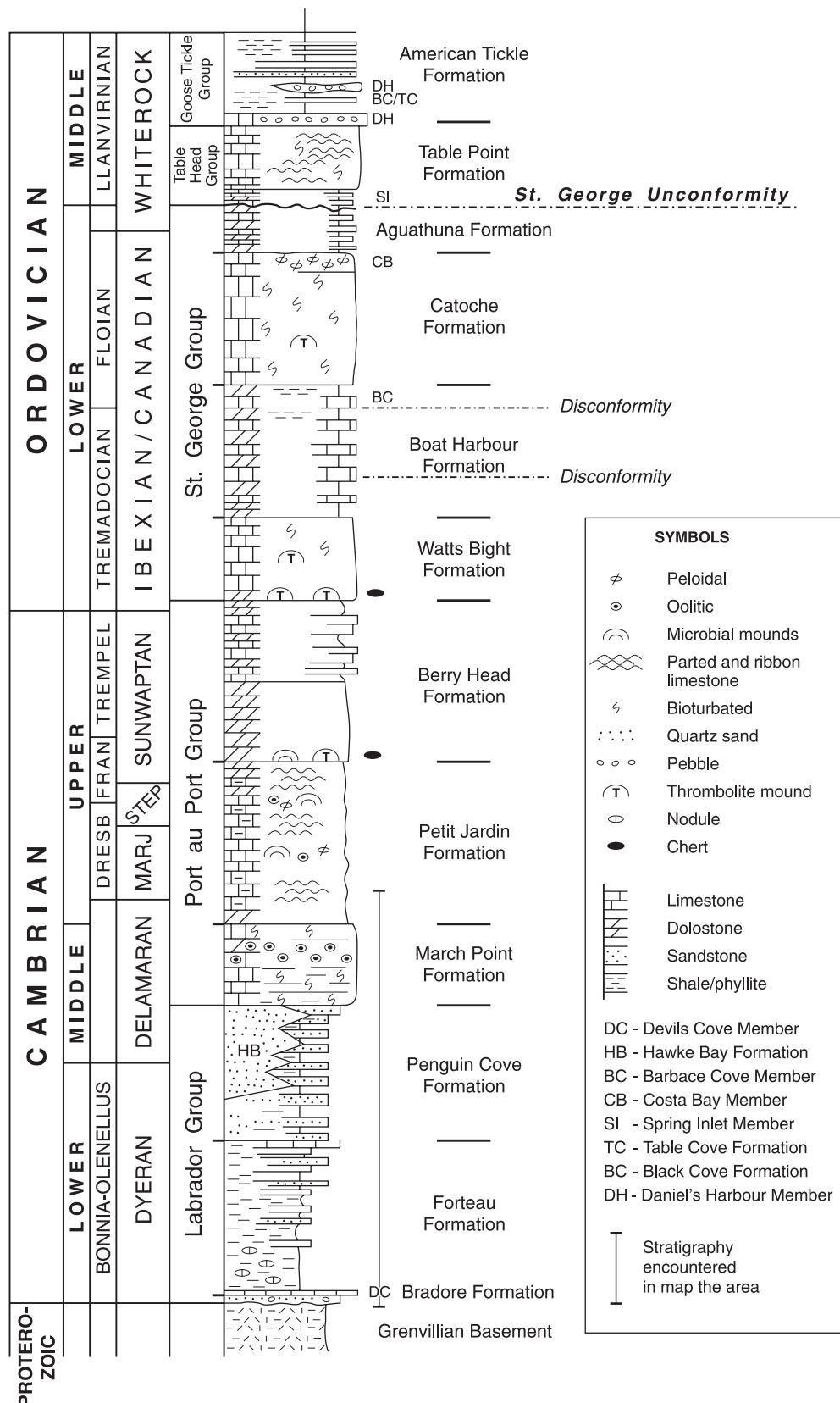
### Bradore Formation

The Bradore Formation is a thin (less than 20 m) interval of purple, black, red-brown and locally green, poorly sorted, coarsely grained sandstone and pebbly sandstone (Plate 1) rich in potash feldspar, blue opalescent quartz and heavy mineral lamination and beds of purple quartz-rich arenite. The formation is strongly magnetitic. The thin interval is the same as the upper member of the formation at Canada Bay where it overlies a lower member of red arkosic sandstone (Knight, 1987). It can be traced south to White Bay (Kerr and Knight, 2004) and west as far as the Phillips Brook anticline in the Stephenville area (Knight and Boyce, 2000).

The formation, which lithologically compares closely to the section seen in Gros Morne National Park (James *et al.*, 1988), rests unconformably upon Proterozoic basement. The unconformity is locally exposed in the area north of Angle Pond where it forms a steeply southwest-dipping undulose surface, locally featuring elongate scoop-shaped depressions (Plate 2). Elsewhere in the map area, the formation appears to be structurally overlain by the basement rocks, as for example north of Owl Pond. From Smelt Pond eastward to Wolf Pond, the basal Labrador Group is truncated by the Smelt Pond thrust, although the highly wooded area in the valley between the two ponds, which has yet to be mapped, could hide the ancient land surface and its attendant sandstone cover.

