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Palynological analysis of Chevron et al. South Labrador N-79, Hopedale Basin, Labrador Shelf, offshore eastern Canada

G.L. Williams

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Palynological analysis of Chevron *et al.* **South Labrador N-79**, Hopedale Basin, Labrador Shelf, offshore eastern Canada

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G.S.C. Locality No.: D-190

Location: 55°48'75"N, 58°26'49"W

Elevation Sea level to R.T.: 11.3 m Water Depth: 449.9 m

Total Depth: 3571.5 m

Spud Date: 3 August 1980 Interval Studied: 3571.5-720 m

Casing Points:762 mm at 535 m; 508 mm at 715.7 m; 340 mm at 1493 m

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Introduction

Chevron *et al.* South Labrador N-79 is in the southern part of the Hopedale Basin on the Labrador Shelf (Figure 1). My study is based on the analysis of 188 cuttings samples from the interval 720-3571.5 m. I am indebted to the Canada-Newfoundland Offshore Petroleum Board for providing the unwashed cuttings samples which were processed for palynomorphs.

A comprehensive summation of the stratigraphy and maturation history of South Labrador N-79 was displayed in Biostratigraphy/Maturation Data, Panel IV in the Labrador Sea Basin Atlas (Bell, J.S., coordinator, 1989). This publication has provided me with a source of paleoenvironmental data, which can be compared with my results.

Biostratigraphy

Figure 2 provides a summary of my biostratigraphic and paleoenvironmental conclusions for South Labrador N-79. The results are based on the analysis of dinoflagellates (dinocysts), spores and pollen and equated with the lithostratigraphy and well logs. I also provide a series of bioevents, generally representing Last Appearance Datums (This - the highest, latest or youngest occurrance of a taxon in a well or surface section - is commonly denoted by the acronym LAD. The First Appearance Datum - the lowest, earliest or oldest occurrence of a taxon in a well or surface section - is commonly denoted by the acronym FAD) of taxa but sometimes denoting abundance or reworking.

Age interpretations for South Labrador N-79 are based primarily on the known stratigraphic ranges of dinocysts in European sections (Powell, 1992; Bujak, 1994; Willliams *et al.*, 1999, 2001, 2004) and from older wells and coreholes from offshore eastern Canada and western Greenland (Williams, 1975; Williams and Brideaux, 1975; Williams and Bujak, 1977; Barss *et al.*, 1979; Williams *et al.*, 1990; Sønderholm *et al.*, 2003; and Nøhr-Hansen, 2003a, 2003b, 2004). Another major source of information has been a compilation of LADs of dinocysts, spores and pollen and other palynomorphs by Nøhr-Hansen, Fensome and Williams (pers. comm.). These three have collated their analytical data from 17 wells in the Labrador Sea and Davis Strait to derive a plot, which has regional applicability.

Throughout this study, I have adhered to the time scale proposed by Gradstein and Ogg (1996). This has been used in the transposing of ages given for individual dinocyst species but derived from other sources.

The only published biostratigraphic study of South Labrador N-79 is that of the Bujak-Davies Group

(1987). These authors presented age determinations based on palynomorphs and foraminifera and paleoenvironmental interpretations based on foraminifera. Miller and d'Eon (1987) also provided paleoenvironmental results, but these were based on lithological data. I incorporate the results from both papers - generally as synthesized in Gradstein, Helenes, Miller and Moir *in* Bell (1989) - in this section and in Paleoenvironments.

South Labrador N-79 bottomed in unnamed Precambrian igneous rocks at 3571.5 m: this extends to 3548 m. Two samples from the interval 3571.5-3548 m contain the dinocysts *Vesperopsis mayi* and *Oligosphaeridium asterigerum*. Neither of these species provide precise information on the age of the overlying rocks. The lowest occurrence of an age diagnostic dinocyst is in the sample from 3540-3550 m, which contains *Cerbia tabulata*. Duxbury (2001) placed the LAD of *Cerbia tabulata* at the top of the Aptian, which is 112.2 Ma according to Gradstein and Ogg (1996). This is confirmed in Williams (2003a), who noted that the LAD of *Cerbia tabulata* consistently equates with the Aptian-Albian boundary in wells of offshore eastern Canada.

A single specimen of the spore *Pilosisporites verus* in the same cuttings is significant if in place, since the Bujak-Davies Group (1987) placed its LAD in the Barremian. Rather than being too specific, I am assigning a Barremian-Aptian age to the interval 3550-3510 m. Bujak-Davies Group (1987) assigned 3571.5-3515 m to the Barremian-Aptian.

There appears to be a major hiatus above 3510 m in South Labrador N-79. The sample immediately above, at 3490-3480 m, contains the dinocysts *Heterosphaeridium difficile, Senoniasphaera protrusa* and *Senoniasphaera rotundata*. At 3460-3450 m is a single specimens of *Odontochitina porifera* and *Circulodinium* cf. *tabulatum.*

The Bujak-Davies Group (1987) recognized a *Heterosphaeridium difficile* Zone, which they considered to be Campanian. From their naming of this zone, the Bujak-Davies Group obviously extended the LAD of *Heterosphaeridium difficile* to the Campanian-Maastrichtian boundary. Williams *et al.* (2004) gave the LAD of this species as 86.78 Ma in Northern Hemisphere mid latitudes, which is within the late Coniacian. Nøhr-Hansen (2003b) placed the LAD of *Heterosphaeridium difficile* at the top of the early Santonian, citing as justification Costa and Davey (1992). I prefer to follow Williams *et al.* (2004), whose data are based on independently dated surface or cored sections.

Odontochitina porifera is a distinctive species, which is easy to recognize, but there is some confusion over its range. Williams *et al.* (2004) gave its stratigraphic range as 84.21 (Santonian) to 71.3 Ma (top of the Campanian) for Northern Hemisphere mid latitudes. This contrasts with Williams *et al.* (1999), who considered the overall range to be 89 (base of the Coniacian) to 84.7 Ma (Santonian). Costa and Davey (1992) stated that *Odontochitina porifera*'s range was Cenomanian-late Campanian.

Based on the above, I conclude the sample at 3490-3480 m, which contains *Heterosphaeridium difficile*, to be Coniacian. And, I place the sample at 3460-3450 m, which contains one specimen of *Odontochitina porifera*, in the Campanian.

The Bujak-Davies Group (1987) show general agreement with my conclusions, although they assigned 3495-3485 m to the Santonian. They also found *Heterosphaeridium difficile* whose LAD, as noted above, they considered Late Campanian, and *Oligosphaeridium cephalum* [considered to be a taxonomic junior synonym of *Oligosphaeridium complex* by Lejeune-Carpentier and Sarjeant (1981)]. The interval from 3465-3425 m was included in the early Campanian and the interval from 3405-3395 m in the late Campanian by the Bujak-Davies Group (1987).

The Campanian appears to extend from 3460-3390 m, based on the presence of *Spiniferites scabrosus*. According to Williams (2003b) this species has its LAD in the Campanian in Skua E-41 on the Grand Banks. The Campanian is only 70 m in South Labrador N-79. Gradstein and Ogg (1996) regarded the Campanian as lasting from 83.5 to 71.3 Ma or about twelve million years. Thus, it can be assumed that there is a section missing, which included the Santonian and much of the Campanian.

I assign the interval 3370-3300 m to the Maastrichtian. The dinocyst *Amphidiadema nucula* has its LAD at 3310-3300 m. Another key species, *Impagidinium victorianum* has a single occurrence at 3340-3330 m, with five specimens in the underlying sample at 3370-3360 m. Gradstein and Williams (1976) proposed the *Amphidiadema nucula-Hexagonifera chlamydata* zone, which they considered to be Maastrichtian. Williams and Bujak (1985) recorded *Amphidiadema nucula* only in the Maastrichtian. Based on this evidence Williams (in press a) recognized the Maastrichtian in Bjarni O-81, a well which is also in the southern Hopedale Basin.

The Bujak-Davies Group (1987) named their early Maastrichtian subzone for a taxon they identified as *Impagidinium* #LL. This is probably conspecific with the species I have identified as *Impagidinium victorianum*. In Bjarni O-82, Williams (in press a) placed the top of the early Maastrichtian at the horizon where is the LAD of *Impagidinium victorianum* . The Bujak-Davies Group (1987) included the interval 3375-3365 m in their *Impagidinium* #LL Zone. This suggests that the sample at 3370-3360 m is early Maastrichtian. The interval 3340-3300 m may be late Maastrichtian.

According to the Bujak-Davies Group (1987), the Maastrichtian, as determined in part from the foraminifera, extends from 3375-3275 m with 3255-2915 m being early Paleocene. They included the interval 3345-3335 m in the *Spongodinium delitiense* Zone and 3315-3005 m in the *Spongodinium* #LA Zone; the latter - a palynological zone - is early Paleocene. I include the interval 3280-3000 m in the Danian or early Paleocene.

