Current Research (2006) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 06-1, pages 243-256

GEOMETRY OF A FOLD-AND-THRUST BELT NEAR LAKE BOND (NTS MAP AREAS 12H/1; 12A/16), CENTRAL NEWFOUNDLAND

B.H. O'Brien
Regional Geology Section

ABSTRACT

Near Lake Bond, the Ordovician Roberts Arm Group comprises a lithotectonic sequence of stratified and intrusive rocks. It is represented by a thrust-imbricated, basalt-dominant volcanic belt in the west and a complexly folded, mainly volcaniclastic sedimentary belt in the east. Structural maps and sections of the Roberts Arm Group and adjacent units in this region, indicate that the present geometry of the fold-and-thrust belt evolved over several stages of tectonic development.

Early formed, synmetamorphic oblique-slip thrusts, together with less common fold nappes and back thrusts, were shortened and reorientated by open doubly plunging folds to create several northwest-trending domes and basins. Different parts of the original Roberts Arm thrust stack are observed in these structural culminations and depressions. During the formation of a large orogenic flexure, parts of the fold-and-thrust belt were ductilely reactivated when northeast-trending periclinal folds and associated bivergent reverse faults overprinted the regional dome-and-basin structures. Subvertical brittle fracture systems affect the Roberts Arm Group (and the deformed rocks of the Springdale and Badger groups) after the posttectonic emplacement of the Siluro-Devonian Skull Hill pluton.

INTRODUCTION

The region around Lake Bond occurs in the Appalachian Dunnage Zone (Williams, 1979) of north-central Newfoundland and is tectonically situated near the generally northwest-dipping Red Indian Line structural zone (Williams *et al*., 1988; O'Brien, 2003; Figure 1). At this locality, in the immediate hanging-wall sequence of the Red Indian Line, the peri-Laurentian Notre Dame Subzone is represented by the late Early–Middle Ordovician Roberts Arm Group (Dunning *et al*., 1987; Swinden *et al*., 1997; Zagorevski *et al., in press*). A terrestrial overlap sequence accumulated above the magmatic arc rocks of the Notre Dame Subzone in the Early to Late Silurian (Chandler *et al*., 1987). Locally termed the Springdale Group, this terrestrial succession originally comprised an unconformable cover upon Roberts Arm Group basement (Espenshade, 1937; Bostock, 1988).

The Middle Ordovician and older peri-Gondwanan rocks of the Exploits Subzone do not crop out in the area surveyed for this report. However, they are inferred to underlie the marine turbidites of the Badger Group, which is exposed about 5 km southeast of Lake Bond. Historically, this unit has been regionally interpreted as a Late Ordovician–Early Silurian overlap sequence lying above the magmatic arc rocks of the Exploits Subzone (Colman-Sadd *et al*., 1992; Williams, 1995). Rocks of uncertain tectonic affinity structurally underlie the Roberts Arm Group to the northeast of the area surveyed (Figure 1). There, broken and unbroken parts of the Sops Head–Boones Point complex, probable metamorphic equivalents of this melange-bearing volcanosedimentary unit, and batholithic enclaves of paragneiss, amphibolite, migmatite and felsic orthogneiss are poorly exposed (Dickson, 1999; O'Brien, 2004).

The map area is underlain by variably metamorphosed and inhomogeneously deformed Ordovician and Silurian rocks, although the Ordovician rocks of the Roberts Arm Group constitute, by far, the most regionally extensive tract. All of these stratified and hypabyssal rock units are crosscut by posttectonic felsic and mafic intrusions that probably range in age from the Early Silurian to the Early Devonian (Kean and Jayasinghe, 1982; Whalen *et al.*, 1987; Whalen and Currie, 1988).

LITHOTECTONIC SUBDIVISIONS OF THE ROBERTS ARM GROUP

In the region around Lake Bond, the Roberts Arm Group is disposed in several fault-bounded tectonic panels that lie parallel to the regional structural grain (Figure 2).

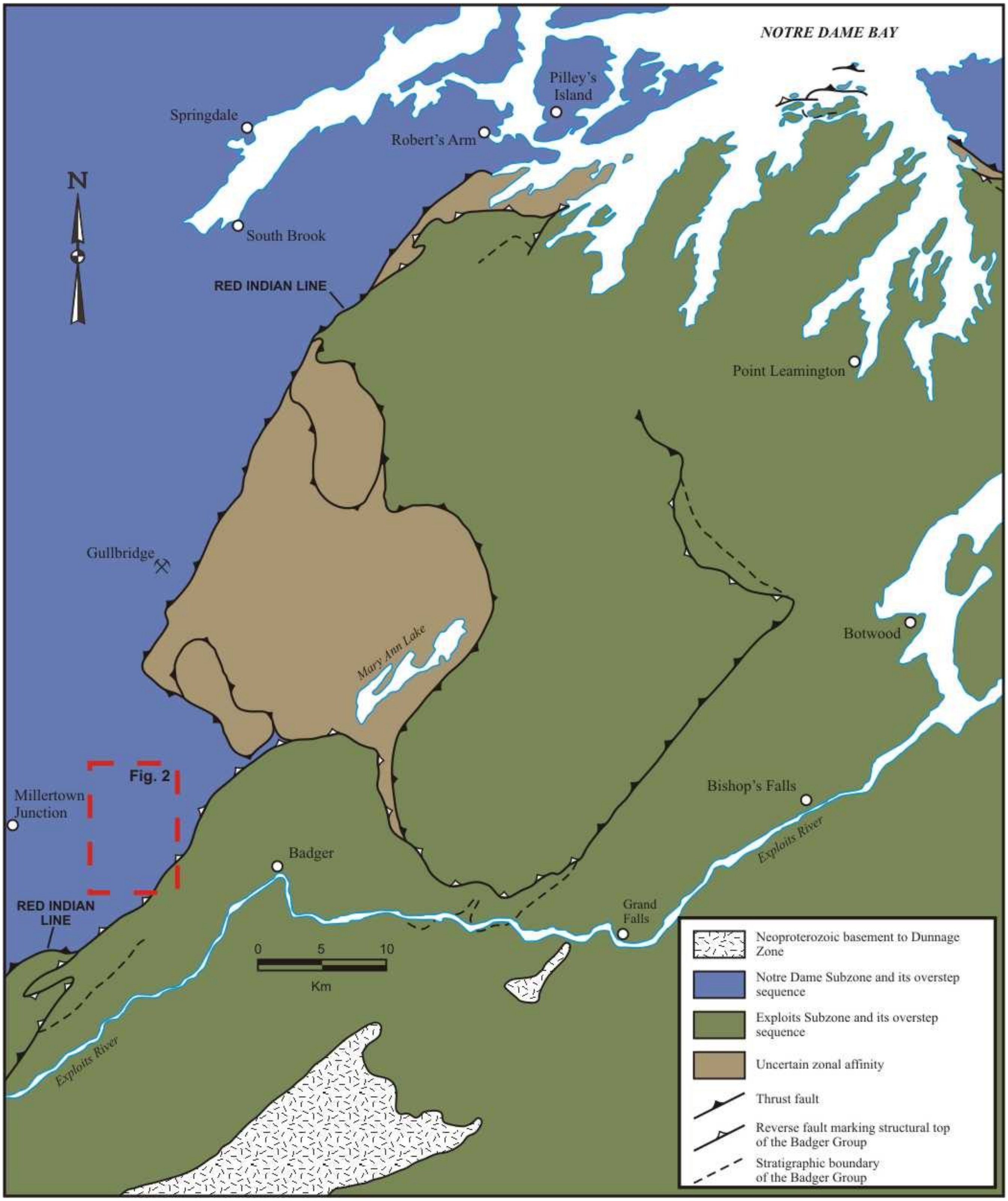

Figure 1. *Simplified tectonic map illustrating the setting of Roberts Arm Group rocks near Lake Bond (outlined in red) in the context of the regional geology of the Dunnage Zone. Note that, in the area surveyed, the Red Indian Line is locally coincident with the northwest-dipping reverse fault bounding the Badger Group. Modified, in part, from Dickson (1999), O'Brien (2001), Rogers and van Staal (2005) and Rogers* et al. *(2005).*