### Forteau Formation

The Forteau Formation is generally only seen in the eastern part of the Goose Arm thrust stack where it consists of the Devils Cove Member overlain by a thick succession of slates and phyllites and thin limestone and siltstone interbeds (Plate 3). Within the Jack Ladder triangle (Figure 3), however, the succession is dominated by extensive dark-grey slate and phyllite that locally becomes more crystalline and micaceous due to metamorphism. Bedding is largely obliterated by cleavage and schistosity (Plate 4). The phyllites underlie much of the White Hills Brook valley and the large bogs west of Angle Pond. An intensely flattened and folded, rusty-weathering, dark-grey, argillaceous, ribbon to nodular limestone is intercalated by deformation within the phyllites in the valley of Underground Brook, 2 km southeast of Angle Pond (Plate 5). It is possible that it could be



**Figure 2.** Lithostratigraphy of Lower Paleozoic rocks of the Lomond map area showing the stratigraphic interval encountered in the area of the 'Jack Ladder triangle'.



**Plate 1.** Pebby purple sandstone of the basal Bradore Formation, Long Range Massif, north of Angle Pond. Arrows point to some of the numerous pebbles of blue opalescent quartz. Lens cap is 5.5 cm across.



**Plate 3.** A thin bed of dolomitic siltstone within a grey slate, Forteau Formation, Long Pond. The cleavage is at a low angle to bedding.



**Plate 2.** Bradore Formation sandstone lying in a shallow depression eroded into Grenvillian granitic basement on the southwest-dipping basal Cambrian unconformity just north of Angle Pond, southern end of the Long Range Massif. Dashed line follows the unconformity. The depression trends at 200°. Lens cap is 5.5 cm across.

the Devils Cove Member because the limestone locally retains its original nodular fabric and lies topographically and by implication stratigraphically below most of the phyllite in this area.

Cleaved dark-grey shale with thin interbeds of fine-grained limestone and siltstone occur along the shores of Upper Long Pond and Long Pond near the southeast edge of 'triangle' (Plate 3). Cleaved shale with limestone nodules and thin calcareous siltstones also overlie the Bradore For-

mation along the southern edge of the Long Range Massif north of Angle Pond. Thin limestones, some of which are grainstone hosting burrows and the cone-shaped mollusc *Salterella*, occur in the formation on the western slopes of the northwest-trending valley southeast of Wiltondale. The Devils Cove Member, at the base of the formation, was found in only one outcrop. The pink crystalline limestone occurs east of Owl Pond where it lies close to rubble of the Bradore Formation.

#### Penguin Cove Formation

The Penguin Cove Formation is the time equivalent of the Lower to Middle Cambrian Hawke Bay Formation. In the study area, the sequence consists of a lower interval of thin-bedded, ribbon sandstone and shale (Plate 6) and an upper interval of metre-scale sequences of thin-bedded shale and fine-grained sandstone alternating with massive white quartz arenite units up to a few metres thick (Plate 7). Rare lenses of limestone occur locally. Where the succession is less deformed in the west, the quartz arenites display wedge-shaped bodies between gently inclined planar scours, hummocky cross-stratification (HCS), crossbeds, planar thin stratification, lamination and soft sediment structures, such as load casts and rarely, ball-and-pillow structures. *Skolithus* and *Arenicolites* burrows have been locally recognized at better preserved outcrops along the Newfoundland Power transmission line. Unfortunately, except in some local areas, the overwhelmingly thin-bedded heterolithic succession is affected by moderate to severe transposition of bedding into the plane of the foliation and cleavage (Plate 8). This makes measurement of bedding and recognition of younging direction often difficult throughout much of the area and signals caution when interpreting cleavage-bedding relationships at the outcrop.

