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NEW GRAPTOLITE DISCOVERIES FROM THE ORDOVICIAN OF CENTRAL NEWFOUNDLAND

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ABSTRACT

Black shales on Long Island, western Notre Dame Bay that were previously assigned to the widespread 'Caradoc' black shale, actually belong to two stratigraphically distinct units associated with felsic volcanics and limestone breccia. The lower shale unit yields a late Arenig I. v. maximus *Zone fauna, whereas the upper unit contains a rich lower Llanvirn graptolite assemblage. The newly discovered graptolite faunas agree more closely with ages established using shelly macrofossils and conodonts, and are of open-ocean affinity, permitting an accurate correlation with many other localities both in western Newfoundland and throughout the world.*

Additional collecting and further studies of the graptolites from Snooks Arm on the Baie Verte Peninsula and Corner Pond at the southern end of Grand Lake, show the black shales to be lower Arenig (probably lower D. bifidus *Zone and* P. fruticosus *Zone, respectively) and close, but not identical in age. Thus, there is no one geographically widespread Lower Ordovician black shale in the Dunnage Zone, in contrast to that of the ubiquitous Middle Ordovician (Llandeilo-Ashgill?) unit.*

The Point Leamington Greywacke and greywackes of similar late Caradoc to Ashgill age in the Badger area, should probably be included within the Sansom Greywacke, with the base defined at the first coarse greywacke unit. However, formal definition is withheld pending further investigation. Some range in the timing of the onset of greywacke deposition throughout the area is evident, but this only encompasses an interval equivalent to parts of the D. clingani *and* P. linearis *zones of southern Scotland (perhaps two million years of less). Systematic change across the region cannot be demonstrated and previous claims for such a hypothesis included evidence from localities where the black shale is in tectonic, rather than stratigraphic, contact with greywacke. Graptolites have been recovered from an interval of alternating black and grey silty shales within the Point Leamington Greywacke at Point Leamington, indicating a correlation with the* D. anceps *Zone (mid to late Ashgill) of southern Scotland. These are by far the latest Ordovician graptolites discovered anywhere in Newfoundland, confirming the possible presence of the Ordovician–Silurian boundary within the Point Leamington Greywacke and Goldson Conglomerate.*

INTRODUCTION

This report summarizes the findings made during the past year, relating to the study of graptolites from central Newfoundland. Although the primary objective is a biostratigraphic and taxonomic revision of faunas from the widespread Middle Ordovician black shale unit (see Williams, 1988), the majority of collecting carried out during the summer of 1988 was from much earlier units, and from greywackes overlying the shale. Most of this work is directed at providing high-resolution correlations in order to better understand the geological evolution of the area. However, several localities have provided exciting and totally unexpected age dates, particularly on Long Island and at Point Leamington (Figure 1). Additional research will be undertaken on other Lower Ordovician sediments during the next two years, which will no doubt permit further refinement of the geological history.

LOWER ORDOVICIAN STRATA

Long Island

The stratigraphy on Long Island, northwestern Notre Dame Bay, is currently being revised by A. Szybinski (Department of Earth Sciences, Memorial University of Newfoundland), as part of his Ph.D program in the Halls Bay area. Included within the Cutwell Group is black siliceous shale, which previously has been assigned by Dean (1978, p. 121) and others, to the 'Caradoc' black shale of central Newfoundland. Dean (1978, p. 204) recorded four graptolite taxa from the south side of Lushes Bight harbour (Figure 2, locality 3), which had been identified by D. Skevington as:

Climacograptus sp. cf. *C. brevis* Elles and Wood
Cryptograptus tricornis (Carruthers)
Didymograptus sp. cf. *D. saggiticaulis* Gurley
Glyptograptus sp. cf. *G. euglyphus* (Lapworth)

