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A GEOLOGICAL NOTE ON A PROBABLE FOOTWALL IMBRICATE STACK (POSSIBLE DUPLEX) TO THE GRAND LAKE THRUST, HARRYS RIVER MAP SHEET (NTS 12B/09), WESTERN NEWFOUNDLAND

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ABSTRACT

An imbricate stack (possible beheaded duplex) that developed in Grenvillian basement and the immediately overlying rocks of the Early Cambrian Labrador Group, occurs in the immediate footwall to the Grand Lake Thrust. The imbricate stack is exposed in a narrow, incised, boulder-strewn stream (a tributary of Trout Brook) that empties off the northwestern edge of the Long Range Mountains, just southwest of Hare Hill. The hanging wall to the stack comprises crystalline Grenvillian rocks of the Long Range terrane. The imbricate stack lies east of, and probably structurally against, polydeformed Cambrian to Ordovician carbonate shelf rocks of the southwestern extension of the Blue Pond thrust stack.

The Grenvillian crystalline rocks consist of green granitic gneiss cut by pink granite veins and mafic dykes. The cover rocks assigned to the Labrador Group comprise a basal unit, approximately 28 m thick, of metaquartzite, sandstone and minor phyllite, which is correlated with the Bradore Formation. It is overlain by about 10 m of white, pink and cream, coarsely crystalline, banded limestone marble that is characterized by folds and green to light-grey, chloritic and sericitic folia partings. This unit is equated with the Devils Cove Member of the Forteau Formation. It is, in turn, overlain by polydeformed and recessively weathering, pencil-grey phyllites, typical of the lower part of the Forteau Formation. These rocks compare closely to a succession of metasediments lying unconformably upon Grenvillian basement that was mapped previously in the hanging wall of the Grand Lake Thrust, a few kilometres north of Grand Lake.

The imbricate stack, which is approximately 500 m wide and can be traced for up to 1.6 km along strike, consists of at least 4 panels that repeat the stratigraphy. The leading thrusts are east-dipping and west-verging. The thrust planes are mostly sharp and planar, although a strongly mylonitic psammite enclosing west-verging carbonate augen and folds characterizes one of the thrust zones. A possible pop-up bounded by both east- and west-dipping faults occurs in the inner part of the stack. A basal décollement between the basement and the cover is preserved in the innermost panel. There is still some doubt about the position of both the floor of the stack and its northwestern leading edge.

The imbricate stack is host to a broad rusty-weathering alteration zone and to vein-hosted galena and pyrite/marcassite mineralization in the basal sedimentary cover and the underlying basement rocks. The alteration zone assayed a few percent Pb and less than 1 percent Zn and appeared to have no anomalous gold and only a few ppm of silver. Nonetheless, the alteration and mineralization is located in the same stratigraphic and structural setting to gold mineralization known in the Sops Arm area of White Bay.

INTRODUCTION

The Harrys River map sheet (NTS 12B/09), east of the Trans-Canada Highway, is geologically dominated by two terranes separated by the Grand Lake Thrust (Williams, 1985; Williams and Cawood, 1989), also called the Grand Lake fault (Currie *et al*., 1986; Currie and van Berkel, 1992; Figure 1). To the east of the fault is a terrane of mostly crystalline basement rocks of Grenvillian age that are overlain by late Proterozoic to Early Cambrian metasedimentary rocks of the Mount Musgrave Group and Fleur de Lys Supergroup and are intruded by red leucocratic granite of the Hare Hill complex (Williams, 1985; Currie *et al*., 1986; Currie and van Berkel, 1992; Williams and Cawood, 1989; Cawood and Van Gool, 1994). West of the fault, Cambro-Ordovician shelf rocks are deformed in the Blue Pond thrust stack (BPTS), a complex, polydeformed, multipanelled, thrust stack mapped and defined northwest of Grand Lake

