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INTERNAL AND EXTERNAL RELATIONSHIPS OF THE SOUTH LAKE IGNEOUS COMPLEX, NORTH-CENTRAL NEWFOUNDLAND (NTS 2E/5, 6): ORDOVICIAN AND LATER TECTONISM IN THE EXPLOITS SUBZONE?

B.H. O'Brien
Newfoundland Mapping Section

ABSTRACT

The South Lake Igneous Complex of north-central Newfoundland occurs in a portion of the Exploits Subzone (Dunnage Zone) that is characterized by Early and Middle Ordovician plutonic and volcanic rocks, which formed within the Iapetan oceanic crust, and by Late Ordovician sedimentary rocks that accumulated above this substrate. Bodies of gabbro, diorite and tonalite, along with several swarms of mafic dykes, constitute the igneous complex, and make up distinctive tracts of ophiolitic and magmatic arc rocks. Their interrelationships establish, and relative ages bracket, several Ordovician periods of ductile deformation, dynamothermal metamorphism and mesozonal plutonism that were internal to the South Lake Igneous Complex. They also point to the important role of shear zones in ophiolitic basement and their control on the tectonic development of younger rocks.

The external relationships of the Lower–Middle Ordovician South Lake Igneous Complex with the Middle Ordovician Wild Bight Group and Upper Ordovician Point Leamington greywacke are interpreted to mean that the complex was exhumed and eroded by the Ashgill, having been accreted to Exploits Subzone rocks of overlapping age by the Llanvirn. Structurally, the South Lake Igneous Complex is a parautochthonous unit, externally bounded by high-angle reverse faults of possible Late Silurian age.

OBJECTIVE

The northern portion of the South Lake Igneous Complex and adjacent parts of the Point Leamington greywacke and Wild Bight Group were examined as part of a regional mapping project in central Notre Dame Bay (Figure 1). The data obtained from these rocks will be integrated with those in other regions of the Exploits Subzone in a regional study that, amongst other objectives, will deal with the interrelationships of rocks of Early, Middle and Late Ordovician age (O'Brien, 1991a,b; Dec *et al.*, *this volume;* Williams *et al.*, *this volume*).

RELATIONSHIPS INTERNAL TO THE COMPLEX

Between Martin Lake and Cramp Crazy Lake, the South Lake Igneous Complex (Dean, 1977) is composed of several types of plutonic rocks and a variety of minor mafic intrusions, all of which are variably deformed and metamorphosed. Mappable bodies of mafic to felsic plutonic rocks (Figure 2) are, from oldest to youngest, metagabbro, hornblende diorite, quartz tonalite and quartz diorite. Lorenz and Fountain (1982) considered these rocks to be representative of the entire complex.

THE OPHIOLITE TRACT

The oldest exposed part of the South Lake Igneous Complex, originally referred to as the South Lake Ophiolite (Dean, 1977), is restricted to a relatively small tract in the northern part of the complex.

Metagabbro (Unit 1)

Identified as Unit 1 metagabbro in Figure 2, the ophiolitic tract consists of northeast- to east-trending zones of cumulate-layered, schistose and flaser-banded gabbro. That intrusion of younger phases of this purported ophiolite (Dean, 1977) accompanied deformation and metamorphism of its older phases is witnessed by the field relationships of *lit-par-lit* leucogabbro veins to variably mylonitized metagabbro (Plate 1). Sheeted mafic dykes, which constitute the oldest recognizable swarm in the South Lake Igneous Complex (Table 1), were emplaced into wrench-type shear zones,

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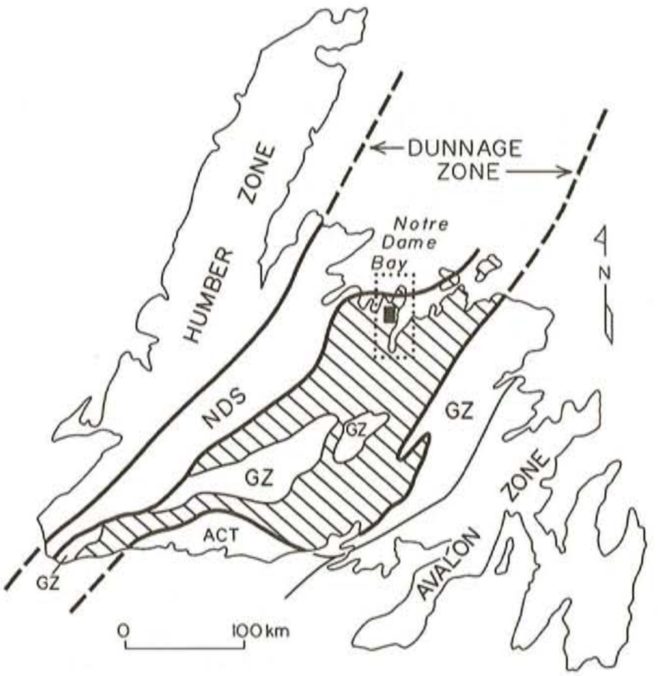

Figure 1. *Location of the study area illustrated in Figure 2 (solid square) within the context of the central Notre Dame Bay mapping project (dotted square). The Exploits Subzone of the Dunnage Zone is indicated by dashed lines. The abbreviations NDS, GZ and ACT represent the Notre Dame Subzone, the Gander Zone and the Avalon Composite Terrane, respectively.*

synkinematically, along with late magmatic veinlets (Plate 2). Such variably sheared dykes, although discordant to the regional structural grain of the ophiolitic metagabbro, were preferentially intruded into subvertical, northwest-oriented, ductile shear zones that developed contemporaneously with dyke-swarm emplacement (Plate 3). In this regard, Unit 1 of the South Lake Igneous Complex is typical of certain zones in the lower parts of fossilized sections of oceanic crust (Dunning, 1987), and structurally similar to preserved fragments of upper mantle that evolved near paleo-transform faults (Suhr *et al.*, 1991).