This is based on the LAD of *Cerodinium diebelii* in the sample at 3010-3000 m. *Cerodinium diebelii* has a LAD of 59.95 Ma in Northern Hemisphere mid latitudes (Williams *et al.*, 2004). Gradstein and Ogg (1996) placed the Danian-Selandian boundary at 61 Ma. Nøhr-Hansen (2004), in his analysis of the nearby North Leif I-05 well, marked the LAD of *Cerodinium diebelii* at the Danian-Selandian boundary. This event indicates the top of the Danian.

Other dinocyst taxa with their LADs in this interval include *Hystrichokolpoma bulbosum* (3280-3270 m), *Spongodinium delitiense* (3250-3240 m), *Phelodinium kozlowskii* (3100-3090 m), *Trithyrodinium evittii* (3070-3060 m), *Hystrichosphaeridium tubiferum* subsp. "*perforatum*" (3040-3030 m) and *Spongodinium* sp. (3010-3000 m). Williams *et al.* (2004) placed the LAD of *Hystrichokolpoma bulbosum* at 61-58 Ma in Northern Hemisphere mid latitudes. Williams (in press b) placed the LAD of *Phelodinium kozlowskii* at the top of the Danian in Gilbert F-53 in the Saglek Basin. According to Williams *et al.* (1999) the LAD of this species is at 61.33 Ma, that's almost on the Danian-Selandian boundary. *Spongodinium delitiense* has its LAD at 63.72 Ma in Northern Hemesphere mid latitudes, according to Williams *et al.* (2004). If its LAD in South Labrador N-79 is in place, the interval 3280-3240 m could be considered early Danian. *Trithyrodinium evittii* in Northern Hemisphere mid latitudes supposedly has a LAD of about 60 Ma (Williams *et al.*, 2004). But in a study of Gilbert F-53, Williams (in press b) considered its youngest occurrence to be between 63.72 and 60 Ma. In North Leif I-05, Nøhr-Hansen (2004) named his Danian zone for *Trithyrodinium evittii* and placed the LAD of this species at the Danian-Thanetian boundary. My data indicates that the LAD of *Trithyrodinium evittii* is within rather than at the top of the Danian.

Nøhr-Hansen (2003a) subdivided the Paleocene into the Danian, lower Thanetian, mid Thanetian and

upper Thanetian. The three Thanetian intervals from oldest to youngest are: the *Palaeoperidinium pyrophorum* interval (P4), the *Areoligera gippingensis* interval (P5) and the *Apectodinium* Acme interval (P6). Although not recognizing the Selandian, Nøhr-Hansen (2003a) used several of the species that occur in South Labrador N-79. The top of his *Palaeoperidinium pyrophorum* interval is marked by the LADs of *Palaeoperidinium pyrophorum* and *Palaeocystodinium bulliforme*. Thus, Nøhr-Hansen's (2003a, 2004) P4 zone or early Thanetian equates with my usage of Selandian. I believe there is a thin interval from 2980-2940 m that is Selandian. This is indicated by the LAD of *Palaeocystodinium bulliforme* and *Palaeoperidinium pyrophorum* in the sample at 2950-2940 m. Williams *et al.* (2004) gave the LAD for *Palaeocystodinium bulliforme* as 57.9 Ma and the LAD for *Palaeoperidinium pyrophorum* as 58.04 Ma, both for Northern Hemisphere mid latitudes. Gradstein and Ogg (1996) placed the top of the Selandian at 57.9 Ma, which shows agreement with my placement of the Selandian-Thanetian boundary at about 2935 m in South Labrador N-79.

The LADs of two other key dinocysts occurring in South Labrador N-79 are *Alisocysta margarita* and *Hystrichosphaeridium tubiferum*. *Alisocysta margarita* has an LAD of 57.35 Ma for Northern Hemisphere mid latitudes. The LAD of *Hystrichosphaeridium tubiferum* is generally considered to be much younger. For example, Williams *et al.* (2004) placed it at 46.33 Ma, or within the early Lutetian, in Northern Hemisphere mid latitudes. But, Nøhr-Hansen (2004) placed the LAD of *Hystrichosphaeridium tubiferum* at the top of the Danian.

In South Labrador N-79, the Thanetian extends from 2920 to 2490 m. The LADs of *Cerodinium "glabrum"*, *Areoligera gippingensis* and *Apectodinium parvum* occur in the sample at 2500-2490 m. The species *Cerodinium speciosum*, of which *Cerodinium "glabrum"* was formerly a subspecies, has an LAD of 53.96 Ma according to Williams *et al.* (1999). Gradstein and Ogg (1996) placed the Thanetian-Ypresian boundary at 54.8 Ma, which is less than one million years earlier. The youngest Paleocene zone in both Gradstein and Williams (1976) and the Bujak-Davies Group (1987) was the *Cerodinium speciosum* Zone. And Nøhr-Hansen (2004) in his study of the North Leif I-05 well, considered the LAD of *Cerodinium speciosum* subsp. *glabrum* to be in the late Thanetian. Further confirmation is provided by Nøhr-Hansen, Fensome and Williams (pers. comm.), who placed the LAD of *Cerodinium speciosum* and *Cerodinium "glabrum"* close to the top of the Thanetian.

The stratigraphic range of *Areoligera gippingensis* is somewhat enigmatic, because of the difficulty of previous identifications of this and related taxa. Williams and Downie (1966) described the taxon *Areoligera* cf. *medusettiformis*, which Fensome and Williams (2005) considered a taxonomic synonym of *Areoligera gippingensis*. However, Jolley (1992) did not consider the two taxa synonymous when he erected *Areoligera gippingensis*. Many authors, including Nøhr-Hansen (2003a), regard the two as separate taxa with *Areoligera gippingensis* being restricted to the Paleocene. Williams *et al.* (2004) considered *Areoligera gippingensis* to have a stratigraphic range of 58-57 Ma in Northern Hemisphere mid latitudes; that's roughly earliest Thanetian. Personally, I use the name *Areoligera gippingensis*.

Other dinocysts with LADs in the Thanetian of South Labrador N-79 include *Apectodinium parvum* and *Muratodinium fimbriatum*. Williams *et al.* (1999) placed the LAD of *Apectodinium parvum* at 54.31 Ma for Northern Hemisphere mid latitudes. Nøhr-Hansen, Fensome and Williams (pers. comm.) recorded the LAD of this species just above the Thanetian/Ypresian boundary, so its co-occurrence with *Cerodinium "glabrum"* at 2500-2490 m is the basis for considering that sample to be latest Thanetian.

In their subdivision of the Paleocene in South Labrador N-79, the Bujak-Davies Group (1987) gave the following ages: early Paleocene (3225-2915 m, as noted earlier); late Paleocene (2895-2400 m). The zones recognized were: *Spongodinium* #LA Zone (3315-3005 m), *Alisocysta circumtabulata* Zone (2925-2760 m), *Cerodinium* (as *Ceratiopsis*) *speciosum* Zone (2740-2640 m), *Dracodinium condylos* Zone

(2620-2220 m). My Danian (3280-3000 m) would approximate with the *Spongodinium* #LA Zone. The Selandian (2980-2940 m) shows close agreement with the *Palaeoperidinium pyrophorum* Zone. With the Thanetian the correlation is more speculative. According to my data the Thanetian-Ypresian boundary is at about 2480 m. That's within the *Dracodinium condylos* Zone of the Bujak-Davies Group (1987). I found two specimens of *Alisocysta circumtabulata* at 2650-2640 m, which would place the top of the *Alisocysta circumtabulata* Zone about 120 m higher than the Bujak-Davies Group. I have determined the top of the Thanetian on the highest occurrence of *Cerodinium "glabrum"* in the sample at 2500-2490 m. This is somewhat higher than the top of the *Cerodinium speciosum* Zone.

I consider the interval from 2470 to 1920 m to be Ypresian, with the interval from 2500 to 2220 m as basal or early Ypresian. Within this stage, the dinocysts exhibit maximum species diversity in South Labrador N-79. This is a trend seen in most Labrador Sea-Davis Strait wells.

The LAD of *Diphyes brevispinium* occurs in the sample at 1930-1920 m. Nøhr-Hansen (2003a), in his zonation of the Paleocene-Eocene of offshore western Greenland, defined seven intervals in the Ypresian. The youngest interval, the *Charlesdowniea columna* (E3b) interval, extends into the Lutetian. The top of this interval was marked by the LADs of *Charlesdowniea columna* and *Diphyes brevispinum.*

Nøhr-Hansen's (2003a) intervals are based on the zonation of Bujak (1994), who also placed the LADs of *Charlesdowniea columna* and *Diphyes brevispinum* together and just below the top of the Ypresian. Thus my placement of the top of the Ypresian at 1920 m conforms with the interpretations of Bujak (1994) and Nøhr-Hansen (2003a).

Other dinocyst taxa with LADs in the Ypresian of South Labrador N-79 are: *Eocladopyxis peniculata* (2320-2310 m), *Cordosphaeridium gracile* (2300-2310 m), *Palaeocystodinium golzowense* (2300-2290 m), *Dracodinium condylos* (2260-2250 m), *Komewuia*? "*unicornis*" (2200-2190 m), *Adnatosphaeridium superpetellum* (2050-2040 m), *Homotryblium abbreviatum* (2050-2040 m), *Thalassiphora pelagica* (2020-2010 m), *Deflandrea* sp.B Williams and Bujak, 1977 (2020-2010 m), *Apectodinium fleximorphum* (1990-1980 m), *Charlesdowniea columna* (1960-1950 m), *Achilleodinium bicellulum* (1930-1920 m), *Homotryblium tenuispinosum* (1930-1920 m), and *Hystrichokolpoma incertum* (1930-1920 m).

