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Palynological analysis of Eastcan et al. Snorri J-90, Hopedale Basin, Labrador Shelf, offshore eastern Canada

G.L. Williams

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1 Challenger Drive (PO Box 1006)

Dartmouth, Nova Scotia B2Y 4A2

Williams, G.L.

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G.S.C. Locality No.: D-152

Location: 57°19'74"N, 59°57'74"W

Elevation Sea level to R.T.: 11.3 m

Water Depth: 140.8 m

Total Depth: 3209.8 m

Spud Date: 28 July 1975

Interval Studied: 384-3209 m

Casing Points: 762 mm at 176.5 m; 508 mm at 373.4 m; 340 mm at 1127.5 m; 244 mm at 2696 m

Introduction

Eastcan *et al.* Snorri J-90 is on the northwest flank of the Hopedale Basin on the northwest Labrador Shelf (Figure 1). The well flowed gas and condensate from the interval 2502-2493 m, in the Gudrid Formation.

A comprehensive summation of the stratigraphy and maturation data of Snorri J-90 has been published in the Labrador Sea Basin Atlas (Bell, J.S., coordinator, 1989).

Biostratigraphy

This biostratigraphic study of Snorri J-90 is based on the palynological analysis of 82 cuttings samples covering the interval 3209 to 384 m, two samples from conventional core at 2499.67-2499.37 m and 2497.54-2497.23 m, and 20 sidewall cores between 3127.56 and 1295.4 m. I am indebted to the Canada-Newfoundland and Labrador Offshore Petroleum Board for providing the unwashed cuttings samples and the conventional cores from which the slides were prepared after palynological processing.

Figure 2 provides a summary of my biostratigraphic and paleoenvironmental conclusions for Snorri J-90. The results are based on the analysis of dinoflagellates (dinocysts), spores and pollen, and tied to the lithostratigraphy and available well logs. To assist in interpretation, I also include the last appearance datums (LADs) of species, as well as occurrences representing significant fluctuations in relative abundances of those I consider as reworked.

The age interpretations for Snorri J-90 are based primarily on the known stratigraphic ranges of dinocysts in European sections (Powell, 1992; Bujak, 1994; Williams *et al.*, 1999, 2001, 2004) and from other 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; S nderholm *et al.*, 2003; N hr-Hansen, 2003a, 2003b). Another valuable source of information has been a compilation of LADs of dinocysts, spores and pollen by N hr-Hansen, Fensome and Williams (pers. comm.). These three have pooled their analytical data from 17 wells drilled in the Labrador Sea and Davis Strait to produce a bioevents chart for dinocysts, spores and pollen for regional application.

In this paper, I key all stratigraphic ranges of palynomorph taxa to the time scale of Gradstein and Ogg (1996).

Previous biostratigraphic studies of Snorri J-90 were carried out by Gradstein (1976; pers. comm.) and

Barss *et al.* (1979). The former is based on foraminifera; the latter utilizes dinocysts, spores and pollen. Paleoenvironmental interpretations from lithological evaluation were provided by Miller and d'Eon (1987). Moir (1987, 1989) gave the lithostratigraphic breakdown for this well and others on the Labrador Shelf.

At total depth of 3209.55 m, Snorri J-90 is in Precambrian gneiss, which extends up to 3146.8 m. The caved palynomorphs in this interval and those up to 3025.45 m indicate that the oldest rocks in Snorri J-90 are Barremian. The dinocysts include only one taxon, *Balmula tripenta*, which has previously been recorded from Aptian and Albian rocks. But this species can not be relied upon for a precise age, because of the restricted paleoenvironments in which it occurs. Spores and pollen are the most reliable stratigraphic indicators in this interval (3127-3025 m). Species occurring in the sidewall cores include the pollen *Alisporites grandis*, *Callialasporites dampieri*, *Callialasporites obrutus*, *Cerebropollenites mesozoicus* and *Parvisaccites amplius* and the spores *Appendicisporites jansonii*, *Cicatricosporites australiensis* and *Klukisporites areolatus*.

In their biostratigraphic study of Labrador Shelf wells, Gradstein and Williams (1976) defined a *Cerebropollenites mesozoicus* assemblage of Barremian-Aptian age. In Hermine E-94 on the Grand Banks, Williams (2006) considered that *Cerebropollenites mesozoicus* and *Callialasporites dampieri* had their LADs in the Barremian in the Scotian Basin. Thus it seems plausible to regard the interval from 3146.8 to 3025.45 m as Barremian, especially considering the presence of *Balmula tripenta*.

The only published information on the age of the interval 3127 to 3025 m is in Barss *et al.* (1979). These authors considered the sidewall core at 3127 m to be Jurassic-?Barremian and 3037 and 3025 m to be Barremian. These determinations are similar to mine.

I consider the interval 3002.9 to 2962.66 m as Danian, based on the Last Appearance Datum (This - the highest, latest or youngest occurrence of a taxon in a well or a 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 a surface section - is commonly denoted by the acronym FAD) of the dinocyst *Cerodinium diebelii* in the cuttings sample at 2971-2962 m. Williams *et al.* (2004) gave the LAD of *Cerodinium diebelii* as 59.95 Ma in Northern Hemisphere mid latitudes. Gradstein and Ogg (1996) placed the Danian-Selandian boundary at 61 Ma. That the LAD of *Cerodinium diebelii* can be used for the top of the Danian has been confirmed by Nøhr-Hansen (2004) in his palynological analysis of the North Leif I-05 well, which is also in the Hopedale Basin: in this well he marked the LAD of that species at the Danian-Selandian boundary. This is further substantiated in Nøhr-Hansen, Fensome and Williams (pers. comm.) who, in their plots of the LADs and acmes of palynomorph taxa, also placed the LAD of *Cerodinium diebelii* at the top of the Danian.

The occurrence of the dinocyst species *Cerodinium striatum* at 3002-2993 m is further support of a Danian age for this interval. In Gjoa G-37 (Williams, in press c) the LAD of this species is in the Danian.

The attenuated thickness of the Danian and the absence of key index species such as *Trithyrodinium evittii*, *Trithyrodinium "verrucatum"*, *Tanyosphaeridium xanthiopyxides* and *Phelodinium kozlowskii* indicate that only the late Danian is present in Snorri J-90.

Barss *et al.* (1979) included the interval 3002-2962 m in the early Paleocene, which approximates with the Danian. That agrees with my findings in the present study.

From 2941 to 2889.5 m I assign to the Selandian. The sidewall core at 2889 m contains the LAD of

Alisocysta margarita. Williams *et al.* (2004) gave the LAD for *Alisocysta margarita* as 57.35 Ma for Northern Hemisphere mid latitudes. Gradstein and Ogg (1996) placed the Selandian-Thanetian boundary at 57.9 Ma, close enough for me to equate it with the LAD of *Alisocysta margarita*. Nøhr-Hansen, Fensome and Williams (pers. comm.) agree in their chart of LADs for the Paleogene of the Labrador Sea-Davis Strait.