Engulfment of small fragments of Dunnage Zone ophiolites by syntectonic, dioritic to tonalitic batholiths is a typical feature of the Taconian magmatic arc in southwestern Newfoundland (Dunning and Chorlton, 1985). In the South Lake Igneous Complex, subvertical northeast-trending mylonite zones, each several metres wide, rework metagabbro and originally discordant mafic dykes, where such ophiolitic rocks locally form the complex's western margin (Figure 2). Mylonite zones of this age are no younger than the faulted contact with external units and, based on regionally crosscutting intrusive contacts, are apparently older than some of the other plutonic rocks that made up the complex.

THE MAGMATIC ARC TRACT

Volumetrically, most of the northern part of the South Lake Igneous Complex is made up of diorite and tonalite intrusions. Hornblende diorite, blue-quartz tonalite and quartz diorite are herein distinguished as Units 2, 3 and 4, respectively (Figure 2).

Hornblende Diorite (Unit 2)

The oldest unit of the purported arc-related suite is hornblende diorite, which crops out as northeast- and northwest-trending, subvertically dipping bodies throughout the South Lake Igneous Complex. Because Unit 2 is seen to occur as septa and as screens, it possibly may have once been a more contiguous entity. Hornblende diorite varies from fine to coarse grained, equigranular to schlieren-textured, and commonly contains mafic pegmatites in diffuse pods or cavities. Most bodies of Unit 2 are unfoliated or weakly schistose, and are rarely altered. Hornblende diorite is host to variably sheared, mafic—felsic, composite dykes (Table 1), which are localized in small northwest-trending trains near segments of the intrusions rich in accidental and cognate xenoliths. Such assemblages of dykes and xenoliths are most common in the northern part of the complex; however, they are not present in all of the hornblende diorite bodies in the area.

A narrow unfoliated appendage of the northwesternmost body of hornblende diorite was apparently intruded into one of the northeast-trending shear zones that rework dyke swarm 1 (Table 1; Figure 2). The main part of this hornblende-diorite body, which crosscuts the complex's oldest dyke swarm as well as significant expanses of flaser gabbro, contains large xenoliths of previously altered and strongly foliated material of felsic composition. The included tectonites are similar to those found in adjacent but younger parts of the complex, suggesting persistent sampling of the same source rock at depth.

Hornblende diorite is closely associated with quartz tonalite throughout that portion of the South Lake Igneous Complex shown in Figure 2. Mafic—felsic composite dyke injection in hornblende diorite might herald blue-quartz tonalite intrusion and indicate that diorite and tonalite are largely comagmatic in origin.

Quartz Tonalite (Unit 3)

The most lithologically distinctive and physiographically prominent unit of the South Lake Igneous Complex is blue-quartz tonalite. Unit 3 tonalite is intruded as a series of anastomosing and tapering sheets in metagabbro and hornblende diorite (Figure 2). Where the complex is composed of alternating diorite septa and tonalite screens, the latter typically contain elongate, variably sized, hornblende-diorite fragments, and the former are commonly concordantly injected by tonalite stringers and overgrown by metasomatic feldspars. Near Martin Lake, ductile shear zones in diorite septa are absent in adjacent tonalite screens, possibly implying that the initiation of diorite deformation may have preceded tonalite intrusion in some areas.