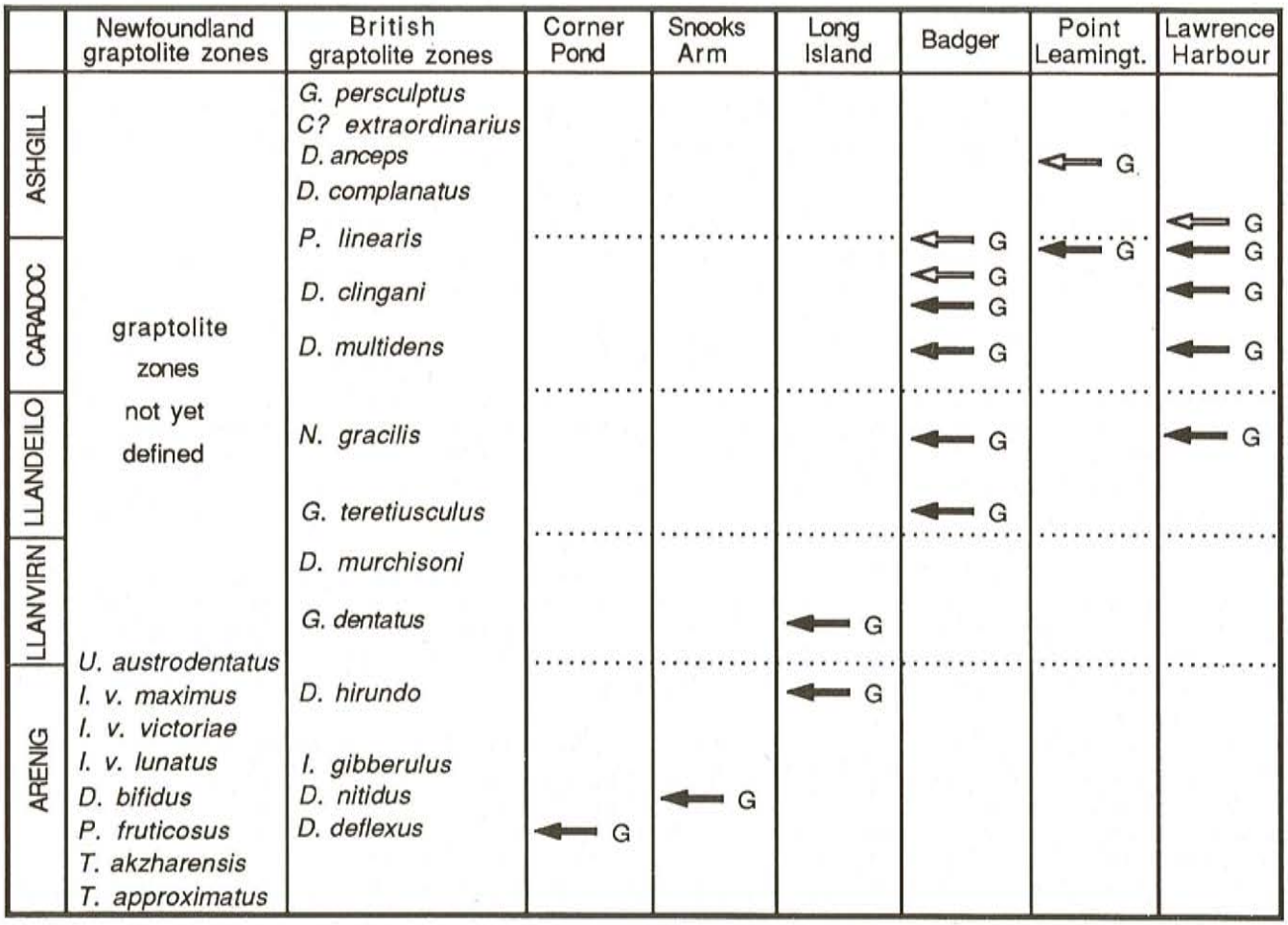


Figure 1. *Graptolite occurrences in the Ordovician of central Newfoundland discussed in the present paper; closed arrows indicate graptolites in black shale, open arrows in greywacke; additional data is taken from Williams (1982a, 1982b, 1988) and Williams and Stevens (1988).*

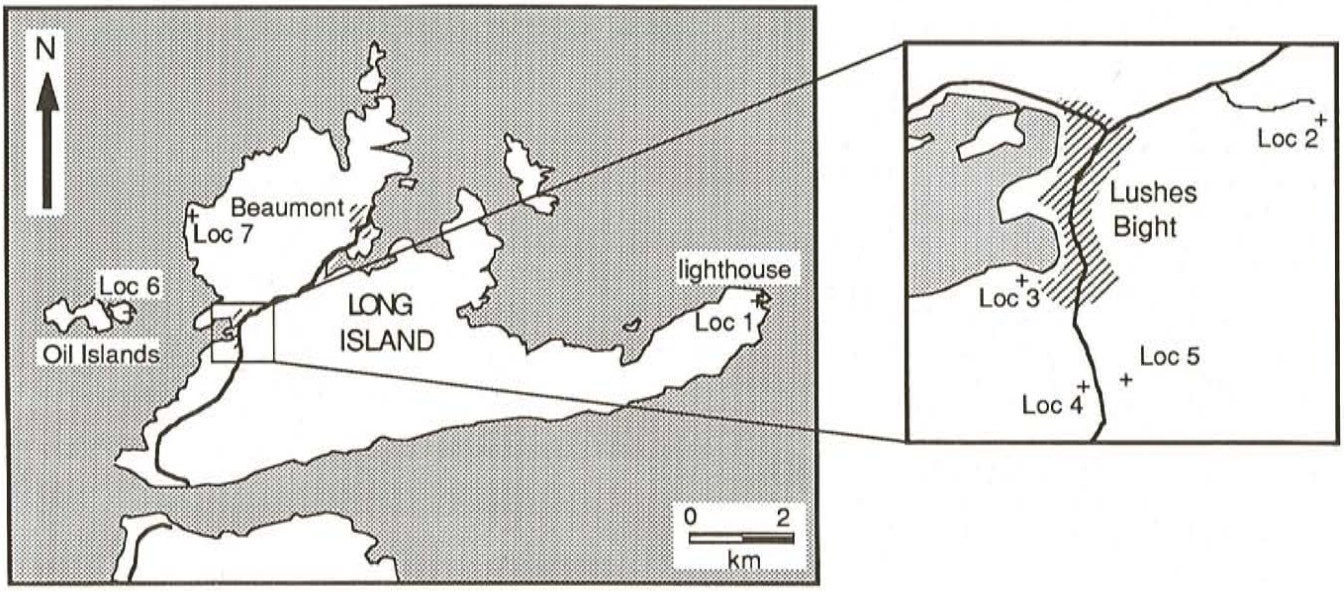


Figure 2. *Sketch map of Long Island, showing position of localities discussed in text.*

