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A STRUCTURAL WINDOW INTO ROBERTS ARM GROUP (?) BASALT AT BURNT POND (NTS 12H/1) – A METAMORPHIC-INVERSION HYPOTHESIS

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ABSTRACT

Mafic volcanic rocks exposed near Burnt Pond are veined and altered, regionally weakly metamorphosed, and complexly faulted and folded. Whereas the main mineralized belt of Roberts Arm volcanic rocks structurally overlies a younger unit of metasedimentary rocks, the Burnt Pond basalts may represent a structurally detached inlier of the Roberts Arm Group that lies beneath such a high-grade schist belt. Farther northeast, within the younger metasedimentary unit, paragneiss and hornfelsic schist are tectonically emplaced above a belt of phyllitic turbidites carrying regionally developed slaty cleavage.

INTRODUCTION

The highly prospective Buchans–Robert's Arm volcanic belt has been postulated to occur in the northeasternmost part of the Notre Dame Subzone of the Dunnage Zone immediately northwest of the Red Indian Line (Swinden *et al*., 1997). Dominated by altered andesitic and basaltic rocks, it comprises the Iapetus Ocean-facing side of a complexly deformed, low-pressure metamorphic belt (Upadhyay and Smitheringdale, 1972; Pehrsson *et al.*, 2003) within the composite Laurentian continental-margin magmatic arc of west-central Newfoundland (Cawood *et al.*, 1995; Waldron and van Staal, 2001).

The Buchans–Robert's Arm volcanic belt crosses the Trans-Canada Highway near the access road to the past-producing Gullbridge base-metal mine in southernmost Green Bay district (Figure 1). In this part of the NTS 12H/1 map area, the southeastern boundary of the Ordovician Roberts Arm Group has been traditionally drawn immediately west of Burnt Pond along the southeast contact of an inhomogeneously foliated, regionally northwest-facing sequence of folded greenstones that crop out to the northeast of Lower Gull Pond (Figure 1).

To the north and east of Burnt Pond, Kalliokoski (1954) described a belt of greywacke interbedded with various amounts of grey shale, slate, conglomerate, minor basalt and minor black pyritic shale (Units 1sg and 3 in Figure 1). He originally grouped these rocks and their metamorphosed equivalents within a lower division of the now defunct Badger Bay Series (Espenshade, 1937) and positioned these predominantly quartzofeldspathic siliciclastic rocks stratigraphically below the greenstone subunit.

West of Burnt Pond, the greenstone subunit is composed of dominantly northwest-dipping (right-side-up) intervals of pillow lava and mafic breccia (Figure 1), and is crosscut by numerous deformed sills of veined and altered gabbro. These mafic volcanic and hypabyssal rocks are immediately overlain by a tightly folded sequence of red chert, siliceous argillite, tuffaceous wacke, mafic breccia and felsic tuff (Figure 1). Kalliokoski (1954) placed this volcanosedimentary sequence within the middle part of his Badger Bay 'series'. Such weakly metamorphosed strata were deemed to lie stratigraphically below and southeast of the bimodal andesites and rhyolites of his Roberts Arm 'formation', which was assigned to the uppermost part of his Badger Bay 'series'.

Kalliokoski (1954) originally correlated the sedimentary rocks in his middle Badger Bay 'series' with Espenshade's Crescent Lake Formation. Subsequently, Williams (1972) included this stratigraphic unit in the newly defined Roberts Arm Group. In the most recent regional mapping of the study area, the greenstones and overlying sedimentary strata are assigned to the Roberts Arm Group but not necessarily to the Crescent Lake Formation, e.g., *see* Swinden and Sacks (1996) and Dickson (2001).

North of Rocky Pond, the structurally discontinuous Crescent Lake Formation consists of a sedimentary division of red argillite and green wacke and a volcanic division of northwest-facing pillow lava, mafic tuff and limestone (Figure 1). There, these fault-bounded subunits occur along the southeast margin of the Roberts Arm Group (O'Brien, 2003a). In the Burnt Pond area, and elsewhere, it was Kalliokoski's (1954) view that his older metagreywacke unit was stratigraphically separated from the Crescent Lake sed-

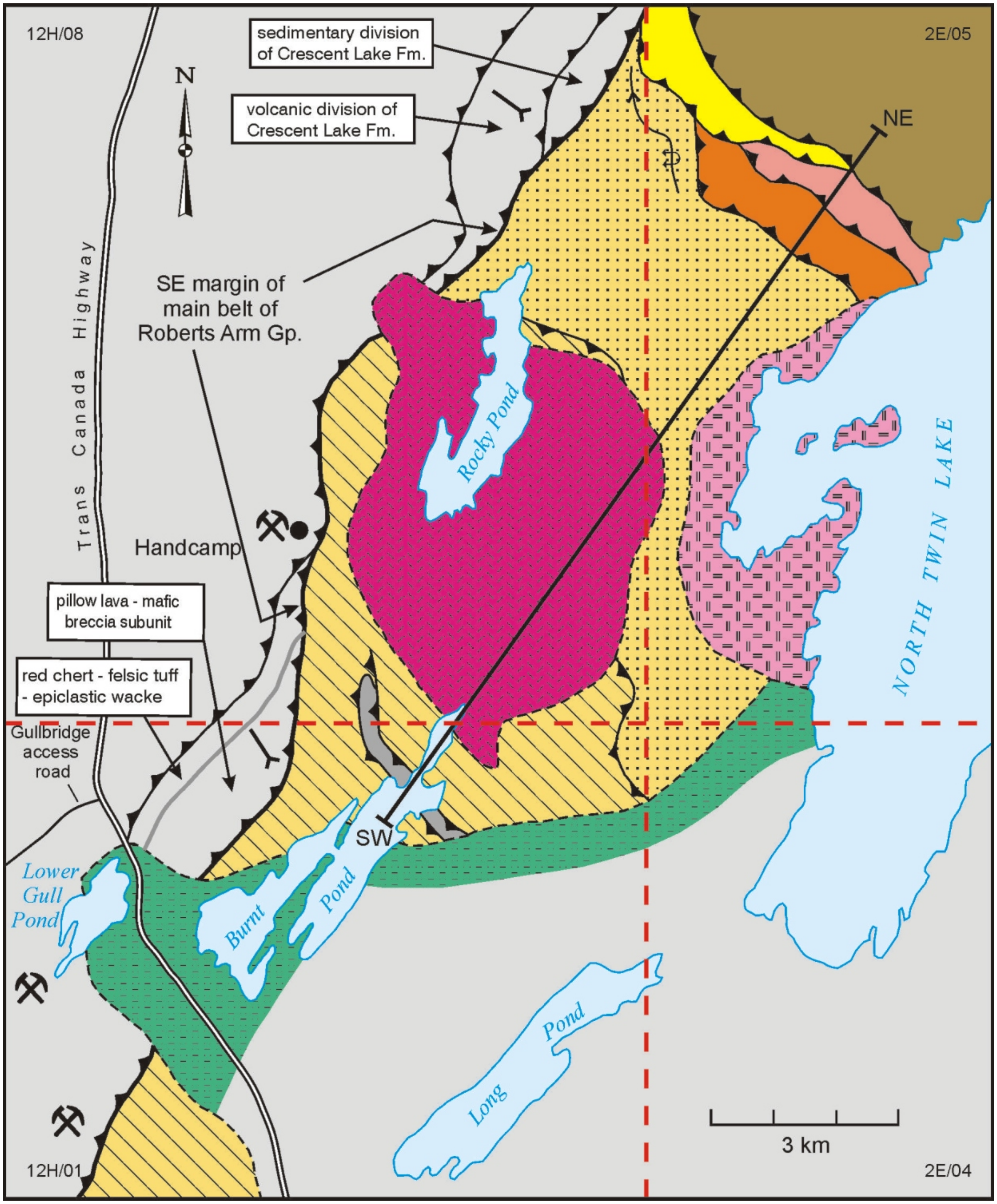


Figure 1. *Simplified geological map of stratified and intrusive rocks outcropping immediately southeast of the Robert's Arm volcanic belt in parts of the NTS 12H/1, 8 and 2E/4, 5 areas. The basalt subunit at Burnt Pond is coloured grey. Also indicated is the northeast–southwest line of the Figure 2 cross-section.*