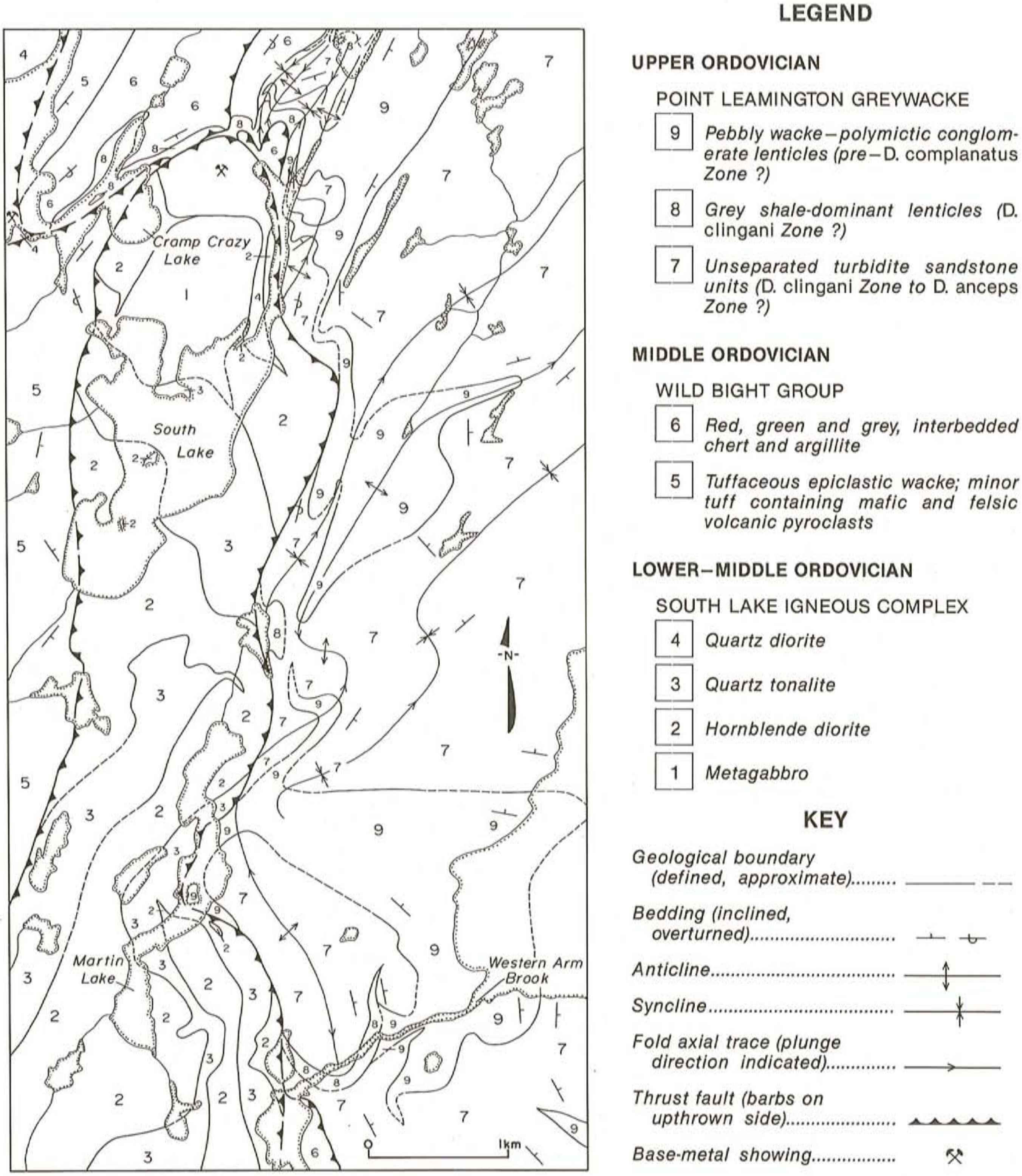

Figure 2. *Geological map of a portion of the Lower–Middle Ordovician South Lake Igneous Complex and adjacent parts of the Middle Ordovician Wild Bight Group and Upper Ordovician Point Leamington greywacke.*

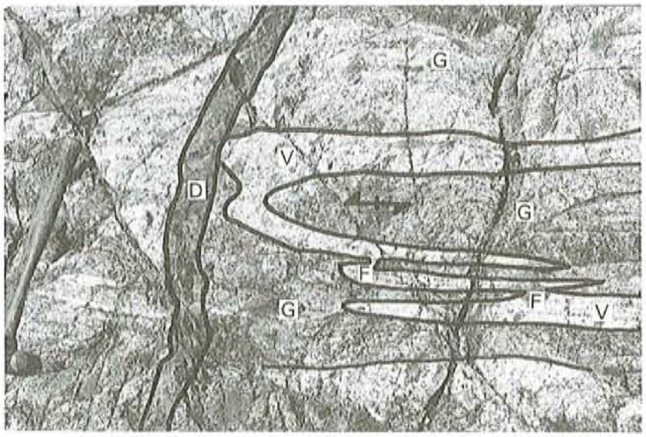

Plate 1. *Host-rock foliation (marked by symbol) is axial planar to isoclinal folds of* lit-par-lit *leucogabbro veins (V) intruding metagabbro (G), indicating a close relationship between magmatism and deformation in this presumed ophiolitic part of the South Lake Igneous Complex. Note that the leucocratic veins infill what were originally a series of branched, asymmetrically forked, shear fractures (F). A mafic dyke (D), belonging to the oldest swarm in the igneous complex, is relatively late in this sequence of events. The dyke illustrated is typical of most of oldest swarm in that it trends across the structural grain of ophiolitic metagabbro but, just outside of the field of view, locally forms T-shaped abuttments with concordant members of this suite of mafic intrusions.*

Generally, quartz tonalite is well foliated but poorly lineated; the fabric defined by a shape fabric in blue-quartz ribbons and by a mineral fabric in aligned ferromagnesian minerals. In both deformed and undeformed states, tonalite bodies are host to the second major swarm of mafic dykes in the South Lake Igneous Complex. However, the initial and waning phases of this dyking event may affect older and younger members of the complex (Table 1).

Undeformed, coarse-grained, quartz-porphyritic tonalite has irregular clots of much finer, ophitic intergrowths of hornblende and plagioclase. This early-crystallized mafic material comprises discrete trains of cognate xenoliths, which are very common in all of the tonalite bodies. They are associated with swarms of distorted, distended and disaggregated (backveined) mafic dykes, especially well developed along intrusive margins of northwest-trending segments of tonalite bodies (Figure 2). The deformation of cognate xenoliths and mafic dykes within tonalite overlapped the deformation of the material backveined from these intrusions. However, there are also numerous localities where strong quartz-ribbon shape fabrics in tonalite are truncated by undeformed mafic dykes.

Accidental xenoliths of mafic, silicic and quartzofeldspathic rocks are found in blue-quartz tonalite. Some of the quartzofeldspathic xenoliths display complex fold-interference patterns and apparently reflect entrapped paragneiss (Plate 4). Though relatively rare, xenoliths of paragneiss may suggest that ophiolitic rocks were overlain by or tectonically intercalated with siliciclastic or epiclastic rocks prior to their intrusion by quartz tonalite. How early (pre-hornblende-diorite) phases of mylonitization might relate to such events, if at all, is unknown. However, xenoliths in which a mafic dyke crosscuts flaser gabbro are present within undeformed blue-quartz tonalite. This indicates that Unit 3 is not allochthonous with respect to the stitched Unit 1—Unit 2 assemblage, and that displacement of ophiolitic metagabbro during the ascent of these arc-related plutonic rocks was regionally insignificant.

Quartz Diorite (Unit 4)

The northernmost part of the South Lake Igneous Complex is underlain by quartz diorite (Unit 4), the youngest member of the complex. For the most part, this medium-grained equigranular rock is rarely foliated and contains uncommon mafic dykes. Internally, the main intrusive bodies are locally saussuritized, sericitized and pyritized. Also, small apophyses of quartz diorite are apparently associated with sulphide-rich alteration zones in those members of the complex that host them.

The margin of the quartz-diorite intrusion north of South Lake is mapped, in part, as transecting the intrusive contact between hornblende diorite and ophiolitic metagabbro and, in other localities, as occupying that boundary (Figure 2). Where quartz diorite net-veins hornblende diorite near their mutual northwest-trending contact, the younger body is observed to have xenoliths of undeformed portions of the older body. Here, medium-grained quartz diorite passes gradationally into fine-grained, porphyritic, marginal phases of this intrusion.

On the shore of South Lake, a north-trending sheet of unfoliated quartz diorite, which crosscuts sheared, northwest-trending Unit 1 dykes, contains accidental xenoliths of mylonite (Plate 5). Distinctive epidote-rich bands within the mylonite suggest derivation, at least in part, from rocks of mafic composition. Near Cramp Crazy Lake, unaltered and unfoliated quartz diorite has xenoliths of highly sheared and partly silicified, blue quartz-bearing, felsic rocks. This material may represent either mylonitic granitoids or strongly deformed, extrusive rocks of felsic composition. The unaltered protolith of these latter xenoliths might be found in adjacent rock groups (Unit 5 of the Wild Bight Group), in older parts of the South Lake Igneous Complex, or in a yet older exotic suite of entirely unrelated rocks.

