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GRAPTOLITE BIOSTRATIGRAPHY WITHIN A FAULT-IMBRICATED BLACK SHALE AND CHERT SEQUENCE: IMPLICATIONS FOR A TRIANGLE ZONE IN THE SHOAL ARM FORMATION OF THE EXPLOITS SUBZONE

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ABSTRACT

Black shale exposures belonging to several lithostratigraphic members of the Shoal Arm Formation have yielded graptolites indicative of the Climacograptus bicornis *and* Dicranograptus clingani *biozones. The various Caradoc ages of the Shoal Arm graptolitic shale demonstrate the overall temporal equivalency of this unit with the Lawrence Harbour formation of the Exploits Subzone, and also indicate important along-strike stratigraphical and sedimentological variations within both formations. Recognition of these graptolite biozones has proved invaluable in establishing the detailed geometry of the thin shale–chert sequences and in elucidating their structural use during tectonic imbrication of the subzone. Where such Middle Ordovician strata are locally juxtaposed against Lower Ordovician igneous complexes, they also aid in discerning the extent of wedging and uplift of the older arc-related rocks during regional deformation.*

INTRODUCTION

Graptolites are common in many Middle Ordovician black shale units in the Notre Dame Bay–Badger–Grand Falls region of the Newfoundland Dunnage Zone. Many of these black shales have been recently reassigned (Williams, *in press*) to an expanded 'Lawrence Harbour formation', now known to be the most widespread lithostratigraphic unit characteristic of the Exploits Subzone (e.g., Williams, 1991; Williams *et al.*, 1992). Commonly unnamed or informally defined, Middle Ordovician black shale formations comprise regional marker-bed sequences within several major rock groups in central Newfoundland (Williams, 1993). They are, consequently, of fundamental importance in the formulation of a revised biostratigraphy for the region's lower and middle Paleozoic graptolite-bearing rocks (Williams, *in press*).

During 1993, a number of collections were made by E. Wheaton and B. O'Brien in the course of regional mapping near the mutual borders of NTS 2E/3, 2E/4 and 2E/6 (Table 1). All of the specimens come from either the Shoal Arm Formation or the Lawrence Harbour formation of the Exploits Subzone. Most contain only poorly preserved graptolites, although a majority have assemblages that permit zonal identification; they belong to the *Nemagraptus gracilis*, *Climacograptus bicornis* and *Dicranograptus clingani* zones (early to late Caradoc).

Table 1. UTM coordinates for localities of graptolite collections made in the Shoal Arm and Lawrence Harbour formations in NTS 2E/3,4,6; see Figure 1

F93-2:	E618600	N5433200	(2E/3)**
F93-4:	E616550	N5453350	(2E/3)
F93-5:	E616450	N5453250	(2E/3)
F93-6:	E616400	N5453100	(2E/3)
F93-7:	E617550	N5451650	(2E/3)
F93-8:	E617450	N5451600	(2E/3)
F93-9:	E612100	N5464350	(2E/6)
F93-10:	E604350	N5451250	(2E/4)
F93-11:	E604650	N5451750	(2E/4)
F93-12:	E603850	N5451600	(2E/4)

** road metal from CNR railway near Jumper's Brook

PREVIOUS RESEARCH

The Shoal Arm Formation was originally recognized and defined by Espenshade (1937) in the Badger Bay region, which occurs along strike and to the immediate northwest of the map area discussed in this paper. Espenshade (1937) grouped the distinctive black shale and multicoloured chert marker-beds of the Shoal Arm Formation with the massive granular wacke

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of the stratigraphically overlying Gull Island Formation and several other units in what he termed the Badger Bay Series. However, as this Dunnage Zone series is now generally viewed as a tectonic collage of various units from both the Notre Dame and Exploits subzones, the term has fallen out of common usage.

Dean (1977) extended a revised version of Espenshade's Shoal Arm Formation into the Botwood region, although he referred to the overlying massive wackes as the Sansom Greywacke (without formally dropping the Gull Island Formation).

In the New Bay Pond area, Kusky (1985) suggested that the Shoal Arm Formation be elevated to group status, and informally erected and named what he considered to be its three internal formations. In doing so, Kusky (1985) appended the lowermost parts of Espenshade's Gull Island Formation (Dean's Sansom Greywacke) to the uppermost Shoal Arm Formation. The redefined massive wacke unit overlying the Shoal Arm Formation was given formational status and correlated with the Point Leamington Greywacke of Helwig's (1967) Exploits Group. Kusky (1985) regarded his Shoal Arm Group's basal formation of red radiolarian chert as stratigraphically overlying the Wild Bight Group.