imentary sequence by the above-mentioned pillow lava and mafic breccia succession west of Burnt Pond. Nevertheless, within the NTS 12H/1 map area, Kalliokoski (*op. cit.*) cautioned that certain rocks in his Crescent Lake 'formation' were difficult to distinguish from younger strata within the northwesterly adjacent Robert's Arm 'formation', as both contained variably reworked fragmental rocks with abundant felsic and mafic volcanic clasts.

LEGEND (Figure 1)

Silurian Intrusive Rocks

Hodges Hill İntrusive suite

Unit 9 - mainly isotropic granodiorite and subordinate granite (Dickson, 1999). This unit intrudes the Wild Bight Group posttectonically on the northeast shore of North Twin Lake (O'Brien, 2001).

Unit 8 - mainly isotropic granodiorite and subordinate diorite porphyry. Tectonically stitching the low-grade and high-grade parts of the Sops Head Complex, this satellite body is a possible correlative of the Twin Lakes complex (Swinden and Sacks, 1996).

Unit 7 - mainly isotropic gabbro. Tectonically stitching the low-grade Roberts Arm Group and the high-grade Sops Head Complex, this unit includes unseparated bodies of granodiorite and granite that crosscut gabbro (Dickson, 1999; 2001).

Ordovician Stratified Rocks

Late Ordovician Shoal Arm Formation

Unit 6 - dominantly graptolitic slate and mottled chert. This unit also includes imbricated tectonic slices of ribbon chert, siliceous argillite and pyritic sandstone which possibly belong to the upper Wild Bight Group or one of the partially broken sedimentary formations of the Sops Head Complex (O'Brien, 2001).

Middle Ordovician Sops Head Complex

Unit 5 - dominantly tectonized block-in-matrix melange (in places transitional to a pyritic pebbly mudstone). In addition, this unit contains slumped nodular siltstones, chaotically-deformed laminated argillites and sulphidic hemipelagites; it may also include other broken olistostromal subunits of the Sops Head Complex (O'Brien, 2001).

Middle Ordovician (?) Crescent Lake Formation of the Roberts Arm Group

Unit 4 - dominantly thin-bedded siltstone, graded sandstone turbidite, banded siliceous argillite and sandy epiclastic wacke (Notre Dame Subzone). Minor gabbro and diabase.

Middle Ordovician Roberts Arm Group (?) / Sops Head Complex (?)

Unit 3 - dominantly altered basalt breccia, subordinate pillow lava, minor interstitial chert and rare gabbro sills. These possibly comprise a structural inlier of the Roberts Arm Group or, alternatively, a partially broken basalt formation within the Middle Ordovician part of the Sops Head Complex (O'Brien, 2001).

Middle Ordovician Pennys Brook Formation of the Wild Bight Group

Unit 2 - dominantly concretionary volcaniclastic wackes and laminated siliceous argillites (Exploits Subzone). Minor gabbro sills.

Middle Ordovician and older(?) Sops Head Complex

Unit 1p - dominantly unbroken formation of phyllitic siliciclastic turbidites (transitional from slate to spotted phyllite near its southwest margin). Located in the structurally lowest part of the complex, this highly indurated unit is mostly composed of thick-bedded granular wackes and graded sandstone turbidites. Near its northeast margin, rare interbeds of basalt breccia, nodular chert and pyritic shale possibly comprise large stratified rafts within the turbidite succession.

Unit 1sg - dominantly psammitic and semi-pelitic metasedimentary rocks (schistose, gneissose and migmatitic parts of the complex). This unit contains abundant spotted and hornfelsic schists which are cut by sheared polymineralic veins and locally altered near tightly folded granitic stringers.

Major overthrust at margin of Robert's Arm volcanics (barbs on hanging wall sequence)

Minor thrust faults in immediate hanging wall and sedimentary footwall sequence of regional overthrust (barbs on hanging wall sequence).

Intrusive contact

Stratigraphic contact

Overturned anticline (with plunge direction indicated)

Younging direction

Mineral prospect

Highway, road

Boundaries of NTS map areas

In certain NTS 12H/1 locations, Dean (1977) placed some of the pillowed basalts lying directly above the older metagreywacke unit into the basal part of the Crescent Lake Formation, although he limited the outcrop of this formation to the area south of Burnt Pond and west of Long Pond (Figure 1). Dean (*op. cit.*) believed that such volcanosedimentary strata comprised a distinctive but laterally discontinuous horizon that lay stratigraphically above the older metagreywacke unit. He correlated the older metagreywackes with the Sansom Greywacke of eastern Notre Dame Bay. Subsequent mapping has shown that Kalliokoski's pillowed basalt subunit is either missing in places or that it occurs northwest of a tuffaceous wacke and felsic tuff subunit, which is locally present at the southeast margin of the Roberts Arm Group (Pudifin, 1993; Dickson, 2001).

Most recently, the older metagreywacke unit of Kalliokoski (1954) and Dean (1977) has been assigned, partially or in whole, to the upper part of the Middle Ordovician Roberts Arm Group (Pope *et al*., 1990), the lower part of the Late Ordovician–Early Silurian Badger Group (Dickson, 2001) or the lower part of the Middle Ordovician Sops Head Complex (McConnell *et al.*, 2002; O'Brien, 2003a). However, regardless of their depositional age and stratigraphic affinity, most workers now believe that these complexly deformed phyllites, schists and gneisses are tectonically juxtaposed with the relatively low-grade andesitic and basaltic rocks of the Roberts Arm Group. Situated within the Red Indian Line structural zone of Notre Dame Bay (Figure 31 of O'Brien, 2003b), such metasedimentary strata lie immediately beneath the structurally overlying rocks of the Notre Dame Subzone and comprise the original footwall sequence of a major overthrust zone (e.g., Nelson, 1981; Pudifin, 1993).

PRESENT CORRELATIONS

The chloritic and sericitic mafic breccias, the gossan-bearing podiform black pelites, the spotted pyritic cherts, the rare pebbly pelitic schists, the banded amphibolites and the sucrose metagabbros of the Burnt Pond phyllite and schist belts (Units 1sg, 1p and 3; Figure 1) invite correlation with less metamorphosed rocks presently included in Dean's (1977) Sops Head Complex. This is also consistent with Kalliokoski's (1954) regional mapping of associated siliciclastic turbidite sequences and, in particular, his inland extension of the greywacke, shale and conglomerate units originally defined along the well-exposed coastal section of Badger Bay (Espenshade, 1937).