THE COMPLEX IN SUMMARY

Episodes of persistently ductile and transiently brittle deformation and associated periods of dynamothermal metamorphism were coeval with much of the plutonism in the South Lake Igneous Complex. A long-lived, crustal-scale, vertical shear zone appears to have been situated near what is now the northern extremity of the complex.

Several of the older episodes of wrench-type shearing were related to the early evolution of what has been recently

Table 1. Sequence of tectonic events in the South Lake Igneous Complex. Dyking events 2, 3 and 4 may represent initial, main and waning phases, respectively, of the same event. Dyking events 2 and/or 4 may or may not relate to dyking events in the Wild Bight Group along the eastern boundary with the South Lake Igneous Complex

MEMBER OF COMPLEX		TECTONIC EVENTS
	DYKING EVENT 4	*(13) sporadic intrusion of mafic dykes and sills*
		(12) localized deformation of quartz diorite and possibly blue-quartz tonalite and Wild Bight Group
		(11) alteration of quartz diorite and possibly hornblende diorite
		(10) incorporation of mylonite that had a mafic protolith
QUARTZ DIORITE		*(9) intrusion of quartz-diorite bodies along and across the intrusive margins of hornblende-diorite bodies*
QUARTZ TONALITE	DYKING EVENT 3	*(8) intrusion of blue quartz-tonalite bodies and inclusion of paragneiss xenoliths. Accompanied emplacement and shearing of orthogonal suites of northeast and northwest mafic dykes (DYKE SWARM 2). Contemporaneous deformation of quartz tonalite and possibly hornblende diorite*
	DYKING EVENT 2	*(7) localized intrusion of composite mafic–felsic dykes*
		(6) restricted development of northeast and northwest shear zones in regionally undeformed bodies of hornblende diorite
		(5) incorporation of metagabbro enclave and exotic xenoliths of altered felsic tectonites
HORNBLENDE DIORITE		*(4) intrusion of hornblende-diorite bodies into northeast shear zones that rework dyke swarm 1*
	DYKING EVENT 1	*(3) emplacement and shearing of sheeted mafic dykes (DYKE SWARM 1), contemporaneous with development of northwest shear zones in metagabbro*
META-GABBRO		*(2) mylonitization and production of northeast structural grain in flaser gabbro and leucogabbro*
		(1) formation of primary cumulates in ophiolitic gabbro

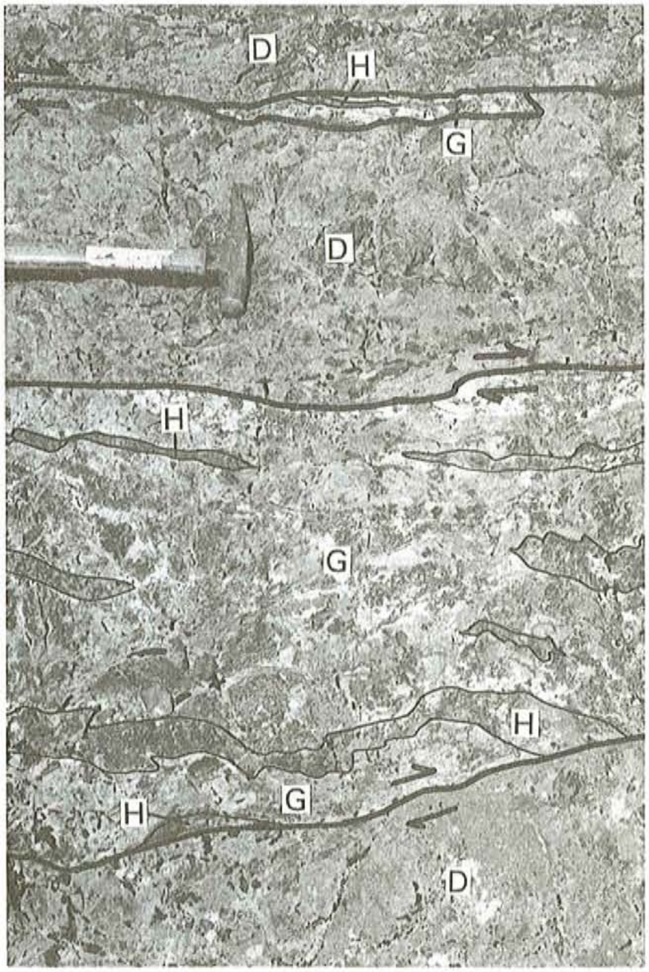

Plate 2. *Injection and crystallization of late magmatic fluids, represented by hornblendite veinlets (H), preceeded mafic dyke (D) intrusion but was, nevertheless, synkinematic with respect to emplacement of sheeted mafic dykes in metagabbro (G). The hornblendite veinlets are interpreted to occupy pinnate tensile fractures, whereas the variably foliated mafic dykes are thought to mark the location of linked shear fractures. Dextral wrench-related structures possibly controlled these discordant members of the oldest dyke swarm. Looking down on a subhorizontal erosion surface at subvertically dipping, west- and northwest-trending contacts of composite dykes,* en echelon *veinlets and altered metagabbroic host rock.*