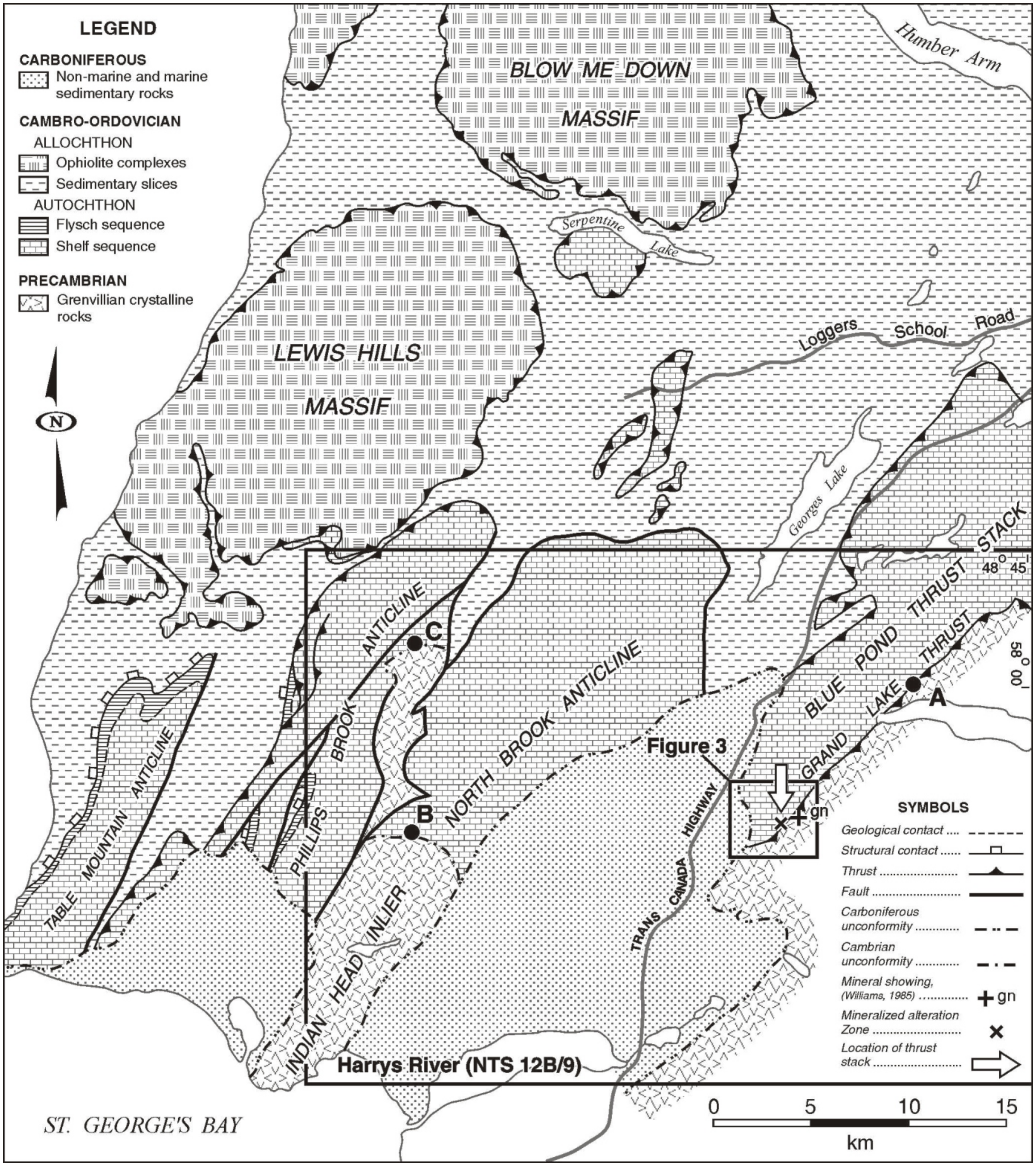


Figure 1. *Simple regional geological map of the central part of western Newfoundland showing the location of the footwall imbricate stack to the Grand Lake Thrust (large arrow) in the Harrys River map area (NTS 12B/09). A, B, and C are localities discussed in the text. A - north of Grand Lake (Knight, 1997), B - Crash Hill (Knight, 2003), C - Indian Head Range (Knight and Boyce, 2000).*

by Knight (1996, 1997; Figure 1). Mapping indicates that the BPTS is emplaced above slaty rocks of the Goose Tickle Group and fine-grained broken sedimentary formations of partly allochthonous origin. The stack extends from Pinchgut Lake southwestward for 20 km to south of Grand Lake, where it is truncated by a Carboniferous unconformity and by Quaternary glacial gravels at the northeast margin of the St. Georges Bay lowlands (I. Knight, unpublished data, 2002; Williams and Cawood, 1989). The BPTS consists almost exclusively of structural panels, detached from basement, of Middle Cambrian to Middle Ordovician carbonate strata of the Port au Port, St. George and Table Head groups. Deformation and metamorphism increases across the stack from its northwestern foreland edge southeastward to the Grand Lake Thrust (GLT). Apart from a narrow sliver of Penguin Cove Formation at the sole of one thrust, no rocks, co-eval with the Labrador Group occur in the stack.

The GLT is shown on a number of maps (Williams, 1985; Currie *et al*., 1986; Currie and van Berkel, 1992; Williams and Cawood, 1989) as an important linear structure that separates the two geological terranes described. Some maps trace the fault northeast to link with the Corner Brook Lake thrust (Williams and Cawood, 1989). Currie and van Berkel (1992, *see also* Currie *et al*., 1986) called the southern portion of the fault the Grand Lake fault and, showed it demarcating the contact of the older Steel Mountain subzone to the southeast (includes Grenvillian basement rocks and Fleur de Lys Supergroup supracrustals) from the Humber Platform subzone to the northwest. The latter subzone is essentially the BPTS. Later mapping of the area, immediately north of Grand Lake, by Cawood and Van Gool (1994) failed to define a linear fault but instead shows a basement cored belt of supracrustal cover rocks locally overlain by the carbonate shelf sequence. Knight (1997) defined a non-linear, unnamed thrust in the same area immediately northeast of Grand Lake. There, the thrust follows the topography and separates Grenvillian basement with a thin cover of metamorphosed Labrador Group to the southeast, from the lower Paleozoic carbonate shelf rocks deformed in the BPTS to the northwest.

Mapping of Cawood and Van Gool (1994) in the area near Corner Brook Lake showed the Corner Brook Lake thrust as separate from the old demarcation of the Grand Lake Thrust/Corner Brook Lake thrust. Instead, the thrust was shown as an imbricate zone of thrust slices that repeated basement and cover in the Corner Brook Lake area only. Cawood and Van Gool (1994) also proposed a new fault called the Humber River fault to demarcate the contact between their Corner Brook Lake belt (essentially the Steel Mountain subzone of Currie and van Berkel, 1992) and their Carbonate belt, which was later mapped as the BPTS by Knight (1997).

Nonetheless, in spite of the uncertainty about the validity and linearity of the GLT north of Grand Lake, the fault, and hence the terrane contact of Proterozoic basement with the BPTS in the area southwest of Grand Lake, appears to be linear even if broadly sinuous (*see* Figure 3). For clarity, the fault discussed in this article will continue to be called the GLT.

A few kilometres north of Grand Lake, Proterozoic basement is overlain by chlorite-grade metasedimentary rocks of the Labrador Group that occur in the hanging wall of the GLT (Knight, 1996, 1997). The cover rocks in this area were mapped either as the Grand Lake group by Williams and Cawood (1989) or the Breeches Pond Formation of the Fleur de Lys Supergroup by Cawood and Van Gool (1994). However, Knight (1997) definitively mapped Grenvillian granitic gneisses overlain unconformably by basal Labrador Group stratigraphy in the immediate hanging wall to the GLT, just under 2 km north of Grand Lake. There, the basal units of the Labrador Group include locally pebbly, quartz-rich psammites and pelites (Bradore Formation), a banded chloritic marble unit (Devils Cove Member, Forteau Formation) and dark-grey phyllite/slate (lower Forteau Formation). The metasedimentary rocks trend north-northeast and are overturned, younging to the northwest. They are in faulted contact with carbonate rocks of the BPTS to the northwest.

This same succession of granitic basement and overlying cover rocks is described here in this article (Figure 2) from an area, about 8 km southwest of Grand Lake, where it lies adjacent to the most southwesterly exposures of the BPTS. The rocks outcrop in a west-flowing tributary stream of Trout Brook, which eventually joins with Harrys River a few kilometres east of Black Duck. Unlike the strata north of Grand Lake, which occur as a single structural unit, the succession in the tributary is repeated by several thrusts to form a small imbricate stack that outcrops along the brook for a hundreds metres or so.

THE IMBRICATE STACK

Rocks involved in the imbricate stack include Proterozoic crystalline rocks of Grenvillian age (Currie and van Berkel, 1992) and overlying lower Paleozoic metasedimentary cover rocks of the Labrador Group. Fine-grained chlorite and sericite in the Devils Cove Member suggest that the rocks were probably metamorphosed at least to sub-greenschist grade. Proterozoic basement rocks consist of green granite gneiss having folded pink granite sills, intruded by mafic dykes and coarse-grained quartz and pink feldspar porphyry veins. Chlorite and epidote occur in the gneisses and granitic veins. The basement is also host to mineralized breccia, veins and clots described later.