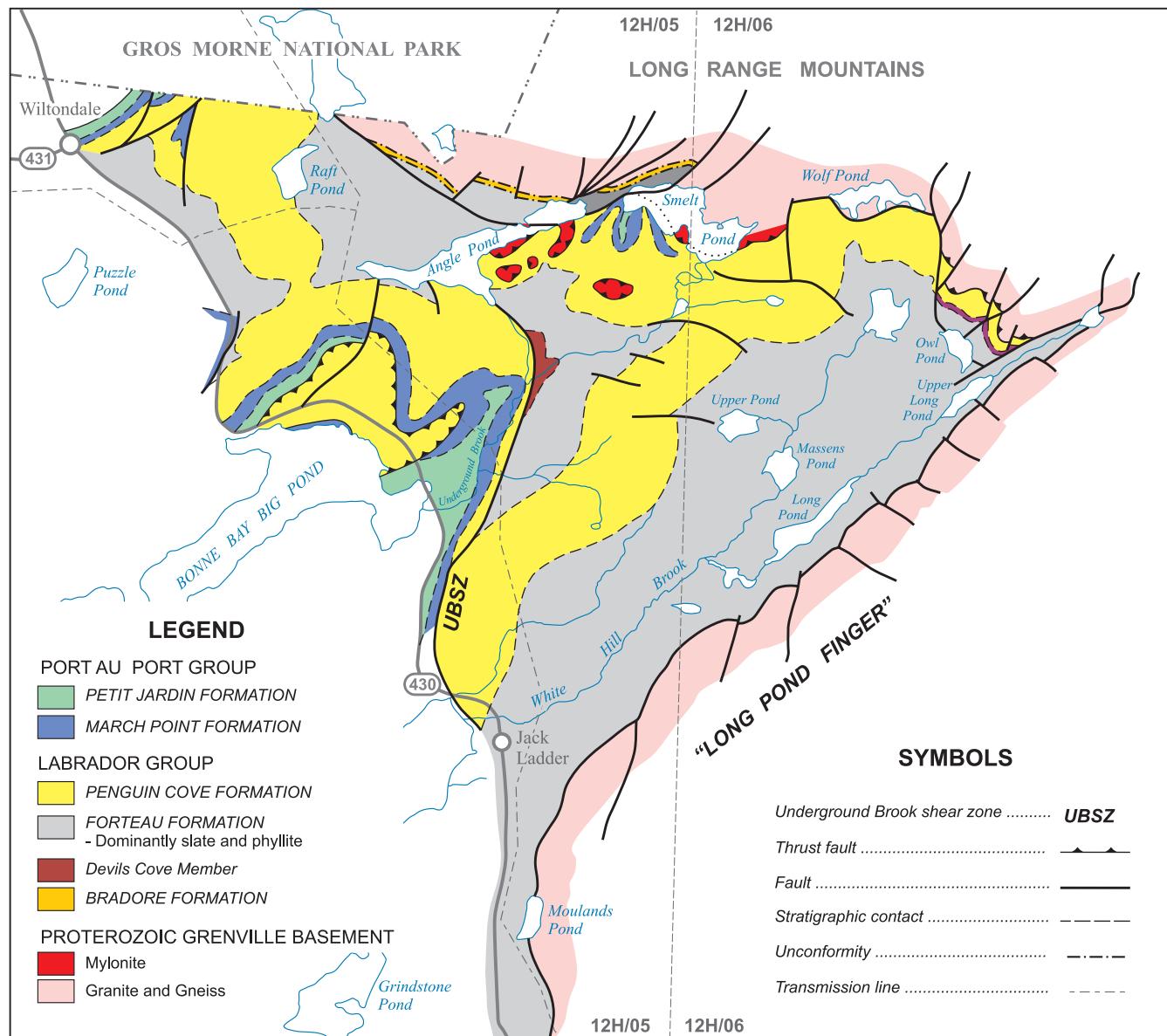


Figure 3. Preliminary geological map of the 'Jack Ladder triangle'.

## PORT AU PORT GROUP

The Port au Port Group in the study area consists mostly of dolomitic limestone of the March Point Formation overlain by yellow-weathering, light-grey, dolostone of the base of the Petit Jardin Formation. Rocks of the March Point and Petit Jardin formations were informally named the Underground and Wiltondale formations, respectively, by Williams *et al.* (1984).

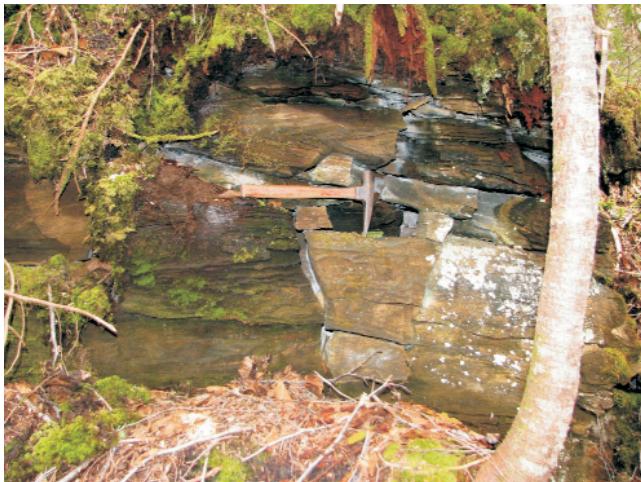
### March Point Formation

The late Middle Cambrian (Delameran) March Point Formation in the map area is dominated by dark-grey, oolitic

grainstone, some of which is rich in oncolites (Plates 9 and 10). Burrowed and ribbon limestone are a lesser part of the formation. A stromatolitic limestone associated with shale occurs locally near the base of the formation. The same lithostratigraphy has been mapped in a number of thrust slices of the Goose Arm thrust stack south and west of the study area (Knight, 1992, 2007; Knight and Boyce, 1991). In the 'triangle' area, the formation outcrops in a number of southwest-plunging synclines and in a thrust slice east of Bonne Bay Big Pond. It has also been mapped high on the valley slopes east of Wiltondale and in tight folds in the immediate footwall of the Smelt Pond thrust along the shores of Smelt Pond. Where the countryside is underlain by this unit, and especially just below the top of the formation,



**Plate 4.** A grey phyllitic slate, most typical of the Forteau Formation throughout much of the Jack Ladder triangle. The main cleavage is crenulated and cut by a later cleavage (arrow). A strong lineation running from top to bottom of the plate may reflect bedding. Quarter (2.4cm) for scale.



**Plate 5.** A folded ribbon and nodular argillaceous limestone of the Forteau Formation, valley slope of Underground Brook, south of Angle Pond. The pinkish tint and the sedimentary fabrics suggest this may be the Devils Cove Member. Hammer is 33 cm long.

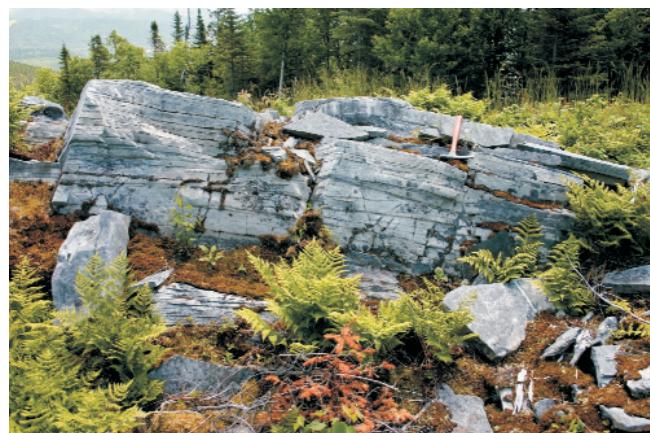
it is characterized by small, sinkholes that are filled by recent sediment.