Another diagnostic taxon at 2941-2932 m is *Areoligera* cf. *coronata*. Mudge and Bujak (2001), in a study of the early Paleogene of the Faeroe-Shetland Basin, stated that this taxon is restricted to the Danian and Selandian, whereas *Areoligera gippingensis* is present only in the Thanetian. In Snorri J-90, the occurrence of *Areoligera* cf. *coronata* agrees with the findings of Mudge and Bujak (op. cit.). As with the Danian, the attenuated thickness of the Selandian indicates missing section in Snorri J-90.

I have identified a thick Thanetian section from 2880 to 2520 m. The age is based on the LAD of *Apectodinium augustum* in the sidewall core at 2520 m, *Cerodinium "glabrum"* in the cuttings sample at 2560-2551 m and the LAD of *Cerodinium speciosum* between 2618 and 2609 m. *Apectodinium augustum* has an LAD of 55 Ma in Northern Hemisphere mid latitudes according to Williams *et al.* (2004). This is just 200,000 years off the Thanetian-Ypresian boundary of Gradstein and Ogg (1996). Mudge and Bujak (2001) were even more definitive that the Thanetian/Ypresian boundary is marked by the extinction of *Apectodinium augustum*.

According to Williams *et al.* (1999) *Cerodinium speciosum*, of which *Cerodinium "glabrum"* was formerly a subspecies, has its LAD at 53.96 Ma. Gradstein and Ogg (1996) placed the Thanetian-Ypresian boundary at 54.8 Ma, which is less than one million years older. The youngest Paleocene zone in both Gradstein and Williams (1976) and the Bujak Davies Group (1987) was the *Cerodinium speciosum* Zone. An identical LAD was assigned by Nøhr-Hansen, Fensome and Williams (pers. comm.), who also consider *Cerodinium "glabrum"* to have its LAD at the Thanetian-Ypresian boundary. Further confirmation comes from Nøhr-Hansen (2004), who placed the LAD of *Cerodinium "glabrum"* (as *Cerodinium speciosum* subsp. *glabrum*) in the late Thanetian. I take the above evidence as confirmation that the LAD of *Cerodinium glabrum* occurs at the top of the Thanetian.

Barss *et al.* (1979) assigned the interval from 2915 to 2499 m Snorri J-90 to the late Paleocene. If I regard the Selandian and Thanetian as the late Paleocene, I can assign from 2941 to 2520 m to this age. The thicknesses determined by me show close agreement with those of Barss *et al.* (op. cit.).

I am including from 2499 m (a conventional core) to the cuttings sample at 2450-2441 m in the basal Eocene. The section includes the LADs of *Apectodinium parvum*, *Dracodinium condylos* and *Hystrichostrogylon mempranophorum* at 2450-2441 m. Williams *et al.* (1999) placed the LAD of *Apectodinium parvum* at 54.31 Ma and the LAD of *Dracodinium condylos* at 51.5 Ma for Northern Hemisphere mid latitudes. Nøhr-Hansen, Fensome and Williams (pers. comm.) recorded the LAD of *Apectodinium parvum* just above the Thanetian/Ypresian boundary with that for *Dracodinium condylos* considerably younger.

This suggests the LAD of *Dracodinium condylos* is depressed in Snorri J-90. Confirmation is provided by Nøhr-Hansen, Fensome and Williams (pers. comm.). Their bioevents chart for the Eocene placed the LAD of *Komewuia? "unicornus"* at the same horizon. In Snorri J-90, the LAD of *Komewuia? "unicornus"* occurs in the cuttings sample at 2368-2359 m. Thus, I feel justified in concluding that the LAD of *Dracodinium condylos* is below its normal occurrence in Snorri J-90.

The remaining Ypresian extends from the sidewall core at 2420 m to the cuttings sample at 2258-2249 m. I base this on the LAD of *Charlesdownia columna* and *Diphyes brevispinum*. To understand the

stratigraphic significance of *Charlesdowniea columna* and *Diphyes brevispinum*, it is necessary to review published zonations. The first is Bujak (1994), who erected eight zones and 23 subzones spanning the Eocene. In the Ypresian, in ascending order, he recognized the *Hystrichosphaeridium tubiferum* acme Zone, the *Areoligera medusettiformis* acme Zone, and the *Eatonicysta ursulae* Zone, which extended into the Lutetian. The other Lutetian zones, from oldest to youngest, were the *Diphyes ficusoides* Zone, the *Systematophora placacantha* abundance Zone and the *Diphyes colligerum* Zone. In each of the two remaining stages, Bujak recognized single zones, the *Heteraulacacysta porosa* Zone in the Bartonian and the *Areosphaeridium diktyoplokum* Zone in the Priabonian.

Significant events in the Ypresian were the LADs of *Dracodinium condylos* in the *Areoligera medusettiformis* acme Zone and the simultaneous LADs of *Charlesdowniea columna* and *Diphyes brevispinum* in the *Eatonicysta ursulae* Zone and just below the Ypresian-Lutetian boundary.

Nøhr-Hansen (2003a) defined seven intervals in the Ypresian of offshore western Greenland. In ascending order the intervals are E1, the *Cerodinium dartmoorium-Deflandrea oebisfeldensis* interval; E2a, the *Wetzelilla astra-Fibrocyta bipolaris* interval; E2b, the *Dracodinium condylos* interval; E2c, the *Areoligera medusettiformis* interval; E3a, the *Eatonicysta furensis* interval; E3b, the *Charlesdowniea columna* interval; and E3c-d, the *Eatonicysta ursulae* interval. The top of the Ypresian was considered to be within the *Eatonicysta ursulae* interval. Another species for which Nøhr-Hansen (2003a) provides LAD data is *Diphyes brevispinum*, which has the same LAD as *Charlesdowniea columna*.

Most of the species that Nøhr-Hansen (2003a) recognized as having LADs in the Ypresian are absent in Snorri J-90. But there are a few that allow correlation. As noted earlier, *Areoligera gippingensis* (as *Areoligera* cf. *medusettiformis*) has its LAD at 2304 m. And *Charlesdowniea columna* and *Diphyes brevispinum* have their LADs at 2249 m. Since Nøhr-Hansen (2003a) equated these two species with the top of his *Charlesdowniea columna* interval and close to the top of the Ypresian, I place the Ypresian-Lutetian boundary at 2249 m in Snorri J-90.

Nøhr-Hansen, Fensome and Williams (pers. comm.) in their Ypresian bioevents chart, include several of the taxa that occur in Snorri J-90. In stratigraphic order from oldest to youngest these include *Apectodinium parvum*, *Dracodinium condylos* and *Komewuia?* "*unicornis*" (noted earlier); and *Apectodinium* "*fleximorphum*", *Charlesdowniea columna* and *Diphyes brevispinum*.