Based on regional correlations, the map units of intrusive rocks illustrated in Figure 1 are presumed to be Silurian. All of these intrusive bodies postdate the ductile deformation and regional metamorphism of the Roberts Arm Group and the Sops Head Complex. Emplacement of the structurally highest plutonic sheet (Unit 8) may have been guided by pre-existing foliation–parallel fault structures, as associated metamorphic tectonites above and below the intrusion also dip gently southwestward (Figure 2). The structurally lowest granodiorite pluton (Unit 9) shown in Figure 2 is thought to be continuous with a compositionally similar intrusion known to crosscut purported Late Silurian structures farther northeast (O'Brien, 2003b).

REGIONAL GEOLOGY

In the regional cross-section illustrated in Figure 2, various subunits of the Roberts Arm Group are shown above the erosion surface of the northeast–southwest line of section (Figure 1). The outcrop pattern of three of these subunits has been mapped in the NTS 12H/8 map area about 4 km northwest of the line of section (O'Brien, 2003a). Regional structural and stratigraphic data collected in this region and the adjacent part of the NTS 12H/1 map area have been projected up-dip and southeastward into the plane of the Figure 2 cross-section. The vertical section shown in Figure 2 approximates to a longitudinal view of Roberts Arm strata that were previously depicted in several northwest–southeast sections of the southeast margin of the Roberts Arm Group (Figure 3 of O'Brien, 2003a).

When viewed in cross-section looking northwestward (Figure 2), the main belt of the Roberts Arm Group is interpreted to occupy the regionally domed, hanging-wall plate of a major northeast-directed overthrust. To the northeast, near the Sops Head Complex melange belt (Unit 5) and the southwest-directed thrust contact with rocks of the Exploits Subzone (Unit 2), the basal thrust at the southeast margin of the Roberts Arm Group is postulated to have been folded from its primary inclination to dip northeastward (Figure 2). Early formed structures in underlying rock units are also interpreted to have been affected by the observed folding of the overthrust plate about gently northwest-plunging axes.

On passing from southwest to northeast, different subunits of the Roberts Arm Group and a small duplex of the older Hall Hill Complex are locally present above the roof thrust of the Sops Head Complex for at least 12 km along the trace of this major structure (Figure 2). In the NTS 12H/1 map area, they include the Crescent Lake 'formation' of the middle Badger Bay 'series' and the Roberts Arm 'formation' of the 'upper' Badger Bay 'series' (Kalliokoski, 1954). In the NTS 12H/8 map area, the Hall Hill Complex (Unit 2 of Figure 1 *in* O'Brien, 2003a), a volcanic division of the Crescent Lake Formation (Unit 7 of Figure 1 *in* O'Brien, 2003a) and a sedimentary division of the Crescent Lake Formation (Unit 8 of Figure 1 *in* O'Brien, 2003a) occur directly above the roof thrust (Figure 1).

Such strata are interpreted to be bounded by imbricate splay faults of the regional northeast-directed thrust located beneath the main belt of the Roberts Arm Group. However, southwest of the Hall Hill Complex (Figure 2), the Crescent Lake ‘formation’ of the upper Badger Bay ‘series’ (Kalliokoski, 1954) is probably not correlative with the Crescent Lake Formation of the Roberts Arm Group (O’Brien, 2003a; NTS 12H/8). Nevertheless, the Roberts Arm Group appears to be dismembered and regionally inverted where it rests directly above the Sops Head Complex, i.e., the lowest Roberts Arm sequence consists of mainly right-way-up units that, taken together, are stratigraphically upside-down. This point is based on the assumption that the sedimentary division of the Crescent Lake Formation is younger than the volcanic division of that formation, and also on the assumption that the entire Crescent Lake Formation is younger than the rest of the Roberts Arm Group (O’Brien, 2003a).

The phyllite, schist and gneiss belts that lie beneath the Roberts Arm Group around Burnt Pond contain highly deformed, although still recognizable, stratified and intrusive rocks. In areas where the regional strain is low, a variety of sedimentary and volcanic rock types are identifiable and, in places, geopetal information can be gleaned from relict bedforms. Local younging directions within regionally metamorphosed turbidite sequences are commonly supported by reverse grading in porphyroblasts.

The top-to-the-northeast thrusting of the Roberts Arm Group and associated imbrication of the underlying Sops Head Complex are postulated to antedate the overthrusting and antivergent folding of the Middle Ordovician Wild Bight Group and the Late Ordovician Shoal Arm Formation (Figure 2). However, the absolute age of the earlier deformation is unconstrained. In the study area, it is assumed that the various textural types of metamorphic rocks in Unit 1 developed contemporaneously and were broadly coeval, that the sedimentary protoliths all belonged to the same regional map unit, and that the depositional age of all stratified rocks in this part of the Red Indian Line structural zone is Middle Ordovician or older.

METAMORPHIC AND INTRUSIVE ROCKS

In the study area, Unit 1 contains several fault-bounded tracts of phyllitic turbidites and metasedimentary schists and one tract of paragneisses, all tentatively assigned to the Sops Head Complex (Figure 3). Such metamorphic rocks comprise a northwest-trending belt extending some 8 km across strike from the northeast end of Burnt Pond in NTS 12 H/1 map area, around the southeast margin of Unit 8, to the northeast end of Rocky Pond at the headwaters of the Tommy’s Arm River in NTS 12 H/8 (Figure 1). As illustrated in Figure 2, they are interpreted to form a lithotectonic sequence of regionally, gently dipping rocks, which are bounded by folded thrust faults. The tectonically adjacent rocks of the Roberts Arm Group display many of the typical features of variable temperature–low-pressure metamorphic belts, as exemplified by the strong cleavage in unspotted slates near the gold prospect at Handcamp and by the relict schistosity in granofels and recrystallized hornfels near several base-metal prospects southwest of Lower Gull Pond (Figure 1).

The variably metamorphosed rocks lying beneath the Roberts Arm Group are generally well foliated, coarsely banded and rich in porphyroblastic index minerals. The metasedimentary schists and paragneisses near Burnt Pond are metamorphically contrasted with the structurally overlying, moderately northwest-dipping, low-grade Ordovician strata of the Roberts Arm Group, which only display very rare zones of localized porphyroblastesis. The distribution of porphyroblasts in the underlying spotted schists and phyllites is apparently unrelated to the proximity of the adjacent intrusive rocks (Units 7, 8 and 9). This observation is supported by reports of stoped xenoliths of sheared porphyroblastic schist in similar unfoliated plutonic rocks (Upadhyay and Smitheringale, 1972).

In the area surveyed, the sharply fault-bounded belts of phyllitic, schistose and gneissose rocks are all truncated by a younger intrusive body composed of a central phase of isotropic granodiorite and a marginal phase of diorite porphyry (Unit 8; Figures 1, 2 and 3). Best exposed near Rocky Pond, this intrusion was emplaced along and across several of the imbricate structures associated with the Tommys Arm Fault. An early syn-metamorphic structure within this fault zone defines the bottom of the Roberts Arm Group and the top of the Sops Head Complex in the NTS 12H/8 map area (O’Brien, 2003a). Whereas sheared porphyroblastic schists are confined to the lowest 100 m of the Roberts Arm Group, the underlying Sops Head Complex commonly displays such schists over a thickness estimated to be in excess of one kilometre.