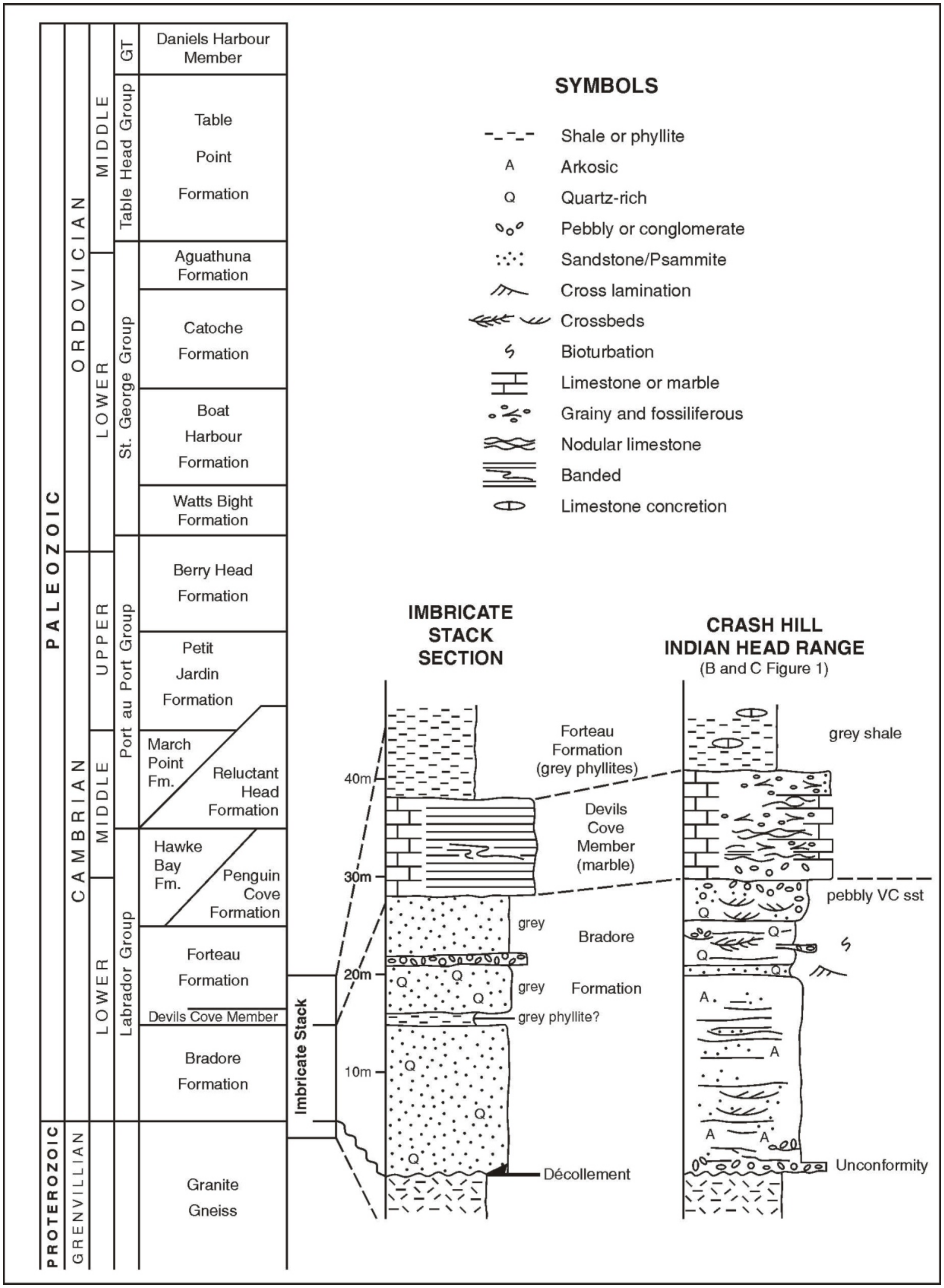


Figure 2. *Correlation of sections through the lower part of the Labrador Group between the imbricate stack and Indian Head Range. The stratigraphy of the Cambro-Ordovician shelf of western Newfoundland are shown to the left. GT - Goose Tickle Group.*

The lower Paleozoic cover rocks of the Labrador Group, preserved in the stack, consist of three units. At the base, and lying above the basement with structural detachment, is a succession of white- to reddish- to grey-weathering psammitic rocks that include metaquartzite, metasandstone, granular conglomerate and minor phyllite. These rocks compare to the Bradore Formation described in the neighbouring basement terrane north of Grand Lake (Knight, 1997). Both these sections are similar to the formation in the Crash Hill area of the North Brook Anticline near Black Duck (Knight, 2003), although quartz-rich sandstones dominate the stack section compared to the mixed arkose to quartz arenite succession at Crash Hill.

The Bradore Formation is approximately 28 m thick and consists of a basal quartzite, 15 m thick, which is overlain by a grey phyllite (1 m thick) cut by quartz-feldspar veins. This is in turn overlain by 5 m of grey metaquartzite. At this level, the formation hosts a 1 m bed of granular sandstone to small-pebble conglomerate, consisting of rounded blue-grey quartz grains. It underlies an upper 6 m bed of fine-grained, grey sandstone and some calcareous sandstone at the very top of the formation.

The sandstones are abruptly overlain by a unit of banded, sericitic and chloritic, coarsely crystalline carbonate. The unit, which is about 10 m thick, is hard, recrystallized, calcitic marble displaying a planar, centimetre-thick banding separated by millimetre-partings of sericite and chlorite. The marble, which weathers straw-yellow to orange, varies between white, cream, pink and yellowish on fresh surfaces. It is correlated with the Devils Cove Member of the Forteau Formation (*see* Knight, 1997 and 2003 for comparison to neighbouring outcrops in the region). The banded nature of the limestone and micaceous partings suggest that originally the marble was a fine-grained, clean, ribbon limestone, alternating with shale partings, characteristic of a more distal shelf setting. It appears to be similar to the unit north of Grand Lake (Knight, 1997) but is in marked contrast to the nodular, fine-grained to grainy spectrum of lithofacies seen at Crash Hill in the North Brook Anticline (Knight, 2003).

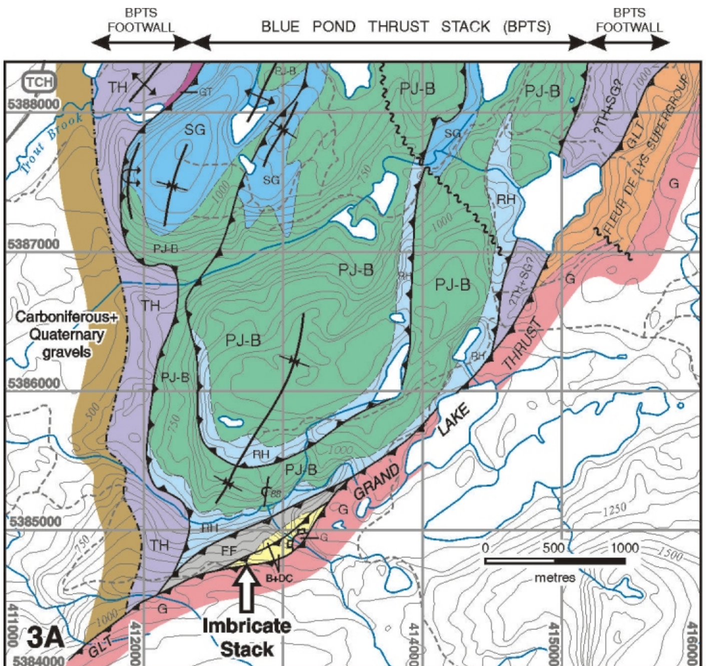
Immediately overlying the marble, there is a succession of polydeformed, dark-grey phyllites and slates that are correlated with the lower shale interval of the Forteau Formation. Strongly weathered outcrops of the dark-grey phyllites, occur along the banks of the tributary stream and in vertical gullies high above the stream bed, just downstream of the complex. Bedding is seen locally in the phyllites as colour bands on cleavage planes and as shale with quartzite laminae in rootless isoclinal folds.