#### Petit Jardin Formation

The early Late Cambrian Petit Jardin Formation rests conformably upon the March Point Formation. Only the lowest unit of the formation is mapped in the study area where it consists of light-grey to cream thick-bedded, micro-crystalline dolostone, dololaminite and pale green-grey, argillaceous dololaminite (Plate 11). The thick-bedded dolo-



**Plate 6.** Deformed thin ribbon-bedded fine quartzose sandstones and pale-green phyllites typical of the lower part of the Penguin Cove Formation, Jack Ladder triangle. Northeast-trending ridge west of Upper Pond. Coin 1.8 cm.



**Plate 7.** One of the thicker units of white quartz meta-arenite of the Penguin Cove Formation in the Jack Ladder triangle, transmission line, south of Angle Pond. Note the wedge-shaped units of planar stratification with generally low angle scours. It overlies a unit of finer grained thin-bedded sandstone. Hammer is 33 cm long.

stones are generally featureless but the dololaminite displays tepees, mudcracks and fenestral fabrics. The unit is mapped near Underground Brook and the entrance to White-wash Road.

### STRUCTURE OF THE 'JACK LADDER TRIANGLE' THE SMELT POND THRUST

Mapping along the northern edge of the Jack Ladder triangle area indicates that Proterozoic granite-dominated basement of the Long Range Massif is thrust over the Cambrian metasediments along the Smelt Pond thrust, the latter



**Plate 8.** Severely transposed ribbon sandstone and shale of the lower Penguin Cove Formation in an outcrop east of Underground Brook and south of Angle Pond. Finger is 7 cm long.



**Plate 9.** Dark-grey, styllobedded, dolomitic, oolitic grainstone, March Point Formation. Powerline near Underground Brook. Hammer handle is 3.8 cm across.

named for the feature where it was first discovered (Plate 12). This previously unrecognized thrust appears to have three zones to it (Figure 2). From Fox Pond in the northwest to Angle Pond, the granite in the hanging wall carries unconformably overlying Bradore Formation sandstone (see Plate 2) and Forteau Formation shale along the southern edge of the Long Range Massif. The sandstone and shale dip moderately to steeply south to southwestward. No structural fabric occurs in the Bradore Formation but steeply southward-dipping ( $\sim 80^\circ$ ) and locally overturned Forteau Formation shale is cut by a moderately west and north-dipping cleavage (25 to  $40^\circ$ ). This hanging-wall association is thrust upon phyllites of the Forteau Formation. Although concealed by



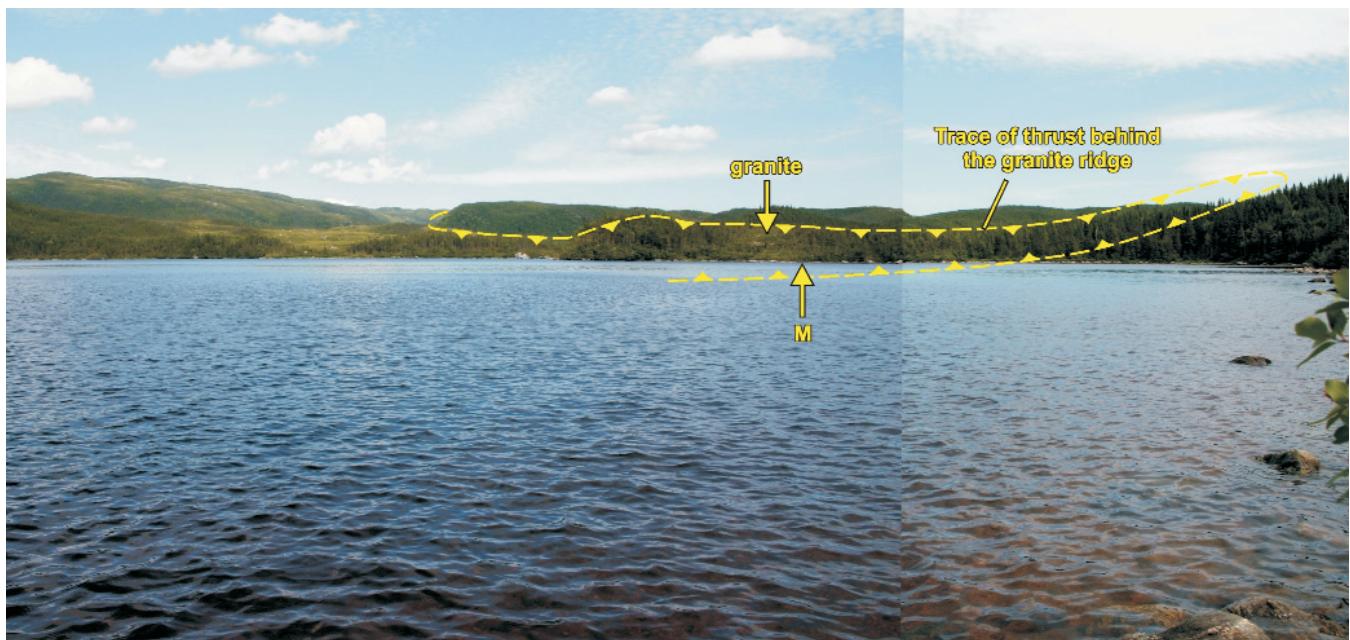
**Plate 10.** Oncrolites floating in a matrix of oolitic grainstone, March Point Formation. Powerline near Underground Brook. Finger 1.8 cm across.