Similar metamorphic rocks are also crosscut posttectonically by an isotropic gabbroic intrusion in the central and southern parts of Burnt Pond. Here, at the northern margin of the Hodges Hill intrusive suite (Dickson, 2000), the gabbro body is thought to dip steeply northeastward, although it appears to form a moderately west-dipping cupola near the Trans-Canada Highway (Figure 1). The relationship of the Hodges Hill gabbro and the Rocky Pond granodiorite is unknown. However, based on the presence of the cupola and the geometry of the overlying Rocky Pond granodiorite and metasedimentary schists (Figure 2), the gabbro contact may possibly flatten out farther to the northeast.

STRUCTURAL GEOLOGY

Inhomogeneously foliated and tightly folded, mafic plutonic sheets and less common, syn-tectonic, felsic plutonic bodies are observed to intrude a generally gently dipping belt of spotted schist, hornfelsic schist, psammitic gneiss and boudinaged migmatitic gneiss between Burnt Pond and northern Rocky Pond (Figures 1 and 2). In places, such high-grade metamorphic rocks display intrafolial folds of foliation and a linear shape fabric developed on crosscutting quartz veins and granitic dykes (Plate 1). In other locations, the bedding-parallel foliation in flat-lying metasedimentary schist is overgrown by randomly oriented amphibole porphyroblasts, which developed in the contact aureoles of weakly foliated metagabbro intrusions.

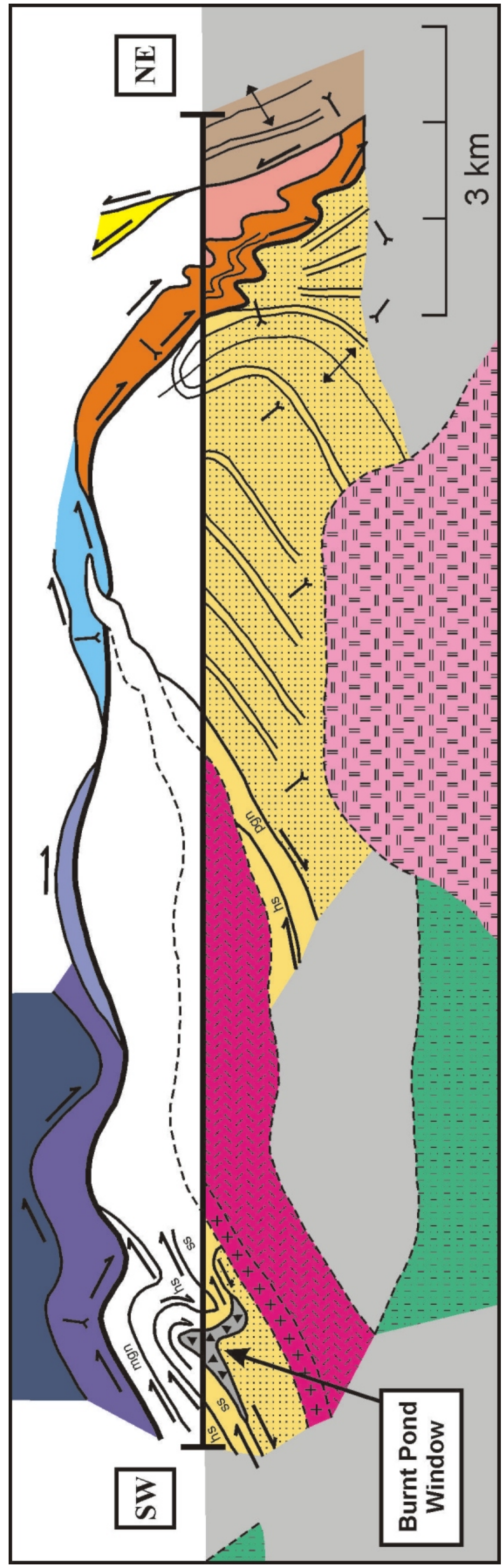
Mafic mylonitic gneiss lying immediately beneath the structurally overlying Roberts Arm Group (Figure 2) is leached and altered, extensively recrystallized and locally converted to an isotropic hornfels in the region north of Burnt Pond and south of Handcamp (Figure 1). The relationship of this poorly exposed mafic gneiss tract to the less-deformed and metamorphosed basalt sequence at Burnt Pond is unknown. Smaller metabasite bodies displaying similar texture are, however, interlayered with sulphidic metasedimentary schist immediately northeast of the basalt subunit near the outflow of the pond (Figures 3 and 4).

Detailed structural data collected from metamorphic rock exposures along the north and south shore of Burnt Pond were used to construct the generalized cross-section shown in Figure 4. It illustrates an interpretation of the relative disposition and vertical distribution of the phyllite, schist and gneiss belts in the southwestern part of the study area.

Phyllite. Low-grade rocks of definitive volcanic, sedimentary and intrusive origin carrying a slaty, spaced or crenulation cleavage occur in at least three discrete thrust sheets bounded by folded D_1 faults (Figure 4). In all localities, these phyllites are overlain by porphyroblast-rich net-veined strata illustrating a higher regional metamorphic rank. In general, the phyllitic rocks are the least strained, so they commonly preserve primary depositional features.

The phyllitic sedimentary rocks in the northeasternmost thrust sheet portrayed in Figure 4 are right-side-up beneath paragneiss and display upward-facing S_1 and downward-facing S_2 foliation. In the immediate footwall of the southwesterly adjacent D_1 overthrust, they contain spotted porphyroblasts augened by the southwest-dipping S_2 foliation.

In the discontinuous thrust sheet of phyllitic sedimentary rocks located farther southwest (the smaller of the two units of Ps in Figure 3), where a single cleavage is weakly developed, stratigraphically continous turbidite successions can be measured over a thickness of at least 100 m. However, along strike to the southeast, such phyllitic sedimentary rocks and an overlying belt of hornfelsic metasedimentary schists are not present on the south shore of Burnt Pond (Figure 3) and are presumed to have been tectonically excised near the line of section. Such low-grade, negligibly strained phyllitic sedimentary rocks are, however, structurally overlain by a tightly F_2-folded D_1 thrust sheet of spotted schist and straightened hornfelsic schist, and are structurally underlain by a D_1