The stratigraphic significance of many of the above species has been verified by Nøhr-Hansen, Fensome and Williams (pers. comm.). Their Ypresian bioevents of LADs include from oldest to youngest: *Apectodinium augustum* (at the Thanetian-Ypresian boundary), *Apectodinium parvum, Dracodinium condylos* and *Komewuia*? "*unicornis*" which occur together, *Apectodinium fleximorphum* and *Adnatosphaeridium "superpetellum"*. In South Labrador N-79, I am provisionally using the LAD of *Komewuia*? "*unicornis*" to mark the top of the early Ypresian at 2200-2190 m. Since the LAD of *Dracodinium condylos* is at 2260-2250 m, this seems a reasonable compromise.

Bujak-Davies Group (1987) included the interval 2380-1920 m in the early Eocene, which is equivalent to the Ypresian. The top at 1920 m appears to be based on the LAD of species that characterize the foraminiferal *Bulimina ovata* Zone. I am assuming that the base is derived from placement of the top of the foraminiferal *Glomospira chiroides* Zone at 2400 m. The dinocyst zones recognized in this interval are: the *Dracodinium condylos* Zone (2620-2220 m), the *Trinovantedinium* #LA Zone (2200-1950 m), and the *Eocladopyxis* #LA Zone (1930-1890 m). *Trinovantedinium* #LA, which appears to equate with my informal species *Apectodinium "fleximorphum"*, has its LAD in the cuttings sample at 1960-1950 m and is obviously the basis for the early Eocene age determination of the Bujak-Davies Group (1987). I found two specimens of *Trinovantedinium* #LA (as *Apectodinium "fleximorphum"*) in the sample at 1900-1890 m and two at 1990-1980 m. However, these occurrences were not critical because of *Diphyes brevispinum* in the interval 1930-1920 m. These results agree with those of the Bujak-Davis Group

(1987).

My recognition of the Lutetian section in South Labrador N-79 is based on the occurrence of several fungal spores. These include: *Brachysporisporites* sp.B. Parsons and Norris, 1999, *Callimothallus pertusus, Diporicellaesporites laevigataeformis* and *Pluricellaesporites*. Nøhr-Hansen, Fensome and Williams (pers. comm.) noted a peak of fungal spores on their bioevents chart for the Lutetian of the Labrador Sea-Davis Strait: they also recorded several dinocyst events in the Lutetian that do not occur in South Labrador N-79. These absences plus the thin Lutetian section indicate to me that much of this stage is absent in the well.

I conclude that the Bartonian, which extends from 1750 to 1410 m, is more or less complete. This opinion is based primarily on pollen. The LAD of *Pistillipollenites mcgregorii* occurs in the cuttings sample at 1420-1410 m. Nøhr-Hansen, Fensome and Williams (pers. comm.), in their bioevents chart for the Labrador Sea-Davis Strait wells, place the LAD of *Pistillipollenites mcgregorii* at the Bartonian-Priabonian boundary.

Other index pollen species for the Bartonian are *Cicatricososporites auritus* and *Extratriporopollenites* spp. *Cicatricososporites auritus* has its LAD at 1480-1470 m in South Labrador N-79. Williams (in press c) placed the LAD of *Cicatricososporites auritus* at the top of the Bartonian. This is slightly at variance with Nøhr-Hansen, Fensome and Williams (pers. comm.), who concluded that the LAD of this species was within, but close to the top of the Bartonian. The sample at 1510-1500 m contains three specimens of *Extratriporopollenites*, confirming my inclusion of this interval in the Bartonian.

Dinocyst species having LADs in the Bartonian of South Labrador N-79 include *Hystrichokolpoma "gilbertii"* and *Glaphyrocysta divaricata*. However, I have recorded only two specimens of *Glaphyrocysta divaricata* and suspect they are reworked. Williams (in press b) recorded several specimens of *Hystrichokolpoma "gilbertii"* in the Bartonian of Gilbert F-53. Further, Nøhr-Hansen, Fensome and Williams (pers. comm.) placed the LAD of this species at the Bartonian/Priabonian boundary on their bioevents chart.

The Bujak-Davies Group (1987) considered only 280 m, that's from 1990-1710 m, to be middle Eocene. This determination appears to be based on the foraminiferal *Haplophragmoides acutidonatium* Zone, which encompasses the same interval. According to these authors' palynological data, the interval 1870-1440 m is assigned to the *Areosphaeridium fenestratum* Zone. Since I have used pollen for my control, it is difficult to compare the two sets of data. But it is significant that the Bujak-Davies Group (1987) also regarded the middle Eocene section as attenuated.

As in some other Labrador Sea wells (such as Snorri J-90; Williams, in press d), dinocysts are more abundant in the Priabonian than in the Lutetian-Bartonian. I include in the Priabonian the interval from 1390-1170 m, determining the top of the stage from the LAD of *Trithyrodinium "circellum"* and *Phthanoperidinium multispinum*. Williams (in press c) and Nøhr-Hansen, Fensome and Williams (pers. comm.) have recorded *Trithyrodinium "circellum"* in the Priabonian of other Labrador Shelf wells. Although common in the Eocene there are no known Oligocene occurrences, thus indicating its LAD in the Labrador Sea is in the Priabonian.

Phthanoperidinium multispinum has its LAD in the Priabonian of several wells, offshore eastern Canada. These include Skua E-41 on the Grand Banks (Williams, 2003b), Bjarni O-82 in the Hopedale Basin (Williams, in press a) and Gilbert F-53 in the Saglek Basin (Williams, in press b). Thus, I consider it a reliable index species for the top of the Priabonian in the Labrador Sea.

Other dinocyst taxa with LADs in the interval 1170-1390 m are *Lentinia "glabra", Phthanoperidinium levimurum* and *Schematophora speciosa*. In Gilbert F-53 (Williams, in press b), *Lentinia "glabra"* has its LAD just below the top of the Priabonian. The LAD of this species and the closely related *Lentinia serrata* commonly indicate the top of the Eocene in Grand Banks wells (Williams, 2003a, 2003c). Williams *et al.* (2004) gave the LAD for *Lentinia serrata* as 33.5 Ma. This is 0.2 Ma above the Priabonian-Rupelian boundary, which Gradstein and Ogg (1996) placed at 33.7 Ma.

The Bujak-Davies Group (1987) included the interval 1690-1320 m in the late Eocene or Priabonian. This seems to be based on the LAD of *Deflandrea* #LR which extends from 1420 to 1320 m. I conclude that *Deflandrea* #LR equates with my informal species *Trithyrodinium*? *"circellum"*. As noted earlier, this species has its LAD at the top of the Priabonian. But I find *Trithyrodinium*? *"circellum"* in the cuttings sample at 1180-1170 m, so place the Priabonian top somewhat higher than the Bujak-Davies Group (1987).

Tentatively, I consider the early Oligocene or Rupelian to be present from 1150 to 990 m in South Labrador N-79. This is based on the LAD of the pollen *Pterocaryapollenites* and the spore *Zlivisporis*. Williams (in press b) considered the LAD of both taxa to equate with the Rupelian-Chattian boundary. Williams and Bujak (1977) also recorded *Pterocaryapollenites* from the Oligocene of the Labrador Shelf. In South Labrador N-79, the late Oligocene appears to be missing.

My interpretation differs from that of the Bujak-Davies Group (1987). They include 1300-1170 m in the early Oligocene or Rupelian and the interval 1150-990 m in the Oligocene. Their ages are obviously based on recognition of the *Areosphaeridium arcuatum* Zone between 1300 and 1170 m and the *Chiropteridium galea* (as *Chiropteridium mespilanum*) Zone between 1150 and 990 m. I have checked their analytical data and cannot determine the basis for placing the top of the *Areosphaeridium arcuatum* Zone at 1170 m. The top of the *Chiropteridium mespilanum* Zone, however, must be based on the presence of *Deflandrea granulosa* in the sample from 1000-990 m. This shows good agreement with my placement of the top of the Rupelian.

The difficulty with assigning an age to the interval 970-720 m is the high number of reworked palynomorphs, both Cretaceous and early Tertiary. Based on the presence of *Cordosphaeridium cantharellus* in the sample at 820-810 m, I am including the interval 970-810 m in the early Miocene. Williams *et al.* (2004) gave the LAD of *Cordosphaeridium cantharellus* in Northern Hemisphere mid latitudes as 19.5 Ma. On the Gradstein and Ogg (1996) time scale, this equates with the early Burdigalian. The two ages recognized in the early Miocene are the Aquitanian (23.8-20.5 Ma) and Burdigalian (20.5-16.4 Ma). Therefore it seems reasonable to include 970-810 m in the early Miocene.