DIMENSIONS OF THE IMBRICATE STACK AND ITS BOUNDING GEOLOGY

The imbricate stack probably extends no more than 1.6 km along strike (i.e., northwest to southeast) and is less than 500 m in width (Figure 3). The southwestern end of the stack is obscured by forest and gravel deposits but mapping in the area, combined with airphoto interpretation, suggests that it is structurally cut out by the merging of the floor thrust with the GLT. Similarly, the floor thrust to the stack probably merges to the northeast with the GLT because the stack and its relevant stratigraphy is absent 700 m to the northeast in the nearest brook, which is also physically incised. There, vertically dipping, shaly ribbon limestones of the Reluctant Head Formation (Figures 2 and 3) are juxtaposed against Grenvillian gneisses, which are intruded by narrow mafic dykes. The Proterozoic gneiss forms a massive upland fronted by a northwest-facing scarp over which the brook plunges into a deep gorge eroded into the ribbon limestones. No more than fifty metres separates the gneiss and ribbon rock, and although the contact is not exposed, there is insufficient space to accommodate the thick succession of Labrador Group strata known to occur elsewhere in western Newfoundland. This implies a faulted contact in the brook. Ribbon limestones of the Reluctant Head Formation are mapped at the sole of several of the more eastern thrust slices in the BPTS (Knight, 1997) where they stratigraphically underlie a thick dolostone sequence of the Petit Jardin Formation, Port au Port Group.

The imbricate stack appears to lie in the footwall to the GLT, which is most probably steeply east-dipping (*see* cross section, Williams and Cawood, 1989). Granitic gneisses intruded by mafic dykes and the Hare Hill Granite lie in the hanging wall.

The floor of the imbricate stack is less certain. It may be the foremost leading thrust exposed in the stream bed. Alternatively, it may lie to the west of the exposed stack itself, buried by Quaternary gravels. In this case, the floor thrust may lie below outcrops of Forteau Formation phyllite that outcrop just downstream of the gorge. Traced both to the northeast and southwest, the phyllites appear to be cut out between the GLT and the BPTS. This fault, therefore, merges with the GLT along strike in either direction and may be the leading edge of the floor thrust of the stack. In addition, mapping of the BPTS in the immediate area west of the imbricate stack, indicates that both the sole thrust of, and the footwall to, the BPTS strike south to a branch point that essentially coincides with the branch point of the floor fault of the imbricate stack and the GLT (Figure 3).



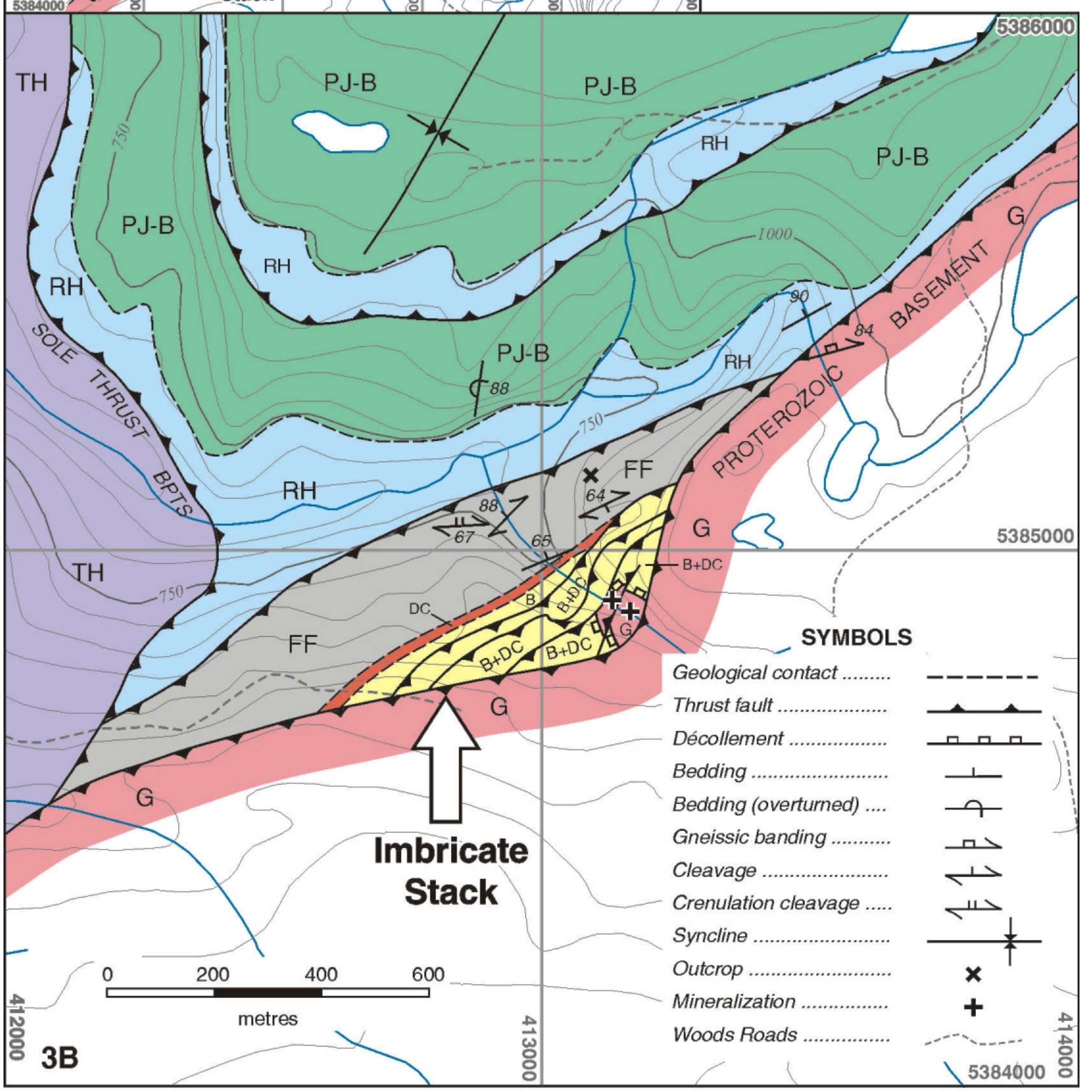


Figure 3a and b. *Geological maps of the stream that hosts the postulated footwall imbricate thrust stack, Grand Lake Thrust. GT - Goose Tickle Group, includes Daniels Harbour Member; TH - Undivided Table Head Group; SG - Undivided St. George Group; PJ-B - Undivided Petit Jardin and Berry Head formations; RH - Reluctant Head Formation; FF - Forteau Formation, phyllite; B+DC - Undivided Bradore Formation and Devils Cove Member; G - Grenvillian basement. Note: contours in fee above sea level.*