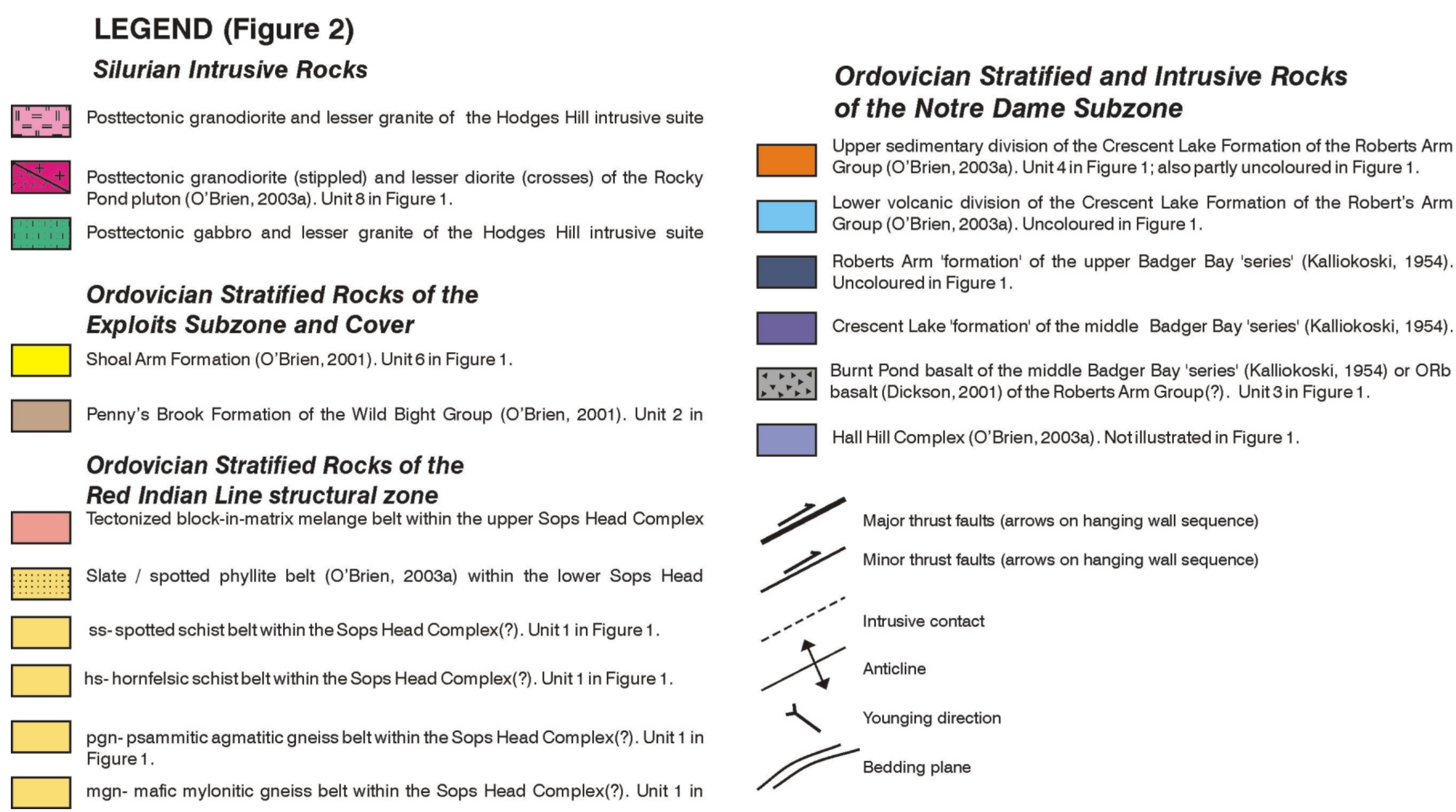


Figure 2. *Schematic cross-section, viewed looking northwestward, of Ordovician stratified rocks and Silurian intrusive rocks near the southeast margin of the Roberts Arm Group. Regional structural setting of the Burnt Pond window is depicted in the southwest part of the cross-section; the northeastern portion is drawn from a modified geological map of the North Twin Lake area (O'Brien, 2001).* See *Figure 1 for the northeast–southwest line of section. Vertical scale is exaggerated; horizontal scale as illustrated.*

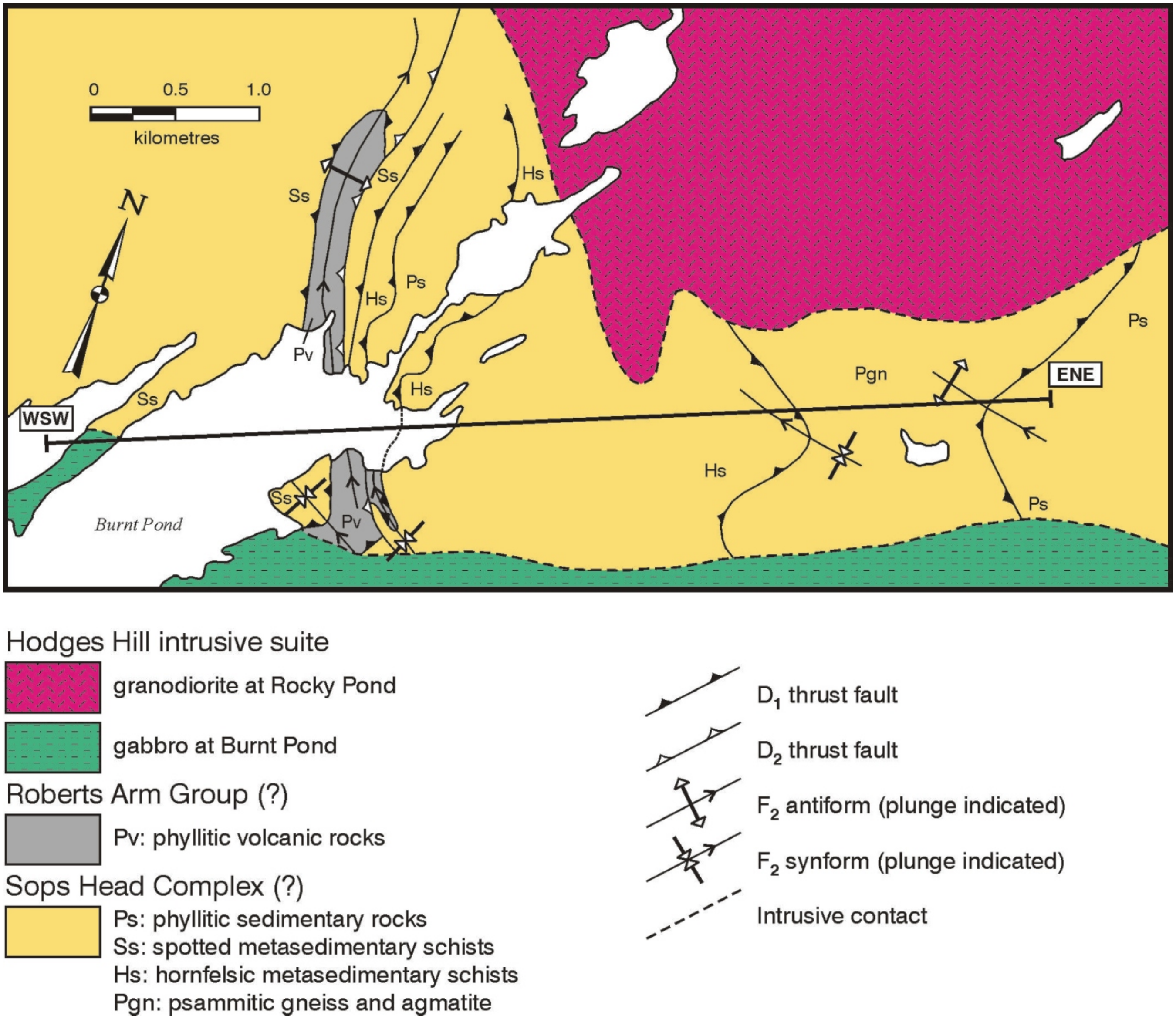


Figure 3. *Structural sketch map of metamorphic and plutonic rocks near the outflow of Burnt Pond, highlighting a fault-bounded and folded inlier of phyllitic mafic volcanic rocks. Also shown is the west-southwest–east-northeast line of a cross-section depicted in Figure 4.*

thrust sheet of hornfelsic schist that shows complex F_1 - F_2 fold interference patterns.