Other palynomorphs with LADs in the early Miocene of South Labrador N-79 include *Batiacasphaera micropapillata* (910-900 m), *Geiselodinium tyonekense* (910-900 m), *Spiniferites ovatus* (940-930 m), and *Osmundacidites claytonites* (820-810 m). Williams and Bujak (1977) considered *Osmundacidites claytonites* to have an LAD in the middle to late Miocene of the Labrador Shelf. According to Head (1997), *Batiacasphaera micropapillata* has its LAD at 3 Ma, that's within the Pliocene. *Geiselodinium tyonekense* was described by Engelhardt (1976) from non-marine Miocene sediments of Alaska. Its age is not precisely known. *Spiniferites ovatus*, originally recorded from the late Miocene (Matsuoka, 1983), has a known range of Chattian (Powell, 1986) to late Miocene. Thus the only species that designates the early Miocene age is *Cordosphaeridium cantharellus*.

I consider the sample at 790-780 m to be mid Miocene. This is based on the presence of *Tiliaepollenites* sp., which is identical to *Bombacacidites* sp.A of Williams (1975) and Williams and Bujak (1977). Williams (1975) considered the LAD of *Tiliaepollenites* sp. to be middle Miocene in Scotian Basin

wells. Williams and Bujak (1977) recorded the species from the Labrador Shelf *Operculodinium centrocarpum* assemblage, to which they assigned a provisional middle to late Miocene age. Williams (in press b) followed Williams (1975) in placing the LAD of *Tiliaepollenites* sp. in the middle Miocene. It seems logical to agree with Williams (1975) that the age is probably middle Miocene.

The Bujak-Davies Group (1987) included the interval 970-810 m in the early Miocene and 760-750 m in the Plio-Pleistocene or older. This was based on recognition of the dinocyst *Cordosphaeridium cantharellus* Zone at 820-810 m and the pollen *Tsugaepollenites igniculus* Zone at 760-750 m. These authors analyzed a sample at 790-780 m to which they did not assign an age, but from which they recorded *Lejeunecysta cinctoria*. According to PALYNODATA (a database compiled over the last 35 years by a consortium of several major oil companies and the Geological Survey of Canada. PALYNODATA stores taxonomic, bibliographic, geographic and biostratigraphic information from all known pre-Quaternary palynological publications), there are no known post-Miocene records of this species. Therefore, it is reasonable to include 780-790 m in the Miocene.

Tsugaepollenites is the only taxon that appears to be indigenous in the two uppermost samples at 760-750 m and 730-720 m. Williams and Bujak (1977) defined a *Tsugaepollenites igniculus* assemblage which they considered Pliocene-Pleistocene. From this, I conclude that the interval 760-720 m in South Labrador N-79 is Pliocene-Pleistocene. It appears that much of the Miocene, especially the middle and late and some of the Plio-Pleistocene sections are missing in South Labrador N-79.

There are some major hiati in South Labrador N-79 that can be related to the regional unconformities recognized in the Labrador Shelf and more northerly areas by McWhae *et al.* (1980) and McWhae (1981). The oldest, the Labrador Unconformity, marks the contact of the Precambrian with the overlying Barremian-Aptian. McWhae *et al.* (1980) stated that the Labrador Unconformity was early Cretaceous. My data confirm this.

In South Labrador N-79, the Barremian-Aptian is immediately overlain by Coniacian-Santonian rocks. McWhae *et al.* (1980), used the term Avalon Unconformity for the mid Cretaceous unconformity on the Labrador Shelf and which is present in South Labrador N-79. The term Avalon Unconformity was proposed by Jansa and Wade (1975) for a late Jurassic to early Cretaceous unconformity on the Grand Banks. In South Labrador N-79, the missing section denoting the unconformity represents Albian, Cenomanian and Turonian rocks.

Most of the Campanian is absent in South Labrador N-79. McWhae *et al.* (1980) did not recognize a regional unconformity in the late Cretaceous but in South Labrador N-79 there's a hiatus.

McWhae *et al.* (1980) defined the Bylot Unconformity as of early Paleocene age. In South Labrador N-79, there is an attenuated Selandian section, indicating a major mid Paleocene hiatus. This discrepancy in the ages may reflect the degree of precision in the age determinations or the aerial extent of the unconformities.

The late Paleocene (Thanetian) and early Eocene appear to be mostly complete. This contrasts with the middle Eocene which is attenuated and much of the Lutetian is absent. McWhae *et al.* (1980) did not recognize a mid Eocene regional unconformity. But from this and other Labrador Sea wells, I consider there is a regional hiatus of middle Eocene age.

According to McWhae *et al.* (1980), the Baffin Bay Unconformity is early Oligocene. In South Labrador N-79, I have identified a major hiatus, with early Miocene sediments directly overlying the Rupelian. This is somewhat younger than postulated by McWhae *et al.* (1980). I regard the hiatus in South

Labrador N-79 as compatible with the Baffin Bay Unconformity.

Within the Miocene of South Labrador N-79 there is a major hiatus. McWhae *et al* (1980) defined the Beaufort Unconformity, which they considered late Miocene. This correlates with the missing section in South Labrador N-79, which must be partly middle but mainly late Miocene in age.

In summation there are seven major hiati in South Labrador N-79, five of which show some agreement with the five regional unconformities defined by McWhae *et al.* (1980) and McWhae (1981). The additional two are within the late Cretaceous and in the Lutetian. Data from other wells indicate that both occur elsewhere, although the age of the late Cretaceous hiatus is more variable.

Paleoenvironments

Paleoenvironmental studies are a prerequisite for modelling basin evolution and interpreting the history of potential source rocks. Although this has long been recognized, the number of disciplines that can deliver such data on the offshore wells of eastern Canada are declining. Previously foraminiferal studies were the key but these are no longer being undertaken. Consequently, it has become necessary to refine palynological analyses so that meaningful paleoenvironmental conclusions can be drawn.

How does one do this and what are the known problems? Since the vast majority of samples are drill cuttings, the data must be qualitative and quantitative. Although caving is a major problem, species counts will show the more obvious trends and permits larger groupings. Thus for dinocysts, the gonyaulacalean/peridinialean/ceratiacean ratio, as used by Lister and Batten (1988), is one possible option.

One major advantage of palynomorphs is the diversity of paleoenvironments they represent. Spores and pollen yield information on the terrestrial world, while dinocysts provide a key to the aqueous domains, from fresh water to open ocean. But there are caveats. One is that dinocysts represent the encysted stage of the motile dinoflagellate, which is a planktonic organism. Consequently, it has been widely accepted that dinocyst distribution patterns exhibit a minimal relationship to water depths. In a literal sense this is correct. But dinoflagellates and hence the corresponding dinocysts do show distinct environmental preferences, especially when related to salinity and/or nutrient availability. Thus, some dinocysts are restricted to (or more abundant in) non-marine, lagoonal, coastal, inshore, offshore or open ocean settings. This means that it is feasible to make paleoenvironmental interpretations. For example, open ocean can be equated with a deeper water or bathyal environment.

Using control provided by other fossil groups and lithostratigraphy will ultimately lead to the development of a sophisticated paleoenvironmental model for dinocyst species, providing it is based on both quantitative and qualitative data at the species level. This concept is not new, as demonstrated by the pioneering research of Gocht (1969), Downie *et al.* (1971), Islam (1984) and Köthe (1990). The early results soon highlighted the need for quantitative data to obtain reproducible and predictive results. Thus, the model presented by Brinkhuis (1992), which represented a major advancement in dinocyst paleoenvironmental studies, must be keyed to quantitative data.

Brinkhuis (1992), in his study of the Priabonian, illustrated lateral changes in dinocyst assemblages across a transect from lagoonal to open ocean environments. I have used the modified version of this model, as presented in Sluijs *et al.* (2005), in my paleoenvironmental interpretations for South Labrador N-79. One significant change I have tried to introduce, however, is the use of species. Sluijs *et al.* (2005) referred exclusively to genera. Sometimes this will give a degree of environmental control but at other times, as with *Hystrichokolpoma, Lingulodinium* and *Spiniferites*, one needs to evaluate species fluctuations.

I have used quantitative data for dinocysts and spores and pollen, since ratios of the two groups often reveal relationships to third-order sequences. Where possible, the quantitative data are based on counts of 200 palynomorphs. Some samples, especially in the upper part of the well, contained less than 200 specimens but it was still possible to detect significant abundance fluctuations. The paleoenvironmental curve, representing my interpretations based on palynomorph fluctuations, is presented in Figure 1. I have not included the spore/pollen to dinocyst ratio but have incorporated those data into the text.

In South Labrador N-79, the paleoenvironments fluctuate from non-marine to bathyal. The history is complicated, especially in the bottom 60 m. The well bottomed at 3571.5 m in Precambrian syenite, which extends up to 3548 m. Within this interval are three cuttings samples, which contain the dinocyst species *Vesperopsis mayi* and *Balmula tripenta*. These species and morphologically similar taxa seem to denote fresh water to lagoonal paleoenvironments (Zippi, 1998), indicating that the sediments immediately overlying the syenite are non-marine to marginal marine.