Dean (1978, p. 125) concluded that this assemblage represented a 'definite *Nemagraptus gracilis* Zone fauna'. As the shales were overlain by felsic volcanics, it was concluded that post-Caradoc volcanism had occurred in northern Notre Dame Bay, north of the Lobster Cove–Chanceport Fault, in contrast to the entirely pre-Caradoc Ordovician volcanism elsewhere to the south. However, the assigning of this unit to the 'Caradoc' black shale was in conflict with evidence from other faunal groups, particularly conodonts in limestones on the southern shore of Long Island, which were subsequently recorded as Llanvirn (Stouge, 1980). Strong and Kean (1972) had previously recorded a shelly macrofauna from the same limestone beds, which they considered to indicate a tentative 'Middle Ordovician' age. Elsewhere, conodonts were recorded by Williams (1962) from rocks on Limestone Island (offshore Little Bay Island), which are probably equivalent to those on Long Island, and the fauna identified as indicating 'early Middle Ordovician (Llanvirn?)'.

The two diplograptid species listed by Skevington (*in* Dean 1978, p. 204) are small, indistinct forms, while taxa similar in appearance to *C. tricornis* and *D. saggiticaulis* range from late Arenig to late Llandeilo–early Caradoc. The latter, combined with the apparently contradictory faunal evidence outlined above, questions the reliability of Skevington's graptolite identifications and subsequent correlation. New samples from Dean's original locality, and from two additional roadside outcrops in Lushes Bight (Figure 2, localities 4 and 5), failed to reveal more diagnostic material or identifiable taxa. However, the strata were only sparsely graptolitic, in marked contrast to the black shales belonging to the *N. gracilis* Zone elsewhere in central Newfoundland, casting further doubt on the age identification.

Szybinski (personal communication, 1988) subsequently discovered a few poorly preserved graptolites in a quarry, off the road leading from Lushes Bight to Beaumont (Figure 2, locality 2). Last summer (1988), additional material was collected from the quarry, which yielded a rich, abundant fauna. The shale unit is associated with the limestone breccia and overlain by felsic volcanics, demonstrating that it is the same unit exposed elsewhere in Lushes Bight. The collection has yet to be systematically described and identified, but provisional identification of the fauna includes the following:

Sinograptus typicalis Mu
Cardiograptus crawfordi Harris
Xiphograptus sp.
Acrograptus sp. cf. *A. cognatus* (Harris and Thomas)
Cryptograptus sp. cf. *C. antennarius* (J. Hall)
Paraglossograptus sp. cf. *P. tentaculatus* (J. Hall)
Skiagraptus sp. cf. *S. gnomonicus* Harris and Keble
Undulograptus? sp.
diplograptid spp.
dendroid sp. indet.

This assemblage, particularly the presence of *Sinograptus* sp., indicates an unequivocal lower Llanvirn age. It is similar to the fauna recorded by Lenz and Jackson (1986) from the *P. tentaculatus* Zone of the Canadian Cordillera. To a slightly lesser extent it compares to that listed by Finney and Skevington (1979), from the Table Cove Formation of the Table Head Group, western Newfoundland and considered by them to be equivalent to the *D. decoratus* Zone (Darriwilian 3) of Victoria, Australia. The same assemblage was also found at an additional locality on the coast north of Lushes Bight (Figure 2, locality 7), and the sparse remains found at the previous three localities can also be attributed to these taxa. Such a rich, cosmopolitan fauna is clearly of open-ocean type (see Fortey and Cocks, 1986), in direct contrast to that found in coeval black shales deposited in marginal, partially restricted areas, such as those of the type Llanvirn in South Wales.

An additional exposure of highly siliceous, black shale on the easternmost point of Long Island, about 200 m north of the lighthouse (Figure 2, locality 1) proved graptolitic and yielded the following forms:

Xiphograptus svalbardensis (Archer and Fortey) (deflexed form)
Isograptus victoriae maximus Harris
Pseudisograptus ensiformis (J. Hall)?
sigmagraptid sp.
dendroid sp. indet.

This assemblage indicates the late Arenig *I. v. maximus* Zone, defined recently by Williams and Stevens (1988) in the Cow Head Group of western Newfoundland, and shows the shale to be a distinctive stratigraphic unit from that of Lushes Bight. Such an assemblage is of open-ocean affinity (Fortey and Cocks, 1986). However, the shale is both underlain and channelled by welded tuffs, suggesting small, steep-sided, oxygen-starved basins adjacent to explosive volcanism.