Primary depositional and high-level intrusive contacts are, however, preserved inside many of these structural slices through the original Roberts Arm stratigraphy; regionally developed marker beds are completely absent in the area surveyed. Moreover, none of the Roberts Arm Group rocks have been biostratigraphically or isotopically dated. Because strata were hydrothermally altered to varying extent in most tectonic panels carrying mafic volcanic rocks, and because lithofacies variations are suspected along the depositional strike of the subaqueous felsic volcanic units, it is difficult to firmly establish, or to refute, the recurrence of a certain lithodemic assemblage over a particular lithostratigraphic interval.

Epidotized, albitized and locally chloritized, orange-hued lime-green metabasites, transitional to dark-grey pillowed basalt and basaltic breccia, comprise Unit 1 of the Roberts Arm Group. Displaying highly deformed quartz-chlorite veinlets and polymetallic sulphide stringers (Hudson and Swinden, 1990), this subdivision probably correlates, in part, with the Burnt Island Basalt of Swinden and Sacks (1996). Folded sills of siliceous pyritic gabbro intrude Unit 1 basalt and, in several discrete structural slices, these mafic extrusive and intrusive rocks appear to be succeeded by silicified felsic pyroclastic rocks of limited areal extent (Figure 2). In the area surveyed, Unit 1 is the most widespread subdivision of the Roberts Arm Group. However, it may be that the six tectonic panels of Unit 1 identified near Lake Bond do not all contain a characteristic type of basalt or even the same age of basalt.

The second subdivision of the Roberts Arm Group (Unit 2) is composed of red hematitic basalt, porphyritic andesite replaced by jasper, and minor pillow breccia. This lithologically distinctive unit contains veinlets and disseminations of sphalerite and chalcopyrite; ubiquitous pyrite is commonly observed to be partially replaced and surrounded by hematite. Similar rocks host the mineralized sequence at both the Lake Bond and Gullbridge base-metal deposits. In most localities in the vicinity of Lake Bond, the reddened silicified basalts of Unit 2 are faulted against the lime-green basalts and metabasites of Unit 1 (Figure 2). However, in the southeastern part of the map area near the fault with the Badger Group, jasperitized mafic pyroclastic rocks tentatively assigned to Unit 2 possibly have gradational contacts with green chloritic basalts typical of Unit 1. It is uncertain if Unit 2 stratigraphically overlies or underlies a part of Unit 1, or whether Unit 2 simply represents a hydrothermal alteration facies of Unit 1.

The dominantly red sedimentary rocks of Unit 3 of the Roberts Arm Group crop out within an overturned syncline near Two Bit Pond (Figure 2) and are thought to stratigraphically overlie the hematitic basalts of Unit 2. Strata assigned to Unit 3 include red chert and iron formation, red siliceous argillite interbedded with grey-green sandstone, and minor feldspathic wacke crosscut by bifurcating jasper veins. Such sedimentary rocks comprise a part of the mineralized Roberts Arm sequence at the Lake Bond deposit. At the former Gullbridge Mine, red chert and iron formation are reported to form a thin cap rock to an altered sequence of basalt and interbedded felsic tuff (Pudifin, 1993). Although an overlying unit is not preserved in the core of the doubly plunging syncline, the pervasive replacement of Unit 3 epiclastic wacke, and of rare laminated quartz-feldspar crystal tuff, by jasper may suggest an original stratigraphic position lying beneath the relatively unaltered horizons of flow-banded and flow-folded felsic volcanic deposits and voluminous rhyolite-rich epiclastic strata seen elsewhere in the Lake Bond region (*see below*).

Unit 4 of the Roberts Arm Group is made up of intercalated mafic and felsic pyroclastic rocks and it is probably a partial correlative of the Gullbridge Bimodal Volcanic Unit (Pudifin, 1993), which is well exposed north of the map area near Great Gull Lake. Where the mafic and felsic pyroclastic subunits each measure at least several metres in thickness, Unit 4 is observed to structurally overlie, and possibly be in depositional contact with, a substrate of relatively thick and unaltered basalt flows. Here, fine-grained felsic tuffs interbedded with schistose mafic breccia illustrate vertical grading from a lithic-rich base to a crystal-rich top. Although the mesoscopic scale intercalation of mafic and felsic volcanic rocks in this subdivision is evidently a secondary structural feature in many places, occurrences of outsized felsic volcanic blocks in basaltic breccia confirm primary interstratification in other localities. The relationship of the lower thin-bedded part of Unit 4 with the Unit 1 sequence of altered felsic fragmental rocks and underlying grey-green silicified basalt is unknown.

In the area surveyed, bimodal volcanic rocks belonging to Unit 4 of the Roberts Arm Group occur in three variably sized tectonic panels (Figure 2). Generally fault-bounded and poorly exposed, this subdivision locally preserves what appears to be a gradational lower stratigraphic boundary with a pillowed basalt sequence assigned to Unit 1 and a gradational upper stratigraphic boundary with a relatively thick sequence of massive to flow-banded rhyolites (*see below*). The lithotectonic sequence of Unit 4 gossan-bearing rocks in the large southernmost panel is made up of thick felsic and mafic subunits, although its outcrop pattern has been mainly established by the writer's interpretation of geophysical data (Oneschuk *et al.*, 2002). With a minimum structural thickness estimated at 500 m, it represents the thickest known interval of bimodal volcanic rocks in the Roberts Arm Group.