A rapid change to inner neritic conditions is indicated by the dinocyst taxa from the cuttings samples at 3550-3540 and 3525-3515 m, which contain the dinocysts *Endoceratium pflugii, Endoceratium* sp. and *Cerbia tabulata*. Williams (in press a) interpreted the occurrence of *Cerbia tabulata* in Bjarni O-82 as indicating the onset of rifting in the Labrador Sea. This fits with the species presence in South Labrador N-79, also in the southern part of the Hopedale Basin.

Paleoenvironmental interpretations of the South Labrador N-79 have also been published by Miller and d'Eon (1987) and the Bujak-Davies Group (1987). Miller and d'Eon based their conclusions on lithological analysis: The Bujak-Davies Group (1987) used foraminifera. Collation of the data of these authors produced the paleoenvironmental bar-graph published in Bell (1989) and Figure 2. The bar-graph was compiled by F.M. Gradstein, J. Helenes, P.E. Miller and P.N. Moir and represents a compromise between the lithological and foraminiferal data generated by these authors. I shall compare my paleoenvironmental data from South Labrador N-79 with that presented in the bar-graph in Bell (1989; Figure 2).

The taxon *Endoceratium* is a ceratiacean cyst that is a close relative of *Muderongia*. Cornu and Monteil *in* Monteil (1990) used the *Muderongia/Phoberocysta* ratio as a proximity to shore indicator. The higher the value, that is the greater the number of *Muderongia* specimens relative to *Phoberocysta* specimens, the farther offshore the location. This suggests that during the Barremian-Aptian the South Labrador N-79 site could have been well offshore. This is confirmed by Gradstein, Helenes, Miller and Moir *in* Bell (1989), who indicate a rapid transition from inner to middle to outer shelf paleoenvironments.

Within the late Cretaceous, that's from 3490-5250 m, there is an initial deepening phase from inner neritic to open ocean (interpreted here and elsewhere as bathyal), with the paleoenvironment then remaining deeper water. The sample at 3490-3480 m contains a rich dinocyst assemblage, with *Heterosphaeridium difficile*, *Tenua hystrix* and *Spiniferites furcosus* being frequent. I categorize the paleoenvironment as inner neritic.

Interpretation of distance from shore for the interval 3460-3390 m is difficult because of the dominance of specimen which I consider represent caved species. This is indicated by the high counts of *Apectodinium homomorphum* at 3430-3420 m and *Areoligera gippingensis* at 3400-3390 m. Because of the presence of *Impagidinium victorianum* in both samples and its continuing occurrence in higher samples to 3270 m, I am assuming that bathyal conditions persisted throughout the later Cretaceous.

Impagidinium is one of the few dinocyst genera which appear to be restricted to open ocean, deeper water environments. Wall *et al.* (1977) were the first to recognize that *Impagidinium* species (then

included in *Leptodinium*) were indicative of oceanic realm environments. Brinkhuis (1992) incorporated this concept into his Priabonian model and Dale (1996) confirmed the validity of *Impagidinium* dominance among organic-walled dinocysts in the oceanic realm. The *Impagidinium* signal has been used in studies of other Labrador Sea wells (e.g. Williams, in press a).

Initially in the early Paleocene (Danian), there is shallowing to outer neritic from 3220-2880 m. Within this interval, the spore and pollen/dinocyst ratio tends to be equal or less than 1. Dinocyst taxa include common *Palaeoperidinium pyrophorum* at 3220-3210 and 3070-3060 m. The preferred paleoenvironments of the motile stage that produces the dinocyst *Palaeoperidinium pyrophorum* is conjectural. The first concern is whether the species was autotrophic or heterotrophic. *Palaeoperidinium pyrophorum* is a peridinialean but is it a protoperidiniacean, most of which are heterotrophic. The problem has been resolved by Evitt *et al.* (1998), who noted that the species has five cingular plates. All known protoperidiniacean species have three cingulars only.

Knowing that *Palaeoperidinium pyrophorum* is a peridiniacean and not a protoperidiniacean still leaves unanswered the probable feeding mode. But there is a plausible explanation for the high abundance of this species in South Labrador N-79, if we assume it prefers normal marine to hypersaline or reduced salinity paleoenvironments. As a normal marine dweller, surely the motile stage would thrive in areas of upwelling, to be shut down and therefore forced to encyst when the seasonal upwelling cycle switched off in the fall. Thus, I think it reasonable to assume that *Palaoeperidinium pyrophorum*'s abundance reflects a location just off the shelf, in an area of upwelling.

How do my results compare with those of Gradstein, Helenes, Miller and Moir *in* Bell (1989)? These authors interpreted the interval 3480 to 2915 m as being deposited in a lower bathyal paleoenvironment. But the dinocysts indicate shallower water conditions from 3200 to 2900 m. Possibly deposition was close to the shelf edge during deposition of this interval, so that many of the dinocysts are allochthonous.

In South Labrador N-79, the thick Paleocene section extends up to 2490 m. After the slight shallowing to mid to outer shelf in the Danian and Selandian, paleoenvironments became more outer shelf with occasional bathyal episodes in the Thanetian. My interpretation is based on the dominance of *Pinuspollenites* and *Taxodinium*, both in the spores and pollen and in the spore/pollen:dinocyst ratio. However, I think the absence of *Impagidinium* indicates that the location of South Labrador N-79 during the Paleocene was close to the shelf edge.

A major event just above the base of the Selandian, is the dominance of *Areoligera gippingensis* in the sample at 2940-2950 m. The high abundance of *Areoligera* in the Paleocene has been noted in other Labrador Shelf, Davis Strait (Williams, in press, a, c) and Grand Banks (Williams, 2003a, 2003c). Powell *et al.* (1996) were the first to describe *Areoligera* dominated assemblages, which occurred in the type Thanetian of southern England. In the Pegwell Bay section, there are three levels where *Areoligera* is "super abundant" and three where it is "abundant". According to Powell *et al.* (op. cit.), such horizons denote restricted high energy, marginal marine settings of a transgressive regime, although the species *Areoligera gippingensis* is considered indicative of offshore marine environments (Heilmann-Clausen, 1994).

Powell *et al.* (1996) interpreted the samples with the highest abundances of *Areoligera* as being close to the most condensed sequence or maximum flooding surface. Because it is a gonyaulacacean cyst, *Areoligera* is presumably the cyst of an autotrophic dinoflagellate. Its presence in such high numbers at 2950-2960 m indicates to me that it was in an area of upwelling, just off the shelf edge.

The paleoenvironmental interpretations of Gradstein, Helenes, Miller and Moir *in* Bell (1989) for the

interval 2915 to 2180 m are upper to bathyal. The palynomorph data is in general agreement (Figure 2).

The highest Thanetian sample at 2490-2500 m is characterized by an abundance of the dinocyst *Apectodinium homomorphum*. According to Bujak and Brinkhuis (1998), *Apectodinium homomorphum* is a warmer water species. Crouch *et al.* (2001) have shown that the onset of *Apectodinium*-dominated assemblages seems to be synchronous on a global scale. One such peak occurred during the Paleocene-Eocene thermal maximum (PETM), which lasted for about 220 ky at about 55 Ma. And it can be correlated with a negative carbon isotope excursion (CIE), a benthic foraminifera extinction event and a calcareous nannofossil zonation. The *Apectodinium* influx denotes higher water temperatures and an increase in productivity. A decline in the *Apectodinium* abundance presumably indicates cooler conditions. From the numbers of *Apectodinium homomorphum* at 2500-2490 m, I am postulating that warmer water conditions existed during deposition of this interval and that it lies close to the Paleocene-Eocene boundary.

Only minor fluctuations in paleoenvironments occur in the Eocene. As shown by the presence of *Impagidinium* in several samples between 2470 and 1920 m, bathyal conditions persisted throughout the Ypresian. Further support for this interpretation is the occasional occurrence of *Nematosphaeropsis labyrinthea* and *Hystrichokolpoma* spp., plus the high relative abundance of *bivesiculates* and *Taxodinium*.

Within the Ypresian, *Apectodinium homomorphum* is frequent between 2470 and 2370 m. This indicates warmer water conditions. I assume that this interval is within the early Ypresian. In the vicinity of South Labrador N-79, bathyal paleoenvironments persisted throughout the Lutetian and Bartonian. The first significant changes occurred in the Priabonian, with shallowing to outer neritic, then inner neritic.

The characteristic features of the Lutetian-Bartonian palynomorph assemblages are the continuing high spore and pollen to dinocyst ratios and the sporadic occurrence of *Hystrichokolpoma* "*gilbertii*" and species of *Impagidinium*. In the Priabonian, shallowing to outer to inner neritic paleoenvironments is indicated by the presence of *Phthanoperidium multispinum* and *Trithyrodinium* "*circellum*".

My paleoenvironmental interpretations show agreement with those of Gradstein, Helenes, Miller and Moir *in* Bell (1989). According to these authors, from 2180 to 1945 m is upper bathyal, 1945 to 1700 m is outer neritic to upper bathyal, 1700 to 1500 m is outer neritic, 1500 to 1320 m is middle to outer neritic, and 1320 to 1170 m is inner to middle neritic (Figure 2). The palynological data likewise indicate a general shallowing in the late Eocene and Oligocene.