The volcanic phyllites are restricted to the Burnt Pond basalt, which is interpreted to occupy a tight F_2 antiform offset by a D_2 reverse fault (Figure 4). This major D_2 fold structure is outlined by a strong bedding-parallel S_1 schistosity at the structural top of the mafic volcanic rocks and by small D_1 thrust faults developed at the base of the overlying thrust sheet of spotted schist. The latter are especially well developed in a subunit of black sulphidic pelite. The tight F_2 antiform is paired with an open-to-close F_2 synform to the southwest (Figure 4). The upside-down phyllitic breccias and pillowed basalts face downwards on minor D_2 structures in a structural window created through the overlying thrust sheet of generally right-way-up metasedimentary rocks.

Spotted schist. A belt of schistose porphyroblastic turbidites directly overlies the phyllitic volcanic rocks exposed in the Burnt Pond window and extends southwestward for at least 1 km to its intrusive contact with the Hodges Hill gabbro (Figure 4). Here, the porphyroblasts overgrow a penetrative, bedding-parallel, relatively coarse-grained S_1 schistosity. Although ubiquitously developed throughout the spotted schist belt, the S_1 foliation is rarely observed to be axial planar to minor F_1 folds.

Plate 1. *Subcrop of banded paragneiss in the Sops Head Complex (?) east of Rocky Pond. Partially detached isoclinal folds are defined by light-grey and dark-grey compositional layers as well as a layer-parallel foliation, quartz lits and granite veins. In the top of the photograph, certain layers and folds are boudinaged. In the middle distance, fine-grained zones of weakly foliated agmatite are preferentially developed in boudin necks. In the bottom of the photograph, a folded zone is bounded by a narrow zone of 'straightened' gneiss, which dips gently to the viewer's left, and displays a lineation on the surface of attenuated beds and veins. Looking obliquely northwestward toward geological hammer resting on a subhorizontal erosion surface.*

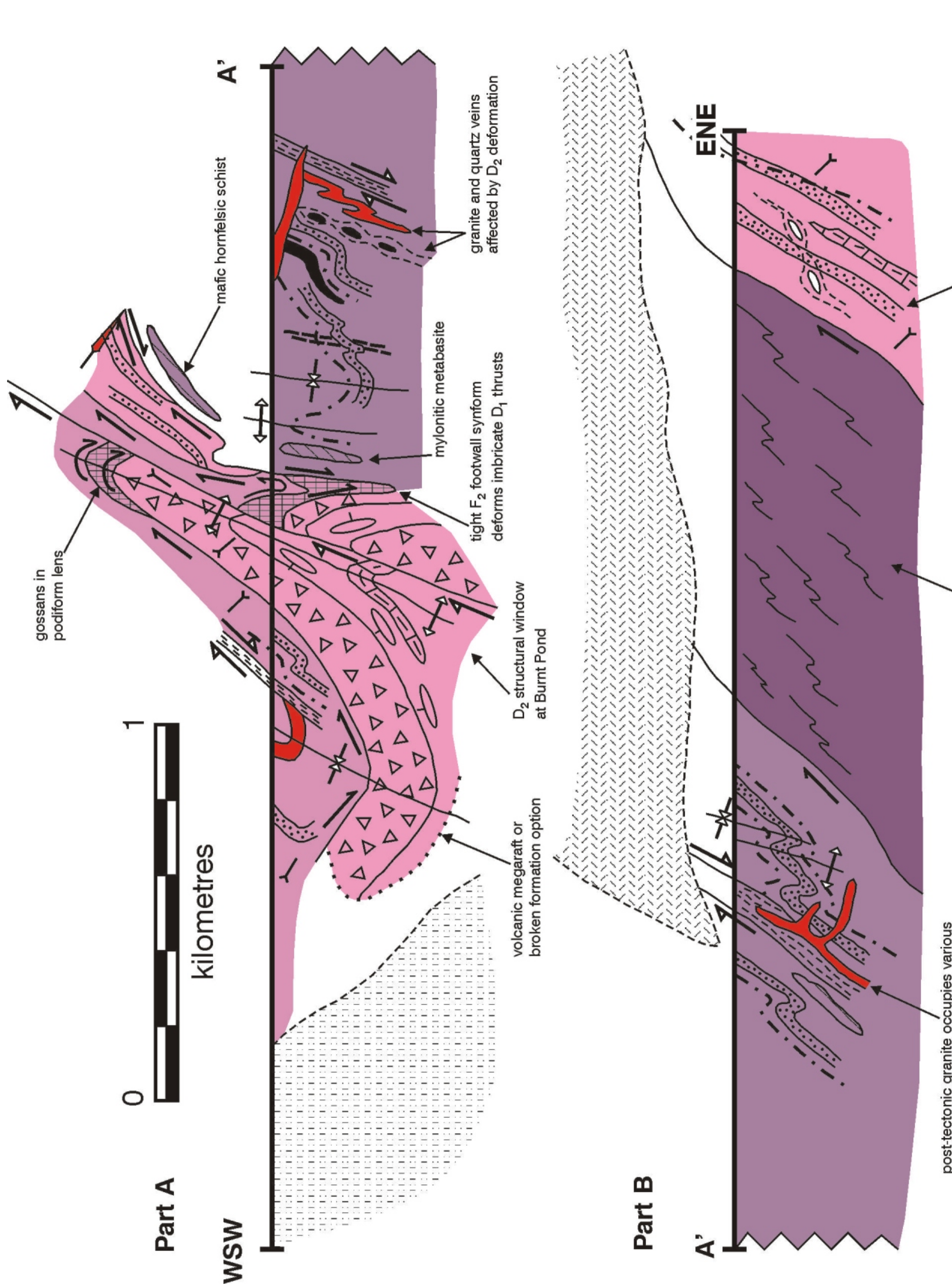
In some localities, the steeply southwest-dipping S_2 foliation is seen to augen some of the porphyroblasts that developed in the spotted schists. It is commonly present at a high angle to the more gently dipping S_1 foliation. In other locations in the spotted schist belt, the S_2 foliation makes a large angle with gently dipping strata that are thoroughly recrystallized but otherwise preserve primary bedforms. Spotted schists in the open hinge zone of the southwesternmost F_2 regional synform at Burnt Pond (Figures 3 and 4) are intruded by F_2-folded granodiorite dykes that locally crosscut the bedding-parallel S_1 foliation.

Minor F_2 folds are outlined by porphyroblast-rich compositional layers, which show a completely transposed and mimectically recrystallized S_1 foliation. The S_2 foliation is observed to be axial planar to such folded layers. In shoreline exposures, S_2 intensifies where northeasterly overturned F_2 folds pass from being open to tight; a finer grained platey version of the S_2 crenulation cleavage lies parallel to the S_2 $>>L_2$ shape fabric formed within small southwest-dipping D_2 reverse shear zones. The F_2 fold pair outlined by the D_1 thrust fault at the base of the spotted schists, southwest of the D_2 reverse fault in Figure 4, is thought to be representative of the major D_2 structures in the area surveyed.