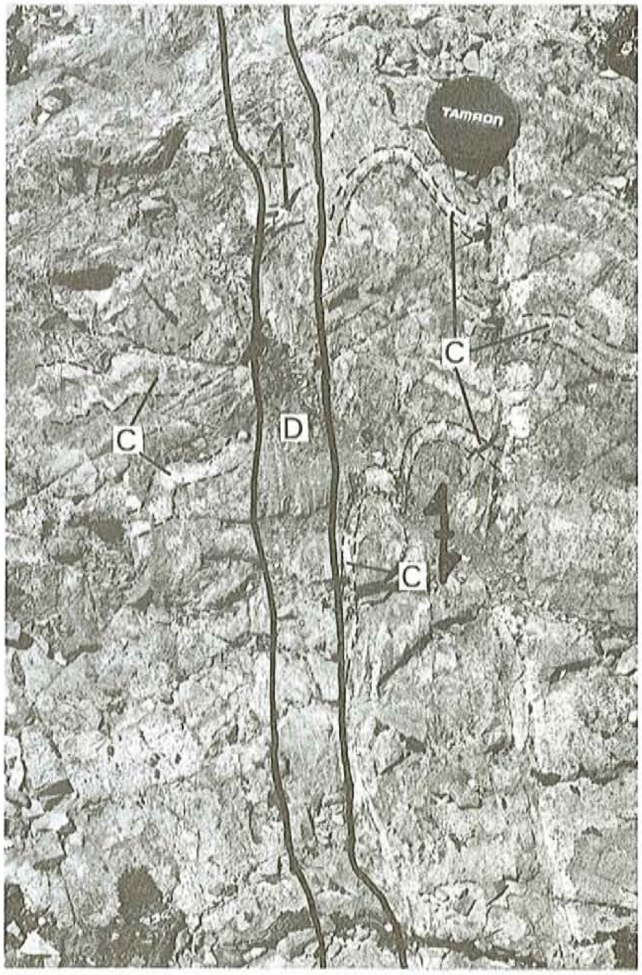

Plate 3. *An internal, wall-to-wall foliation (open symbol) in a discordant, sheared mafic dyke (D) is parallel to a host-gabbro foliation (closed symbol), which is axial planar to minor folds of primary (cumulate) layering (C). Note that the apical angle of such folds decreases toward the dyke margin, the site of a small ductile shear zone. Restricted to zones of dyke intrusion and contemperaneous with emplacement of the oldest swarm, the foliation illustrated is perpendicular to the mylonitic foliation in adjacent tracts of flaser gabbro.*

deemed the complex's ophiolitic tract (Table 1). Such deformation produced zones of flaser gabbro and strongly foliated gabbro separated by zones displaying primary igneous texture, and may have occurred entirely within Ordovician oceanic crust. It imparted, to the ophiolitic tract, a variably developed, north- to northeast-trending structural grain (see also Lorenz and Fountain, 1982). A somewhat later episode of shearing in metagabbro was associated with the emplacement of the oldest mafic dyke swarm in the complex and resulted in the development of an internal system of west- to northwest-trending shear zones. Less abundant, northeast-trending shear zones, also apparently confined to the ophiolitic tract, reworked earlier structures and the originally discordant dykes of the oldest northwest-trending swarm.

A mesozonal shear zone, whose effects were mostly manifested in the magmatic arc tract in the north of the complex, nucleated in what is now a rhombohedral enclave of ophiolitic metagabbro. There, the regional partitioning of hornblende-diorite and quartz-tonalite bodies is strikingly evident. However, in the southern parts of the complex, their relative disposition and local outcrop patterns are much more irregular and the mutual relations of diorite and tonalite are less readily discernible. It seems that sheet intrusions in the southern parts of the complex have had their emplacement less controlled by pre-existing and contemporaneous structures than those in the north. Lorenz and Fountain (1982) regarded the magmatic arc tract as a petrogenetically related, subduction-generated plutonic suite and hypothesized that

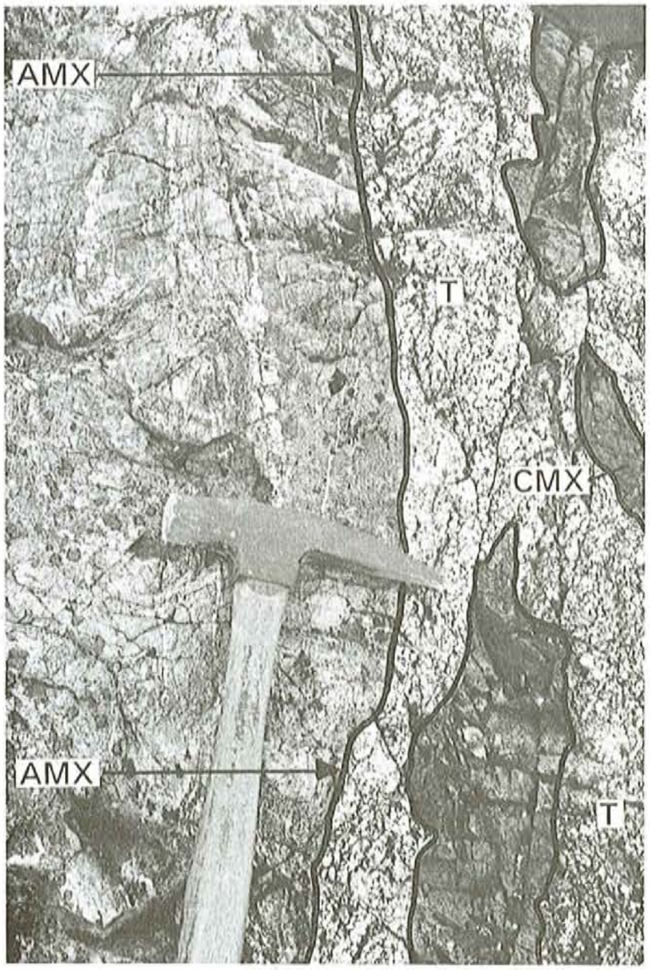

Plate 4. *Weakly foliated, blue-quartz tonalite (T) of the South Lake Igneous Complex contains cognate mafic xenoliths (CMX) and accidental paragneissic xenoliths (APX). Note the folded metamorphic banding and migmatitic segregation lits within the xenolith of paragneiss. An exotic lithology uncharacteristic of adjacent rock groups, paragneiss is also unrecognized as an internal unit of the igneous complex at present erosional level.*

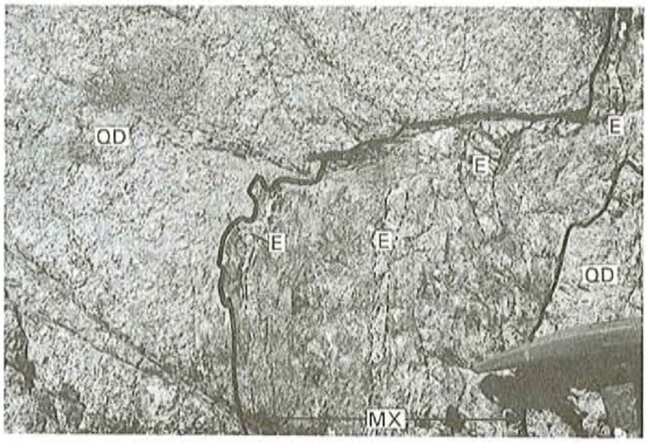

Plate 5. *Unfoliated, well-jointed, quartz diorite (QD) is host to an accidental xenolith of mylonite (MX). Along part of the external boundary of the xenolith, quartz diorite is seen to crosscut the mylonitic foliation. Note the presence of foliation-parallel, epidote-rich layers (E) within the xenolith, possibly suggesting that the protolith of the mylonite was mafic in composition.*

these plutons originated in a marginal basin and formed below an ensimatic volcanic island arc.