A comparison of the two data sets indicates closer agreement than with Nøhr-Hansen (2003a). This reflects primarily the larger number of species occurring together. But there is general agreement in the sequencing. This is shown by listing the species in the order given above (that is from oldest to youngest) and annotating in parentheses the LAD depth in Snorri J-90: *Apectodinium parvum* (2450-2441 m), *Dracodinium condylos* (2450-2441 m), *Komewuia?* "*unicornis*" (2368-2359 m), *Apectodinium* "*fleximorphum*" (2313-2304 m), *Charlesdowniea columna* (2258-2249 m) and *Diphyes brevispinum* (2258-2249 m).

The high numbers of *Azolla*, which occur in other Labrador Sea-Davis Strait wells such as Gjoa G-37 and Hekja O-71 (e.g. Williams, in press c,d), are absent from Snorri J-90. In the samples examined I have found only three specimens, the highest at 1947 m in the Bartonian. Either that part of the Ypresian to Lutetian section is missing or there was no influx of *Azolla*. I prefer the former explanation because of the obvious gaps in the Ypresian-Lutetian sequences in Snorri J-90.

I include the interval 2240 to 2072 m in the Lutetian: both samples are sidewall cores. The top of the Lutetian is based on the LAD of *Diphyes colligerum*, following the determination of Bujak (1994) and Nøhr-Hansen, Fensome and Williams (pers. comm.), who placed its LAD at the Lutetian-Bartonian

boundary. Bujak (1994) presented a four-fold subdivision of the Lutetian. In ascending order, the divisions were: the *Eatonicysta ursulae* Zone of which only one subzone of the four was considered Lutetian; the *Diphyes ficusoides* Zone with four subzones; the *Systematophora placacantha* Zone with two subzones; and the *Diphyes colligerum* Zone with three subzones.

Other dinocyst taxa with LADs in the Lutetian of Snorri J-90 include *Glaphyrocysta divaricata* (2240 m), *Eatonicysta ursulae* (2203-2194 m), *Achilleodinium biformoides* (2161 m), *Dapsilidinium simplex* (2161 m), *Lingulodinium funginum* (2121-2112 m) and *Deflandrea* cf. *phosphoritica* Williams and Bujak (1977) and *Hystrichokolpoma incertum* (both at 2072 m).

The LAD of *Eatonicysta ursulae* above the Ypresian-Lutetian boundary accords with the findings of Bujak (1994) and Nøhr-Hansen (2004).

Dinocysts are rare in the post Lutetian sequences, so I relied increasingly on stratigraphic ranges of pollen and spores. The pollen indicate that Bartonian sediments extend from 2039 to 1865 m, with the top being based on the LAD of *Pistillipollenites mcgregori*, *Cicatricosporites auritus*, *Jussiaea oculus* and *Extratropopollenites*. In the Labrador Shelf well Gilbert F-53, Williams (in press b) correlated the LAD of *Cicatricosporites auritus* with other pollen and dinocysts whose LADs correspond to the top of the Bartonian. In Hekja O-71, Williams (in press d) noted that the LADs of *Cicatricosporites auritus* and *Extratropopollenites* equate with the Bartonian/Priabonian boundary. In this respect he is following Nøhr-Hansen, Fensome and Williams (pers. comm.), who consider the LAD of *Cicatricosporites auritus* to be just below the top of the Bartonian and the LADs of *Pistillipollenites mcgregori*, *Jussiaea oculus* and *Extratropopollenites* to mark the Bartonian/Priabonian boundary.

The thickness of the two middle Eocene stages is roughly equal in Snorri J-90. This is surprising since the Lutetian lasted almost eight million years from 49 to 41.3 Ma, whereas the Bartonian lasted for 4.3 million years from 41.3 to 37 Ma. From this and the gaps in the palynomorph record for the Lutetian, I believe that much of the stage is missing. This conclusion is substantiated by the density log, which shows a major change at about 2161 m. That also might explain the presence of reworked species in the sidewall core at that depth.

I have included the interval 1847 to 1591 m in the Priabonian, basing the top on the LAD of *Trithyrodinium?* "*circellum*" and *Schematophora speciosa* in the cuttings sample at 1597-1591 m. Williams (in press c) stated that the LAD of *Trithyrodinium?* "*circellum*" is a consistent Priabonian marker according to Nøhr-Hansen, Fensome and Williams (pers. comm.), who have recorded it in several Labrador Sea wells. *Schematophora speciosa*, according to Williams *et al.* (1999), has a stratigraphic range of 36 to 35.35 Ma in Southern Hemisphere mid latitudes. Thus, its youngest age is early Priabonian. Based on this I have concluded that the late Priabonian is missing in Snorri J-90. Surprisingly, dinocysts are more diverse and abundant in the Priabonian than in the Bartonian.

Other species with LADs in the Priabonian of Snorri J-90 include *Lentinia serrata* (1792-1783 m), *Phthanoperidinium multispinum* (1792-1783 m), *Cicatricosporites "labatus"* (1737-1728 m), *Rhombodinium draco* (1682-1673 m, common), "*Tallidinium coleothryptum*" (1597-1591 m, frequent), *Phthanoperidinium levimurum* (1682-1673 m), *Baltisphaeridium "scalenofurcatum"* (1597-1591 m).

Williams (2003, in press a,b) considered the LAD of *Phthanoperidinium multispinum* to mark the top of the Priabonian in the Skua E-41 on the Grand Banks, in the Bjarni O-82 in the Hopedale Basin, and in Gilbert F-53 in the Saglek Basin, respectively.

Comparison of the dinocyst LADs in Snorri J-90 with those of Nøhr-Hansen, Fensome and Williams

(pers. comm.) seems to confirm the hiatus at the top of the Priabonian. In their study Nøhr-Hansen, Fensome and Williams (pers. comm.) show the LADs of *Phthanoperidinium levimurum*, *Rhombodinium draco* and "*Tallidinium coleothryptum*" occur below the top of the Priabonian. Williams *et al.* (2004) gave the LAD of *Rhombodinium draco* as 30.5 Ma in Northern Hemisphere mid latitudes. Gradstein and Ogg (1996) placed the Priabonian-Rupelian boundary at 33.7 Ma and the Rupelian-Chattian boundary at 28.5 Ma. Thus the LAD of *Rhombodinium draco* is within the Rupelian. In Snorri J-90, however, the last common occurrence of this taxon seems to be in the Priabonian. The four species with LADs at the top of the stage are rare or absent in Snorri J-90, so cannot be used to differentiate the Priabonian.