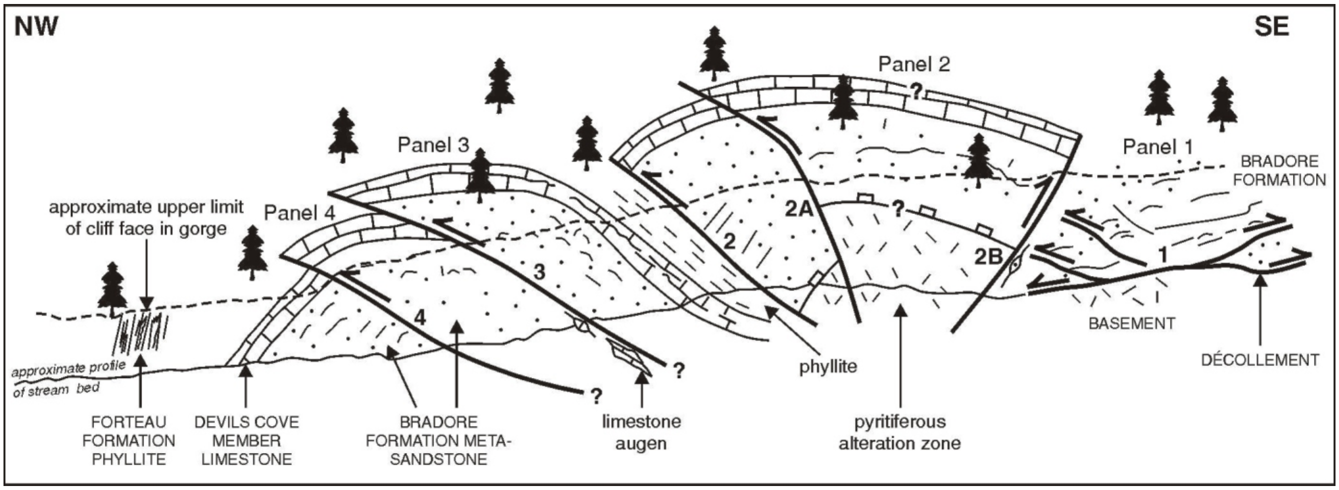


Figure 4. *Speculative, schematic, cross section of the footwall imbricate stack, GLT, based on a crude notebook sketch and photographs of the stack. No scale implied. Structure projected above the top of cliff exposed in the gorge.*

STRUCTURE

Figure 4 is a schematic cross section of the imbricate stack based on a very rough field sketch assisted by photographs taken of the zone. The exposed part of the imbricate stack, from west to east, consists of at least two, northwest-verging panels (Figure 4, Panels 3 and 4), a single panel bounded by both west- and east-verging faults (Panel 2), and a gently dipping panel of cover rocks overlying basement (Panel 1). The most westerly thrust (Panel 4) may form the ramping floor to the duplex although, as discussed above, the floor thrust may lie concealed beneath drift farther to the northwest, and hence lie below the phyllites of the Forteau Formation that outcrop just downstream of this fault. The inner part of the duplex has not been examined systematically, hence it is assumed that the innermost gently inclined panel (Panel 1) lies west of, and immediately in, the footwall to the Grand Lake Thrust, which is also assumed to outcrop just upstream of this panel. A plane of décollement (Plate 1) occurs between the basement and the cover in this gently inclined panel at the east end of the duplex.

Thrust faults 2 and 4 (Figure 4) are sharp planes. Thrust fault 4, which may be the leading edge of the stack, separates hanging-wall and footwall ramps, and thrust fault 2 juxtaposes hanging-wall ramp with footwall flat (Plates 2 and 3). The thrust planes strike and dip 320º/34º northeast[1] and 010º/20º southeast respectively for thrusts 4 and 2. A complex mylonitic shear zone however typifies thrust fault 3. The strongly foliated mylonitic psammite encloses large augen of rusty-weathering marble as well as augened and attenuated quartz carbonate veins (Plates 4). The general sense of shear from the augen give west-directed overthrusting. Recumbent folds, which deform the mylonite and plunge gently to the north, have axial planes that strike and dip at 352º/46º northeast. Locally, the mylonite zone is folded about a broad anticline that plunges 40º due east.

Plate 1. *Basal décollement zone (arrow) between light-coloured Grenvillian basement (foreground) and dark-bedded sandstones (cliff). Gently dipping panel 1 of the inner part of the imbricate stack.*

The hinterland panels of the imbricate stack are a western panel (Panel 2), bounded by oppositely verging faults (possibly a pop-up) and an eastern, and gently dipping panel (Panel 1) having clear detachment of bedded Bradore Formation above Proterozoic basement (Plate 1). Panel 2, which is bounded by thrust fault 2 and a steeply (55º to 85º) west-dipping, north-trending fault zone (thrust fault 2B), is

[1] 320º/34º northeast this format refers throughout to strike of a structural plane/dip of a structural plane.

Plate 2. *East-dipping thrust plane of thrust fault no. 4 (arrow), which forms the foremost thrust in the exposed part of the imbricate stack. Bradore Formation metasandstones occur above and below the fault.*

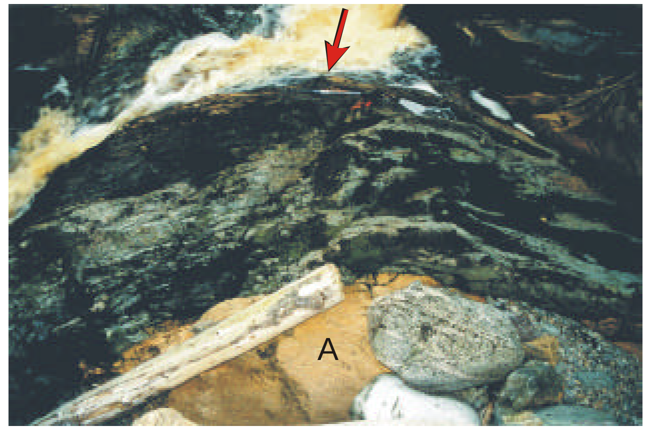


Plate 4. *A large augen (A) of orange-weathering marble within a foliated, mylonitic psammite. The mylonite is broadly folded. Attenuated orange carbonate veins are indicated by the arrow. Trekking stick (arrow) for scale.*

Plate 3. *East-dipping thrust fault no. 2 (arrow) placing Bradore Formation metasandstone above recessively weathering phyllites of the Forteau Formation.*

either a westward-tilted block of Labrador Group having highly altered basement rocks in the east or a panel in which altered basement occurs beneath anticlinally folded Bradore Formation. Only the western limb of the anticline is exposed. The basal Cambrian unconformity or structural décollement is obscured by alteration. The basement rocks are finely brecciated and micro-veined as well as rusty-weathering due to the presence of pyrite. Kinematic indicators in the eastern bounding fault define eastward overthrust of its hanging wall.