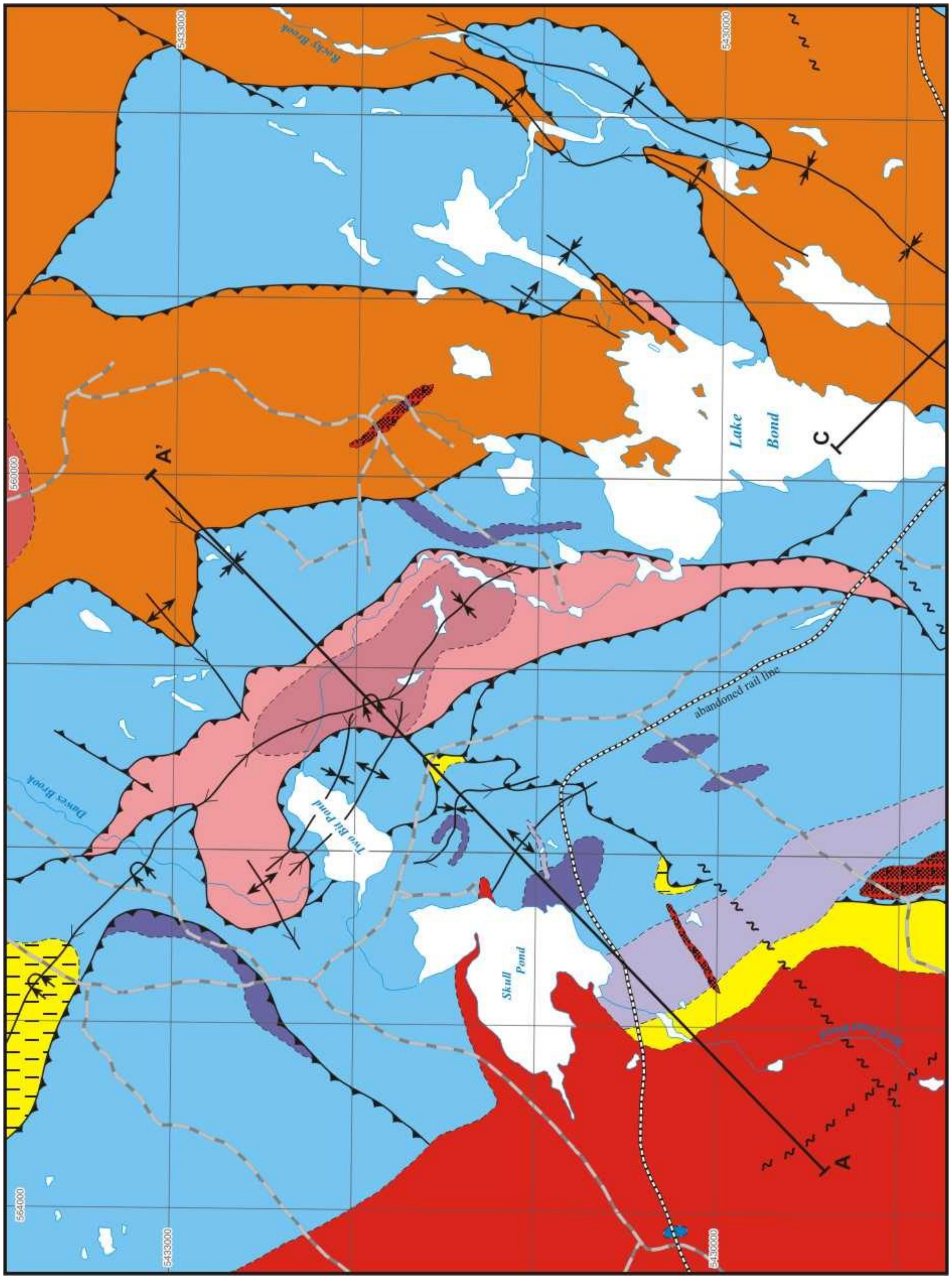
Rocky Brook
5433000
5430000
Lake
Bond
C
A'
560000
abandoned rail line
Dawes Brook
Two Bit Pond
Skull
Pond
A
564000
5433000
5430000

Figure 2.

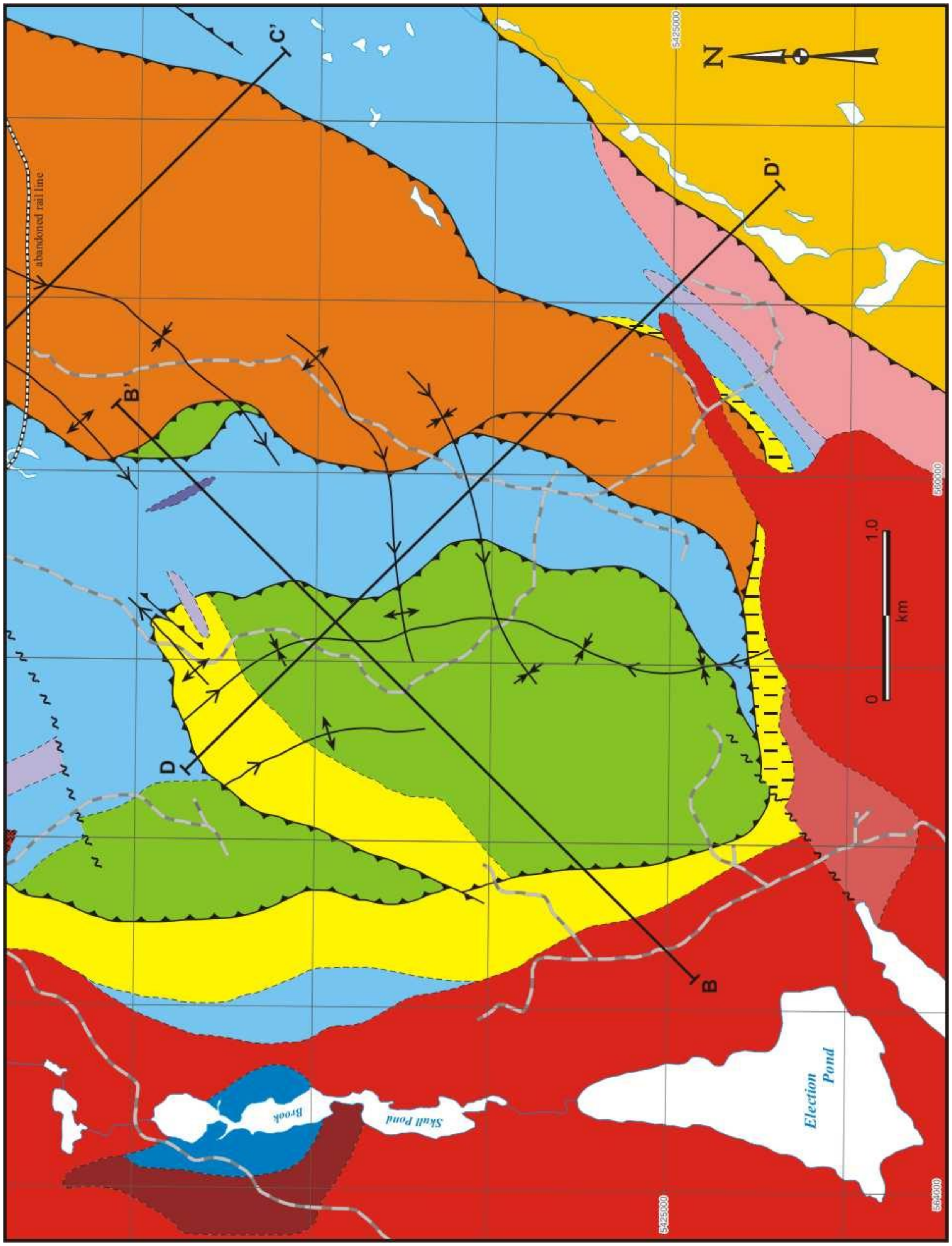

Figure 2. *Geological map of the Ordovician Roberts Arm Group and adjacent rock units in the vicinity of Lake Bond. Local subdivisions of the Roberts Arm Group are informal lithotectonic units, some of which contain the primary boundaries of previously identified subunits near Great Gull Lake (Swinden and Sacks, 1996). In the Legend (next page) for Figure 2, these regionally mappable units are not necessarily listed in order of age. Unit numbers in legend refer to description of units in text.*