How do my Eocene age determinations in Snorri J-90 compare with those of Barss *et al.* (1979)? These authors determined the following: 2497-2293 m, early Eocene; 2258-1947 m, middle Eocene; 1929-1645 m, late Eocene. I considered 2450-2249 m Ypresian, 2240-2072 m Lutetian, 2039-1865 m Bartonian, and 1847-1591 m Priabonian. The only major disagreement is placement of the middle late Eocene boundary. Barss *et al.* (1979) placed this about 100 m lower than I did. That part of the section contains sparse palynomorph assemblages.

The Oligocene appears to be incomplete in Snorri J-90. I could only recognize early Oligocene or Rupelian, which extends from 1572 to 1371 m. There are few dinocysts, the top being picked on the LAD of the spore *Zlivisporis*. Williams (in press c) placed the LAD of this species at the top of the Rupelian. Another taxon that has its LAD in the Rupelian is *Sequoapollenites*, the redwood tree.

In the interval 1353-1261 m, which I regard as early to middle Miocene, there are no age-diagnostic dinocysts and few pollen and spores. The most significant event is the LAD of *Tiliaepollenites* at 1271-1262 m. Williams (1975), in his zonation for the Cenozoic of the Scotian Basin, placed the LAD of *Tiliaepollenites* sp. (as *Bombacacidites* sp.A) in his *Pentadinium laticinctum* Zone, which was mid Miocene. On the Labrador Shelf, Williams and Bujak (1977) recorded this taxon in the *Operculodinium centrocarpum* assemblage of possible mid to late Miocene age. Williams (in press b) gave the LAD of *Tiliaepollenites* as early to mid Miocene marker in the Gilbert F-53 well, Saglek Basin.

Caryapollenites and *Quercoidites* are common to abundant in the early to mid Miocene of Snorri J-90. Other pollen include *Retitricolpites georgensis* and *Retitricolpites maximus*.

According to Gradstein and Ogg (1996), the early to mid Miocene extended from 23.8 to 11.2 Ma. The estimated thickness in Snorri J-90 is less than 100 m. I assume from this reduced thickness that much of the early to mid Miocene is absent.

The late Miocene appears to represent a more complete section, extending from at least 1161 to 1005 m. The two age diagnostic dinocysts are *Dapsilidinium pseudocolligerum*, with a LAD at 1161-1152 m, and *Selenopemphix crenata*, with a LAD at 1014-1005 m. Williams *et al.* (1999) cited the LAD of *Dapsilidinium pseudocolligerum* as 7.1 Ma, that's the top of the Tortonian. Matsuoka and Bujak (1988) described *Selenopemphix crenata* from the late Miocene of the Bering Sea. This supports my interpretation of a late Miocene age for the interval 1161-1005 m in Snorri J-90.

In Snorri J-90, I include the interval from 987 to 810 m in the Pliocene and 789-384 m in the Plio-Pleistocene. I assume that the frequent occurrence of the fern spore *Osmundacidites* and the LADs of *Caryapollenites* and frequent *Taxodiaceapollenites* denote the top of the Pliocene. However, more data are needed to test this hypothesis.

The Plio-Pleistocene section from 789 to 384 m (the highest sample) contains what appear to be reworked specimens of Cretaceous and early Tertiary dinocyst species. These include *Spongodinium*

delitiense, *Chatangiella tripartita*, *Chatangiella victoriensis*, "*Talladinium coleothryptum*", *Wetzeliiella symmetrica* and *Circulodinium distinctum*. Reworked pollen include *Corollina torosus* and *Rugubivesiculites reductus*. One unusual aspect is the degree of reworked acritarchs, with *Veryhachium europeum*, *Veryhachium formosum*, *Veryhachium trispinosum* and *Multiplicisphaeridium* being present. This indicates major erosion and transportation of probably early Paleozoic rocks.

Barss *et al.* (1979) also recognized later epochs of the Cenozoic in Snorri J-90. These authors provided the following breakdown: 1600-1591 m, early Oligocene; 1572-1536 m, early Miocene; 1517-1295 m, mid to late Miocene; and 1271-384 m, Plio-Pleistocene. Barss *et al.* (1979) based their early Oligocene determinations on the LAD of *Charlesdownieae* cf. *coleothrypta*. This appears to be "*Talladinium coleothryptum*", which I have found has its LAD in the Priabonian. Such an interpretation would move the top of the Priabonian to 1597-1591 m, which agrees with my findings.

Barss *et al.* (1979) did not recognize early Oligocene between 1572 and 1371 m, because they were unaware of the stratigraphic significance of *Zlivisporis*. Likewise, placement of the late Miocene top is difficult in the absence of *Selenopemphix crenata*.

In Snorri J-90, reworked and caved material is often informative. For example, the presence of *Impagidinium victorianum* in the lowest sample at 3209-3200 m, indicates that Maastrichtian should be present higher in the well. Reworked Cretaceous dinocysts in the Thanetian and Priabonian to Pliocene presumably represent erosion of rocks of this age, with subsequent transportation into the basin. One surprising aspect is the minimal reworking of early Cenozoic dinocysts. This may reflect the general paucity of the assemblages or, more probably, the abrasive nature of the later Cenozoic clastics during deposition.

Paleoenvironments

The use of palynomorphs to determine paleoenvironments, especially using cuttings from wells, has rarely been attempted. One of the problems is that dinocysts represent the encysted stage of the motile dinoflagellate, which is a planktonic organism. Consequently, it has generally been 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 distinctive environmental preferences, such as non-marine, lagoonal, coastal, inshore, more offshore and open ocean settings. This means that certain assumptions can be made, which lead to meaningful 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 relatively sophisticated paleoenvironmental model for interpreting dinocyst distribution patterns. 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 findings soon highlighted the need for both qualitative and quantitative data to obtain predictable and reproducible results. Thus the model presented in Brinkhuis (1992), which was a major advancement in dinocyst paleoenvironmental studies, must be keyed to quantitative data.

Brinkhuis (op. cit.), in his study of the Priabonian, depicted 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 Snorri J-90. However, I have also utilized quantitative data for the dinocysts and for spores and pollen. Paleoenvironmental curves for wells are fraught with dangers. The most obvious is having to rely on cuttings samples rather than the rarely available conventional or sidewall core samples. Quantitative and qualitative data are both suspect when based on cuttings, primarily because of caving and uncertainty

over the true position of the sample, since cuttings represent a composite rather than a precise depth.

Despite the above drawbacks, cuttings do show quantitative and qualitative trends that allow interpretation of the paleoenvironments. In Snorri J-90, I used quantitative data 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 changes. The paleoenvironmental curve, representing my interpretation based on palynomorph fluctuations, is included in Figure 1. I have not included the spore-pollen to dinocyst ratio, which provides useful information that I have summarized in the text.