Plate 5. *Moderately west-dipping banded marble of the Devils Cove Member, footwall of the thrust stack. Inset A shows block of folded marble. Inset B shows fresh surface of marble.*

The most easterly panel 1 dips gently at 345º/20º northeast steepening somewhat locally near the contact with panel 2 to 260º/32º northwest. The basal décollement surface appears to be inclined approximately 325º/28º northeast. Bedding parallel shortening is accommodated above the décollement by west-verging, flat to low-angle thrusts that cut the well-bedded psammitic rocks in the hanging wall of the décollement with possible east-vergent structures, locally superimposed. Both thrust sets ramp gently away from the décollement zone. Fractures associated with narrow breccias are also common in the décollement hanging wall.

Brecciated to fractured granitic gneiss intruded by mafic dykes characterizes the Proterozoic basement in the footwall of the décollement. Folded pink granitic veins, 10 cm wide, cut the gneiss and appear to trend essentially subparallel to the detachment. Sawn surfaces of the granite veins show coarse quartz and pink feldspar crystals cut by closely spaced imbricate fractures, prior to the growth of chlorite and epidote. Minor east-trending, subvertical faults cut the basement and are associated with mineralized veins, imbricate fractures and breccias.

Exposed in the footwall to thrust fault 4, there is a steeply west-dipping succession of rocks that include the banded marble of the Devils Cove Member (Plate 5) overlying psammites of the top of the Bradore Formation, and overlain itself by phyllitic rocks of the Forteau Formation. Banding in the footwall outcrop is uniformally dipping at 65º to 85ºNW on a strike of 250º. However, the stream bed near, and downstream of the outcrop, is strewn with very large marble boulders, which exhibit impressive disharmonic folding, as well as tight, to more open folds with limb thinning of bands, thickening of micaceous partings in fold noses, and local initiation of mineral-band transposition. Whether these boulders come from the footwall or from hanging-wall outcrops obscured high in the tree-covered sides of the stream gully is not known. It is also uncertain whether the banding is ribbon bedding or is a transposed banding associated with an earlier deformation. Transposed bedding is a common feature of ribbon carbonates associated with thrust stacks in western Newfoundland where it is superimposed on rocks of the Reluctant Head Formation in the Goose Arm and Old Man Pond area of the Goose Arm thrust stack (Knight and Boyce, 1991; Knight, 1994) as well as in the BPTS itself.

Plate 6. *Phyllite of the lower part of the Forteau Formation, footwall sequence just downstream of the marble outcrop (Plate 5).*

The phyllites of the footwall outcrop in the stream bank just downstream of the Devils Cove Member (Plate 6). They are characterized by a steep, west-dipping main cleavage, which strikes 225º and is associated with tight isoclinal folds that plunge steeply to the northeast at 65º. Minor folds and tightly folded quartz–carbonate veins associated with the main cleavage plunge due northeast at 65º. The main cleavage carries a crenulation lineation that plunges 68º on a trend of 085º and is associated with a later crenulation cleavage striking 270º and dipping 67º to 84º north. Small-scale crenulation fold axes strike 081º and plunge 31º to the east.

Other outcrops of phyllite occur north of, and over 70 m above, the tributary stream, in very steep washout stream gullies. There, the main cleavage strikes 035º, dips southeast at 55º to 64º, and is associated with rootless isoclinal folds that plunge steeply southwest and with C–S fabrics that imply a steeply oriented left-handed sense of shear. The phyllites also host the later crenulation cleavage that strikes 060º and dips southeast at 58º. It is associated with crenulation folds that plunge due east at 28º and a crenulation lineation on the main cleavage that ranges from 085º/20º southeast to 120/55º southwest. These elevated gully outcrops may occur in the hanging wall of thrust fault 4 rather than in the footwall succession.

MINERALIZATION

Parts of the imbricate stack are host to a broad zone of pyrite and galena mineralization, principally within altered and brecciated Proterozoic basement but also in overlying rocks of the Bradore Formation. The mineralization is located in panel 2 and in the footwall to the basal décollement of the gently dipping panel 1. In panel 2, there is a broad zone of rusty weathering that hides pyritized, brecciated and altered, crystalline basement rocks (Plate 7). The pyrite occurs as fine stringer veins and disseminations, and the zone also hosts some stringers and veins of galena. The pyritic zone forms a crumbling rock wall, which is at least 30 m wide and several 10’s of metres high. Mineralized calcite and quartz veins show possible carbonitization of chloritized granite breccia fragments. Most of the mineralization is blue-grey galena with isolated grains of brown sphalerite. Pyrite occurs as isolated clots and fine disseminations in the veins as well as in loosely connected strings of small clots.

Plate 7. *Rusty alteration zone in rotted Grenvillian basement rocks, thrust fault 2.*

Veins of galena occur in the basement rocks of panel 1. There, the galena occurs as large and small crystals, large clots and as thin, pencil-line-thin stringers, mostly associated with calcite (Plate 8). Assays of grab samples of the pyritized zone and of some of the vein mineralization are given in Table 1. Zinc values of 1 to 2% and Pb values up to 3.8% occur in the veins. No anomalous Au or Ag values were found in the pyritic alteration zone or in the veins.

A galena showing in basement rocks is marked on the map of Williams (1985). This showing is placed in a second

Plate 8. *Galena–calcite vein cutting Grenvillian basement below décollement of panel 1.*

tributary stream off Trout Brook approximately 1 km northeast of the showing in the imbricate stack. A preliminary search of this stream found no mineralization in either basement rocks or structurally underlying rocks of the Reluctant Head Formation.