LEGEND

POSTTECTONIC INTRUSIVE ROCKS
Topsails Intrusive Suite
Late Silurian - Early Devonian (?)
Skull Hill pluton

Pink isotropic granite, pink to light grey quartz monzonite, and red quartz syenite, each crosscut by diabase dyke swarms

Subunits:

Enclave of gabbro and pyroxenite

Satellite intrusions of gabbro

Quartz feldspar porphyry
(All of the above are locally saussuritized, chloritized and pyritized, especially near faults and related joints)

Hodges Hill Intrusive Suite
Early Silurian (?)
Dawe's Pond pluton

Mainly grey, isotropic, hornblende - biotite granodiorite locally displaying cognate xenoliths; to the south, satellite bodies of granodiorite also include minor gabbro and diabase dykes

ORDOVICIAN AND SILURIAN STRATIFIED ROCKS
Terrestrial Overlap Sequence (Notre Dame Subzone)
Early - Late Silurian
Springdale Group (?)

Vesicular basaltic breccia; minor mafic tuff; amygdaloidal gabbroic sills

Marine Overlap Sequence (Exploits Subzone)
Late Ordovician - Early Silurian (?)
Badger Group

Sandstone turbidite; interbedded quartz wacke; minor polymictic conglomerate and interstratified pebbly wacke; rare siltstone

DUNNAGE ZONE
NOTRE DAME SUBZONE
Early - Middle Ordovician (?)
Roberts Arm Group

7 Sheeted gabbroic intrusions; locally containing chalcopyrite stringers

6 Felsic volcanic-derived pebbly wacke; felsic agglomerate and lithic tuff; grey - green siliceous argillite and maroon chert; minor felsic crystal tuff [partial correlative of the Gull Hill Sedimentary Sequence]

5 Flow-folded felsic extrusions; ash tuff and flow-banded rhyolite; minor quartz - phyric hypabyssal intrusions; rare, laminated siltstone interbedded with lapilli tuff [partial correlative of the Gullbridge Felsic Volcanic Sequence]

Subunit of felsic pyroclastic rocks that may be more appropriately grouped with Unit 1

4 Intercalated mafic and felsic pyroclastic rocks; felsic tuffs having graded lithic and crystal components; basaltic breccias with felsic volcanic blocks grading to chloritic mafic tuff; unseparated gabbro sills [partial correlative of the Bimodal Volcanic Sequence]

3 Red chert and iron formation; red siliceous argillite interbedded with grey - green sandstone; minor feldspathic wacke; rare, jasperitized felsic tuff [part of the Mineralized Sequence at Gullbridge and Lake Bond]

2 Red hematitic basalt; jasperitized andesite; minor pillow breccia [part of the Mineralized Sequence at Gullbridge and Lake Bond]

1 Epidotized, albitized and locally chloritized basalts; metabasite displaying deformed quartz-chlorite veinlets and polymetallic sulphide stringers; transitional to pillowed basalt and basaltic breccia; unseparated, variably altered, gabbroic intrusions [partial correlative of the Burnt Island Basalt]

KEY

Stratigraphic or intrusive contact (approximate) ....

Thrust or reverse fault
(barbs in direction of dip; relative age undifferentiated) ....

Transcurrent fault (sinistral; dextral) ....

Antiform (plunge direction indicated) ....

Synform (plunge direction indicated) ....

Unit 5 of the Roberts Arm Group is exclusively composed of felsic magmatic rocks. These are generally observed to be fresh or weakly altered, highly variable in thickness and irregularly distributed (Figure 2). This subdivision is probably best correlated with that portion of the Gull Hill Felsic Volcanics (Pudefin, 1993), which crops out near the Starke's Pond Fault or, alternatively, with the western part of what Swinden and Sacks (1996) refer to as the Gullbridge Felsic Volcanic Sequence. The felsic extrusive rocks include flow-banded rhyolite, flow-folded ash tuff and welded ignimbrite, all locally intruded by quartz-phyric hypabyssal intrusions. Although some of these possibly erupted above sea level, other felsic extrusions are succeeded, in places, by thinly interbedded intervals of grey-laminated siltstone and buff lapilli tuff. The thickest preserved accumulations of Unit 5 strata contain felsic volcanic rocks that are reminiscent of those outcropping between the Southwest Shaft and Lady Slipper Pond to the southwest of the former Gullbridge Mine. Some of the small structural slices of felsic pyroclastic rocks included in Unit 5 (Figure 2) may be more appropriately grouped with Unit 1.

Fining-upward volcaniclastic turbidites, which comprise most of the sixth subdivision of the Roberts Arm Group (Unit 6), are dominant in the eastern part of the Lake Bond region. A partial correlative of the Gull Hill Sedimentary Sequence of Swinden and Sacks (1996), Unit 6 is most commonly seen to be fault-imbricated with Unit 1 basalt. The lowest observed part of this turbidite sequence contains felsic volcanic-derived pebbly wacke and microconglomerate interbedded with subordinate rhyolitic agglomerate and felsic lithic tuff. Mafic volcanic detritus is a minor constituent of some laminated green sandstone and sandy wacke beds. The highest preserved sequence in Unit 6 is dominated by nodular grey-green argillite, laminated green sandstone and porphyroblastic maroon chert interstratified with minor intervals of quartz-feldspar crystal tuff. Immediately east of the area surveyed for this report, volcaniclastic turbidites similar to those in the lower part of Unit 6 are thought to stratigraphically overlie a thin felsic tuff horizon, situated above pillowed basalt, that could possibly be assigned to either Units 4 or 5 of the Roberts Arm Group.

In the map area, some of the larger altered gabbroic sills and pretectonic sheeted mafic intrusions emplaced into Unit 1 basalt are grouped together as Unit 7 (Figure 2). However, gabbroic intrusions are unseparated within several other subdivisions of the Roberts Arm Group in the Lake Bond region.

STRUCTURAL SECTIONS OF THE ROBERTS ARM GROUP

The folds and thrusts mapped in the Ordovician rocks of the Roberts Arm Group are complexly interrelated. In the region around Lake Bond, some synmetamorphic thrust faults and associated fold nappes serve to outline regional dome-and-basin fold structures (Figure 2). In contradistinction, other ductile reverse faults and allied folds deform these secondary structural features. The highly altered volcanic belt, located northeast of the main Skull Hill intrusion, illustrates this type of fold-and-thrust belt, particularly well.

Throughout most of the area surveyed, rock units assigned to the Roberts Arm Group are bounded by arcuate thrust faults, which strike dominantly northwestward (Figure 2). Most of these fault structures dip southwestward, although some are inclined to the northeast. Several thrust-bounded panels of the Roberts Arm Group can be mapped to gradually pass into a regional northeasterly trend within the southeastern part of the map area (Figure 2). Here, on the northeast-striking limb of a regional orogenic flexure, the predominant dip of thrust faults is northwestward. Thus, across the southeast margin of the Roberts Arm Group, the orientation of map-unit-bounding thrusts becomes parallel to the northeast-trending segment of the Red Indian Line structural zone (Figure 1). However, although many of the reoriented thrusts in the Roberts Arm Group have a similar attitude as the reverse fault marking the structural top of the adjacent Badger Group, they do not necessarily all belong to the same generation of fault structure.