The ductile shear zone hosted by the South Lake Igneous Complex had a movement history revealed, in large part, by mafic dykes that were syntectonically emplaced during four, geologically separable events (Table 1). The shear zone evolved within, and is restricted to, the complex. As hard-rock deformation proceeded, shearing was continuously focused into progressively younger intrusions, although whether synplutonic deformation inhomogeneously affected older rocks in different parts of the complex is unknown. Episodes of mesozonal synplutonic tectonism are bracketed by the ages of the ophiolitic metagabbro and later dioritic and tonalitic plutons. Obliquely oriented to and transected by the generally north-trending faults defining the complex's external boundaries, the shear zone overlapped, with declining influence, the emplacement of the intrusions comprising the South Lake Igneous Complex.

RELATIONSHIPS EXTERNAL TO THE COMPLEX

The external relationships that the Lower–Middle Ordovician South Lake Igneous Complex have to adjacent rocks of overlapping and younger age are exceedingly variable and notably cryptic. Regionally, the complex is located along a major structural culmination within the Middle Ordovician Wild Bight Group; however, through the particular tract of ground shown in Figure 2, it is also tectonically juxtaposed against the Upper Ordovician Point Leamington greywacke. In this region, mafic dykes and sills are ubiquitous in the South Lake Igneous Complex, common in the Wild Bight Group and rare in the Point Leamington greywacke. Generally, within each of these units, the mafic intrusions comprise texturally and compositionally distinct suites, which display variable relations with the local structures found in their host rocks.

Fossils from the Wild Bight Group and Point Leamington greywacke, recently discovered near the South Lake Igneous Complex, have been tentatively identified by S.H. Williams (personal communication, 1991). The youngest Wild Bight formation (Unit 6), which is juxtaposed against the South Lake Igneous Complex, contains graptolites indicating an *Nemagraptus gracilis* Zone age (earliest Caradoc). The oldest known Point Leamington unit so disposed belongs to the *Dicranograptus clingani* Zone (latest Caradoc). The Lawrence Harbour shale of mainly Caradoc age, although present to the immediate north and south of this region, is notably absent adjacent to the South Lake Igneous Complex.

POSSIBLE SILURIAN RELATIONSHIPS OF THE SOUTH LAKE IGNEOUS COMPLEX

The South Lake Igneous Complex is externally bounded by generally steeply east- and west-dipping faults that are openly folded by northeast-trending regional folds (Figure 2). The bounding faults apparently coalesce near Cramp Crazy Lake, where the Wild Bight Group and the Point Leamington greywacke intervene between two separate outcrop areas of the complex. From observation of minor structures developed in adjacent Ordovician stratified units, it is concluded that these faults formed as the Ordovician beds were overturned, before or during the imposition of the regional slaty cleavage. Fold asymmetry and axial-surface inclination, together with the dip direction of attendant slaty cleavage, indicate that the sharply defined, bounding structures are brittle-ductile, high-angle reverse faults or, more rarely, thrust faults (see O'Brien, 1991c for fuller treatment). Because the South Lake Igneous Complex is seen to terminate within the Wild Bight Group, it is considered to occupy a horse in these stratified rocks rather than a klippe lying above such strata (Figure 2).

Although local age control on the complex's bounding faults is currently unavailable, any regional deformation of the South Lake Igneous Complex that also affects the Point Leamington greywacke must be younger than mid-Ashgill (Williams *et al., this volume*). In the Bay of Exploits area, where structures are thought to be correlative and contemporaneous with those discussed above, thrust-related folds and cleavage affect mid-Llandovery rocks as well as the Ashgill Point Leamington greywacke, and are truncated by Long Island quartz monzonite yielding a K–Ar biotite age of 448 ± 10 Ma (Mandville, 1991).

The southernmost portion of the fault along the eastern margin of the South Lake Igneous Complex juxtaposes Point Leamington and Wild Bight strata that define a regional structural domain governed by northwest-trending slaty cleavage, major periclinal folds and high-angle reverse faults (Figure 2). Although this pattern could be interpreted to result solely from coaxially refolding structures that originally trended northeast, most units in the Exploits Subzone occupy such northwest-trending domains, which are known to occur regionally throughout north-central Newfoundland.

Some reported explanations of this phenomenon are that the northwest-trending domains are medial Ordovician to Silurian in age and are overprinted by northeast-trending domains of Late Silurian age (Blewett, 1991) or, alternatively, that the older northwest-trending domains were initiated during sedimentation (Helwig, 1967) of the Middle Ordovician and older (?) parts of the Wild Bight and Exploits groups. Another possibility is that the northeast- and northwest-trending structures mutually overprinted each other, with domains developing contemporaneously on a regional scale (O'Brien, 1991c). In this explanation, the grain of these Late Silurian (?) structures, particularly the northwest set, would be inherited from and initially controlled by the structural architecture (Thon, 1980; Glenn, 1985) of underlying rocks (e.g., the steeply dipping Ordovician shear zones in the South Lake Igneous Complex).