In the most recent work on the area, Swinden and Jenner (1992) essentially retained Dean's (1977) stratigraphical terminology for the region's known Caradoc and Ashgill rocks.

REGIONAL SETTING

The Caradoc Shoal Arm and Lawrence Harbour formations of the Exploits Subzone have been generally considered to crop out on the fault-modified flanks of regional anticlinoria, lying above the presumed Early to Middle Ordovician Wild Bight and Exploits groups, respectively. These older rock groups have been traditionally correlated despite considerable thickness and lithofacies variations. This is mainly because of their presence on opposing limbs of a fault-modified, but essentially stratigraphically unbroken, synclinorium that is cored by rocks of proven early Caradoc to mid Ashgill age. The regional disposition of the Shoal Arm Formation northwest of the transcurrent Northern Arm Fault (Dean, 1977) has been historically explained by the presence of a major southeast-plunging anticline, which also fundamentally controls the outcrop pattern of the underlying Wild Bight Group.

Folds, thrusts and folded thrusts are important structural features produced during regional deformation within the map area and throughout central Notre Dame Bay (O'Brien, 1993). Although the dominant structural grain is northeast, tectonic structures trending northwest formed on at least two distinct occasions (Blewett, 1991; O'Brien, 1993). Both are particularly well displayed by the Caradoc formations of this region.

With respect to the graptolite collections described in this paper (Table 1), eight come from the Shoal Arm Formation; five from the northeast limb and three from the southwest limb of the 'Wild Bight anticlinorium'. Only one graptolite collection was made within the Lawrence Harbour formation in the map area during 1993; however, four others were collected in earlier field seasons and have been previously identified by one of us (S.H. Williams, unpublished 1991 and 1992 contract reports to the Department of Mines and Energy). Of the five Lawrence Harbour collections made within the area considered for this report, four are found on the southwest flank of the 'Point Leamington synclinorium' and the other is located on its faulted southeastern limb. For the sake of completeness and quick reference, the following biozone or general age determinations for the previously documented Lawrence Harbour formation localities are summarized below: *N. gracilis* Zone (F90-32), *D. clingani* Zone (F91-2), Caradoc–Ashgill (F91-3) and *D. clingani* Zone (F91-4).

DESCRIPTIONS, ASSEMBLAGES AND AGES OF GRAPTOLITE LOCALITIES

F93-2

This contains a low diversity fauna including:
Orthograptus cf. calcaratus
diplograptids indet.
The assemblage does not permit a zonal identification, *O. cf. calcaratus* ranging from the *N. gracilis* Zone to *Pleurograptus linearis* Zone or higher.

F93-4

This contains a low diversity fauna including:
Corynoides calicularis
C. calicularis typically ranges from the *C. bicornis* to *D. clingani* zones; the sample, therefore, indicates the presence of one of these two intervals.

F93-5

Dicellograptus flexuosus
Climacograptus spiniferus
Orthograptus cf. amplexicaulis
Neurograptus margaritatus
This assemblage unequivocally demonstrates the presence of the *D. clingani* Zone.

F93-6

Dicellograptus flexuosus
Orthograptus quadrimucronatus
This assemblage indicates the *D. clingani* Zone.

F93-7

Pseudocl. scharenbergi
Normalograptus brevis
Corynoides calicularis
The overlap of *P. scharenbergi* and *C. calicularis* strongly suggests the presence of the *C. bicornis* Zone, although it is possible that *C. calicularis* might first appear late in the *N. gracilis* Zone. *P. scharenbergi* is restricted to the *C. bicornis* and lower zones.

F93-8
Dicranograptus nicholsoni
Climacograptus spiniferus
Lasiograptus harknessi
Corynoides calicularis
This assemblage unequivocally demonstrates the presence of the *D. clingani* Zone.

F93-9
Dicranograptus nicholsoni
Dicranograptus ziczac
Climacograptus bicornis
Normalograptus brevis
Pseudocl. stenostoma
Orthograptus cf. calcaratus
Cryptograptus tricornis
Lasiograptus costatus
Corynoides calicularis
This assemblage unequivocally indicates the *C. bicornis* Zone.

F93-10
Dicellograptus flexuosus
Normalograptus brevis
Orthograptus cf. calcaratus
Corynoides calicularis
This assemblage suggests the *D. clingani* Zone.

F93-11
Normalograptus brevis
Orthograptus cf. calcaratus
Lasiograptus harknessi?
Corynoides calicularis
If *L. harknessi* is actually present, the assemblage would indicate the *D. clingani* Zone. The specimens of *Lasiograptus* are, however, intermediate between typical *L. harknessi* and the larger form, *L. costatus,* which is characteristic of the *C. bicornis* (and possibly *N. gracilis*) Zone.