Early Evolution of the Fold-and-Thrust Belt

A geometrical consequence of the orogenic flexuring of the Roberts Arm Group is that the folded thrust faults affecting the various subdivisions of this rock group can be visualized in true cross section along section lines that are orthogonal to one another. When viewed in serial sections looking to the northwest, early formed thrusts generally lie parallel to stratification and are openly folded about a series of gently plunging antiforms and synforms (Figure 3). These northwest-trending secondary folds also deform an inhomogeneously developed metamorphic foliation (AA') with a northwest–southeast-stretching lineation and associated subrecumbent fold nappes (BB'). Most early formed thrusts have a reverse oblique dip-slip component of displacement compatible with an original southwestward dip; however, other openly folded, northwest-striking faults illustrate a primary northeast-over-southwest polarity.

A stringer stockwork zone hosted by Unit 1 basalt and Unit 7 gabbro is exposed in a northwest-trending antiformal structure in the vicinity of Skull Pond (Figure 2). There, Unit 1 is bounded by a southeast-dipping thrust fault south of the pond, a northwest-dipping thrust fault north of the pond, and a southwest-dipping thrust fault east of the pond. In cross section AA', the southeast-dipping thrust is portrayed as the structure bounding the uppermost part of the

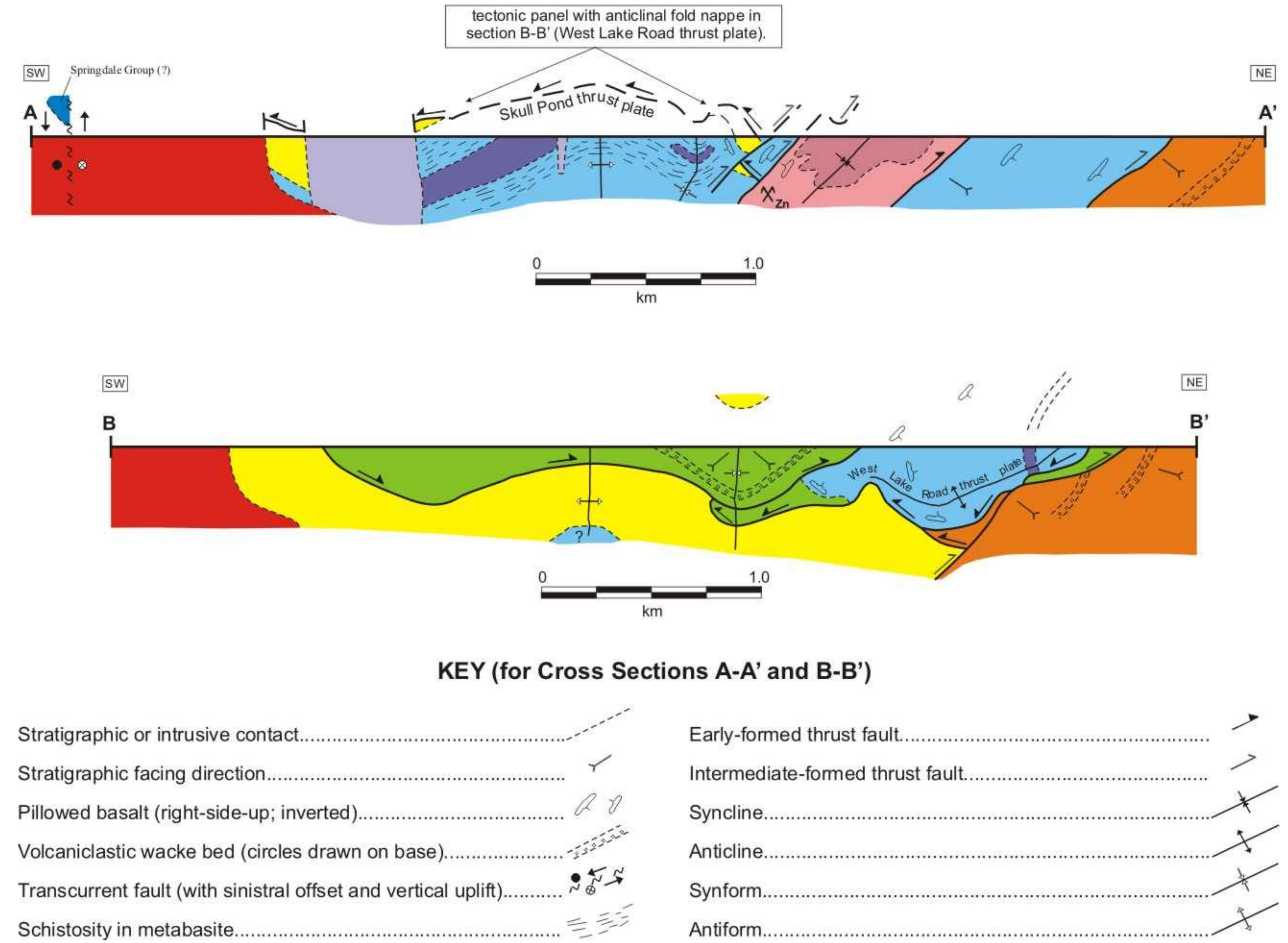

Figure 3. *Cross sections of the Ordovician Roberts Arm Group and adjacent units with viewer looking northwestward. Vertical scale exaggerated. See Figure 2 for the locations of section lines AA' and BB'. Zn indicates the approximate position of the Lake Bond deposit.*

Skull Pond thrust plate (Figure 3). Small bodies of altered felsic fragmental rocks are thought to be locally preserved at the top of Skull Pond thrust plate, where they lie above strongly foliated metabasite rocks and a right-side-up sequence of pillowed basalt. Based solely on composition, they have been assigned to Unit 5; however, these particular felsic volcanic rocks may be more appropriately grouped with the basalt flows of Unit 1 (*see* Legend for Figure 2).

East of Skull Pond, the early formed fault at the top of the Skull Pond thrust plate is folded about a northwest-trending fold pair and is assumed to have been truncated by the above mentioned southwest-dipping thrust (Figure 2). Where it crosses the south end of Two Bit Pond, the south-west-dipping thrust forms the roof of a small duplex that carries a northwest-facing, right-side-up sequence of pillow lavas (section AA' in Figure 3). The strong schistosity found in Unit 1 metabasite at the structural top and base of this duplex is observed to be crenulated and folded about both northwest- and northeast-trending fold axes. Thus, the southwest-dipping thrust is postulated to be an intermediate-formed fault, which ramped through the folded sequence of Unit 1 basalt and Unit 7 gabbro in the Skull Pond thrust plate, offset the early formed boundary thrust, and placed these rocks and structures tectonically above the northeasterly adjacent panel of Roberts Arm volcanic rocks.

The hematized basalts of Unit 2, together with the younger red beds of Unit 3, comprise an even larger duplex structure lying deeper within the imbricate thrust stack of the Roberts Arm Group (Figure 2). The roof thrust of this duplex is mapped to cross Dawes Brook in three places, as the uppermost red rocks of Unit 2 and the tectonically adjacent lime-green rocks of Unit 1 were folded about a secondary northwest-plunging synform and refolded about a later southwesterly plunging antiform. The Lake Bond deposit is situated near the top of this arcuate thrust duplex (AA' in Figure 3). It is located, structurally, on the regionally inverted limb of a northeasterly overturned syncline, which is locally cored by Unit 3 sedimentary rocks.