The following conclusions regarding the black shales on Long Island can be drawn from the data presented: 1) Two distinct black shale units are present, one of late Arenig (*I. v. maximus* Zone) age and one belonging to the early Llanvirn; 2) both graptolites and other fauna (conodonts and shelly macrofossils) are in broad agreement concerning ages and correlation; 3) the intimate association of graptolitic sediments and felsic volcanics is potentially very promising for the linking of radiometric dating with graptolite biostratigraphy and the Arenig–Llanvirn boundary; 4) there was no post-Caradoc Ordovician volcanism on Long Island; it was entirely pre-Caradoc, as found elsewhere in central Newfoundland, and spanned a period of perhaps five million years from late Arenig to early Llanvirn; and 5) the graptolite faunas represent open-ocean assemblages, intimately associated with relatively near-shore volcanism (e.g. welded tuffs).

Snooks Arm

Graptolites were first recorded by Snelgrove (1931) from Snooks Arm on the east coast of the Baie Verte Peninsula. His specimens were identified by Ruedemann as *Loganograptus logani* (J. Hall) and *Didymograptus gracilis* (Törnquist) (also see Ruedemann, 1947, p. 59), indicating an Early Ordovician (Arenig) age. The area was subsequently

remapped by Neale (1957) and Upadhyay (1973), with both authors quoting Snelgrove's Early Ordovician age. Upadhyay (1973) divided the Snooks Arm Group into several formations; his lithostratigraphy was employed by DeGrace *et al.* (1976), who erroneously recorded that Snelgrove's graptolites originated from the Bobby Cove Formation (DeGrace *et al.*, 1976, p. 10). The fauna actually originates from near the base of the Balsam Bud Cove formation, as recorded by Dean (1978, p. 86). Dean (1978), D. Skevington and others collected additional samples, which apparently substantiated the Arenig age. No additional taxonomic identifications have been given since Snelgrove's (1931) original work.

During the summer of 1988, Snelgrove's original locality on the southern shore of Snooks Arm, approximately 400 m southeast of the harbour, was relocated and new material collected (Figure 3, locality 1). Despite heavy fracturing and shearing within the argillites, a much more diverse fauna than previously recorded was obtained, including:

Tetragraptus bigsbyi (J. Hall)
Tetragraptus cf. *T. reclinatus* Elles and Wood
Xiphograptus svalbardensis (Archer and Fortey)
Phyllograptus typus J. Hall
Acrograptus gracilis (Törnquist)
Etagraptus harti (T.S. Hall)
Graptoloid gen. A (*of* Williams and Stevens, 1988)

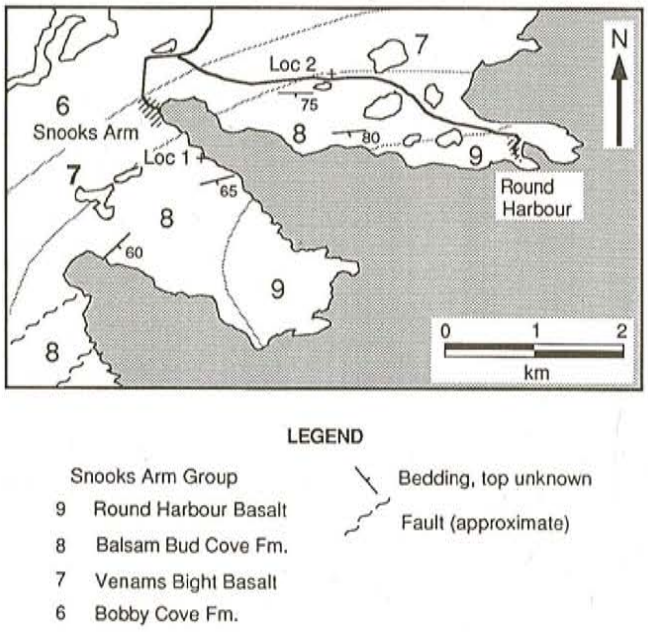


Figure 3. *Geological sketch map of Snooks Arm (after DeGrace et al., 1976), indicating position of graptolite localities.*

These taxa also occur in the Cow Head Group of western Newfoundland; the assemblage compares closely with that recorded by Williams and Stevens (1988) for the *D. bifidus* Zone of lower–middle Arenig age.

Several additional exposures of black cherty argillite occur beside the road between Snooks Arm and Round Harbour. Despite a well-developed, cross-cutting cleavage, one of them (Figure 3, locality 2) yields rare graptolites including *Pendeograptus fruticosus* (J. Hall). If, as is almost certain, these exposures belong to the same graptolitic unit seen in Snooks Arm, the presence of *P. fruticosus* further enhances the precision of correlation with western Newfoundland, as this assemblage is only found there in the lower half of the *D. bifidus* Zone.