**Plate 11.** Dololaminites of the lower Petit Jardin Formation outcropping at the edge of an inactive sinkhole, just above the March Point Formation near Underground Brook and Camp 37 road. Hammer is 33 cm long.

bogs and woods to the northwest of Angle Pond, the thrust likely dips to the north and northeast in this area.

In the middle zone southeast of Angle Pond, the base of the Smelt Pond thrust is marked by a schistose, chloritic mylonite of finely granulated granite protolith, granite augen and a strong foliation and northwestward-trending lineation (Plate 13). Largely undeformed granite cut by subhorizontal chloritic folia occurs several metres above the sole of the thrust (Plate 14). The thrust–mylonite association has been mapped eastward from Angle Pond to Wolf Pond, a distance of 6 km and has also been mapped in a series of small hillock-bounded outliers in the area south of Angle



**Plate 12.** Proterozoic granite (yellow arrow; also see Plate 14) underlying a low point of land projecting north into Smelt Pond. An almost flat-lying mylonite (see Plate 13) at the shoreline (M) forms the sole of the Smelt Pond thrust (yellow dashed line) that carries the Long Range Massif over intensely flattened, polydeformed Cambrian metasedimentary rocks in the wooded hill at the right of the plate. The projection of the thrust northeast of Smelt Pond is shown by the thrust symbol line.



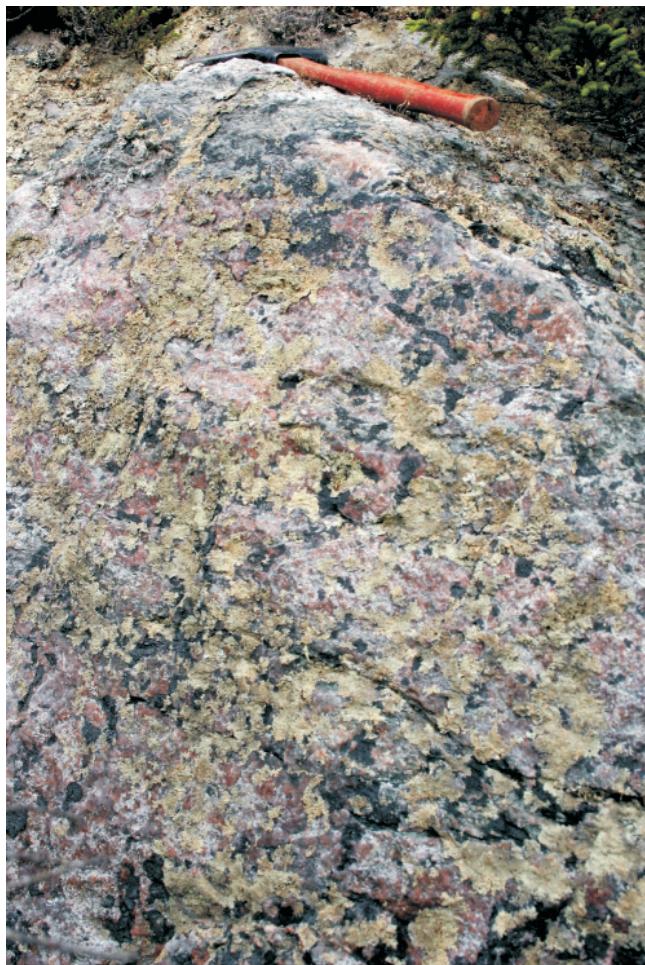
**Plate 13.** Chlorite-granular granite and schistose mylonite at the sole of the Smelt Pond thrust. A northwest-trending lineation (arrow) is carried by the mylonite plane. Lens cap 5.5 cm across.

Pond. The thrust is a low-angle, gently north-dipping structure on the small peninsula that projects into Smelt Pond where it was first discovered (Plate 12).

The thrust, in the most westerly of these outliers, separates strongly foliated and mylonitized granite from footwall rocks that also include purple pebbly sandstone of the Bradore Formation (Plates 15, 16 and 17). The foliated granite, the thrust and the Bradore Formation of the footwall are all folded around a recumbent, east-verging  $D_2$  fold. However, for the most part, the mylonitized granite is carried

above phyllite in the west and strongly flattened and polydeformed quartz metasandstones and phyllite, oolitic limestone and a thin sliver of dolostone belonging to the Penguin Cove Formation, March Point and Petit Jardin formations respectively, along the shores of Smelt Pond (Plates 18, 19 and 20). Isoclinal, recumbent folds deform the footwall, and the strongly flattened tectonic fabric carries a northwest-trending lineation. At the west end of Smelt Pond, a tight, north-plunging fold preserves a sliver of foliated Penguin Cove Formation metasandstone and phyllite lying structurally upon Petit Jardin dolostone. This implies that there is at least one other thin, now largely hidden, thrust panel present below the mylonite in the footwall to the Smelt Pond thrust of this middle zone. This folded thin thrust slice together with the range of stratigraphic relationships in the footwall to the thrust suggest that possibly the immediately underlying footwall complex to the Smelt Pond thrust may be a complex zone of thin thrust imbricates. The mylonite and the flattened footwall rocks are also folded by later southeast-verging, folds and cleavage.