In Snorri J-90, the paleoenvironments are variable, running from non-marine (occasionally) to open ocean (bathyal). But there are distinct trends. Trends can be misleading, however, especially in sections through igneous or metamorphic sequences. The bottom 62 m are in Precambrian gneiss so the lowest viable sample is at 3127 m. Fortunately this is a sidewall core. Spores and pollen dominate the palynomorph assemblages in this sample, but there are a few specimens of the dinocyst *Balmula tripena*. This species generally occupies lacustrine or lagoonal environments, so it is reasonable to assume a freshwater to marginal marine paleoenvironment at 3172 m in Snorri J-90.

The cuttings sample from 3063-3054 m contains a single *Vesperopsis*, indicating a continuation of the freshwater to marginal marine setting. Between 3037 and 3025 m, however, the paleoenvironment is non-marine. The two samples which are sidewall cores, contain an abundance of pollen and spores but no dinocysts.

Miller and d'Eon (1987) determined the paleoenvironments in Snorri J-90 from a lithological study. They considered the rocks from 3149-3064 m to be non-marine, being deposited in a meandering fluvial floodplain. From 3064-3024 m represented a non-marine, floodplain to swamp environment. Thus, Miller and d'Eon (1987) came to similar conclusions to mine for the prevailing paleoenvironments during deposition of the Barremian rocks.

Collation of the data of Miller and d'Eon (1987) and the Bujak Davies Group (1987) for the interval 3040 to 460 m resulted in 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. In view of this, I shall use the bar-graph in Bell (1989) to provide the comparison with my paleoenvironmental data for the interval 3040 to 460 m (Figure 2).

At 3002-2993 m in the Danian, there is a strong influx of dinocysts with *Areoligera gippingensis* being common. Other dinocyst include *Cerodinium* and *Cordosphaeridium gracile*, suggesting an inner neritic setting. In the Thanetian, from 2971 to 2578 m the paleoenvironment varies from predominantly middle to sometimes outer shelf, reflected by the increase in relative abundances of *Pinuspollenites* and the lowered counts for most of the dinocyst species. I interpret the palynomorph compositions to be representative of the oligotrophic zone that is present between the shelf edge and the inner neritic zone. The absence of protoperidinioid cysts in the Paleocene agrees with this interpretation. Protoperidiniaceans are heterotrophic as opposed to gonyaulacaleans and presumably other peridiniaceans including *Cerodinium* and *Deflandrea*. Since protoperidiniaceans tend to be abundant in zones of high productivity, it follows that their productivity was low in the vicinity of Snorri J-90 during this interval.

The high concentrations of *Areoligera gippingensis* that occur in Gjoa G-37 and Hekja O-71 (Williams, in press c,d) are not present in Snorri J-90. This could either reflect different environments or missing

section. I consider it probably reflects a different environment, since *Areoligera* is present from 2313-2304 m (within the Ypresian) to 3002-2993 m. Sixteen specimens are present in the lower sample but concentrations never approach those seen in other wells (e.g. Williams, in press b).

I interpret the interval from 2551-2468 m as a continuing middle shelf setting (Figure 2) but there is a significant drop in relative abundances of dinocysts, which form only 1 to 2% of the total palynomorph assemblages. Bell (1989) interpreted the interval from about 3025 to 2700 m as inner to middle neritic. From 2700 to about 2620 m was shown as neritic, possibly outer, and from 2620 to just above 2550 m as middle to outer neritic. This might explain the unusual dinocyst counts.

My interpretation of Thanetian paleoenvironments is that they were remarkably constant. This compares with the conclusions of Bell (1989), who determined that Thanetian paleoenvironments ranged from inner to outer neritic.

There is a marked change to outermost shelf to bathyal from 2441 to 2072 m (Figure 2), denoted by the consistent presence of *Impagidinium* and several specimens of *Hystrichokolpoma* at 2072 m.

Impagidinium is generally considered to be an open ocean dweller (e.g. Brinkhuis, 1992; Sluijs *et al.*, 2005); its occurrence in other east coast offshore wells (e.g. Williams, in press c) confirms this. Another possible deeper water indicator is *Minisphaeridium*, which occurs in several samples. Thus during most of the Ypresian and much of the Lutetian, deep water conditions prevailed in the Snorri J-90 area.

Gradstein, Helenes, Miller and Moir *in* Bell (1989), in their appraisal of Snorri J-90, interpreted the paleoenvironments as follows: 2500 to 2300 m, outer neritic to upper bathyal, 2300 to 2100 m, upper to lower bathyal; and 2100 to about 1920 m, outer neritic to upper bathyal. I agree with these conclusions for the interval 2490 to 2072 m but find that the palynomorph assemblages indicate shallowing to middle shelf at about 2100 m. Such conditions persisted up to 1737-17728 m in the early Priabonian.

At 1710-1701 m, there is a change to marginal marine to inner shelf paleoenvironments, which persist throughout most of the late Cenozoic. The dinocyst assemblages are generally of low species diversity and low individual counts. But *Rhombodinium draco* is frequent in the sample 1682-1673 m. *Spiniferites* is rarely present, indicating that the paleoenvironments were restricted. In some of the samples, such as at 1572-1563 m and 1490-1481 m, there are high concentrations of *Quercoidites*. These I assume indicate closer-to-shore settings.

In the upper part of Snorri J-90, between 810-536 m, non-marine to marginal marine conditions predominate, with in situ dinocysts rarely being present.

The results of Gradstein, Helenes, Miller and Moir *in* Bell (1989) show parallels. These authors provided the following breakdown: about 1920-1700 m, outer shelf to inner shelf; 1700-1380 m, middle to inner shelf; and 1380 to 460 m, inner shelf to transitional. Transitional equates with my category "coastal or marginal marine".

The general trend in my paleoenvironmental curve agrees with that of Gradstein, Helenes, Miller and Moir *in* Bell (1989) but there are some minor differences in interpretations of water depths. However, the results are encouraging in showing the potential of palynomorph assemblages for determining paleoenvironments.

Correlation of Palynology and Lithostratigraphy

The lithostratigraphy of Snorri J-90, as interpreted by Moir (1989), is presented in Figure 2. Moir (op. cit.) noted that the well encountered an unnamed Precambrian gneiss from 3209.9 to 3148.5 m. The

gneiss is overlain by rocks of the Snorri Member of the Bjarni Formation that occupy the interval 3148.5-3027 m. Umpleby (1979) formally proposed the Bjarni Formation for a sequence of sandstones, conglomerates, calcareous shales and thin coal seams in the Hopedale Basin. He gave the ages as Barremian to early Cenomanian. McWhae *et al.* (1980) restricted the age to Barremian-Albian and interpreted some of the sediments as being deposited in channels, by braided streams, and in swamps.

Umpleby (1979) proposed the term Snorri Member of the Bjarni Formation for a sequence of silty shales, coal seams and sandstones in some Labrador Shelf wells. He did not specify a type section but said that the age of the upper part was Valanginian-Barremian. Barss *et al.* (1979) gave the age of the uppermost 10 m in Snorri J-90 as Barremian. McWhae *et al.* (1980) designated the type section as 3061-3027 m in Snorri J-90. These authors did not consider the Snorri to be distinguishable regionally. Based on the palynomorphs I recorded, the age of the interval 3127-3025 m must be Barremian. At this stage of our knowledge it is not possible to determine if the Snorri Member could be older.