Corner Pond

Within the Dunnage Zone, the only locality farther south that has been reported to yield Arenig graptolites is at Corner Pond, near the southeastern end of Grand Lake (Figures 4 and 5). The black shales and siliceous shales were mapped by Riley (1957) as part of the Glover formation; collections of graptolites were first made in 1970 by P. Dimmell (Noranda Limited) and F.D. Anderson (Geological Survey of Canada). Their collections were studied by R.B. Rickards, whose identifications were recorded by Dean (1976, p. 238) to include the following:

Tetragraptus fruticosus (J. Hall)
Tetragraptus pendens Elles
Tetragraptus cf. *T. reclinatus* Elles and Wood
Loganograptus logani (J. Hall)
Sigmagraptus sp.
Didymograptus extensus (J. Hall)
Didymograptus cf. *D. constrictus* (J. Hall)
Didymograptus cf. *D. similis* (J. Hall)

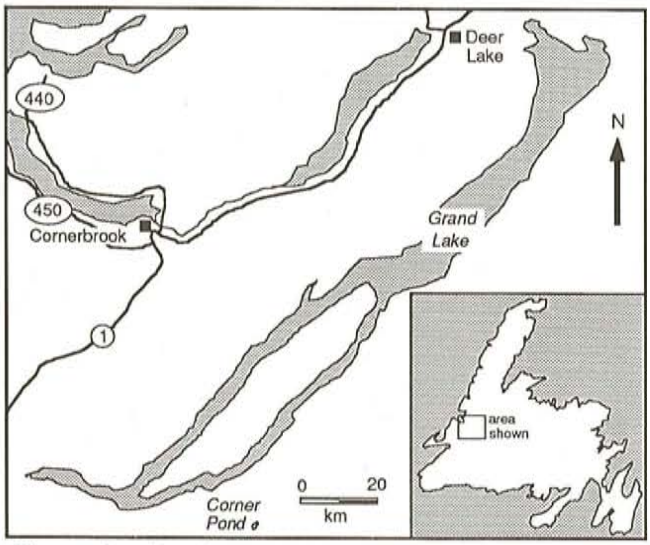
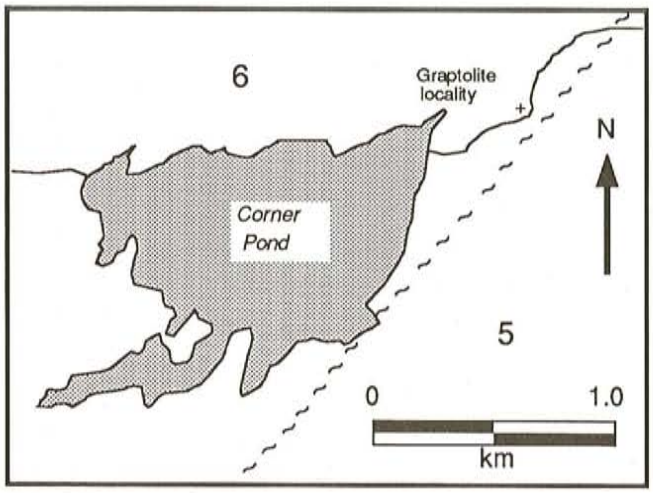


Figure 4. *Sketch map showing location of Corner Pond.*

Additional material was collected by H. Williams in 1977, which D. Skevington stated to include *Phyllograptus anna* J. Hall and *Didymograptus protobifidus* Elles, in addition to those forms reported by Rickards (*in* Williams and St-Julien,



LEGEND

6 Corner Pond Fm.
Glover Group
5 Tuckamore Fm.
Fault (approximate)

Figure 5. *Geological sketch map of Corner Pond (after Knapp, 1982), indicating site of graptolite locality.*

1978, p. 227). Both Rickards and Skevington considered the fauna to indicate the 'Middle Arenig *D. nitidus* Zone'; Williams and St-Julien (1978) further considered the age to indicate a correlation between the strata of Corner Pond and the Snooks Arm Group of Green Bay.

The locality was subsequently described by Knapp (1982, p. 251-255, Figure 8.8), who considered the black shale to belong to the Corner Pond formation rather than the Glover formation, from which it is separated by a fault. In addition to the black shale, the Corner Pond formation also contains red and purple shale, pillow lava, sandstone, conglomerate and a single limestone. Knapp (1982, p. 250) recorded a shelly macrofauna and conodonts from the latter unit, identified by G. Nowlan in 1981 as:

Drepanodus sp.
Periodon flabellum (Lindström)
Protopanderodus rectus (Lindström)
Scolopodus n. sp. cf. *S. gracilis* (Ethington and Clark)
Teridontus? sp.

Nowlan and Thurlow (1986, p. 60) summarized these findings suggesting a mid- to late Arenig age, and further stated that the graptolites indicated the 'mid-Arenig *D. protobifidus* Zone'.