The Rupelian to Plio-Pleistocene represented continuing deposition predominantly in an inner shelf setting, with occasional deepening as in the early Miocene and shallowing in the Plio-Pleistocene. *Quercoidites*, the fossil pollen of oak, is common to abundant in much of the Rupelian. This presumably indicates a closer-to-shore setting. Reworked specimens are a significant part of the assemblages in the early Miocene to Plio-Pleistocene. Primarily the species are late Cretaceous and early Tertiary but there are some older Cretaceous taxa. Throughout this part of the section, spores and pollen are dominant, with dinocysts being rare to absent.

The shallowing of environments in the upper part of South Labrador N-79 is confirmed by Gradstein, Helenes, Miller and Moir *in* Bell (1989). These authors considered the interval 1170 to 920 m to be deposited in an inner to middle neritic paleoenvironment and 920 to 745 m to be deposited in an inner neritic paleoenvironment. From 945 to 920 m was possibly transitional, which is equivalent to my category coastal to marginal marine. The results compare favourable with my results from the palynological data (Figure 2).

In the vicinity of South Labrador N-79, paleoenvironmental conditions remained remarkably stable after the onset of marine deposition in the early Cretaceous. Bathyal conditions, first appearing in the late Cretaceous, continued through the Paleocene and most of the Eocene until the Priabonian. Shallowing in the Priabonian persisted for the remainder of the Cenozoic, with the shallowest conditions in the Plio-Pleistocene. The paleoenvironmental curve provides evidence for initial rifting and for the series of major hiati that are an important part of the evolution of the Labrador Sea.

Correlation of Palynology and Lithostratigraphy

The lithostratigraphic interpretation presented in Figure 1 is derived from Moir (1989). There is a more recent reappraisal by the Canada Newfoundland Offshore Petroleum Board (1998), but this shows no substantive differences, other than omission of the Snorri Member. According to Moir (1989), the bottom 23 m (3548-3571 m) of South Labrador N-79 are unnamed Precambrian rocks. The Canada Newfoundland Offshore Petroleum Board (1998) is more specific, referring to these rocks as representing a Precambrian syenite.

Overlying Precambrian basement are sandstones and shales, which Moir (1989) assigned to the Snorri Member of the Bjarni Formation. Umpleby (1979) formally proposed the Snorri Member for a sequence of dark grey and dark brown to maroon shales, coal seams and sandstones between 3027 and 3061 m in Snorri J-90. Some of the shales contained abundant plant remains. Barss *et al.* (1979) considered the Snorri to be Barremian, at least in the uppermost 10 m. McWhae *et al.* (1980) did not recognize that the Snorri Member regionally and concluded that the coal seams suggested correlation with the upper part of the Bjarni Formation. These authors stated that the unit [Bjarni Formation] is typically a continental deltaic deposit. Paleoenvironments include abundant channels and braided streams, and thinner, coal-forming swamps.

In South Labrador N-79, Moir (1989) included from 3548 to 3496 m in the Snorri Member, whereas the Canada Newfoundland Offshore Petroleum Board (1998) regarded the interval 3548-3527 m simply as ?Bjarni Formation and 3527-2926 m as belonging to the overlying Markland Formation. I consider from 3550-3510 m to be Barremian-Aptian, so place the top intermediate between the top of the Snorri Member according to Moir (1989) and the top of the Bjarni Formation according to the Canada Newfoundland Offshore Petroleum Board (1998).

The Snorri Member is overlain by the Markland Formation, to which Moir (1989) assigned the interval 3496-2432 m. McWhae *et al.* (1980) formally proposed the Markland Formation for a sequence of shales, siltstone, sandstone and thin dolomitic limestone of Cenomanian-Turonian to Danian age on the Labrador Shelf. According to these authors, the Avalon Unconformity separates the Markland Formation from the underlying Bjarni Formation or older rocks; and the Bylot Unconformity or Disconformity separates the Markland Formation from the overlying Cartwright Formation. McWhae *et al.* (1980) concluded that the Markland Formation was deposited in inner neritic to bathyal environments.

In South Labrador N-79, the Markland Formation is Coniacian to Selandian. The age shows good agreement with that determined in Bjarni O-82 (Williams, in press a). When McWhae *et al.* (1980) postulated a Danian age for the youngest parts of the Markland Formation, they were following convention, which subdivided the Paleocene into Danian and Thanetian or early and late

My data indicate that the paleoenvironments during deposition of the Markland Formation were outer shelf to open ocean. This is more restricted than that of McWhae *et al.* (1980).

Moir (1989) assigned the rocks overlying the Markland Formation, and extending from 2935 to 2432 m, to the Cartwright Formation. Umpleby (1979) erected this formation for a mudstone sequence that

grades to siliceous shale with some fine sands. According to Umpleby (1979), the Cartwright Formation was deposited in a marginal to shallow marine environment. However, McWhae *et al.* (1980) interpreted the sands as turbidites and the lutite sequence to be outer shelf to upper slope. In both Bjarni O-82 (Williams, in press a) and Gilbert F-53 (Williams, in press b), I regarded the environment of deposition for the Cartwright Formation to be outer shelf to open ocean. South Labrador N-79 is similar but predominantly open ocean or bathyal.

The age of the Cartwright Formation in South Labrador N-79 is Thanetian-early Ypresian. This shows excellent agreement with my conclusions in Bjarni O-82 (Williams, in press a). McWhae *et al.* (1980) stated that foraminifera in the Cartwright Formation in the nearby Bjarni H-81 indicated a middle Paleocene to early Eocene age. Barss *et al.* (1979) stated that this interval was Paleocene-early Eocene.

In South Labrador N-79 there is a major hiatus at the boundary between the Markland and Cartwright formations, with most of the Selandian absent.

From 2432 to 1446 m is the Kenamu Formation, according to Moir (1989). McWhae *et al.* (1980) defined the Kenamu Formation as an Eocene shale, siltstone, sandstone sequence that is in part glauconitic and calcareous. The sediments were deposited in outer shelf to upper slope environments. In South Labrador N-79 the Kenamu Formation is Ypresian to Bartonian and was deposited in an oceanic milieu. This shows close agreement with my conclusions in Bjarni O-82 (Williams, in press a) and the conclusions of McWhae *et al.* (1980).

As noted under Biostratigraphy, I consider much of the middle Eocene (part of the Lutetian) to be absent in South Labrador N-79. The corresponding hiatus represents an event not recognized in previous studies.

Overlying the Kenamu Formation are the Mokami Formation from 1447 to 775 m and the Saglek Formation from 773 to 546 m. McWhae *et al.* (1980) defined the Mokami Formation as a predominantly claystone and soft shale unit of Eocene to middle Miocene age. In South Labrador N-79, the age is Bartonian to middle Miocene. This agrees with McWhae *et al.* (op. cit.). According to McWhae *et al.* (1980), the Mokami Formation is a shelfal deposit, much of it being laid down in shallow water. There is some disagreement in South Labrador N-79, where the lowest part of the Mokami Formation is oceanic. But for most of the section included in the formation, the paleoenvironment is inner neritic.

My data indicate that there is a significant hiatus in the Mokami Formation, with the Chattian being absent or very attenuated. I equate this hiatus with the Baffin Bay Unconformity, which McWhae *et al.* (1980) placed at the Kenamu-Mokami boundary. These authors also considered the Baffin Bay Unconformity to occur at the end of the Eocene. In South Labrador N-79, if equated with the hiatus, it is younger.

The overlying Saglek Formation was erected by Umpleby (1979) to include all those sediments deposited above the Cartwright Formation and below the Pliocene-Pleistocene on the Labrador Shelf. McWhae *et al.* (1980) revised the formation, restricting it to poorly sorted sandstones, with secondary siltstones and claystones. The environment of deposition was shallow neritic to littoral, predominantly paralic. McWhae *et al.* (1980) stated that the Saglek Formation is probably mid-late Miocene to Pliocene. Barss *et al.* (1979) dated the Saglek, as defined by McWhae *et al.* (op. cit.), as Plio-Pleistocene in the Bjarni O-82 and Snorri J-90 wells. This agrees with my age assignment of Pliocene-Pleistocene for the Saglek Formation in South Labrador N-79. The paleoenvironment, as determined from South Labrador N-79, is inner neritic. This accords with the conclusions of McWhae *et al.* (1980).

McWhae *et al.* (1980) recognized a major regional unconformity, which they named the Beaufort, separating the Mokami and Saglek formations. This would equate with the hiatus between the middle Miocene and Pliocene at about 770 m.

Summary

South Labrador N-79 contains the oldest marine sedimentary rocks known from the Labrador Shelf. These rocks, which contain several dinocysts, are Barremian-Aptian. At total depth, Bjarni O-82 also has Barremian but the sediments are non-marine. Above the Barremian-Aptian, the Cretaceous is attenuated, with the overlying Coniacian-Santonian overlying the Avalon Unconformity. A hiatus separates the overlying thin Campanian and thicker Maastrichtian section. Age control in the early Cretaceous is based primarily on dinocysts but the spores and pollen are useful. In the late Cretaceous only the dinocysts are age-diagnostic.