Moir (1989) assigned the interval 3027-2816 m to the Markland Formation. The Markland Formation was formally proposed by McWhae *et al.* (1980) for a sequence of shales, siltstone, sandstone and thin dolomite limestone of Cenomanian-Turonian to Danian age on the Labrador Shelf. According to McWhae *et al.* (1980), the Markland Formation was deposited in inner neritic to bathyal environments.

McWhae *et al.* (1980) and McWhae (1981) recognized five regional unconformities in the Labrador Sea. These were from oldest to youngest: the Labrador Unconformity; the Avalon Unconformity; the Bylot Unconformity; the Baffin Bay Unconformity; and the Beaufort Unconformity. The Avalon Unconformity separates the Markland Formation from the underlying Bjarni Formation or older rocks: the Bylot Unconformity or Disconformity separates the Markland from the overlying Cartwright Formation.

In Snorri J-90, I determined the age of the Markland Formation as Danian to early? Thanetian. Although I extend the age upwards, there is some agreement with the age of this unit in other wells. For example in Bjarni O-82, the Markland in its uppermost part is Selandian (Williams, in press a). The environment of deposition in Snorri J-90 is inner to mainly outer shelf.

The Markland is overlain by the Cartwright Formation in Snorri J-90. Moir (1989) included in the Cartwright the interval 2816-2515 m. Umpleby (1979) defined the Cartwright Formation as mudstone grading to silicious shale and considered it to have been 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 Snorri J-90, the environment of deposition for the Cartwright Formation is middle shelf. This does not agree with my results in Bjarni O-82 (Williams, in press a) and Gilbert F-53 (Williams, in press b) where the paleoenvironments are outer shelf to bathyal. The age of the Cartwright in Snorri J-90 is Thanetian. McWhae *et al.* (1980) stated that the formation was of mid Paleocene to early Eocene age.

According to Moir (1989), the Cartwright is overlain by the "Upper" Gudrid Formation in Snorri J-90. Umpleby (1979) introduced the term Gudrid Sand Member of the Cartwright Formation for a quartz, feldspar sand. McWhae *et al.* (1980) renamed the unit the Gudrid Formation and considered it a lateral equivalent of the Cartwright Formation. The age was given as Paleocene-early Eocene.

Moir (1989) placed the interval from 2515 to 2491 m in Snorri J-90 in the Gudrid Formation. This interval is basal Ypresian and the paleoenvironment middle shelf.

Overlying the Gudrid is the Kenamu Formation, which extends from 2491 to 1715 m and includes the

Leif Member between 1886 and 1815 m. McWhae *et al.* (1980) defined the Kenamu as an Eocene shale, siltstone, sandstone sequence, which is in part glauconitic and calcareous. The sediments were deposited in outer shelf to upper slope environments. Barss *et al.* (1979) gave an Eocene to possibly earliest Oligocene age for the formation.

The age of the Kenamu Formation in Snorri J-90 is basal Ypresian to early Priabonian. The paleoenvironments are bathyal to outer neritic, with significant shallowing at the top.

The Leif Member was erected by Umpleby (1979), who included it in the Saglek Formation. McWhae *et al.* (1980) considered it a member of the Kenamu Formation. The Leif Member is generally fine grained quartzose sandstone with glauconite, siltstone and mudstone. Barss *et al.* (1979) considered the member to be mid to late Eocene. The Leif Member is Bartonian to early Priabonian in Snorri J-90 and was deposited in an outer neritic environment.

In Snorri J-90, the Kenamu Formation is overlain by the Mokami Formation, which extends from 1715 to 997 m (Moir, 1989). McWhae *et al.* (1980) defined the Mokami as a predominantly claystone and soft shale unit. According to these authors, the age was possibly latest Eocene to mid Miocene: the paleoenvironment was neritic. The age of the Mokami is early Priabonian to late Miocene in Snorri J-90: the paleoenvironments were inner shelf to very occasionally non-marine.

McWhae *et al.* (1980) and McWhae (1981) stated that the Beaufort Unconformity separates the Mokami Formation from the overlying Saglek Formation of Miocene to Pleistocene age. Moir (1989) assigned the interval 997-267 m in Snorri J-90 to the Saglek. The highest sample I analyzed was from 393-384 m. Based on the palynomorph assemblages, I determined that the Saglek is Plio-Pleistocene in Snorri J-90, with 987-810 m being Pliocene. This age is much more restrictive than in some other Labrador Shelf wells such as Bjarni O-82 and Gilbert F-53 (Williams, in press a,b), where the Saglek is early Oligocene to late Miocene.

Age diagnostic palynomorphs in the Saglek of Snorri J-90 include *Osmundacidites* and *Taxodiaceapollenites*, both of which are frequent in the Pliocene. *Ambrosia* and *Tsugaepollenites* occur in the Plio-Pleistocene.

Summary

The Barremian rocks in Snorri J-90 are some of the oldest sedimentary rocks found on the Labrador Shelf. Only one other well, Bjarni O-82, has rocks of an equivalent age. Age control in the Barremian is based, almost exclusively, on spores and pollen.

In Snorri J-90 the Barremian Bjarni Formation is underlain by Precambrian gneiss from which it is separated by the Labrador Unconformity. Overlying the Bjarni are Paleocene rocks of the Markland and Cartwright formations. Following McWhae *et al.* (1980) and McWhae (1981), the hiatus between the Barremian and Paleocene would be the Avalon Unconformity.

Cenozoic sequences in Snorri J-90 are incomplete with inferred missing section in the Lutetian, late Oligocene or Chattian and Miocene. Dinocysts are most abundant in the Ypresian and Lutetian. Spores and pollen are common throughout but dominate Bartonian to Plio-Pleistocene assemblages. By comparing the LADs of these spores and pollen in Snorri J-90, Bjarni O-82 (Williams, in press a), Gilbert F-53 (Williams, in press b), I can include them on the bioevents chart that Henrik Nøhr-Hansen, Rob Fensome and I have compiled for the Labrador Sea Tertiary.

The sediments in Snorri J-90 were deposited in non-marine to oceanic (bathyal) environments, with

deeper water settings in the Ypresian-Lutetian. To determine paleoenvironments, I used qualitative and quantitative data, including spore/pollen:dinocyst ratios. Although the results are encouraging, I need to test them against other Labrador Shelf wells, especially in the Hopedale Basin. This should permit refinement of the paleoenvironmental model I am developing and add another useful parameter to our understanding of the geological evolution of the Labrador Sea.

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Figures

Figure 1 Location of wells discussed in text.

Figure 2 Stratigraphy and paleoenvironments of Eastcan *et al.* Snorri J-90.