The collection, made during 1970, is now housed in the paleontological collections of the Geological Survey of Canada, Ottawa. Examination of some of the material in light of the author's recent revision of Arenig graptolites in the Cow Head Group (Williams and Stevens, 1988), confirms most of Rickard's earlier identifications. Employing the taxonomic revisions made by Williams and Stevens (1988), the samples studied include:

Pendeograptus fruticosus (J. Hall)
Pendeograptus sp. cf. *P. pendens* Elles
Tetragraptus reclinatus Elles and Wood
Loganograptus logani (J. Hall)
Goniograptus thureaui (M'Coy)
Didymograptus (Expansograptus) extensus (J. Hall)
Didymograptus (Expansograptus) constrictus (J. Hall)
Didymograptus (Expansograptus) similis (J. Hall)

This assemblage could be found in both the *P. fruticosus* and *D. bifidus* zones of the Cow Head sequence, but the relative abundances of the faunal elements, the common occurrence of *D. (E.) extensus* and *P. fruticosus* specimens with four stipes, and the absence of *Xiphograptus svalbardensis* (Archer and Fortey) suggest a more likely correlation with the *P. fruticosus* Zone. Interestingly, *D. (E.) constrictus* is restricted to the previous *T. akzharensis* Zone in western Newfoundland, although it has been recorded from later intervals elsewhere (see Williams and Stevens, 1988, p. 48); no species of *Loganograptus* were found in the Cow Head Group. If the report of *Didymograptus (Didymograptellus) protobifidus* (probably *D. (D.) bifidus)* from this locality is correct, it suggests either that the assemblage actually belongs to the lower part of the *D. bifidus* Zone as seen at Snooks Arm or, more likely, that the graptolitic shale exposed at Corner Pond spans both the *P. fruticosus* and *D. bifidus* zones.

Conclusions

Lower to Middle Ordovician (Arenig to Llanvirn) graptolitic shales occur sporadically at several widely dispersed localities within the Dunnage Zone (Figure 1). Unlike the Middle Ordovician (Llandeilo to Ashgill?) black shale, none are widespread. Such localized occurrences of graptolitic black shale are atypical; most units throughout the world are laterally extensive and signify periods of high sea-level stand or widespread anoxia. Those discussed here clearly represent deposition in restricted, periodically anoxic basins, which have sufficient connections to normal oceanic environments to permit habitation by open-ocean graptolite faunas. Such an observation lends support to the currently popular model, whereby central Newfoundland is considered to have formed in a marginal plate setting with a complex series of back-arc and/or fore-arc basins. Additional graptolite research should permit further elucidation and unravelling of the complex geological history of this area.

UPPER ORDOVICIAN STRATA

Badger

Most graptolites previously recorded from the Badger area originate from the Middle Ordovician black shale unit, commonly referred to as the 'Caradocian black shale', and probably range in age from late Llandeilo to late Caradoc (informal zones 1 to 3 of Williams, 1988). Kean and Jayasinghe (1982) referred to this as Unit 4, which provided

the material used by Erdtmann (1976) in his study of graptolites from the Exploits Group. Kean and Jayasinghe (1982, p. 18) also recorded graptolites from their overlying Unit 5 at one locality just east of Badger (this was inadvertantly incorporated in the graptolite assemblages of Unit 4 in Appendix A of their report). The graptolites from Unit 5 were identified by J. Riva (*in* Kean and Jayasinghe, 1982) as *Pseudoplegmatograptus* sp. (=*Arachniograptus* sp.) and *Climacograptus* cf. *tubuliferus* Lapworth, which he suggested indicated a late Caradoc or early Ashgill age (*P. linearis* or possibly *D. complanatus* Zone of the British sequence).

It should be noted that the graptolite locality is not as positioned on the published map (Kean and Jayasinghe, 1982), but occurs in a road-cut on the south side of the Trans-Canada Highway, 1.5 km southeast of the Badger turnoff (see Figure 6, locality 1). The section consists of an overturned, westerly dipping sequence of thinly bedded greywacke with subordinate interbedded black and grey shale. New collections from the shale have revealed the following forms:

Climacograptus tubuliferus Lapworth
C. miserabilis Elles and Wood
Orthograptus quadrimucronatus (J. Hall)
O. amplexicaulis (J. Hall) *sensu lato*
Glyptograptus daviesi Williams?
Plegmatograptus sp. cf. *P. nebula* Elles and Wood

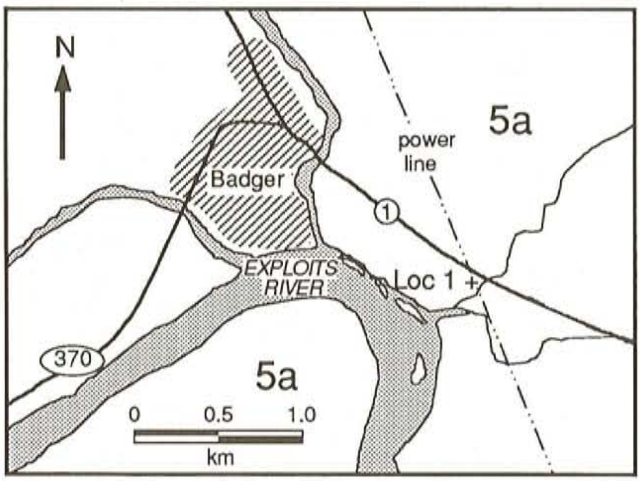


Figure 6. *Geological sketch map of Badger (after Kean and Jayasinghe, 1982) showing position of graptolite locality discussed in text.*

The assemblage is composed entirely of forms that also occur in the lower Hartfell Shale of southern Scotland (Williams, 1982a). Thus, it seems more likely to indicate a correlation with the British *P. linearis* Zone (late Caradoc or early Ashgill—see Williams and Bruton, 1983, for discussion) and informal zone 4 of Williams (1988), rather than the *D. complanatus* Zone (Williams, 1987), due to the occurrence of *O. quadrimucronatus* and possible presence of *G. daviesi*.