There is a thick Paleocene and Eocene section but the Oligocene to Pleistocene is attenuated. The hiatus, which occurs at the Selandian-Thanetian boundary, may be equivalent to the Bylot Unconformity. The Lutetian hiatus does not appear to be equivalent to a regional unconformity. But there is a significant hiatus within the Oligocene that I consider equivalent to the Baffin Unconformity. Likewise the hiatus between the middle Miocene and Pliocene-Pleistocene presumably mark the Beaufort Unconformity of McWhae *et al.* (1980).

The Paleogene contains abundant palynomorphs, especially dinocysts. In the Neogene, spores and pollen are usually common but dinocysts are sparse. What is surprising throughout the Cenozoic is the usefulness of the spores and pollen for age control, especially if related to the control for the dinocysts.

In South Labrador N-79, the paleoenvironments ranged from marginal marine to oceanic but were predominantly outer neritic to oceanic in the late Cretaceous and Paleogene, shallowing only in the Oligocene. Shallow marine (inner neritic) conditions prevailed in the Neogene, becoming more prevalent upwards.

Correlation of South Labrador N-79 with the Bjarni O-82 well indicates that several dinocyst species provide excellent paleoenvironmental signals, especially in the Paleogene. A more detailed late Cretaceous section, such as in nearby South Hopedale L-39 or Skolp E-07 should facilitate a better understanding of late Cretaceous dinocyst assemblages and hence their biostratigraphic and paleoenvironmental significance in northern climes.

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Figures

Figure 1 Location of wells discussed in text.

Figure 2 Stratigraphy and paleoenvironments of Chevron *et al*. South Labrador N-79.

Appendix A

Palynomorph taxa recorded in South Labrador N-79. References for dinocyst taxa are from Fensome and Williams (2004). Informal taxa will be illustrated in one of the proposed palyatlases.

Achilleodinium biformoides (Eisenack, 1954b) Eaton, 1976
Achomosphaera ramulifera (Deflandre, 1937b) Evitt, 1963
Achomosphaera "scabrosa"
Adnatosphaeridium "superpetellum"
Adnatosphaeridium vittatum Williams and Downie, 1966c
Alisocysta circumtabulata (Drugg, 1967) Stover and Evitt, 1978
Alisocysta margarita (Harland, 1979a) Harland, 1979a
Alnipollenites spp.
Alterbidinium acutulum (Wilson, 1967b) Lentin and Williams, 1985
Alterbidinium? bicellulum (Islam, 1983b) Lentin and Williams, 1985
Alterbidinium "fusiforme"
Alterbidinium sp.
Amphidiadema nucula (Cookson and Eisenack, 1962b) Lentin and Williams, 1976
Apectodinium augustum (Harland, 1979c) Lentin and Williams, 1981
Apectodinium "fleximorphum"
Apectodinium homomorphum (Deflandre and Cookson, 1955) Lentin and Williams, 1977b
Apectodinium parvum (Alberti, 1961) Lentin and Williams, 1977b
Areoligera cf. *senonensis* Lejeune-Carpentier, 1938a
Azolla spp.
Balmula tripenta Bint, 1986
Baltisphaeridium "scalenofurcatum"
Batiacasphaera micropapillata Stover, 1977
Bombacacidites sp.
Brachysporisporites sp.
Brachysporisporites sp.B Parsons and Norris, 1999
Caligodinium amiculum Drugg, 1970b
Caligodinium endoreticulatum Stover and Hardenbol, 1994
Callimothallus pertusus Dilcher, 1965
Callimothallus sp.
Caryapollenites spp.
Cedripites canadensis Pocock, 1962
Cerbia tabulata (Davey and Verdier, 1974) Below, 1981a
Cerbia cf. *tabulata* (Davey and Verdier, 1974) Below, 1981a
Cerebropollenites mesozoicus (Couper, 1958) Nilsson, 1958
Cerodinium denticulatum (Alberti, 1959b)
Cerodinium diebelii (Alberti, 1959b) Lentin and Williams, 1987
Cerodinium diebelii sensu McIntyre, 1975
Cerodinium "glabrum"
Cerodinium sp.
Cerodinium striatum (Drugg, 1967) Lentin and Williams, 1987
Charlesdowniea coleothrypta (Williams and Downie, 1966b) Lentin and Vozzhennikova, 1989
Charlesdowniea columna (Michoux, 1988) Lentin and Vozzhennikova, 1990
Chatangiella decorosa (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella ditissima (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella tripartita (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Cicatricosisporites "labatus"
Cicatricosisporites #EAL Davies in Bujak-Davies, 1987

Cicatricososporites auritus
Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986
Cleistosphaeridium ancyreum (Cookson and Eisenack, 1965a) Eaton et al., 2001
Cleistosphaeridium ancyreum subsp. "*brevispinum*"
Cleistosphaeridium diversispinosum Davey et al., 1966
Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978
Cordosphaeridium cantharellus (Brosius, 1963) Gocht, 1969
Cordosphaeridium "*delimurum*"
Cordosphaeridium fibrospinosum Davey and Williams, 1966b
Cordosphaeridium gracile (Eisenack, 1954b) Davey and Williams, 1966b
Cordosphaeridium gracile subsp. "*brevispinum*"
Cordosphaeridium sp.
Corollina torosus (Reissinger) Klaus, 1960
Cribroperidinium giuseppei (Morgenroth, 1966a) Helenes, 1984
Cribroperidinium orthoceras (Eisenack, 1958a) Davey, 1969a
Cribroperidinium wetzelii (Lejeune-Carpentier, 1939) Helenes, 1984
Cyclonephelium vannophorum Davey, 1969a
Dapsilidinium laminaspinosum (Davey and Williams, 1966b) Lentin and Williams, 1981
Dapsilidinium pseudocolligerum (Stover, 1977) Bujak et al., 1980
Dapsilidinium? *simplex* (White, 1842) Bujak et al., 1980
Deflandrea oebisfeldensis Alberti, 1959b
Deflandrea phosphoritica Eisenack, 1938b
Deflandrea cf. *phosphoritica*
Deflandrea sp.B Williams and Bujak, 1977
Dicellaesporites sp.B Parsons and Norris, 1999
Diphyes brevispinum Bujak, 1994
Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965a
Diphyes ficusoides Islam, 1983b
Diporicellaesporites laevigatiformis Ke and Shi ex Sung et al., 1978
"*Downiella megapatula*"
Dracodinium "*articulatum*"
Dracodinium condylos (Williams and Downie, 1966b) Costa and Downie, 1979
Dracodinium cf. *condylos* sensu Williams and Bujak, 1977
Dyadosporites sp.
Eatonicysta ursulae (Morgenroth, 1966a) Stover and Evitt, 1978
Emmetrocysta sp.
Endoceratium pflugii Prössl, 1990
Endoceratium sp.
Eocladopyxis "*brevispinosa*"
Eocladopyxis peniculata Morgenroth, 1966a
Extratriporopollenites spp.
Geiselodinium tyonekense Engelhardt, 1976
Gerdiocysta sp.
Glaphyrocysta divaricata (Williams and Downie, 1966c) Stover and Evitt, 1978
Glaphryocysta exuberans (Deflandre and Cookson, 1955) Stover and Evitt, 1978
Glaphyrocysta intricata (Eaton, 1971) Stover and Evitt, 1978
Glaphyrocysta ordinata (Williams and Downie, 1966c) Stover and Evitt, 1978
Gothanipollis sp.
Hafniasphaera hyalospinosa Hansen, 1977
Heteraulacacysta pustulata Jan du Chêne and Adediran, 1985
Heterosphaeridium difficile (Manum and Cookson, 1964) Ioannides, 1986

Homotryblium abbreviatum Eaton, 1976
Homotryblium tenuispinosum Davey and Williams, 1966b
Hystrichodinium pulchrum Deflandre, 1935
Hystrichodinium voigtii subsp. "*brevispinum*"
Hystrichokolpoma bulbosum (Ehrenberg, 1838) Morgenroth, 1968
Hystrichokolpoma "*gilbertii*"
Hystrichokolpoma? *incertum* Michoux, 1985
Hystrichokolpoma "*pseudoincertum*"
Hystrichokolpoma salacia Eaton, 1976
Hystrichosphaeridium salpingophorum Deflandre, 1935
Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937b
Hystrichosphaeridium tubiferum subsp. "*perforatum*"
Impagidinium maculatum (Cookson and Eisenack, 1961b) Stover and Evitt, 1978
Impagidinium victorianum (Cookson and Eisenack, 1965a) Stover and Evitt, 1978
Isabelidinium belfastense (Cookson and Eisenack, 1961a) Lentin and Williams, 1977a
Jussiaea pollenites
Kenleyia sp.
Kiokansium erectum (Manum and Cookson, 1964) Below, 1982c
Komewuia? "*unicornis*"
Laciniadinium sp.
Lacrimasporonites sp.
Lentinia "*glabra*"
Lentinia serrata Bujak in Bujak et al., 1980
Lentinia? *wetzelii* (Morgenroth, 1966a) Bujak in Bujak et al., 1980
Lingulodinium "*brevispinosum*"
Lingulodinium funginum (Morgenroth, 1966a) Islam, 1983b
Membranilarnacia hapala (Schiøler and Wilson, 1993) Lachkar and Masure in Fauconnier and Masure, 2004
"*Michouxdinium tenuitabulatum*"
Microdinium setosum Sarjeant, 1966b
Microthallus lutosus Dilcher, 1965
"*Minisphaeridium latirictum*"
Multicellaesporites sp.
Multiporopollenites sp.
Muratodinium fimbriatum (Cookson and Eisenack, 1967b) Drugg, 1970b
Nyktericysta sp.
Nyssapollenites spp.
Odontochitina costata Alberti, 1961
Odontochitina operculata (O. Wetzel, 1933a) Deflandre and Cookson, 1955
Odontochitina porifera Cookson, 1956
Oligosphaeridium albertense (Pocock, 1962) Davey and Williams, 1969
Oligosphaeridium asterigerum (Gocht, 1959) Davey and Williams, 1969
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966b
Oligosphaeridium "*complex/pulcherrimum*"
Oligosphaeridium porosum Lentin and Williams, 1981
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983a
Osmundacidites sp.
Ovoidinium scabrosum (Cookson and Hughes, 1964) Davey, 1970
Ovoidinium verrucosum (Cookson and Hughes, 1964) Davey, 1970
Palaeocystodinium bulliforme Ioannides, 1986