Appendix A

Palynomorph taxa recorded in Snorri J-90. References for dinocyst citations are from Fensome and Williams (2004). Informal taxa will be illustrated in one of the proposed palyatlases.

Achilleodinium biformoides (Eisenack, 1954b) Eaton, 1976
Achomosphaera "digitatus"
Achomosphaera ramulifera (Deflandre, 1937b) Evitt, 1963
Alisocysta circumtabulata (Drugg, 1967) Stover and Evitt, 1978
Alisocysta margarita (Harland, 1979a) Harland, 1979a
Alisporites grandis (Cookson, 1953) Dettmann, 1963
Alnipollenites spp.
Alterbidinium? bicellulum (Islam, 1983b) Lentin and Williams, 1985
Alterbidinium "hyporotundum"
Ambrosia
Apectodinium augustum (Harland, 1979c) Lentin and Williams, 1981
Apectodinium "fleximorphum"
Apectodinium parvum (Alberti, 1961) Lentin and Williams, 1977b
Appendicisporites jansonii Pocock, 1962
Araucariacites australis Cookson, 1947
Areoligera cf. *coronata* (O. Wetzel, 1933b ex Deflandre, 1937b) Lejune-Carpentier, 1938a
Areoligera gippingensis Jolley, 1992
Areoligera cf. *senonensis* Lejeune-Carpentier, 1938a
Azolla spp.
Baltisphaeridium "scalenoformatum"
Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961
Callialasporites monoalaporus Sukh Dev, 1961
Callialasporites obrutus Norris, 1969
Callimothallus sp.
Carpatella sp.
Caryapollenites imparalis Nichols and Ott, 1978
Caryapollenites inelegans Nichols and Ott, 1978
Caryapollenites prodromus Nichols and Ott, 1978
Caryapollenites spp.
Castaneapollenites sp.
Cerebropollenites mesozoicus (Couper, 1958) Nilsson, 1958
Cerodinium denticulatum (Alberti, 1959b)
Cerodinium diebelii (Alberti, 1959b) Lentin and Williams, 1987
Cerodinium "glabrum"
Cerodinium speciosum (Alberti 1959b) Lentin and Williams, 1987
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 ditissima (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella tripartita (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Chatangiella victoriensis (Cookson and Manum, 1964) Lentin and Williams, 1976
Cicatricosisporites australiensis (Cookson, 1953) Potonié, 1956
Cicatricosisporites hughesii Dettmann, 1963
Cicatricosisporites labatus
Cicatricosisporites sp.
Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986

Circulodinium paucispinum (Davey, 1969a) Fauconnier in Fauconnier and Masure, 2004
Cleistosphaeridium ancyreum (Cookson and Eisenack, 1965a) Eaton et al., 2001
Cleistosphaeridium diversispinosum Davey et al., 1966
Cleistosphaeridium diversispinosum subsp. "*brevispinum*"
Cleistosphaeridium polypetellum (Islam, 1983) Stover and Williams, 1995
Comasphaeridium cf. *cometes*
Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978
Contignisporites glebulentus Dettmann, 1963
Cordosphaeridium cantharellus (Brosius, 1963) Gocht, 1969
Cordosphaeridium "*delimurum*"
Cordosphaeridium fibrospinosum Davey and Williams, 1966b
Cordosphaeridium gracile (Eisenack, 1954b) Davey and Williams, 1966b
Corollina torosus (Reissinger) Klaus, 1960
Cupaneidites sp.
Cyclonephelium vannophorum Davey, 1969a
Dapsilidinium pseudocolligerum (Stover, 1977) Bujak et al., 1980
Dapsilidinium? *simplex* (White, 1842) Bujak et al., 1980
Deflandrea cf. *phosphoritica* sensu Williams and Bujak, 1977
Deflandrea granulata Menéndez, 1965
Deflandrea phosphoritica Eisenack, 1938b
Densosporites sp.
Dinogymnium heterocostatum (Deflandre, 1936b) Evitt et al., 1967
Diphyes brevispinum Bujak, 1994
Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965a
Diphyes ficusoides Islam, 1983b
Dracodinium condylos (Williams and Downie, 1966b) Costa and Downie, 1979
Eatonicysta sequestra Stover and Williams, 1995
Eatonicysta ursulae (Morgenroth, 1966a) Stover and Evitt, 1978
Elytrocysta sp.
Eocladopyxis "brevispinosa"
Eocladopyxis peniculata Morgenroth, 1966a
Eocladopyxis "verrucosa"
Extratropipollenites spp.
Fibrocysta sp.
Foveotriletes sp.
Glaphyrocysta divaricata (Williams and Downie, 1966c) Stover and Evitt, 1978
Glaphyrocysta exuberans (Deflandre and Cookson, 1955) Stover and Evitt, 1978
Glaphyrocysta intricata (Eaton, 1971) Stover and Evitt, 1978
Glaphyrocysta pastielsii (Deflandre and Cookson, 1955) Stover and Evitt, 1978
Gramineae sp.
Heteraulacacysta pustulata Jan du Chêne and Adediran, 1985
Heterosphaeridium difficile (Manum and Cookson, 1964) Ioannides, 1986
Homotryblium abbreviatum Eaton, 1976
Hystrichokolpoma eisenackii Williams and Downie, 1966a
Hystrichokolpoma globulus Michoux, 1985
Hystrichokolpoma? *incertum* Michoux, 1985
Hystrichokolpoma salacia Eaton, 1976
Hystrichosphaeridium salpingophorum Deflandre, 1935
Hystrichosphaeridium tubiferum subsp. "*perforatum*"
Hystrichostrogylon membraniphorum Agelopoulos, 1964