F93-12
Leptograptus sp.
Corynoides calicularis
The presence of *C. calicularis* indicates the presence of the *C. bicornis* or *D. clingani* zones.

Lawrence Harbour formation at Lawrence Harbour
Dicranograptus rectus
Pseudocl. scharenbergi
Normalograptus brevis
Cryptograptus tricornis
Lasiograptus costatus
Corynoides calicularis
This assemblage probably indicates the *C. bicornis* Zone.

GEOLOGICAL SIGNIFICANCE

The graptolite identifications and biozone determinations reported in this paper establish several important stratigraphic features of the Shoal Arm Formation. First, they indicate that some grey cherts interstratified with black shale are as young as the early to middle Caradoc (*C. bicornis* Zone) and that at least some of the stratigraphically underlying cherts in the lower part of the Shoal Arm Formation, as presently defined, must be Caradoc in age. Second, several decimetre- and metre-scale sandstone turbidite lenticles are observed to be interstratified with Shoal Arm black shales that have yielded a *D. clingani* Zone assemblage. Such strata are all presently included, correctly or not, in the upper part of the Shoal Arm Formation. Finally, a tectonized olistostrome (Kusky, 1985) that locally marks the top of the Shoal Arm Formation in the New Bay Pond area is composed of interbedded wacke–black shale olistoliths, which contain either *C. bicornis* Zone or *D. clingani* Zone assemblages.

The precise age and exact location of the graptolitic shale exposures are also critical factors in determining the regional and local structure of the Shoal Arm Formation (Figures 2 and 3). Controlled sampling along a cross-sectional traverse through the unit indicates that there is at least one area within the shale-dominated part of the formation where older *C. bicornis* Zone strata structurally overlie younger *D. clingani* Zone strata. In the southeastern part of the map area, in particular, it appears that the unit is internally composed of a number of non-continuous (tectonic) sequences, each essentially composed of black shale with variable amounts of chert. Although a dominant-facing direction is commonly recorded across the entirety of any one Shoal Arm section, locally at least, the paleontological data does not permit the formation to be interpreted as a megacyclothemic black shale–chert succession. Rather, internal reorganization of the Shoal Arm Formation has been achieved by duplication and amalgamation of its primary constituent members or through structural excision and fragmentation of parts of the unit (e.g., Figure 3).

It is also evident that the Shoal Arm Formation is non-contiguous along strike (Figure 1). In only a few localities does this unit preserve its original stratigraphical relations with older and younger rocks, and display both its lower and upper primary contacts (e.g., the New Bay Pond area). In most places, at least one of the formation's boundaries is a reverse fault, or else the Shoal Arm boundary is locally defined by a posttectonic intrusion or an even younger strike-slip fault (Figures 1 and 2). In areas where all external boundaries are reverse faults, discontinuous tracts of the Shoal Arm Formation terminate along strike by the combined effect of the fault ramp and fold plunge on individual shale–chert sequences.

To summarize, stratigraphical-facing directions locally confirmed by the discerned ages of graptolite biozones indicate that the Shoal Arm Formation regionally faces southwest on the southwest limb of the 'Wild Bight anticlinorium', but northwest in its apparent hinge zone and southwest on its supposed northeast limb (Figure 1). Southeast of the structural culmination of the Point Leamington Formation, the Shoal Arm Formation faces toward a fault-bounded, southwest-facing succession of the Wild Bight Group and away from a fault-bounded, northeast-facing