The tectonic panel of Unit 1 basalt and Unit 7 gabbro, which structurally underlies the aforementioned duplex, dips regionally southwestward and is mostly composed of a right-side-up sequence of pillowed basalt and pillow breccia (AA' in Figure 3). This geometry might suggest that these mafic volcanic rocks once formed part of the northeast limb of the southwesterly adjacent overturned syncline. However, it is unclear how unoxidized volcanic rocks, which are much less altered, veined and mineralized than Unit 2, could have originally lain stratigraphically beneath a hematitic basalt succession that is host to an extensive stringer stockwork.

Farther northeast along section line AA', but still south of the Dawes Pond pluton (Figure 2), one of the most extensive northwest-striking thrusts in the Lake Bond region marks the lower structural boundary of the main volcanic belt of the Roberts Arm Group (i.e., Units 1, 2, 4, and 5). This cross-folded, southwest-dipping structure also forms the upper structural boundary of Unit 6, the main volcaniclastic turbidite belt in the Roberts Arm Group.

In the southernmost part of the area surveyed, immediately south of section line BB', several tectonic elements of the Roberts Arm thrust stack are openly folded about a regional synform that plunges gently to moderately northwestward (Figure 2). Early formed thrusts are inclined southwestward on the east side of this structural basin, whereas, they dip northeastward along the western margin of the regional tectonic depression. Relatively narrow, fault-imbricated, structural slices of the Roberts Arm Group are observed to dip northwestward in the hinge zone of the synform, as do several discrete mylonite zones and a very strong bed-parallel schistosity in the volcanic rocks.

A large northwest-dipping tectonic panel carrying a mainly right-side-up sequence of Gull Hill metasedimentary rocks is mapped to wedge out near the synformal closure (Figures 2 and 3). As a consequence, an underlying horse made up of Unit 1 basalt and overlying felsic fragmental rocks comes to rest directly against an overlying thrust slice of Unit 1 basalt and Unit 7 gabbro. The variably altered pillowed basalts in the hanging-wall sequence are referred to as the West Lake Road thrust plate in section BB' (Figure 3). They vary from being inverted to being right-side-up as they are traced northwestward for about 6 km to the contact with the underlying Skull Pond thrust plate (AA').

A thick sequence of bimodal volcanic rocks (Unit 4) capped by flow-folded felsic extrusions (Unit 5) are preserved in the structurally highest tectonic panel of the Roberts Arm Group in the Lake Bond region. These mainly northwest-facing rocks are thrust above the normal limb of a subrecumbent fold nappe, which is thought to have developed in Unit 1 basalt near the base of the structurally underlying West Lake Road thrust plate (BB' in Figure 3). Thus, it is possible that some or all of these map units might be structurally repeated at greater depth and, more particularly, that Unit 5 rhyolite could also underlie the deeper parts of this structural basin.

At the northeast end of section line BB', within the small duplex of Unit 4 rocks lying beneath the base of the West Lake Road thrust plate (Figures 2 and 3), minor folds in graded tuff face structurally downward along the prominent southwest-dipping schistosity. This observation could be interpreted to mean that the overlying thrust fault and associated fold nappe have been reoriented from their original upward-facing position. Thus, open folding about northwest-trending fold axes, for example, could result in some parts of an original southwest-directed thrust slice to be locally inclined toward the southwest (BB' in Figure 3).

Late Development of the Fold-and-Thrust Belt

When viewed in serial cross sections looking northeastward (Figure 4), tectonic panels of the Roberts Arm Group are seen to be folded about a series of northeast-trending folds. In certain areas, and within particular rock types, such folds display axial-planar, slaty cleavage. Bounded by folded early- and intermediate-formed thrusts, these tectonic panels are also locally displaced by high-angle reverse faults that are inclined to the southeast and, less commonly, to the northwest.

In cross section CC', a generally right-side-up sequence of Unit 6 volcaniclastic turbidites, correlated with the Gull Hill Sequence of Great Gull Lake, is structurally overlain and underlain by Unit 1 pillowed basalt (Figure 4). The disposition of the stratigraphically highest preserved part of Unit 6 is controlled by a northeast-trending, doubly plunging synform–antiform pair across which slaty cleavage displays a subvertical fan. These upward-facing structures fold the intermediate-formed thrust at the base of the structurally overlying panel of Unit 1 (Figure 2) and also deform an inhomogeneous bed-parallel foliation in the uppermost part of Unit 6 (Figure 4). Near the southeast end of section line CC', a late-formed southeast-dipping fault is interpreted to lie subparallel to slaty cleavage in a locally upside-down section of graded wacke. This reverse fault is postulated to offset the early formed thrust present at the structural base of Unit 6 (Figure 4).

In cross section DD', the same tectonic panel of volcaniclastic turbidites is seen to be much thinner. There, basalt in the southern extension of the West Lake Road thrust plate lies directly above Unit 6 wacke and both tectonic panels are deformed by southwest-plunging, open, upright folds (Figure 2). Some of these northeast-trending fold structures can be traced farther southwestward and deform rocks situated much higher in the original Roberts Arm thrust stack. For example, the early formed thrust at the base of the overlying tectonic panel of Unit 4 bimodal volcanic rocks is probably also affected by this late stage of regional fold development.

The northeast-plunging antiform cored by Unit 5 rhyolite is thought to be a relatively young structural feature (*see* DD' in Figure 4). This fold structure is outlined by the trace of a northwest-dipping thrust, itself responsible for the apparent truncation of several northwest-trending secondary folds within the large structural basin present in the southwest part of the area surveyed (Figure 2). A southeast-dipping high-angle reverse fault is interpreted to have displaced the folded northwest-dipping fault on the southeast limb of this late-formed antiform.

As shown in cross section DD', the thrust plate structurally underlying the "Gull Hill" metasedimentary rocks contains felsic tuff and hematized basalt in addition to the lime-green basalt typical of Unit 1. The lower contact of these variably mineralized Roberts Arm volcanic rocks with the younger Badger Group is thought to be a late-formed, northwest-dipping reverse fault similar to the one portrayed at the northwest end of section line DD'.

Posttectonic Structures in the Fold-and-Thrust Belt

The folded thrusts of the Roberts Arm Group appear to have guided the ascent of the epizonal Skull Hill intrusion into its terrestrial carapace of Springdale Group volcanic rocks (Figure 2). The displacement of this posttectonic pluton and its Ordovician and Silurian country rocks is, however, controlled by an aeromagnetically defined suite (Oneschuk *et al*., 2002) of regional northwest-, northeast- and east–northeast-trending faults. Where these brittle subvertical faults crosscut the Roberts Arm thrust stack, displacement is interpreted to have overlapped the emplacement of a satellite suite of Skull Hill intrusive bodies emanating from the Siluro-Devonian pluton. However, at least one northeast-trending brittle fault is known to offset Carboniferous molasse in the valley of South Brook (O'Sullivan, 1986) and to place netveined reddish-brown conglomerate directly against the metamorphosed Ordovician rocks of the Roberts Arm Group (Drill Core Library ID#216, DRN-Pasadena).