Ilexpollenites sp.
Impagidinium aculeatum (Wall, 1967) Lentin and Williams, 1981
Impagidinium maculatum (Cookson and Eisenack, 1961b) Stover and Evitt, 1978
Impagidinium patulum (Wall, 1967) Stover and Evitt, 1978
Impagidinium victorianum (Cookson and Eisenack, 1965a) Stover and Evitt, 1978
Impagidinium sp.
Inaperturopollenites #EA Davies, 1987
Isabelidinium bakeri (Deflandre and Cookson, 1955) Lentin and Williams, 1977a
Juglanspollenites spp.
Jussiaea oculus
Klukisporites areolatus Singh, 1971
Komewuia? "*unicornis*"
Laciniadinium sp.
Lentinia serrata Bujak in Bujak et al., 1980
Lingulodinium "brevispinosum"
Lingulodinium funginum (Morgenroth, 1966a) Islam, 1983b
Liquidamberpollenites sp.
Maceopolipollenites rotundus Leffingwell, 1971
Melitasphaeridium sp.
Membranilarnacia compressa Bujak, 1994
Membranophoridium aspinatum Gerlach, 1961
Microdinium sp.
"Minisphaeridium fibrospinosum"
"Minisphaeridium minimum"
Momipites sp.
Momipites wyomingensis Nichols and Ott, 1978
Multiplicisphaeridium sp.
Nyssapollenites spp.
Odontochitina costata Alberti, 1961
Oligosphaeridium albertense (Pocock, 1962) Davey and Williams, 1969
Osmundacidites sp.
Palaeocystodinium golzowense Alberti, 1961
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967b
Paralecaniella indentata (Deflandre and Cookson, 1955) Cookson and Eisenack, 1970b
Parvisaccites amplius Brenner, 1963
Parvisaccites radiatus Brenner, 1963
Pentadinium goniferum Edwards, 1982
Perinopollenites elatoides Couper, 1958
Pesavis sp.
Phelodinium sp.
Phthanoperidinium levimurum Bujak in Bujak et al., 1980
Phthanoperidinium multispinum Bujak in Bujak et al., 1980
Phthanoperidinium stockmansii (de Coninck, 1975) Lentin and Williams, 1977b
Pilosporites verus Delcourt and Sprumont, 1955
Pistillipollenites mcgregori Rouse, 1962
Pistillipollenites sp.
Pterocaryapollenites sp.
Pyxidopsis waipawaensis Wilson, 1988
Quercoidites sp.
Retitricolpites georgensis Brenner, 1963

Retitricolpites maximus Singh, 1971
Retitricolpites vulgaris Pierce, 1961
Rhombodinium draco Gocht, 1955
Rhombodinium rhomboideum (Alberti, 1961) Lentin and Williams, 1973
Rugubivesiculites reductus Pierce, 1961
Samlandia chlamydophora Eisenack, 1954b
Sapotaceaepollenites sp.
Schematophora speciosa Deflandre and Cookson, 1955
Schizocystia rugosa Cookson and Eisenack, 1962a
Selenopemphix crenata Matsuoka and Bujak, 1988
Sequoapollenites sp.
Spinidinium echinoideum (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Spinidinium sp.
Spiniferites "digitatus"
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854
Spiniferites sp.W
Spongodinium delitiense (Ehrenberg, 1838) Deflandre, 1936b
Spongodinium sp.
Subtilidinium sp.
"Talladinium coleothryptum"
"Taurodinium" sp.
Trithyrodinium? "circellum"
Tsugaepollenites? *pseudomassulae* Mädlar, 1964b
Ulmipollenites sp.
Veryhachium europeum Stockmans and Willière, 1960
Veryhachium formosum Stockmans and Willière, 1960
Veryhachium trispinosum Stockmans and Willière, 1960
Vitreisporites pallidus (Reissinger) Potonié, 1960
Vitreisporites sp. Singh, 1972
Wetziella simplex (Bujak, 1979) Lentin and Vozzhennikova, 1989
Wetziella spinula (Bujak, 1979) Lentin and Vozzhennikova, 1989
Wetziella symmetrica Weiler, 1956
Zlivisporis sp.

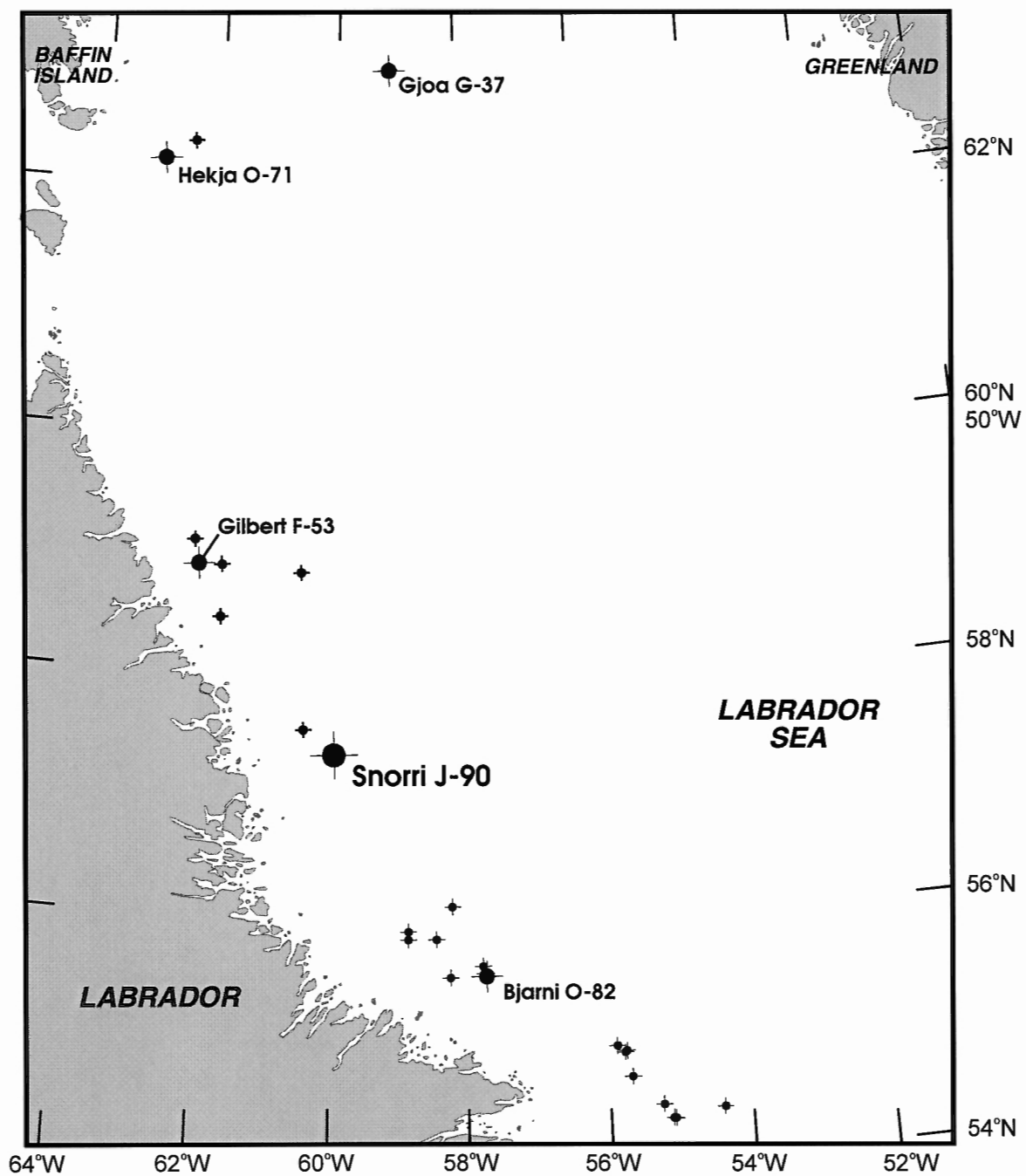


Figure 1. Location of wells discussed in text.