The faulted contact of the South Lake Igneous Complex crosscuts internal stratigraphic boundaries within the Middle to Upper Ordovician part of the Wild Bight Group, the latter also being locally thrust imbricated between the South Lake Igneous Complex and the Point Leamington greywacke (Figure 2). However, if previous assumptions about the age of the South Lake Igneous Complex are correct, then the complex is too old to have originally intruded the Point Leamington greywacke. This means that either post-Late Ordovician fault displacement is large and the whole igneous complex is allochthonous, or that the South Lake Igneous Complex and the Wild Bight Group are essentially parautochthonous relative to the Point Leamington greywacke and any younger intrusive rocks. The latter scenario may be supported by a preserved interbedded relationship between Unit 6 of the Wild Bight Group and Unit 7 of the Point Leamington greywacke (cf. Helwig, 1967), a feature only observed near the South Lake Igneous Complex (see section on Relationships of Unit 3).

As a generalization, dynamothermal metamorphism that accompanied deformation in the complex's internal system of shear zones occurred at much higher grades than that which was contemporaneous with the external system of bounding brittle-ductile faults. In addition, mylonite zones are far more common within the complex than outside of it. Therefore, while it is possible that differential movement of certain units of the South Lake Igneous Complex was contemporaneous with the development of its bounding faults, any displacements producing significant unit offset could have equally well occurred during the complex's amalgamation or, later, as the complex was exhumed. However, if displacements are not large and none of the complex's units are allochthonous relative to each other or adjacent stratified units, then the original boundary between the South Lake Igneous Complex and the Point Leamington greywacke would have been necessarily stratigraphical.

POSSIBLE ORDOVICIAN RELATIONSHIPS OF THE SOUTH LAKE IGNEOUS COMPLEX

Relationships with Wild Bight Intrusions

Though regionally developed throughout the group, minor intrusions of mafic composition are locally concentrated in the Wild Bight Group to the immediate west of the South Lake Igneous Complex. There, in Unit 5 of the Wild Bight Group (Figure 2), sills generally trend northwest and dykes northeast. Some of these rocks, traditionally held to be of medial Ordovician age, intrude coarse-grained, felsic pyroclastic deposits and show irregular diffuse margins indicative of a penecontemporaneous synvolcanic origin. Other mafic dykes and sills were intruded after sericitic and silicic alteration of these Wild Bight tuffs and apparently postdated foliation development in the group, at least in this location. It is possible that some of these minor intrusions are also present in quartz diorite (Unit 4) of the South Lake Igneous Complex (Table 1).

Relations with Wild Bight Strata

Dean (1977) stated that certain members of the presumed medial Ordovician and older South Lake Igneous Complex intruded the Wild Bight Group. This relationship is not observed along the margins of any of the regionally mappable bodies depicted in Figure 2, although xenoliths with pre-incorporation fabrics in Unit 4 could be argued to belong to the adjacent Wild Bight Group. However, taken together with the relations of the synvolcanic or syntectonic dykes in Unit 5 and the conformity of the Unit 5—Unit 6 succession, this would imply Ordovician deformation of a Wild Bight volcanosedimentary sequence at a time when, according to abundant fossil evidence, most of the Exploits Subzone was being blanketed by anoxic pelagic sediment (i.e., Lawrence Harbour shale and equivalents). Until it can be demonstrated that deformation of this age affects stratified rocks in the region, it should not be assumed that any South Lake Igneous Complex unit has intrusive relationships with the Wild Bight Group.

Relations with Point Leamington Strata

One of the most critical external relationships of the South Lake Igneous Complex is the one it possibly once had with Ashgillian strata of the Point Leamington greywacke. Laterally discontinuous lenticles of polymictic conglomerate and pebbly wacke (Figure 2) are characteristic of a variably thick succession that records the interval between the *Dicranograptus clingani* and *Dicellograptus complanatus* graptolite biozones around most, if not all, of the Point Leamington basin margin (Williams *et al., this volume*). In most places, the conglomerate-wacke sequence is underlain and overlain by thin-bedded sandstone—argillite sequences in the lowest part of the Point Leamington succession. Conglomeratic and pebbly flysch lenticles cropping out near the eastern margin of the South Lake Igneous Complex have complexly interlinked protrusions or tongue-like splits, presumably related to events that caused the stratigraphic wedging of the host turbidite succession. In those parts of the Point Leamington basin that are not adjacent to the South Lake Igneous Complex, black anoxic mudstone of the Lawrence Harbour shale forms the substrate to a similar Ashgillian succession.

Relationships of Units 8 and 9

Pebbly wacke-polymictic conglomerate sequences on Western Arm Brook and near South Lake comprise two separate bodies of Unit 9, both of which directly overlie Unit 8 grey shale of the Point Leamington greywacke (Figure 2). In both localities, the thin grey shale horizons underlying Unit 9 wacke contain probable *Dicranograptus clingani* Zone graptolite assemblages. The underlying grey shales are, however, lithostratigraphically distinct entities. The grey shale lenticle on Western Arm Brook is intercalated with Unit 7 of the Point Leamington greywacke, whereas the lenticle near South Lake gradationally overlies *Nemagraptus gracilis* Zone strata belonging to Unit 6 of the Wild Bight Group. Unit 8 shale and Unit 9 wacke of the Point Leamington greywacke are locally separated by a shale-matrix olistostrome that contains large blocks of coral-bearing limestone and celadonite-bearing chert at its base. Some of the transported material in the debris flow located on Western Arm Brook is also found *in situ*, and as reworked clasts, in Unit 6 of the Wild Bight Group. Only short distances along strike from the olistostrome, where neither *D. clingani* shale nor pre-*D. complanatus* conglomerate form part of the Upper Ordovician flysch, splits or wedges within the host turbidite sandstone succession are not observable.