East of Wolf Pond, the granite is thrust over Bradore Formation near Owl Pond. The footwall also includes Devil's Cove Member nearby. The thrust is a sharp, low-angle, northeast-dipping surface with no obvious deformation in the sandstones of the footwall. The thrust is not marked by a mylonite but the granite exhibits a well-developed chloritic foliation parallel to the thrust in the immediate hanging wall.

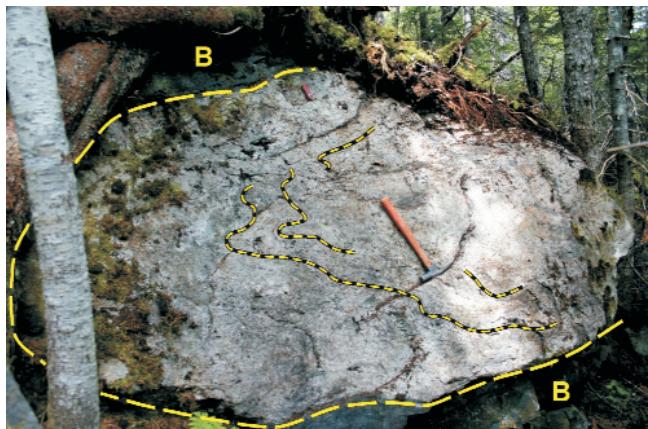


**Plate 14.** Virtually undeformed megacrystic granite lying above the mylonite of Plate 13, just about 10 m above the sole of the Smelt Pond thrust (yellow arrow on Plate 12). Hammer is 33 cm long.

Mapping along this northern boundary of the 'triangle' suggests that the sole thrust to the Long Range Massif is offset by a series of later faults, one of which runs along the trace of Angle Pond and may support local back thrusting between the northwest and the middle zone of the thrust.

#### THE SOUTHEAST MARGIN OF THE JACK LADDER TRIANGLE

The southeastern edge of the Jack Ladder triangle coincides with the steep scarp edge of the 'Long Pond finger', a southwest-trending upland of Proterozoic basement gneiss and granite. The contact, although not exposed, is postulated to be a steeply northwest-dipping to subvertical fault based on steeply northwest-dipping foliation fabrics in the basement near Long Pond and Owl Pond and again near Moulards Pond (Plate 21). In addition, mapping shows an abrupt change from basement to Forteau Formation phyllite suggesting that the Bradore Formation is absent throughout



**Plate 15.** A southeast-verging fold in foliated granite that has been thrust over magnetic purple sandstones of the Bradore Formation exposed in a hill-bound outlier just south of Angle Pond. Dashed lines indicates folded thrust and foliation in granite. B = Bradore Formation. Hammer is 33 cm long.



**Plate 16.** Close-up view of foliated granite structurally above Bradore Formation (B) sandstone in Plate 15. Note the later crenulation folds. Hammer is 33 cm long.



**Plate 17.** Mylonitized, schistose, granite basement in the same outlier as Plate 15. Note the recumbent isoclinal folds of the intensely flattened mylonite fabric and quartz veins. Hammer is 33 cm long.



**Plate 19.** Folded limestone mylonite enclosing augen of dolostone lying in the footwall of the Smelt Pond thrust, the western shore of Smelt Pond. The original limestone belonged to Middle Cambrian March Point Formation. Hammer is 33 cm long.



**Plate 18.** Southeast-verging  $D_2$  folds deforming foliated dolomitic limestone of the Middle Cambrian March Point Formation in the footwall to the Smelt Pond thrust. Hammer is 33 cm long.



**Plate 20.** Intensely flattened quartz arenite of the Penguin Cove Formation lying in the footwall zone of the Smelt Pond thrust, south of Angle Pond. Lens cap is 5.5 cm across.

this area from Upper Long Pond to Moulards Pond. In the Moulards Pond area, a well-developed, early, northwest-dipping foliation in the granite closely resembles that seen in the granite–mylonite outliers near Angle Pond. The foliated granite occurs no more than a few metres from an outcrop of Forteau Formation phyllite where the foliation is deformed by southeast-verging folds associated with a northwest-dipping cleavage. This locality, and the other evidence outlined above, strongly suggest that the original structural relationship was a thrust (likely the Smelt Pond thrust) that is now in an inverted position southeast of the Jack Ladder triangle. Numerous cross faults intersect with and locally offset the fault.

#### DEFORMATION OF THE METASEDIMENTS OF THE JACK LADDER TRIANGLE

Geological mapping of the Jack Ladder triangle is not yet complete. Mapping does however suggest that the stratigraphy generally youngs from southeast to northwest, although it is very unlikely that the succession is in tact and that some important contacts may be surfaces of decollement or thrusts. Nonetheless, it appears that the metasediments of the Jack Ladder triangle are deformed by at least three deformations of which the first two are the most important.



**Plate 21.** *Folding ( $D_2$ ) of a strong foliation in Proterozoic basement along the southeastern edge of the Jack Ladder triangle. The fabrics suggest the present contact is an inverted thrust that placed the basement over Lower Cambrian metaclastics of the lower Labrador Group. Hammer 33 cm long.*

#### First Deformation $D_1$

$D_1$  is largely represented by a strong transposition and foliation fabric in the metasediments. It is particularly strong in the area near Underground Brook, Angle Pond and east of Smelt Pond. The first deformation probably controls the original disposition of the basement and metasedimentary terrane, emplacing basement northwestward over the shelf sequence. Some thin, folded footwall thrust imbricates mapped in Smelt Pond and Angle Pond area are likely also  $D_1$  thrusts.