Kean and Jayasinghe (1982, p. 18) divided their Unit 5 into two; the lower subunit 5a (which yielded the graptolite fauna), consists of sandstone, minor conglomerate, shale and chert, whereas the upper subunit 5b is less extensive and consists of conglomerate. The authors correlated subunit 5a with the Sansom Greywacke of Notre Dame Bay and considered subunit 5b as a likely equivalent of the Goldson Formation. These suggestions appear eminently reasonable on both faunal and lithological grounds, and would further suggest that both subunit 5a and the Point Leamington Greywacke should be assigned to the Sansom Greywacke, which has historical precedence owing to its earlier definition by Heyl (1936).

The transition from continuous shale to alternating greywacke and shale, is exposed at Little Red Indian Falls, 19 km southwest of Badger (Williams, 1988). The graptolite fauna from this interval is dominated by *Climacograptus caudatus* Lapworth, which Williams (1982a, p. 252) recorded as typical of the lower part of the *D. clingani* Zone in southern Scotland. Therefore, deposition of clastics in this area, equivalent to the Sansom and Point Leamington greywackes, began in zone 3 of Williams (1988), and extended upward into zone 4. The thickness of succession separating the two graptolitic levels recorded here is unknown, as is the upper age limit of subunit 5a.

Point Leamington and Lawrence Harbour

Much has been informally discussed concerning the base of the Point Leamington Greywacke since it was first recorded as being diachronous by Bergström *et al.* (1974). The problems addressed here are twofold; first, how should the base of the Point Leamington Greywacke be defined and second, are the observations regarding age variation correct?

When Helwig (1967, 1969) defined the Point Leamington Greywacke, he included the upper section of the Middle Ordovician black shale within its base, subsequently referred to as 'an unnamed argillite' (Bergström *et al.*, 1974, p. 1634). Dean (1978, p. 135) considered these shales to be so distinct and important a lithostratigraphical marker that they should not be included within the formation. This author concurs with the view of Dean (1978); lithologically they are almost (if not entirely) inseparable from the Lawrence Harbour Shale. The distinction was based in most cases on purely faunal evidence (i.e., *'N. gracilis'* or *'D. multidens'* zones as opposed to *'D. clingani'* or *'P. linearis'* zones). A stratigraphic or regional structural break between the older and younger strata has always been assumed, although no real evidence has been presented for a hiatus. Formal redefinition of the various lithostratigraphical units will require additional research, but the present paper follows Dean (1978) in assuming the base of the Point Leamington Greywacke to be marked by the first recognizable greywacke bed. This means that the contact with the underlying unit is gradational, with a passage through increasingly coarser and paler grey silts and shales; many formation boundaries are similarly diffuse and no problems in subsequent definition are envisaged.

Bergström *et al.* (1974, p. 1635) stated that shales underlying the Point Leamington Greywacke at Cull Island, Mussel Bed Island, Western Arm Brook and at Cooper's Farm, Point Leamington, belong to the *D. clingani* Zone or to an interval transitional with the *P. linearis* Zone, whereas those at Lawrence Harbour are of *P. linearis* Zone age. They concluded from this evidence that the base of the greywacke was older to the west and south of New Bay than it was on the eastern side. This observation has been quoted widely in subsequent literature (e.g., Dean, 1978); however, considering that most graptolite zones in the Ordovician span one to two million years, and the diachronism encompasses perhaps half a zone, its significance is marginal at best. Furthermore, current investigations at both Cull Island and Western Arm Brook show quite clearly that the graptolitic shales at the first locality are not near the greywacke, whereas at the second locality they are in fault contact. Many additional localities remain to be visited, but to date the gradational interval between black shale and greywacke has been found at only one exposure in Notre Dame Bay, namely Lawrence Harbour (Figure 7, locality 2). Here shales associated with the transition yield a low diversity assemblage including:

Leptograptus flaccidus macer Elles and Wood
Dicellograptus pumilus Lapworth
Orthograptus amplexicaulis (J. Hall)