A small tectonically disrupted unit of black sulphidic pelite forms a distinctive lithological marker at the structural base of the spotted schist belt (Figure 4). The discontinuous podiform shape of this graphitic and siliceous pelite probably reflects the sporadic distribution of this porphyroblast-rich unit along the folded trace of a major D_1 thrust. However, elsewhere in the Sops Head Complex, similar black sulphidic pelites are spatially associated with large slumped blocks of basalt flows and gabbro sills (McConnell *et al.*, 2002). Disseminated sulphides are widespread within the black pelite and numerous lens-shaped gossans are also present. Subsequent to the syn-D_2 metamorphism, pyrite was grain coarsened and recrystallized as large cubic porphyroblasts.

Hornfelsic schist. Near the outflow of Burnt Pond, a 2-km-wide belt of generally southwest-dipping hornfelsic schist is in D_1 fault contact with a structurally underlying belt of migmatitic paragneiss and a structurally overlying belt of spotted schist and minor phyllite (Figures 3 and 4). These hornfelsic schists are marked by the common occurrence of both pretectonic and posttectonic granitic intrusions. They also contain a variety of metabasite bodies, some of which are recognizable mafic intrusions. Although younging directions within these metaturbidites cannot be reliably discerned due to the complexity of the minor folding and the degree of metamorphic recrystallization, it may be that at least parts of the section are upside-down. The hornfelsic schist belt and the mafic mylonitic gneiss belt outcropping near the southwest end of Burnt Pond, and schematically illustrated in Figure 2 directly beneath the Roberts Arm Group, have unknown relations with this particular tract of hornfelsic schist.

In the study area, the hornfelsic schists commonly possess conspicuously large post-S_1 porphyroblasts. Structurally, they display well-developed D_2 shape fabrics, especially



Fiure 4. *Caption and legend on facing page.*

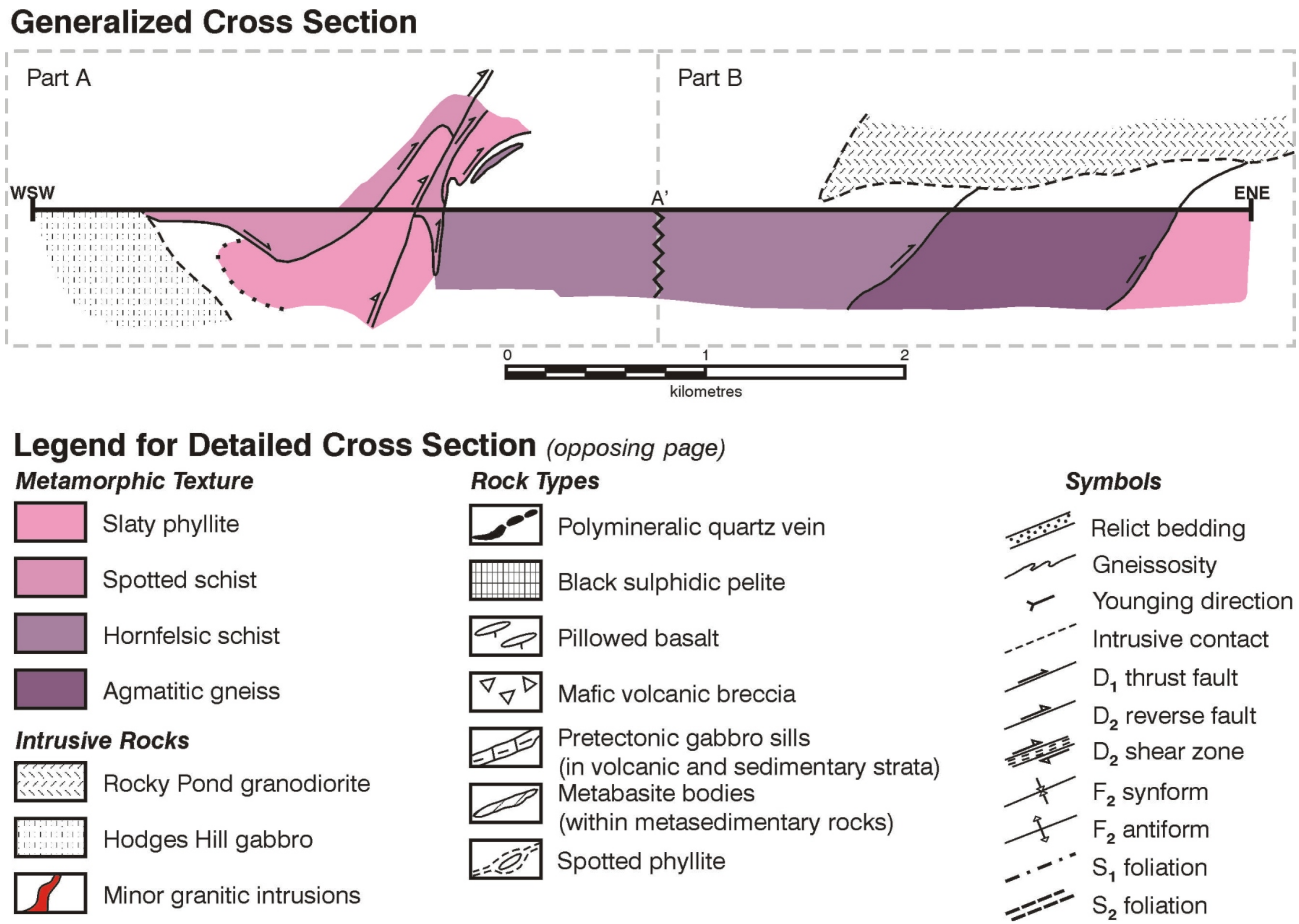


Figure 4. *Cross-section, viewed looking north-northwest, of variably metamorphosed strata near the outflow of Burnt Pond. Selected minor structures of D_1 and D_2 age are shown in relation to the major structures responsible for disposition of metamorphic textural types and regional rock units. Relationships of gabbro sills, granite dykes and polymineralic quartz veins to two phases of fold and foliation development in relict sedimentary and volcanic beds are schematically displayed. Vertical scale exaggerated; horizontal scale as illustrated.*

in the relatively abundant lit-par-lit segregations and polymineralic veins. However, hornfelsic schist typically appears massive in outcrop and is seen to be poorly foliated in fresh hand specimens. Under the hand lens, these sucrose schists illustrate a granoblastic matrix, distinguished by the static growth of late-stage quartz, polygonal sulphide and randomly oriented phyllosilicate.

The orientation of the bedding-parallel S_1 schistosity in the tectonic panel of hornfelsic schist is generally controlled by a D_2 train of Z-shaped F_2 folds. For the most part, these fold structures plunge gently to moderately northwestward and have large apical angles between the steeply southwest-dipping D_2 shear zones. However, isoclinally folded granodioritic dykes and polymineralic quartz veins hosted by S_2-foliated hornfelsic schist pass into sheared granodioritic stringers and podiform quartz lits in straightened zones of sucrose platey schist near the outflow of Burnt Pond. The various types of D_2 deformation zones are each occupied by dykes and sills of posttectonic granite (Figure 4).

Paragneiss. A poorly exposed belt of banded paragneiss outcrops east of Rocky Pond near the margin of the Rocky Pond granodiorite (Figure 1) and also to the east of Burnt Pond between this granodiorite body and the Hodges Hill gabbro (Figure 3). The gneiss belt structurally overlies the lowest grade part of the Sops Head Complex and is assumed to be bounded by southwest-dipping D_1 thrust faults (Figure 4).