#### Second Deformation $D_2$

The  $D_1$  fabrics are folded and cut by later  $D_2$  folds and cleavage. The  $D_2$  structures that dominate the structural style of the area at outcrop scale trend northeast and verge southeast. The structures are characterized by a low northwest-dipping cleavage, axial planar to east-verging asymmetrical folds that also fold the thrusts in the area as discussed above. If the interpretation of the relationships of the basement to the metasediment of the triangle is correct *i.e.*, the basement was thrust over the metasediments, this suggests that the large-scale map pattern of basement enclosing metasediment on two sides may reflect a large  $D_2$  buckle fold where basement is flexed around hinges near Smelt Pod and northeast of Upper Long Pond and the southeastern limb is overturned to the southeast.

#### Third Deformation, $D_3$

The third deformation is marked by a faint to locally strong, crenulation lineation preserved on the main  $D_2$  cleavage planes (Plate 22). The lineation is associated with a



**Plate 22.**  *$D_3$  crenulation lineation crenulating  $D_2$  slaty cleavage in the Forteau Formation. Quarter 2.4 cm across.*

southeast-trending crenulation cleavage that dips to the south at relatively steep ( $>45^\circ$ ) angles.

#### THE UNDERGROUND BROOK SHEAR ZONE

The Underground Brook shear zone is a broad-curving, north- to north-northeast-trending zone that coincides with the valley of Underground Brook and can be traced over 10 km along strike. Although it is yet to be interpreted, it is likely of fundamental importance in that it separates metasedimentary rock terrains that contrast markedly in the degree of deformation and metamorphism. West of the shear zone, Penguin Cove Formation siliciclastic rocks generally show well-preserved sequences and sedimentary structures (Plate 7). Oolitic and oncocolitic limestones of the March Point Formation and dolostones of the Petit Jardin Formation in the same area retain grain fabrics such as ooids and laminated algal oncocolites as well as stylo-bedding and other sedimentary structures (see Plates 9, 10 and 11). One cleavage, belonging to southeast-verging  $D_2$  structures, is most common but it is clear from the mapping of these rocks and the distribution of units such as the March Point and Petit Jardin formations that the folding of these rocks is complex and will require significant additional work to understand the terrain, a task likely to be frustrated because of poor exposure. To illustrate this point, large and impressive, outcrop-scale Z folds are exposed in a roadstone quarry in Petit Jardin Formation dolostones near western end of Underground Brook, just east of the Viking Highway (Plate 23). Nowhere in the immediate countryside is there a hint of such structures. Furthermore, interpretation of the map and stratigraphic relationships in this area suggests that the folds are downward facing, possibly  $D_1$  folds characterized by northwest-dipping axial planes rather than southeast-verging  $D_2$  folds.



**Plate 23.** Folded dolostone strata of the *Petit Jardin Formation* in a roadstone quarry near *Underground Brook* just east of *Route 430*. Mapping relationships suggest that the beds young to the right and the Z-folds face downward as an anticlinal synform and synclinal antiform couple. Quarry face is about 10 m high.

To the east of the shear zone, the geological terrain is polydeformed and strongly transposed. Pelitic rocks are dominated by phyllite and fine micas and chlorite are present in the foliated sediments in the footwall to the *Smelt Pond* thrust. Entering the shear zone, metasandstones and phyllite of the *Penguin Cove Formation* and dolomitic limestones of the *March Point Formation* to the west become intensely flattened, isoclinally folded and transposed (Plates 24 and 25). Similarly, phyllites and limestone of the *Forteau Formation* (see above) to the east of the shear zone become highly flattened to mylonitic over a wide area. The limestone, (possibly *Devils Cove Member*) in particular, has a strong mylonitic fabric and is deformed by recumbent and isoclinal folds with axes plunging gently both to the south and the northwest and with axial planes essentially co-planar with the mylonitic fabric (Plates 26 and 27). Re-folded folds also occur. Lineations on the foliations generally trend northwest. The lithological appearance of siliciclastic rocks of the quartz-rich, stratigraphically higher *Penguin Cove Formation* mapped in this same area of high strain in the eastern terrain resemble psammites and semipelites of the *Mount Musgrave Group*, east of the *Humber Gorge*.

The shear zone can be projected southward toward *Grindstone Pond* where several thrust faults and a major shear zone, the *Grindstone Pond shear zone* were mapped between the same rock units and are thought to be one of a number of now vertical to overturned  $D_1$  thrusts that are part of the *Goose Arm thrust stack* in the *Lomond* and *Pasadena* map areas (Knight, 2007; Figure 2 and Plates 2 to 4). The *Underground Brook shear zone* is here projected northward to a narrow cove midway along the southern shore of *Angle*



**Plate 24.** Strongly foliated and folded quartz arenite of the *Penguin Cove Formation* west of the *Underground Brook* shear zone. *Underground Brook* valley. Hammer 33 cm long.



**Plate 25.** Strongly transposed dolomitic ribbon limestone of the lower part of the *March Point Formation*, west of the *Underground Brook* shear zone. Sinkhole along the outer part of *Underground Brook* valley. Pen is 16 cm long.

*Pond* (see also Williams *et al.*, 1984) suggesting that it probably lies hidden below bogs to the north of the pond.