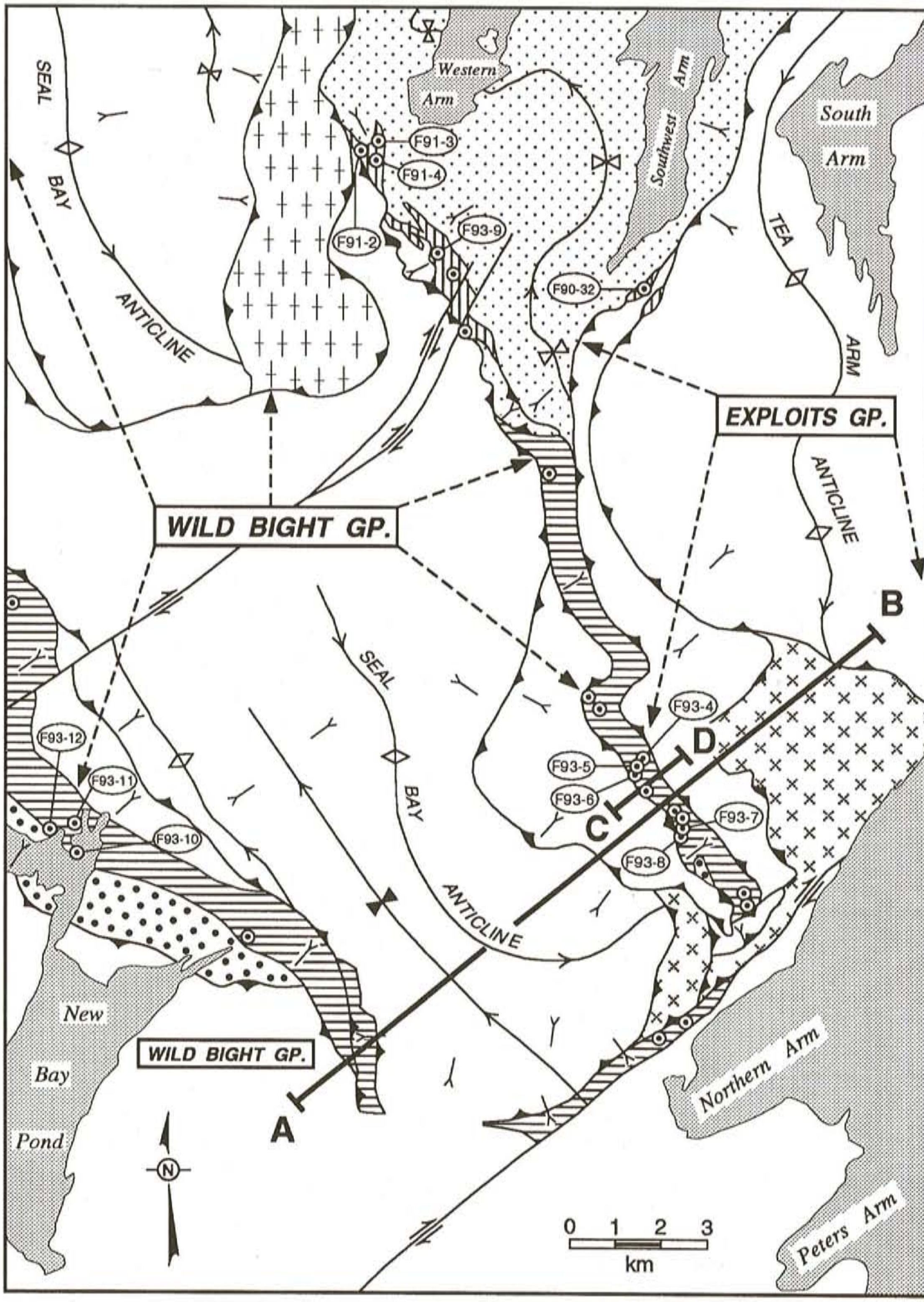
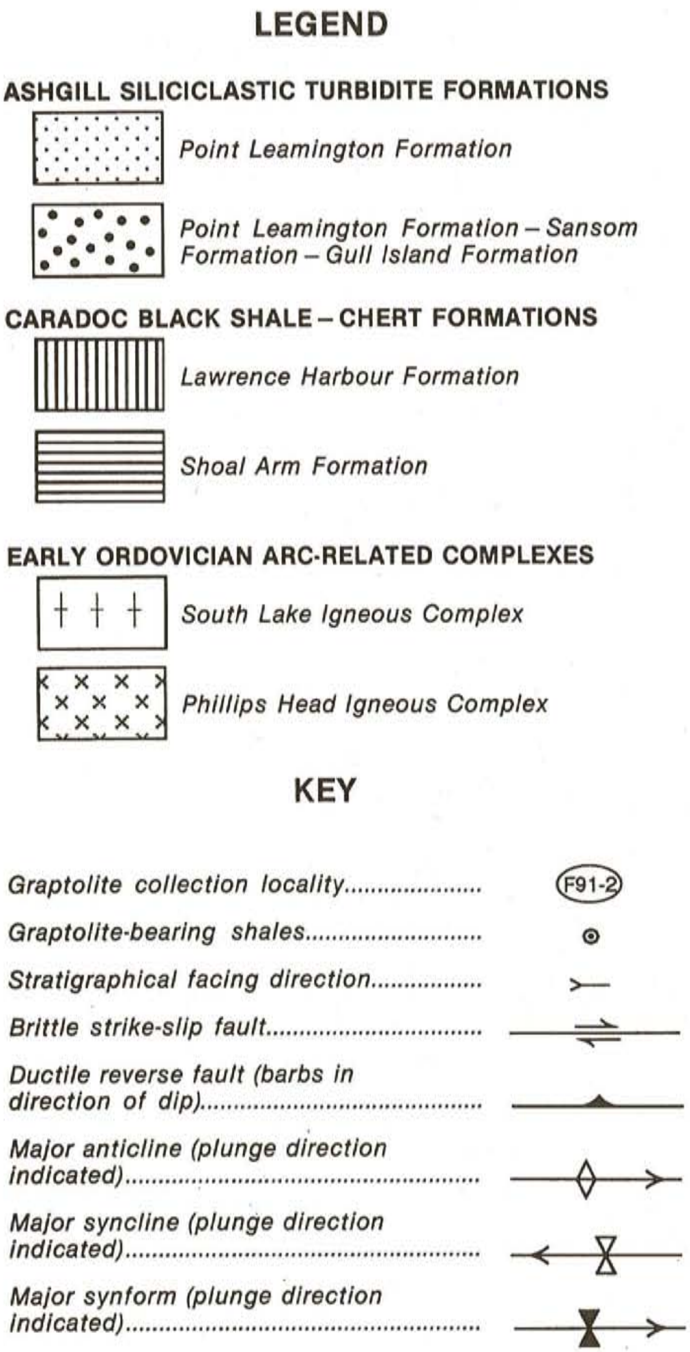