In the four exposures of the gneiss belt examined east of Burnt Pond, the banding in the psammitic gneiss and less-common semipelitic gneiss, dips gently to moderately southwestward. As in the schist belts, the compositional layering of the gneissose rocks partly reflects the primary interstratification of the sedimentary protoliths (Plate 1). The banding is, however, enhanced by a relatively coarse-grained metamorphic foliation that lies parallel to the original bedding. As this foliation is observed to be axial planar to isoclinal intrastratal folds, as well as detached isoclines of granite veins and quartz lits, the gneissosity may represent an upgrading of the composite S_2/S_1 schistosity seen in the schist belts. Alternatively, if the gneissose foliation is a D_1 feature, then granitic veins were emplaced at an earlier stage of the regional metamorphism in the gneiss belt than in the tectonically adjacent hornfelsic schist belt.

Although large porphyroblasts developed extensively in the gneissose rocks, it is the presence of a deformed melt phase in the agmatitic gneisses that, in the field, distinguish the rocks of the gneiss belt from those in the adjacent schist belts. Another characteristic feature is the ubiquitous presence of boudinaged layers in the net-veined gneisses, especially in the migmatitic part of the gneiss belt. Such competancy differences are less significant in the polyphase folded strata of the schist belts, suggesting a more fluid-enhanced viscous flow in gneiss than in schist.

HYPOTHESES

Metamorphic inversion. In the general region of Burnt Pond, a spotted metasedimentary schist belt is interpreted to structurally overlie a phyllitic greenstone belt carrying penetrative slaty cleavage (Figures 3 and 4). This configuration of metamorphic rocks is essentially a pre-D_2 reconstruction. It is based upon a rationalization of the effect of northwest-trending F_2 folds superimposed on schistosity-parallel D_1 thrusts. These primary and secondary tectonic features are well displayed on megascopic scale in shoreline exposures on both sides of the pond (Figure 4).

Along the south side of Burnt Pond, low-grade mafic volcanic rocks are observed to be upside-down immediately beneath the metasedimentary schists. Within this tract, the basalt subunit appears to be structurally inverted throughout most of its outcrop area; however, some basalt flows may be right-side-up immediately northwest of the basal D_1 fault (Figure 3). In contrast, the overlying porphyroblast-rich turbidites are regionally southwest-facing, i.e., there are dominantly right-side-up sequences preserved within several tectonic panels of these metasedimentary rocks.

Similarly, on the basis of form line mapping of the strike and dip of the main foliation surfaces east and west of Rocky Pond, a southwest-dipping belt of hornfelsic schist and psammitic agmatitic gneiss is interpreted to structurally overlie a multiple-deformed belt of phyllitic sedimentary rocks (Figures 2 and 3). The phyllitic rocks display localized zones of porphyroblastesis in the extreme southwest part of this particular Ps unit and, directly beneath the high-grade paragneiss belt, porphyroblasts in phyllite are observed to be augened by the S_2 foliation (Figure 4). However, farther northeast, such phyllites are transitional into a belt of well-cleaved metasedimentary strata that is completely devoid of porphyroblasts. Where a bedding–cleavage intersection is observable in the relatively low-grade phyllite belt, it can be shown that at least the structurally lowest rocks are derived from graded siliciclastic turbidites. Moreover, it can be demonstrated that such metaturbidites are not structurally inverted beneath high-grade gneiss for any significant distance (Figure 2).

Strata that illustrate an inverted metamorphic field gradient have relatively high-grade rocks at the structural top of a metamorphosed sequence and relatively low-grade rocks at the structural base. However, near Burnt Pond, the regional metamorphic gradient does not decrease with increasing depth within a single structural block and, equally important, nor do the various textural types of post-S_1 regional metamorphic porphyroblasts crosscut the D_1 thrust faults. Southwest of Rocky Pond, the relatively 'cold' rocks of the Roberts Arm Group were structurally emplaced over the relatively 'hot' rocks of the Sops Head Complex, and not vice versa. The type of metamorphic inversion witnessed in the study area is, thus, unlikely to result from a true geothermal inversion.

Tectonic window. The Burnt Pond basalt is interpreted to be bounded above and below by early formed thrusts and to be overlain and underlain by the metasedimentary rocks of the Sops Head Complex (Figures 2 and 3).The northwestward termination of the Burnt Pond basalt subunit can be explained in several ways.

The most simple explanation is that several lithological and structural constituents of the northeast-directed D_1 thrust stack are folded about a moderately northwest-plunging F_2 antiform. Along the shore of Burnt Pond, and in areas farther north, the core of the antiform is occupied by basalt and gabbro; whereas, the fold limbs expose fault-bounded turbidite sequences that show a variety of metamorphic textures and porphyroblast types. The thrust at the top of the Burnt Pond basalt is probably offset by a high-angle D_2 reverse fault and the inhomogeneously deformed hangingwall basalts are further modified by northwest-trending D_2 shear zones (Figure 4). Together, these secondary structures are responsible for additional tapering of the Burnt Pond basalt toward the northwest.

A second possibility is that the thrust sheet carrying the basaltic subunit was initially augen-shaped in three dimensions. It may have comprised an original thrust duplex, whose roof thrust defined a 'lift-off' fold adjacent to an incompetent lens of black sulphidic pelite. Graded phyllitic breccias near the southeasternmost exposures of the Burnt Pond basalt are possibly right-side-up adjacent to an unexposed floor thrust situated above the Sops Head Complex and below the basalt subunit (Figure 3).

In a third interpretation, the above-mentioned tectonic structures are presumed to have deformed a laterally discontinuous stratigraphic interval (*see* dotted boundary around the southwesternmost part of the volcanic rock unit in Figure 4). Opting for this explanation, all the basalts and interflow cherts in the Burnt Pond subunit could be interpreted as forming an outsized exotic block in the upper Sops Head Complex, or as representing one of the partially broken mafic volcanic and chert formations in the middle Sops Head Complex. Assuming a constant level of erosion, the limited regional distribution of the Burnt Pond subunit, taken together with its absence in several other regional F_2 antiforms cored by the Sops Head Complex, may indicate that this basalt sequence does not represent the autochthonous volcanic substrate of the Notre Dame Subzone.

CONCLUSIONS

The basalts and phyllitic breccias at Burnt Pond are bounded by tightly folded thrust faults believed to have originally dipped southwestward. Such weakly metamorphosed rocks may represent an isolated tectonic fragment of the Ordovician Roberts Arm Group, situated well to the southeast of the known volcanic rocks in this group. The mafic volcanic rocks are exposed in a tectonic window that developed within overlying fault-imbricated metasedimentary rocks.

The metamorphosed turbidite sequences around Burnt Pond are relatively thick and lithologically distinct from those in the Roberts Arm Group. They are tentatively correlated with similar deposits found within parts of the age equivalent and younger Sops Head Complex along the coast of Badger Bay. Low-grade sedimentary rocks of the Sops Head Complex may have been regionally metamorphosed to high-grade schist and paragneiss in the Rocky Pond–Burnt Pond–Lower Gull Pond segment of the Red Indian Line structural zone.

In conclusion, the phyllite, schist and gneiss belts in the study area are postulated to locally comprise a metamorphically inverted sequence of stratified rocks. This lithotectonic assemblage lies above the lowest grade part of the Sops Head Complex and beneath the main tract of the Roberts Arm Group.

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