DISCUSSION

STRATIGRAPHY AND FACIES

The stratigraphy in the rock of the imbricate stack exposed in the incised tributary stream of Trout Brook, southwest of Grand Lake, includes sedimentary rocks belonging to the lower part of the Labrador Group. The strata consist of Bradore Formation and Forteau Formation, of which the latter is divided into the basal Devils Cove Member carbonate and an overlying sequence of polydeformed phyllites. It is one of only a few localities in the southeastern edge of the external Humber (tectonostratigraphic) Zone in western Newfoundland to provide exposure of the basal Cambrian unconformity and its immediately overlying stratigraphy. Another locality is in the narrow belt of lower Paleozoic shelf rocks near Coney Arm in White Bay (Kerr and Knight, *this volume*). These localities vary somewhat from more westerly occurrences such as the classic roadside locality in Gros Morne National Park (James *et al*., 1988), and the recently described locality in the Indian Head Range to the northwest of Grand Lake (Knight and Boyce, 2000; Knight, 2003) although they also share some common features (*see below*). The unconformity and its cover are also well exposed along the eastern side of Canada Bay (Knight and Saltman, 1980; Knight, 1987) but there, their character is unique within western Newfoundland. For instance, the unconformity is locally underlain by Neoproterozoic rift facies of the Lighthouse Cove Formation and it is characterized by a sub-unconformity paleo-regolith. Also, the overlying Bradore Formation consists of tens of metres of fluvial arkosic sandstones overlain by marine sandstones that are similar to the rocks at Indian Head, Gros Morne and Coney Arm (Knight, 1987).

The lithofacies of the Labrador Group preserved in the stack suggest that the succession occupies a more distal position on the ancient Iapetan margin than the Indian Head occurrences. The Bradore Formation is almost exclusively quartz arenite with minor shale interbeds, locally, and a single bed of clean small quartz-pebble conglomerate. This suggests a well-sorted and clean nearshore marine sand body similar to the unit north of Grand Lake (Knight, 1997) but in contrast to the mixed arkose and quartz arenite (fluvial to shore) seen 20 km to the northwest at Crash Hill (Knight, 2003) and the Indian Head Range (Knight and Boyce, 2000; *see* Figure 2). The quartz arenites, however, appear to lie in the same facies belt as the Bradore Formation in White Bay, 175 km along strike to the northeast (Kerr and Knight, *this volume*), and the exposures of Bradore Formation, in Gros Morne (James *et al.*, 1988). At all of these localities, the formation is only 10 to 20 m thick in contrast to the section beneath Port au Port Peninsula (*see* Knight and Boyce, 2000) and most of the Great Northern Peninsula sections of northern Newfoundland, where it averages about 150 m thick and is dominated by arkosic fluvial sedimentary rocks (Knight, 1991; Knight and Cawood, 1991).

The Devils Cove Member limestone is a persistent regional marker, both for foreland sections such as the Great Northern Peninsula, where it is essentially pristine, although locally dolomitized, and metamorphosed hinterland sections such as near Grand Lake. Everywhere it is mapped, it is a few metres to 15 m thick. However, the fine-grained, ribbon-bedded nature of the member with its accompanying shale partings in the Grand Lake area contrasts to the nodular parted fine-grained limestone overlain by grainstone in its nearest counterpart 20 km to the northwest at Crash Hill and Indian Head Range (Knight, 2003; Knight and Boyce, 2000). This suggests a more distal shelf setting in the Grand Lake area for this basal transgressive Early Cambrian carbonate.

STRUCTURE

The incised tributary stream of Trout Brook provides an opportunistic window into a small imbricate stack that formed west of the GLT, as mapped by Williams and Cawood (1989). It is probable that, if not for the stream, the stack would be completely hidden by thick forest overgrowth on the steep, generally poorly exposed hillsides in the foothills to the spine of the southern Long Range Mountains. Even if not concealed, however, the only rocks likely to occur in the high ground of the foothills are phyllitic rocks of the Forteau Formation that occur structurally and

Table 1. Geochemical analyses of grab samples from the mineralized alteration zone, Grand Lake Thrust

Sample #	UTM Easting	UTM Northing	Map Sheet	Zone	NAD	Mo ppm	Cr ppm	P ppm	Zn ppm	Pb ppm	Co ppm	Ni ppm	Fe %
K-02-41C-1	413099	5385052	12B/09	21	27	0	17	494	22	10	15	10	3.60
K-02-41C-2	413099	5385052	12B/09	21	27	1	22	1985	41	17	61	23	9.94
K-02-41C-3A	413099	5385052	12B/09	21	27	2	21	521	21	26	8	7	1.81
K-02-41C-3B	413099	5385052	12B/09	21	27	2	25	534	29	24	7	13	2.60
K-02-41C-4	413099	5385052	12B/09	21	27	0	14	150	11	4	3	7	2.79
K-02-41C-5	413099	5385052	12B/09	21	27	4	30	72	5521	37119	5	17	1.76
K-02-41C-6	413099	5385052	12B/09	21	27	4	3	53	14278	37945	7	14	4.88
K-02-41C-7	413099	5385052	12B/09	21	27	3	14	76	10173	38358	6	18	2.23

Sample #	Ca %	Nb ppm	Cu ppm	Na %	Zr ppm	Dy ppm	Sc ppm	Y ppm	Al %	Mn ppm	Sr ppm	La ppm	Ce ppm	Ba ppm
K-02-41C-1	0.57	13	42	0.55	132	3.0	4.1	18	2.33	139	34	20	45	1226
K-02-41C-2	1.20	37	40	0.66	220	6.4	9.4	41	4.28	506	65	20	56	91
K-02-41C-3A	4.10	37	20	0.68	387	8.8	9.2	59	6.53	508	101	47	85	256
K-02-41C-3B	1.04	35	19	0.77	353	11.8	10.5	66	8.34	170	88	100	171	349
K-02-41C-4	0.18	9	107	0.49	98	0.6	2.3	7	1.28	49	13	7	19	184
K-02-41C-5	25.15	7	403	0.04	5	77.5	5.7	315	0.39	1853	87	300	598	42
K-02-41C-6	25.84	9	250	0.02	7	71.4	1.6	309	0.18	2239	66	265	520	42
K-02-41C-7	25.18	6	717	0.30	7	76.4	4.3	318	0.69	1835	111	276	559	79

stratigraphically above the rocks involved in the stack and in which the structural clarity, afforded by the gorge section, would be obscured. Incised stream beds, a few kilometres to the northeast, indicate that the stack is areally of limited dimensions in that direction. To the southwest, it also likely pinches out structurally as the floor thrust reaches a branch point with the GLT. However, this relationship is covered by Quaternary gravels and forest and its limits are extrapolated based on the projection of other thrusts and geological terranes of the BPTS into the immediate area.

Still other uncertainties remain to be clarified by additional field work. Of these uncertainties, the most pressing and least easy to resolve will be the position of the northwestern leading edge of the stack. Two interpretations are possible based on the available knowledge of the area. The first and simplest model picks thrust fault 4, which outcrops at the entrance to the gorge, as the leading edge of the complex. The most westerly exposures in the stream section, which include the top of the Bradore Formation, the Devils Cove Member carbonate and the Forteau Formation phyllites, would then occupy the footwall to the stack. This would imply that the phyllites would be overlain by rocks of the Penguin Cove Formation and then the outcropping Reluctant Head Formation. However, mapping suggests that a fault separates the phyllites from the deformed carbonates of the BPTS, implying that unless the fault is a later fault (*see below*), this model is probably unlikely.