Figure 1. *Simplified geological map of the southeastern termination of the Wild Bight Group. The regional disposition of the Caradoc Shoal Arm and Lawrence Harbour formations is shown in relation to the Seal Bay Anticline. Graptolite occurrences and collection localities are depicted (see also Table 1); cross-section lines AB and CD are indicated.*

succession of the Exploits Group. Northwest of the above mentioned regional culmination, the Lawrence Harbour formation faces northeast, away from a locally preserved depositional contact with a Strong Island Chert correlative, and toward the stratigraphically overlying Point Leamington Formation.



DISCUSSION

STRATIGRAPHICAL CONSTRAINTS

The new information on graptolite biozones provides fundamental constraints on the local stratigraphical evolution of known Caradoc-aged map units in the area surveyed. Black shale deposition appears to represent a shorter time interval in the Shoal Arm Formation than in the Lawrence Harbour formation (Table 2), although this is possibly a function of the limited amount of paleontological collecting carried out during regional mapping. Likewise, chert deposition apparently continued for a longer duration in the former than in the latter formation.

With regard to the accumulation of younger siliciclastic turbidite deposits (Table 2), those above the Shoal Arm shale substrate began earlier than some, although not all, of those above the Lawrence Harbour shale substrate. Early onset of granular, pebbly or conglomeratic turbidite deposition above both the Shoal Arm and Lawrence Harbour formations occurred where olistostromes are locally scoured into *D. clingani* Zone shales. In the upper part (*D. clingani* Zone) of the Shoal Arm Formation, accumulation of sandstone turbidites had begun before olistostrome emplacement. In contrast, prior to the same late Caradoc–early Ashgill debris flow-forming event, the Lawrence Harbour strata only record evidence of quiescent pelagic deposition.

STRUCTURAL IMPLICATIONS

The notion that part of the Shoal Arm Formation is contained within a structural triangle zone sited at the regional contact between the Wild Bight and Exploits groups (Figures 2 and 3) is supported by the overall distribution of the unit's graptolite-bearing members. This triangle zone is interpreted to have developed as a result of the interference of dual-polarity, northwest-trending reverse faults, which are typical of the region in general. Where the Shoal Arm Formation is everywhere bounded by syn-cleavage faults (Figures 1 and 3), it is assumed that this particular tract of the Caradoc unit is completely detached from older surrounding rocks (Figure 2). The formation's cross-sectional triangular geometry is considered to have been caused by the up-dip truncation of two northeast-inclined thrust and reverse faults and by the younger southwest-inclined, high-angle reverse fault (Figure 2). Mapping of the southwest-directed contraction faults indicates down-dip coalescence. Significantly, the fossil localities within the black shales of the triangle zone are located, structurally, within separate southwest-directed and northeast-directed thrust sheets (Figure 3).

In the northeastern tract of the Shoal Arm Formation, southwest- and northeast-dipping faults are deemed to display their original thrust-sense of shear. In the southwestern tract of this unit, both sets of these reverse faults occur on the southwest limb of an open, moderately to steeply northwest-plunging synform (Figure 2). There, such late-stage folding is responsible for regional reorientation of Shoal Arm delimiting contraction faults, so that they now display the geometry of older-over-younger extensional faults (cf. Kusky, 1985).