## DISCUSSION

The mapping of the *Jack Ladder triangle* on the *Lomond* and *Cormack* map areas highlights a previously unrecognized thrust believed to lie at the sole of the *Long Range Massif*. This thrust, which was folded by later  $D_2$  structures, appears to suggest that the massif may be allochthonous rather than parautochthonous, and now sits, at least in the south, on lower Paleozoic shelf metasediments.

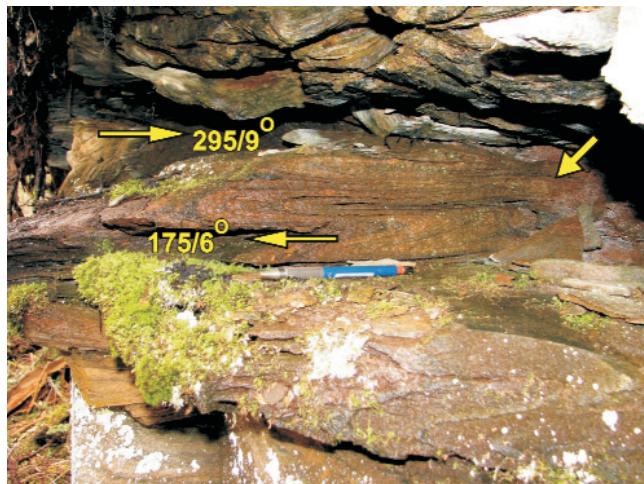


**Plate 26.** Mylonite and folds developed in the Devils Cove Member limestone east of the Underground Brook shear zone, south of Angle Pond. Hammer 33 cm long.

The map-scale terrain pattern suggests that the thrust is folded about a large  $D_2$  buckle fold that involves steep inversion of the thrust along the southeastern edge of the 'triangle' and that the overthrust is greater than 15 km.

Locally along the northern edge of the Jack Ladder triangle, the thrust likely dips to the north at various angles as for example the Smelt Pond area. Northwest of Smelt Pond, hanging-wall relationships suggest a southwest-verging rollover of basement and cover above the thrust. A strong northwest-trending lineation is associated with the chloritic schistose mylonite at the base of the granite-dominated massif and with intensely flattened footwall metasediments immediately below the sole. This suggests that the massif moved northwestward when it was emplaced. Overall, these various relationships associated with the thrust along the north edge of the 'triangle' suggest that there at least, the rocks preserve a segment of a north-dipping, southwestern lateral ramp below the massif rather than form a frontal thrust. Nonetheless, the absence of a basal mylonite beneath the massif in the east and in the northwest (perhaps an artifact of exposure) in contrast to the Smelt Pond area where the mylonite can be mapped in outliers some distance from the edge of the massif is a puzzle. It possibly suggests that the history of the emplacement of the massif is complex and some of the structural relationships in the area reflect out-of-sequence events.

The deformation is known to predate the late Mississippian Deer Lake Group, which onlaps unconformably the assembled structural terranes. Deformation of the thrust and its footwall by  $D_2$  structures, however, suggests that the thrust may have been emplaced fairly early as  $D_2$  southeast-verging structures are known to deform the Goose Arm thrust stack. Since the stack was emplaced above Humber



**Plate 27.** Isoclinal folds including refolded folds (above pen) developed in the Devils Cove Member limestone east of the Underground Brook shear zone, south of Angle Pond. Axes of different folds (see arrows) plunge to the south and northwest. Pen is 14.5 cm long.

Arm Allochthonous rocks and foreland basin flysch, it must postdate Taconic emplacement of the allochthons.

Within the map area, the Underground Brook shear zone is a major structure that juxtaposes intensely deformed, Lower Cambrian rocks to the east against less tectonized Middle Cambrian rocks to the west. The shear zone may represent the northern extension of the Grindstone Pond shear zone but will require further work to delineate its extension and to understand its nature.

## ACKNOWLEDGMENTS

Brian Sutton provided excellent assistance throughout the summer's mapping. Many thanks. Tony Paltanavage drafted the figures. Elliot Burden read and improved the manuscript.

## REFERENCES

James, N.P., Knight, I., Stevens, R.K. and Barnes, C.R.  
 1988: Sedimentology and paleontology of an early Paleozoic continental margin, western Newfoundland. GAC MAC CSPG Field trip Guide B1, St John's, Newfoundland, 121 pages.

Kerr, A. and Knight, I.  
 2004: Preliminary report on the stratigraphy and structure of Cambrian and Ordovician rocks in the Coney Arm area, western White Bay (NTS map area 12H/15). In Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 04-1, pages 127-156.

Knight, I.  
1987: Geology of the Roddickton (12I/16) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 87-1, pages 343-357.

1992: Geology of marmorized Lower Paleozoic, plat-formal carbonate rocks, "Pye's Ridge", Deer Lake. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 141-157.

2007: Geological studies in the Lomond (NTS 12H/5) and adjacent map areas of the eastern part of the Goose Arm Thrust Stack, western Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 07-1, pages 45-54.

Knight, I. and Boyce, W.D.  
1991: Deformed Lower Paleozoic platform carbonates, Goose Arm—Old Man's Pond. *In* Current Research. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 141-153.

2000: Geological notes on the Cambro-Ordovician rocks of the Phillips Brook anticline, north of Stephenville. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 2000-1, pages 197-215.

Williams, H, Quinn, L., Nyman, M. and Reusch, D.N.  
1984: Geology of Lomond map area 12H/5, western Newfoundland. Geological Survey of Canada Open File 1012, 1:50 000 geology map.