The mafic and felsic hypabyssal rocks of the Skull Hill suite (Figure 2) probably occupy high-level dilational structures. In the western part of the map area, indurated fault breccia zones hosted by posttectonic intrusive rocks contain comminuted blocks and matrix that are saucceritized, chloritized and locally pyritized. Mineralized structures are particularly common where graben, preserving down-dropped roof pendants of Springdale volcanic rocks, lie adjacent to horst blocks underlain by tectonically uplifted and locally reddened Skull Hill granite (Figure 3). Intersecting mineralized kink bands related to the fault breccia zones occur in the adjacent country rocks of the Roberts Arm Group. There, northwest-trending structures with a component of normal fault offset are displaced by northeast-trending structures with a component of strike-slip offset (Figure 2).

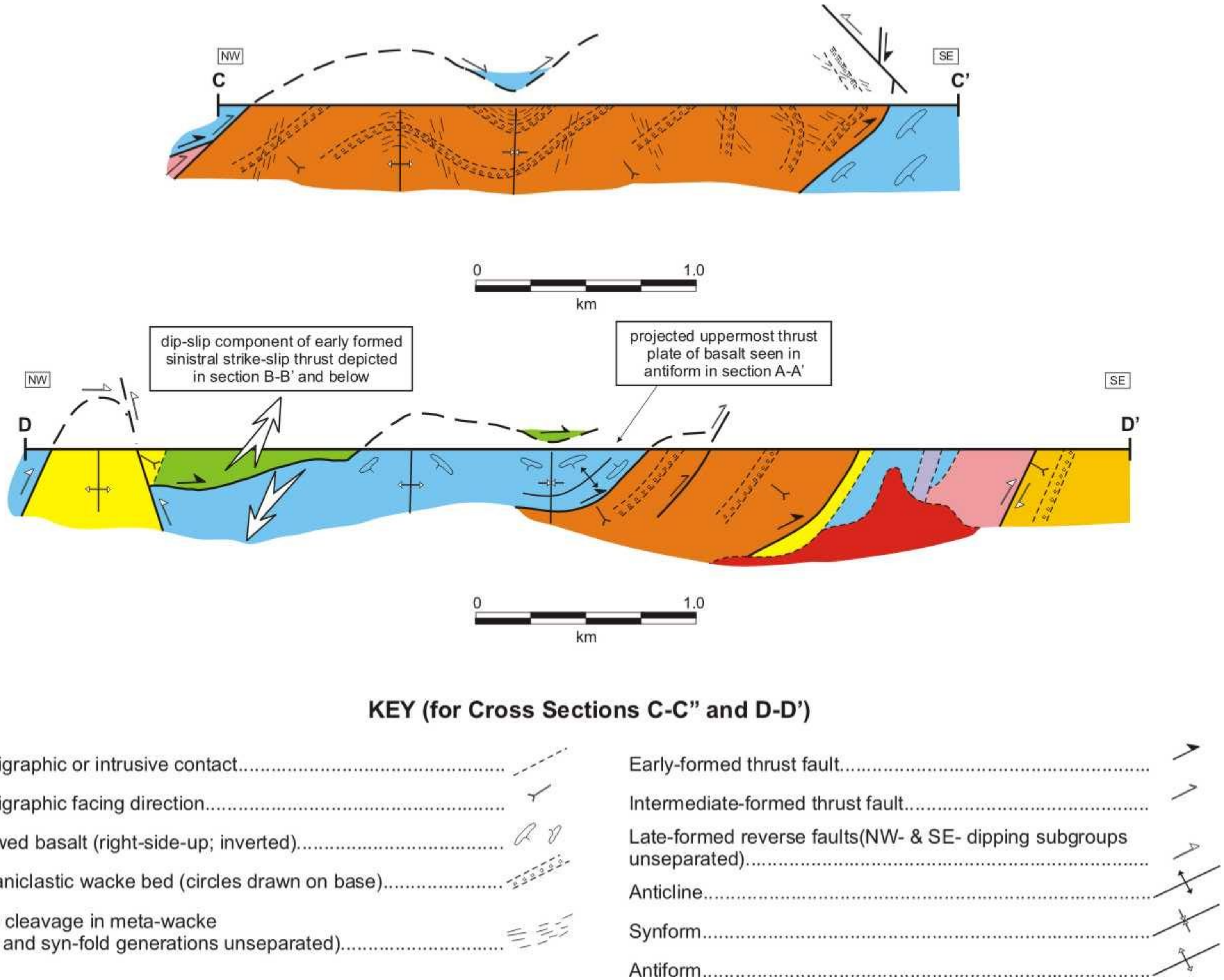

Figure 4. *Cross sections of the Ordovician Roberts Arm Group and adjacent units with viewer looking northeastward. Vertical scale exaggerated. See Figure 2 for the locations of section lines CC" and DD'.*

Correlative Fold-and-Thrust Belts

The antiformal thrust stack of variably mineralized volcanic rocks identified by Thurlow (1996) in the Roberts Arm Group on Pilley's Island (Figure 1) shares certain geometrical aspects of the fold-and-thrust belt near Lake Bond. Arcuate northwest-trending structures (e.g., the folded Liquor Street Fault) could possibly be interpreted as the lateral strike-slip ramps of early formed, northwest-dipping frontal thrusts. These may have been subsequently folded about northeast-trending fold axes (e.g., the doubly plunging CDF Fault) and then crosscut by thrust faults that consistently display southeast-over-northwest displacement (e.g., the Loadabats Fault).

Not unexpectedly, the closest structural correlation with the Lake Bond fold-and-thrust belt is found immediately northeast of the map area near Powderhorn Lake. There, Dickson (2001) identified a regional northwest-trending structural dome (Figure 1) in Roberts Arm Group and adjacent rocks. His geological map shows a mineralized felsic volcanic unit bounded by a thrust fault that was folded about a doubly plunging antiformal culmination situated near the Red Indian Line.

INTERPRETATION AND CONCLUSION

The northwest-striking thrust faults that can be mapped throughout the Roberts Arm Group are believed to have developed early in the structural history of the Lake Bond region and to have initially formed with different tectonic polarities. Those that originally dipped southwestward are interpreted as sinistral oblique-slip thrusts. Those that originally dipped northeastward are interpreted as back thrusts. Near the margins of some tectonic panels, fold nappes probably developed in association with both thrust sets. Subsequently, all of these early formed ductile structures were openly folded about variably doubly plunging folds to produce upright domes and basins. Elliptical antiforms create tectonic windows into the deeper levels of the imbricate thrust stack without the aid of significant erosion and the development of high topographic relief. Similarly, the structural basins in the Lake Bond region are tectonic depressions in which some of the higher parts of the Roberts Arm thrust stack are preserved.

Throughout the map area, northwest-trending synforms and antiforms were locally modified by later formed faults and folds. The oldest structural features known to modify the fold-and-thrust belt are northeast-directed (intermediate-formed) thrust and reverse faults. These northwest-trending structures crosscut the folded and bodily rotated oblique-slip and back thrusts, and yet they are still affected, in places, by the shortening event that produced the dome-and-basin interference pattern.