Relationships of Unit 3

In several locations, polymictic conglomerate lenticles of the Point Leamington greywacke are in direct contact with Unit 2 diorite and Unit 3 tonalite of the South Lake Igneous Complex (Figure 2). On Martin Lake, Point Leamington wackes (Unit 9), lying tectonically adjacent to Unit 3, contain abundant, euhedral, blue-quartz clasts and rare prisms of fresh hornblende in addition to pebbles of tonalite, other granitoids, felsic volcanic rocks and celadonitic chert. This implies insignificant chemical weathering of the clasts' source area and little mechanical breakdown of the wackes' detrital constituents. A nearby provenance is likely; the adjacent body of blue-quartz tonalite apparently being preferentially eroded and locally transported. Furthermore, these observations suggest that the South Lake Igneous Complex and the Wild Bight Group were already in close proximity to each other by late Caradoc time, with both supplying detritus to the Point Leamington sedimentary basin. Onlap of the stratigraphically lowest conglomeratic sequence or uplift of this source area, along the basin margin immediately prior to the beginning of the *Dicellograptus complanatus* interval, may have resulted in Unit 9 wacke being originally deposited on Unit 3 of the igneous complex. Alternatively, either a locally anomalous amount of tectonic removal of underlying strata (Unit 7) has occurred where Unit 9 is in direct contact with Unit 3, or the northwest-trending pericline affecting Units 7 and 9 formed prior to the northeast-trending fault bounding Unit 3 (Figure 2).

Summary of Late Ordovician Interrelationships

Deposition of the stratigraphically lowest, 'feather-edged' lenticles of conglomerate and wacke was apparently triggered by localized syn-sedimentary uplift during an interval overlapping the Caradoc—Ashgill boundary. At least one of the accumulation sites of polymictic conglomerate was initially controlled by gravity-driven slumping and mass wasting within a specific submarine channel, peculiar to one of the margins of the Point Leamington basin.

Ashgillian uplift and resedimentation of Caradoc black mudstone occurred during the *Dicellograptus complanatus* and *Dicellograptus anceps* intervals (e.g., Williams *et al., this volume*); it affected those parts of the basin underlain by the Lawrence Harbour shale. As discussed above, uplift of that portion of the basin margin, which abutts the South Lake Igneous Complex, occurred earlier. Apparently, such uplift and related erosion also affected hemipelagic chertcovered ridges (Unit 6), only partially blanketed by a more oxidized, grey mudstone facies. Locally, seamounts composed of South Lake tonalite (Unit 3) and adjacent Wild Bight volcanic rocks (Unit 5) may have been sampled. Although such tectonic uplift was aerially restricted, the phenomenon may be regionally significant. Olistrostrome-related erosion and scouring of gullies in Caradoc mudstone is also seen at the base of an Ashgill–Llandovery hemipelagic succession on Upper Black Island, where the Late Ordovician–Early Silurian flysch is regionally juxtaposed against the Point Leamington greywacke (O'Brien, 1991c).

DISCUSSION

Distinct mesozonal phases of Ordovician mafic dyking occurred during the tectonomagmatic evolution of the South Lake Igneous Complex (Table 1). Within the dyke rocks and plutons of this complex (Lorenz and Fountain, 1982), and within the dyke rocks and volcanic rocks of the Wild Bight Group (Swinden *et al.*, 1990), important Ordovician episodes of post island-arc, rift-related, tholeiitic-alkalic magmatism have been recognized through petrogenetic analyses. In both lithostratigraphic units, such magmatism was interpreted in terms of a spreading back-arc basin model, although precise age constraints on the rift types of magmatism were unavailable to any of the above workers.

Any temporal or spatial linkage between late Wild Bight volcanism and late South Lake plutonism must await an integrated geochronological, paleontological and allied petrochemical study. However, based on the data presented in this paper, one might provisionally hypothesize that both units were exhumed, uplifted and in proximity to each other by the early Ashgill, prior to much of the infilling of the Point Leamington sedimentary basin. As previously suggested, related tectonism may have affected several formations of the Exploits Group underlying the lower Middle Ordovician Strong Island chert (O'Brien, 1991b,c), with faulting associated with this regionally extensive phase of tectonic movement being locally focused in the New Bay Fault Zone (Williams *et al.*, *this volume*). In this regard, it is noteworthy that dyke swarm-related fracture patterns in ophiolite-spreading centres have been reported to control the future site of olistostrome-filled, paleotopographic valleys in oceanic basement at evolving ocean-continent transform margins (Harper *et al.*, 1985; Arnott *et al.*, 1985).

In the area examined, submarine canyon-fill deposits of Late Ordovician age are interpreted to have been carved into small, fault-bounded basins of upward-coarsening flysch, which lay adjacent to exhumed Iapetan tracts of Early Ordovician ophiolitic and magmatic arc rocks. Such a scenario is also envisaged for similar aged rocks in the Appalachian–Caledonian foldbelt of Norway (Minsaas and Sturt, 1985). There, subaerially exposed, arc-ophiolite terrains formed uplifted ranges on the flanks of a Late Ordovician–Early Silurian marginal basin, which incorporated numerous, partially isolated depocenters. These Norwegian mid-Paleozoic sediments are thought to provide evidence of renewed, post-obduction rifting of Iapetan ophiolites and magmatic arcs, previously accreted to the continental margin of Baltica (Thon, 1985). In north-central Newfoundland, the Middle to Upper Ordovician rocks in Unit 6 of the Wild Bight Group (partial equivalent of the Strong Island chert ?) may represent the oldest part of an analogous, if not correlative, overstep sequence seaward of the Gondwanan continental margin.

CONCLUSIONS

As first suggested by Lorenz and Fountain (1982), the South Lake Igneous Complex records the mid-crustal evolution of a Lower–Middle Ordovician magmatic arc emplaced into a probable ophiolitic relic of the Dunnage Zone. During the rise of the arc magma in precursor and contemporaneous shear zones, sialic material, which appears to be exotic relative to the preserved enclave of oceanic crust, was entrapped in each successive member of the igneous complex. Its relationships with Ordovician stratified rocks of overlapping and younger ages in the Exploits Subzone are complicated by later tectonism of presumed Late Silurian age. Unfaulted contacts between plutonic rocks of the South Lake Igneous Complex and volcanic rocks of the Wild Bight Group were not observed, although both may have shared common mafic dyking episodes during the initial phase of uplift and excumation of the magmatic arc, and during subsequent regional deformation. A siliciclastic flysch of uppermost Caradoc and Ashgill age (Point Leamington greywacke) is postulated to have originally infilled a small, fault-controlled, cover basin (cf., Arnott *et al.*, 1985), whose local basement included the South Lake Igneous Complex and the Wild Bight Group.

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