METALLOGENIC CONNOTATIONS

The northwest-trending sole thrust of the Shoal Arm Formation triangle zone may possibly represent the continuation of the displaced West Arm Brook Thrust (Figure 2). Swinden and Jenner (1992) demonstrated that this thrust separated arc and non-arc volcanic successions in the Wild Bight Group. In naming the fault, they underscored its metallogenic significance as a structure, which not only delimits Shoal Arm strata, but also massive sulphide-bearing volcanic rocks. In this regard, the localized occurrence of tectonically fragmented, arc-related igneous rocks lying

Table 2. Chart comparing the principal elements of the known lithostratigraphy and biostratigraphy of the Shoal Arm Formation with that of the Lawrence Harbour formation

Unit	Lithostratigraphy	Biostratigraphy
LAWRENCE HARBOUR FORMATION	(1) in stratigraphic and/or structural contact with a younger unit of sandy and argillaceous turbidites with conglomerate lenticles (i.e. the lower Point Leamington Formation in its type area) (2) in stratigraphic and/or structural contact with an older, variably thin, Exploits Group unit of green, green-grey and red radiolarian chert and volcanogenic wacke (early Llanvirn in part) underlain by pillow lava with limestone intercalations (i.e. the Strong Island Chert and Lawrence Harbour Head Formation) (3) the lower boundary of the Formation's basal division of grey, bioturbated, mottled chert, which lies sharply on volcanics or gradationally above sediments, is drawn at the first underlying interbed of wacke or variegated chert (4) earliest Ashgill olistostromes locally mark the top of the Formation in a few localities (5) tectonically juxtaposed against an Early Ordovician (arc-root) igneous complex	(1) *N. gracilis* Zone assemblages occur at the top of the basal, grey, bioturbated, mottled chert (2) *N. gracilis* zone also ranges stratigraphically downwards (presumably through the Formation) into a Strong Island Chert-equivalent in the uppermost Wild Bight Group (3) black shales and carbonaceous siltstones of the Formation overlying the basal division cherts contain *N. gracilis, C. bicornis* and *D. clingani* Zonal assemblages (4) in places, within the Formation, interbeds of grey and black shale belonging to the *P. linearis* Zone occur below the lowest sandstone turbidite beds of the Point Leamington Formation. In other localities, discontinuous lenticles of interbedded grey and black shale containing *D. clingani* Zone assemblages occur within the lower sandstone turbidites of the Point Leamington Formation
SHOAL ARM FORMATION	(1) in stratigraphic and/or structural contact with a younger unit of granular and sandy turbidites without conglomerate lenticles (i.e. the lower Gull Island Formation or Sansom Formation) (2) in stratigraphic and/or structural contact with an older, variably thick, Wild Bight Group division of volcanogenic wacke–pyroclastic units interstratified with pillow lava units (e.g. Big Lewis Lake basalt and intercalated sediments or the upper Pennys Brook Formation) (3) ferruginous, red and green, radiolarian cherts and subordinate volcanogenic wackes at the base of the Formation directly beneath bioturbated, grey, mottled cherts may be, in part, the lithological equivalent of the upper portion of the Strong Island Chert. (4) probable earliest Ashgill olistostrome marks the top of the Formation in one locality. (5) tectonically juxtaposed against a presumed Ordovician arc-related igneous complex	(1) black shales and carbonaceous siltstones of the Formation contain *C. bicornis* and *D. clingani* Zone assemblages; the *N. gracilis* Zone has not been identified (2) thin black shales beds interstratified with grey mottled cherts contain *C. bicornis* Zone assemblages in the lower part of the Formation (3) several sandstone turbidite lenticles, one metre or greater in thickness, occur interstratified with *D. clingani* Zone black shales and siltstones in the uppermost part of the Formation (as presently defined) (4) the tectonized olistostrome that locally marks the Shoal Arm Formation–Gull Island Formation boundary is composed of interbedded wacke–black shale olistoliths, which contain either *D. clingani* Zone or *C. bicornis* Zone assemblages