The tectonic panels comprising the Lake Bond belt were later cross folded, reverse faulted and locally foliated during the formation of a regional orogenic flexure marked by the Red Indian Line (Figure 1). Interpreted as northeast-trending bivergent structures, some of these tectonic features may have developed contemporaneously with the folded thrust faults that define the structural top of the Badger Group.

Mafic and felsic hypabyssal rocks of the Skull Hill satellite suite were emplaced across the Roberts Arm thrust stack utalizing a regional suite of northwest-, northeast- and east–northeast-trending brittle faults. Recording a vertical displacement and a horizontal offset, these subvertical structures are associated with mineralized fault breccia zones in posttectonic Siluro-Devonian plutonic rocks and deformed Silurian and Ordovician country rocks.

ACKNOWLEDGMENTS

Bryan Sparrow is thanked for field assistance during the summer of 2005. Lawson Dickson kindly provided point data that aided in the preparation of Figure 2 and also read a preliminary version of this manuscript. Gerry Hickey is acknowledged for excellent logistical support and his skilled boatmanship.

REFERENCES

Bostock, H.H.
1988: Geology and petrochemistry of the Ordovician volcano-plutonic Roberts Arm Group, Notre Dame Bay, Newfoundland. Geological Survey of Canada, Bulletin 369, 84 pages.

Chandler, F.W., Sullivan R.W. and Currie, K.L.
1987: The age of the Springdale Group, western Newfoundland, and correlative rocks - evidence for a Llandovery overlap assemblage in the Canadian Appalachians. Transactions of the Royal Society of Edinburgh (Earth Sciences), Volume 78, pages 41-49.

Colman-Sadd, S.P., Stone, P., Swinden, H.S. and Barnes, R.P.
1992: Parallel geological development in the Dunnage zone of Newfoundland and the Lower Paleozoic terranes of southern Scotland: an assessment. Transactions of the Royal Society of Edinburgh (Earth Sciences), Volume 83, pages 571-594.

Dickson, W.L.
1999: Geology of the Hodges Hill (NTS 2E/4) map area. Scale 1: 50 000. Newfoundland Department of Mines and Energy, Geological Survey, Map 99-16, Open File 002E/04/1070.

2001: Geology of the eastern portion of the Dawes Pond (NTS 12H/1) map area, Newfoundland. Scale 1:50 000. Newfoundland Department of Mines and Energy, Geological Survey, Map 2001-21, Open File 012H/01/1606.

Dunning, G.R., Kean, B.F., Thurlow, J.G. and Swinden, H.S.
1987: Geochronology of the Buchans, Roberts Arm and Victoria Lake groups and Mansfield Cove Complex, Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1175-1184.

Espenshade, G.H.
1937: Geology and mineral deposits of the Pilleys Island area. Newfoundland and Labrador Geological Survey, Bulletin No. 6, 60 pages.

Hudson, K.A. and Swinden, H.S.
1990: The Lake Bond deposit: superimposed volcanogenic and synorogenic base and precious metal mineralization in the Robert's Arm Group, central Newfoundland. Atlantic Geology, Volume 26, pages 11-25.

Kean , B.F. and Jayasinghe, N.R.
1982: Geology of the Badger map area (12A/16), Newfoundland. Newfoundland and Labrador Department of Mines and Energy, Mineral Development Division, Report 81-2, 37 pages.

O'Brien, B.H.
2001: Geology of part of the Robert's Arm map area (NTS 2E/5),western Notre Dame Bay. Scale 1: 50 000. Newfoundland Department of Mines and Energy, Geological Survey, Map 2001-38, Open File 002E/05/1160.

2003: Internal and external relationships of the Ordovician Roberts Arm Group in part of the Springdale (NTS 12H/8) map area, west-central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 03-1, pages 73-91.

2004: A structural window into Roberts Arm Group (?) basalt at Burnt Pond (NTS 12H/1): a metamorphic-inversion hypothesis. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 04-1, pages 187-201.

Oneschuk, D., Tod, J. and Kilfoil, G.
2002: Red Indian Line airborne geophysics compilation (Part II, Volume 1 of 3), central Newfoundland. Geological Survey of Canada Open File 4254 [NDME Open File NFLD/2773]; CD.

O'Sullivan, J.
1986: Assessment Report on Geochemical, Geophysical, Geological Surveys and Diamond Drilling on Licenses 2560 and 2603 for 1985 (Esso Minerals Canada). Newfoundland and Labrador Department of Mines and Energy, Geofile 12H/1(923); 11 pages.

Pudifin, M.
1993: Roberts Arm volcanics in the Gullbridge Mine area: deep exploration for Kuroko-type massive sulphides. *In* Ore Horizons, Volume 2. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, pages 77-88.

Rogers, N. and van Staal, C.R.
2005: Geology, Grand Falls, Newfoundland and Labrador. Scale 1: 50 000. Geological Survey of Canada, Open File 4545.

Rogers, N., van Staal, C.R. and McNicoll, V.J.
2005: Geology, Badger, Newfoundland and Labrador. Scale 1: 50 000. Geological Survey of Canada, Open File 4546.

Swinden, H.S. and Sacks, P.E.
1996: Geology of the Roberts Arm belt between Halls Bay and Lake Bond, Newfoundland (parts of NTS 12H/1 and 8). Scale 1: 50 000. Newfoundland Department of Mines and Energy, Geological Survey, Open File 012H/1367.

Swinden, H.S., Jenner, G A. and Szybinski, Z.A.
1997: Magmatic and tectonic evolution of the Cambrian - Ordovician margin of Iapetus: geochemical and isotopic constraints from the Notre Dame Subzone, Newfoundland. *In* Nature of Magmatism in the Appalachian Orogen. *Edited by* A.K. Sinha, J.B. Whalen and J.P. Hogan. Geological Society of America, Memoir 191, pages 337-365.

Thurlow, J.G.
1996: Geology of a newly discovered cluster of blind massive sulphide deposits, Pilley's Island, central Newfoundland. *In* Current Reseach. Newfoundland Department of Natural Resources, Geological Survey, Report 96-1, pages 181-189.

Whalen, J.B., Currie, K.L. and van Breemen, O.
1987: Episodic Ordovician - Silurian plutonism in the Topsail igneous terrane, western Newfoundland. Transactions of the Royal Society of Edinburgh (Earth Sciences), Volume 78, pages 17-28.

Whalen, J.B. and Currie, K.L.
1988: Geology, Topsails igneous terrane, Newfoundland. Scale 1: 200 000. Geological Survey of Canada, Map 1680A.

Williams, H.
1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

1995: Chapter 2 - Temporal and Spatial Divisions. *In* Geology of the Appalachian Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada Series No. 6, pages 3-19.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectonic - stratigraphic subdivisions of central Newfoundland. *In* Current Research, Part B.Geological Survey of Canada, Paper 88-1B, pages 91-98.

Zagorevski, A., Rogers, N., van Staal, C.R., McNicoll, V., Lissenburg, C.J. and Valverde-Vaquero, P.
In press: Lower to Middle Ordovician evolution of peri-Laurentian arc and back-arc complexes in Iapetus: Constraints from the Annieopsquotch Accretionary Tract, central Newfoundland. Bulletin of the Geological Society of America (2006).