Palaeocystodinium golzowense Alberti, 1961
Palaeohystrichophora infusorioides Deflandre, 1935
Palaeoperidinium cretaceum (Pocock, 1962) Lentin and Williams, 1976
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967b
Palaeoperidinium cf. *pyrophorum*
Paralecaniella indentata (Deflandre and Cookson, 1955) Cookson and Eisenack, 1970b
Parvisaccites radiatus Brenner, 1963
Perinopollenites elatoides Couper, 1958
Pesavis tagluensis Elsik and Jansonius, 1974
Phelodinium kozlowskii (Górka, 1963) Lindgren, 1984
Phelodinium magnificum (Stanley, 1965) Stover and Evitt, 1978
Phthanoperidinium alectrolophum Eaton, 1976
Phthanoperidinium amoenum Drugg and Loeblich Jr., 1967
Phthanoperidinium coreoides (Benedek, 1972) Lentin and Williams, 1976
Phthanoperidinium crenulatum (de Coninck, 1975) Lentin and Williams, 1977b
Phthanoperidinium echinatum Eaton, 1976
Phthanoperidinium levimurum Bujak in Bujak et al., 1980
Phthanoperidinium multispinum Bujak in Bujak et al., 1980
Pilosisporites verus Delcourt and Sprumont, 1955
Piriurella sp.
Pluricellaesporites sp.
Podocarpidites sp.
Polyadosporites type B Parsons and Norris, 1999
Polysphaeridium zoharyi (Rossignol, 1962) Bujak et al., 1980
Pseudoceratium iveri Nøhr-Hansen, 1993
Pterocaryapollenites sp.
Pterodinium cingulatum (O. Wetzel, 1933b) Below, 1981a
Pterodinium sp.
Pterospermopsis helios Sarjeant, 1959
Quilonia sp.
Retitricolpites georgensis Brenner, 1963
Retitricolpites maximus Singh, 1983
Retitricolpites vulgaris Pierce, 1961
Rhoipites sp.
Rottnestia borussica (Eisenack, 1954b) Cookson and Eisenack, 1961b
Rugubivesiculites rugosus Pierce, 1961
Sapotaceaepollenites spp.
Schematophora sp.
Schematophora speciosa Deflandre and Cookson, 1955
Senoniasphaera protrusa Clarke and Verdier, 1967
Senoniasphaera rotundata Clarke and Verdier, 1967
Sepispinula huguoniottii (Valensi, 1955a) Islam, 1993
Sequioapollenites sp.
Spinidinium echinoideum (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Spiniferella sp.
Spiniferites "digitatus"
Spiniferites ovatus Matsuoka, 1983b
Spiniferites scabrosus (Clarke and Verdier, 1967) Lentin and Williams, 1975
Spongodinium delitiense (Ehrenberg, 1838) Deflandre, 1936b
Spongodinium sp.
Stiphrosphaeridium dictyophorum (Cookson and Eisenack, 1958) Lentin and Williams, 1985

Subtilisphaera perlucida (Alberti, 1959b) Jain and Millepied, 1973
Surculosphaeridium longifurcatum (Firtion, 1952) Davey et al., 1966
Surculosphaeridium cf. *longifurcatum*
Tanyosphaeridium xanthiopyxides (Wetzel, 1933b ex Deflandre, 1937b) Stover and Evitt, 1978
Tenua hystrix Eisenack, 1958a
Thalassiphora pelagica (Eisenack, 1954b) Eisenack and Gocht, 1960
Tiliaepollenites spp.
Trichodinium castanea Deflandre, 1935
Trinovantedinium "brevispinosum"
Trinovantedinium sp.
Trithyrodinium "circellum"
Trithyrodinium evittii Drugg, 1967
Trithyrodinium "scabratum"
Trithyrodinium " verrucatum"
Tsugaepollenites? pseudomassulae Mädler, 1964b
Ulmipollenites sp.
Vesperopsis mayi Bint, 1986
Wetzeliella symmetrica Weiler, 1956
Xenascus ceratioides (Deflandre, 1937b) Lentin and Williams, 1973
Zlivisporis sp.

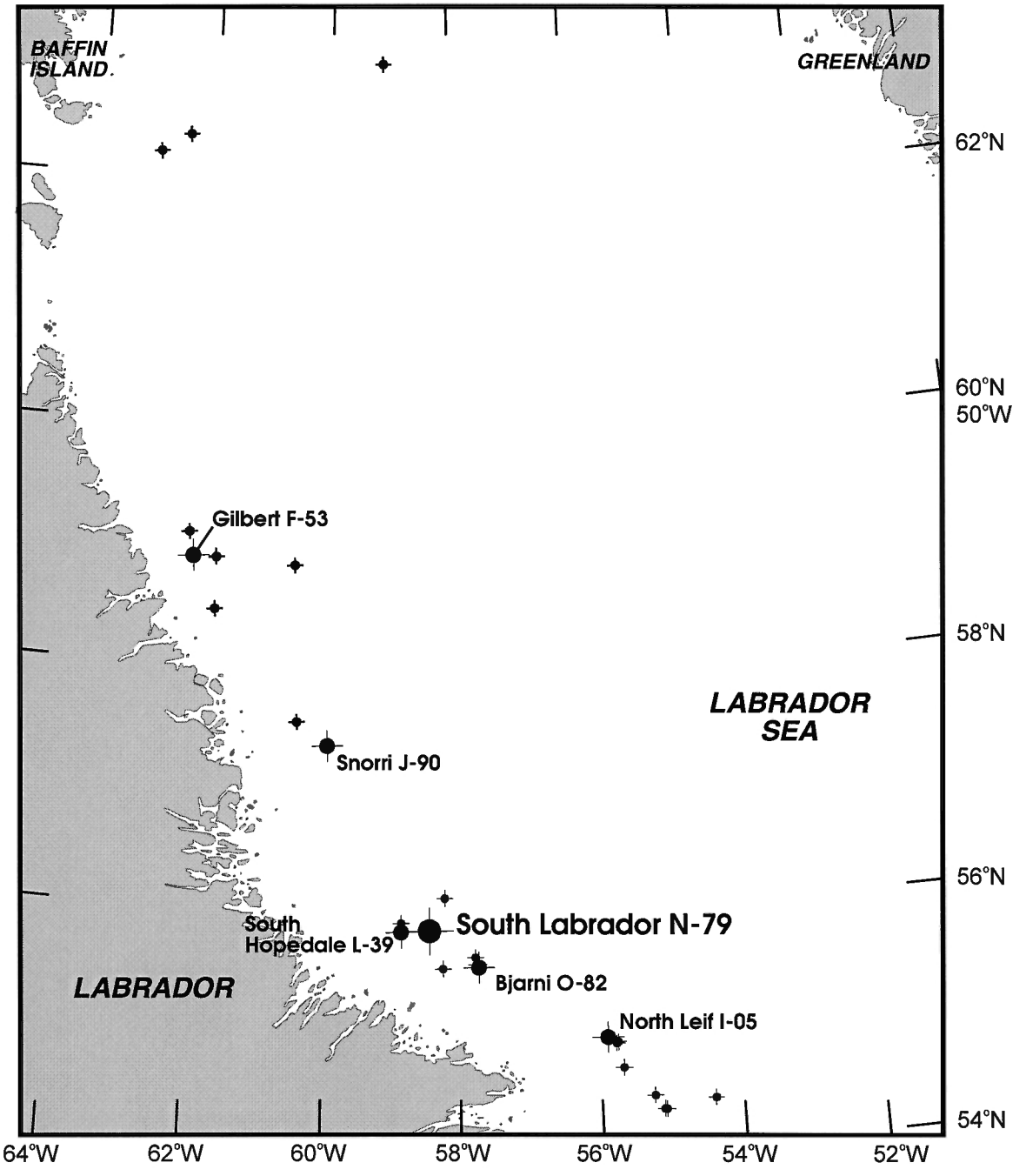

Figure 1. Location of wells discussed in text.