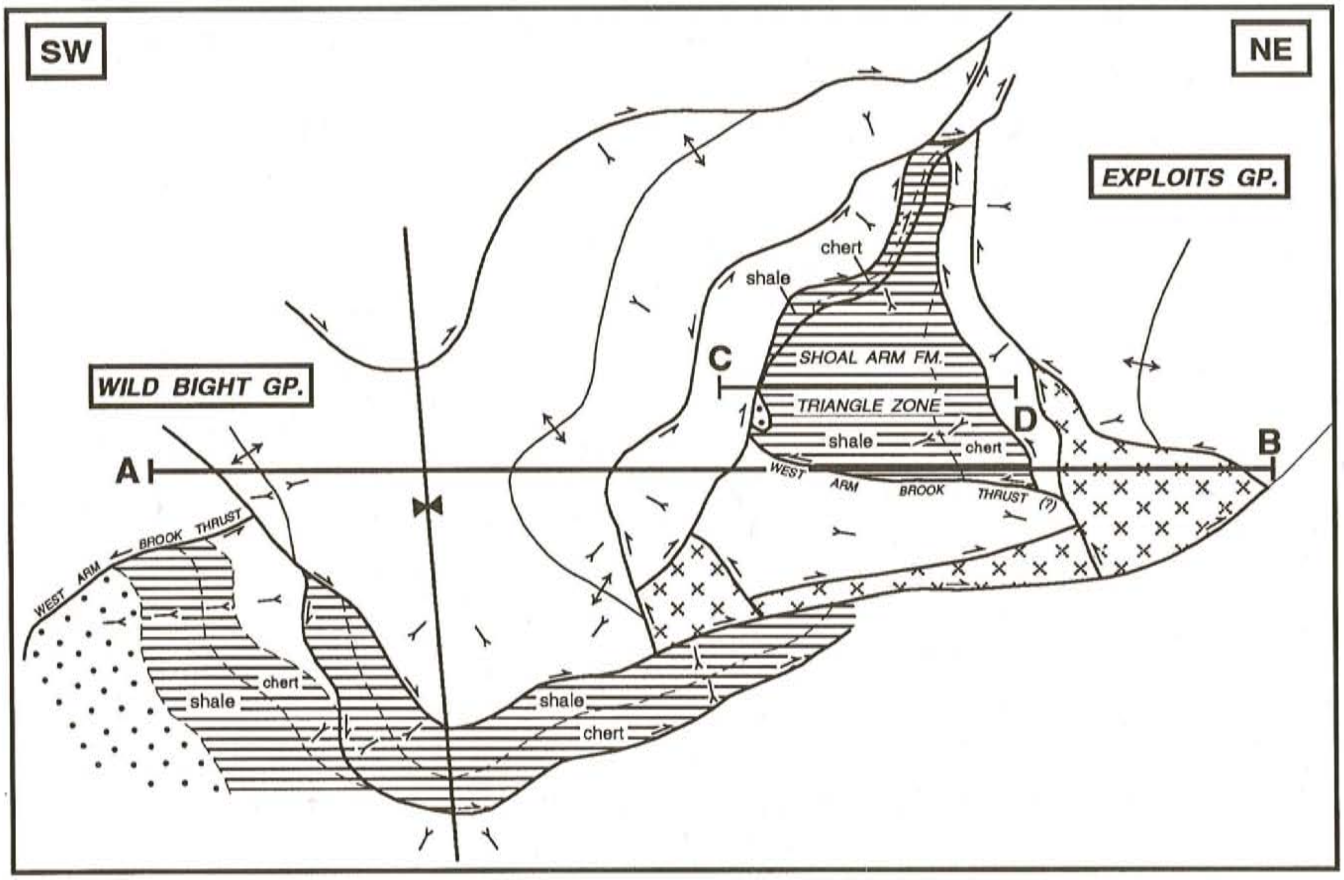


Figure 2. *Unbalanced cross section AB, viewed looking northwest, illustrating regional-scale fault imbrication of the Shoal Arm Formation. Note the triangle zone formed by the dual-polarity reverse faults demarcating this formation, and the partial detachment of the formation from the older Wild Bight and Exploits groups. Some of the geological relationships seen at present erosion level along the section line have been projected to the subsurface. Vertical scale is exaggerated. Legend symbols as are for Figure 1. Structural setting of Figure 3 (cross section CD) is also indicated.*

adjacent to graptolitic shale and chert might be an economically significant feature of the map area.

The proven Middle Ordovician age of the regionally deformed, graptolitic shales locally provides a lower age limit for the development of the northwest-trending, strata-parallel faults and a related series of northwest-trending folds. Such ductile features clearly did not form during sedimentation of the Wild Bight and Exploits groups (cf. Helwig, 1967), although they may have been site-controlled by pre-Caradoc structures (Williams *et al.*, 1992; O'Brien, 1993). Shoal Arm graptolitic shales and overlying, unfossiliferous, siliciclastic turbidites are also host to undated gabbro, diorite and porphyritic diabase bodies, which crosscut the early northwest-trending structures but are themselves variably deformed, carbonatized and pyritized.

CONCLUSIONS

The ages of graptolites from the different fossil collections verify the lithostratigraphic order of the Shoal Arm Formation, independently document its internal tectonic duplication, and establish its biostratigraphic affinity with the Lawrence Harbour formation. Moreover, the graptolite-based biostratigraphy deduced for the Shoal Arm Formation conclusively demonstrates that its present boundaries with adjacent earliest Caradoc and older rock groups cannot be primary in the eastern and southern parts of the map area. Specifically, in the vicinity of the southeastern termination of the Wild Bight Group (Figure 1), the stratigraphical-facing direction and regional disposition of Caradoc shale–chert sequences is incompatible with brittle strike-slip offset of a regional southeast-plunging anticline.