The second model extrapolates that the floor of the stack lies beneath the Forteau Formation phyllites seen downstream of the gorge. In this model, the frontal thrust or leading edge of the structure is hidden to the west beneath the gravels and floodplain of the tributary system. The structural termination of the stack and the Forteau Formation phyllites only a few hundred metres to the northeast between hanging wall Grenvillian basement, and footwall Reluctant Head Formation ribbon carbonates of the BPTS suggests that this interpretation may be valid. This is the model adopted in Figure 4.

If model 2 is correct (i.e., the leading edge of the stack is now hidden to the west and the stack is limited by a leading edge branch line that merges the floor thrust of the stack with the GLT), it is possible to argue that the floor thrust is the frontal expression of the GLT. If so, then the leading edge branch line of the GLT lies west of the thrust as it is drawn on the map of Williams and Cawood (1989) and the stack is in the hanging wall to the GLT. This is more in accord with the map relationships north of Grand Lake (Knight, 1996, 1997) than with the generally straight, steeply dipping structure mapped by Williams and Cawood

Table 1. Geochemical analyses of grab samples from the mineralized alteration zone, Grand Lake Thrust

Mg %	Cd ppm	Ti ppm	V ppm	Be ppm
0.37	0.1	3146	42	0.6
1.53	-0.2	7023	56	1.1
0.19	0.0	8262	59	1.1
0.31	0.0	8857	67	1.5
0.12	-0.1	1954	45	0.5
0.40	12.6	183	23	0.0
0.26	40.9	97	19	-0.1
0.32	23.5	153	22	0.0

Li ppm	K ppm	As ppm	Au ppb	Ag ppm
9.9	1.69	8	-5	0.3
31.3	2.85	28	-5	0.4
12.6	5.50	7	-5	0.3
8.9	6.25	6	-5	0.4
4.1	0.62	1	-5	0.2
8.2	0.18	7	-5	6.2
5.2	0.17	37	15	9.3
6.3	0.24	7	15	4.8

(1989), which is interpreted to be a thrust overprinted by later deformation. Both sections appear to have roughly similar structural and metamorphic character that support a common structural history. Thus, regardless of which model is better suited to the geology, the map relationships suggest that the GLT had an early history when the imbricate thrust stack was formed and a later one, when it was reactivated to break through its trailing edge and form a straighter, penetrative fault.

The map relationships are also open to another interpretation that invokes interference by a later, high-angle fault with the imbricate stack and its footwall. The later, high-angle fault would have juxtaposed rocks of the BPTS to the west against different parts of the imbricate complex. In some places, the high-angle fault would mark the contact between the phyllites to the east and the BPTS to the west, and at others the contact between BPTS and Grenvillian basement. The later, high-angle fault may displace the footwall of the stack in model 1, or displace or replace the leading edge and the floor thrust of the complex, as outlined in model 2.

A décollement probably occurs at the contact of the cover rocks and the Proterozoic basement based on the relationships exposed in the hinterland thrust panels. Since the elevation of the stream is higher in these inner panels and the décollement is hidden at depth in the outer panels, the floor of the stack must be deeper towards the foreland, suggesting that the complex as a whole has been tilted to the west. This is compatible with reactivation of the GLT after the imbricate stack had formed

The décollement probably formed early in the formation of the stack and was the fundamental discontinuity that allowed bedding parallel shortening of the cover sequence that marks the west-verging stack. The architectural geometry of the stack plus the folding of an early foliated psammitic mylonite encasing large carbonate augen of the Devils Cove Member, as in panel 3 indicates that the stack propagated forward and northwestward. Panel 2 could be a pop-up structure that accommodated shortening of the hanging wall to the décollement. However, since it involves basement rocks as seen within the alteration zone and must cut rather than use the basal décollement plane, this implies that the east-verging eastern-bounding fault was activated later in the history of the stack and the fault-bounded panel 2 is not a true pop-up (*see* Butler, 1982; Park, 1989).

Based on the internal geometry of the thrust panels and the interpretation of the branch points as limiting the lateral extent of the stack both to the northeast and southwest, it is possible that the stack is actually an erosional remnant (i.e., the lower part) of a truncated or partly unexposed duplex rather than an imbricate stack. If it is in fact a duplex, poor exposure of the polydeformed, phyllitic rocks of the Forteau Formation at higher structural levels of the complex may hide the roof thrust, which would be the diagnostic feature. Rootless folds in some of the outcrops high above the gorge may support this idea.

The phyllitic rocks of the lower Forteau Formation preserve a northeast-trending main cleavage and a later crenulation cleavage that strike essentially due east. Co-axial folds with the main cleavage plunge both northeast and southwest. Crenulation lineations and folds associated with the crenulation cleavage plunge consistently to the east. Recent mapping of the southwestern end of the BPTS (I. Knight, unpublished data, 2002) indicates the presence of both of these cleavages with essentially the same dispositions as those mapped in the imbricate stack. However, the main cleavage in the BPTS is axial planar to folds, which deform its thrusts. The main cleavage also postdates foliations and folds related to the D_1 thrusts. This suggests that the main cleavage is at least a D_2 structure and the crenulation cleavage a D_3 structure. The preservation of D_2 and D_3 structures in rocks associated with the imbricate stack suggests that the stack itself was deformed by the D_2/D_3 events. This plausibly implies that it formed during earlier D_1 west-verging thrusting that regionally affects the lower Paleozoic shelf and foreland basin stratigraphy and formed large regional thrust stacks such as the Blue Pond, Goose Arm and the Canada Bay-Hare Bay thrust stacks (Knight and Saltman, 1980; Knight, 1986, 1987, 1994, 1997; Knight and Boyce, 1991). All these stacks deformed structurally overlying Taconian allochthonous rocks of the Humber Arm, Old Man Pond and the Hare Bay allochthons. These formed the roof complexes that were broadly folded and locally steepened by the construction of the underlying stack culminations.

MINERALIZATION

The pyrite–galena–sphalerite mineralization associated with a broad rusty alteration zone in the Grenvillian basement and the basal Bradore Formation is comparable in its stratigraphic association with mineralization currently being studied in the White Bay area (Kermode Resources, 2002; Kerr and Knight, *this volume*; Kerr, *this volume*). Also, it has an analogous structural setting to the White Bay mineralization in that it lies adjacent to an important fault, the GLT (*cf.* Doucer's Valley fault complex of Smyth and Schillereff, 1982). Gold is present in both basement and cover rocks in the White Bay area but appears to be absent in the imbricate stack showings.

The mineralization postdates the formation of the stack since it occurs on both sides of the basal décollement but it may possibly predate the east-verging fault that uplifts the basement and cover and exposes the main rusty alteration zone of panel 2. Consequently, even though the exposed area of the mineralization is limited to the 1st and 2nd panels of the inner part of the stack, this may be an artifact of the westward deepening of the structure and mineralization could also lie concealed beneath the forward part.

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