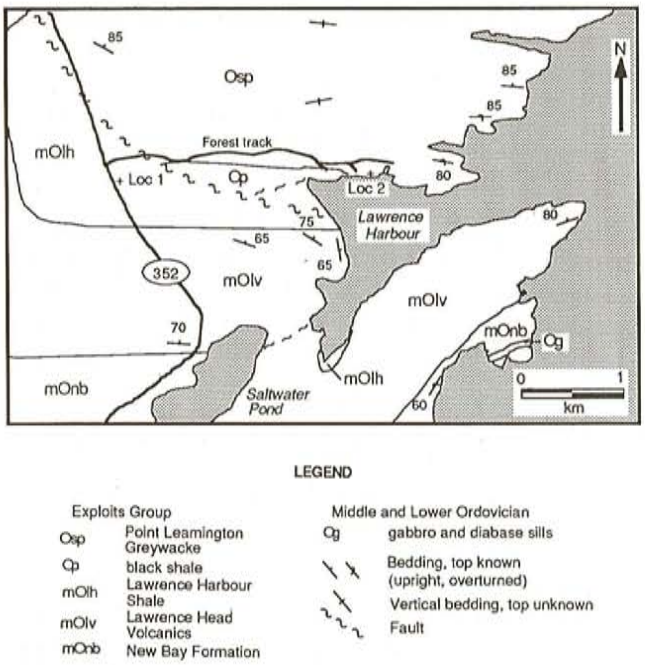


Figure 7. *Geological sketch map of Lawrence Harbur (after Dean and Strong, 1975), indicating position of graptolite localities discussed in text.*

Possible specimens of *Pleurograptus linearis* (Carruthers) are also present, but confirmation of this taxon awaits further material. *D. pumilus* is characteristic of the *P. linearis* Zone in southern Scotland (Williams, 1982a), so despite the paucity of material, it is almost certain that the base of the greywacke at Lawrence Harbour falls within an interval equivalent to the *P. linearis* Zone of Britain (informal zone 4 of Williams, 1988).

Findings from this study thus confirm a diachronous onset of greywacke deposition following the Middle Ordovician black shales (Figure 1), but over a wider area than that discussed by Bergström *et al.* (1974). Until additional localities are found with complete transitions between the shale and greywacke, and the Point Leamington Greywacke is formally recognized as being either distinct or synonymous with the Sansom Greywacke (see above), no conclusions regarding systematic variation in age can be made.

The locality north of Point Leamington recorded by Bergström *et al.* (1974, table 4) as yielding a *P. linearis* Zone fauna was relocated during the present study (Figure 8, locality 3), but proved to be a fault-bounded, highly deformed exposure of the underlying black shale. The low diversity faunal assemblage, dominated by *Orthograptus quadrimucronatus* (J. Hall) could equally well be found in the *D. clingani* Zone and is here considered biostratigraphically inconclusive. Two new graptolite localities, within a sequence of alternating grey and black silty shales, were discovered last summer (1988) much nearer Point Leamington (Figure 8, localities 1 and 2). These yielded locally abundant specimens of *Climacograptus longispinus*

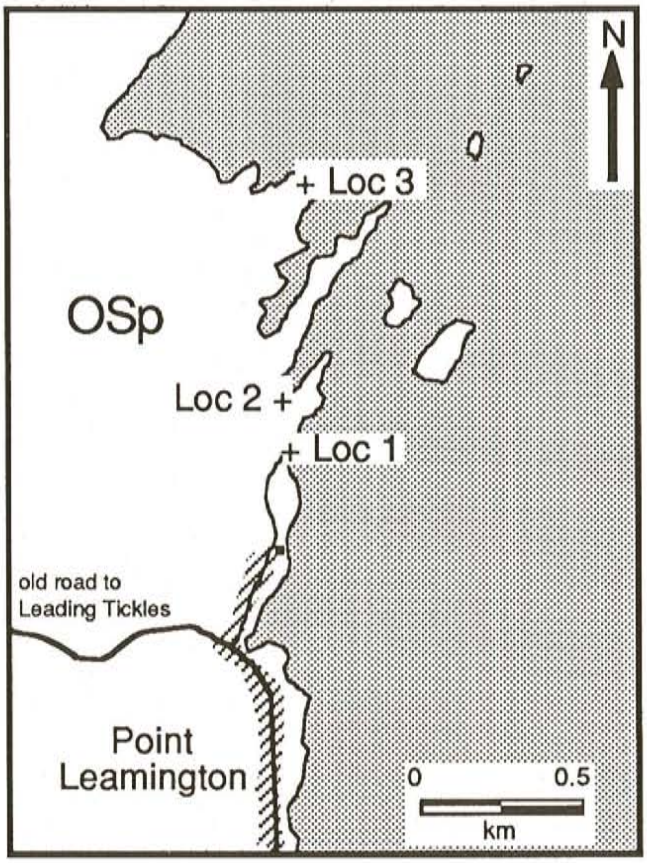


Figure 8. *Geological sketch map of Point Leamington (after Dean and Strong, 1975), indicating position of graptolite localities discussed in text (Osp = Point Leamington Greywacke).*

supernus Elles and Wood and *Orthograptus abbreviatus* Elles and Wood, both characteristic of the *D. anceps* Zone in southern Scotland (Williams, 1982b). The stratigraphical position of this very distinctive facies within the Point Leamington Greywacke has yet to be established. However, it demonstrates unequivocally that greywacke deposition continued into at least middle–late Ashgill times. This was assumed previously, but was unproven on faunal grounds, with the exception of supposed Llandovery corals in limestone blocks within an olistostrome near the gradational boundary with the overlying Goldson Formation (Helwig, 1967, 1969; Pickering, 1987).

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