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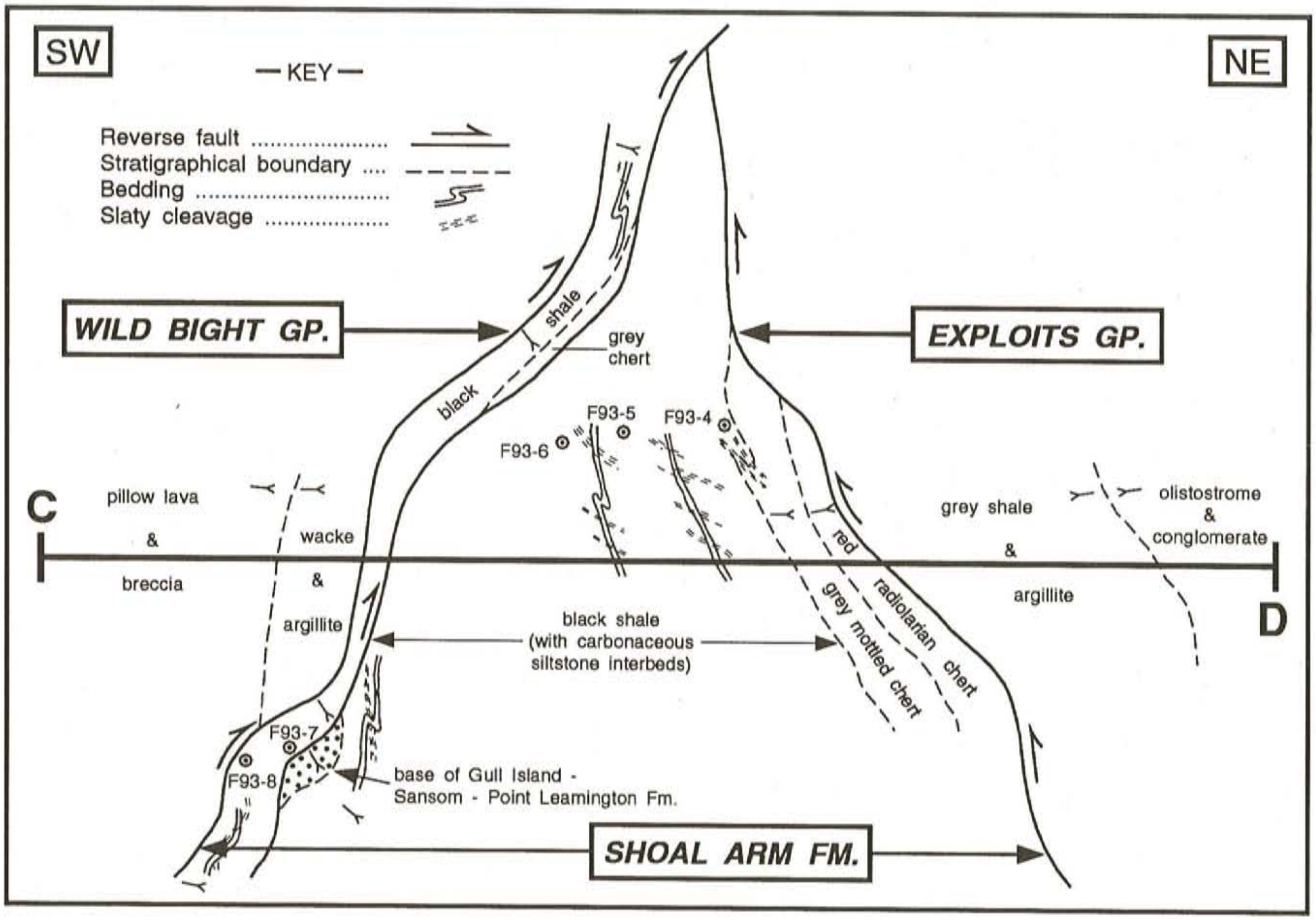

Figure 3. *Unbalanced cross section CD, viewed looking northwest, showing the upper part of the triangle zone outlined by the Shoal Arm Formation in Figure 2. The five graptolite collection localities that occur within this structure are accurately represented in two-dimensional space relative to each other; their lithostratigraphical position is illustrated in the context of the formation's constituent members. Selected minor structures are schematically depicted; vertical scale is exaggerated.*

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