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Palynological Analysis of Pan American-Imperial Grand Falls H-09, Whale Basin, Grand Banks of Newfoundland

G.L. Williams

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Williams, G.L.
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G.S.C. Locality No.: D-26 Unique ID: 300H094530052000

Location: 45º28'19"N, 52º00'03"W

Elevation Sea level to R.T.: 9.4 m (30.8') Water Depth: 78 m (255.9')

Total Depth: 1600.2 m (5249.9')

Spud Date: 16 August 1966 Interval Studied: 219.46-1581.92 m (720-5190')

Casing Points: 762 mm at 109.1 m (30" at 358'); 508 mm at 167.3 m (20" at 549'); 340 mm at 532.5 m (13 ⅜ at 1747'); 244 mm at 1602 m (9 ⅝ at 4901')

Introduction

Pan American-Imperial Grand Falls H-09 is in the Whale Basin on the southern Grand Banks. The well was drilled on a structure to a depth of 1600.2 m. Bartlett and Smith (1971) reviewed the stratigraphy of Grand Falls and recognized several hiatuses. Although McAlpine (1990) did not refer to Grand Falls H-09 when he formalized many of the Mesozoic lithostratigraphic units, Moir (1989, pers.comm.) described the lithostratigraphy using the same names. In this report, I use Moir's formation tops.

My study is based on the palynological analysis of 128 cuttings samples from the interval 219-1581 m. I have also incorporated the data from some of the sidewall cores analysed by the Bujak-Davies Group (1988). All the slides are the property of the Geological Survey of Canada (GSC) and were processed at GSC Atlantic.

Biostratigraphy

My age assignments for Grand Falls H-09 (Figure 1) are based on the stratigraphic ranges of dinoflagellate cysts (dinocysts), spores and pollen. For control, I use known ranges of dinocysts in European sections (Williams *et al*., 1999, 2001, in press) and in other wells and core holes on the Grand Banks (Williams, 1975; Williams and Brideaux, 1975; Bujak and Williams, 1978; Barss *et al*., 1979; Bujak-Davies Group, 1987; Williams *et al*., 1990; Williams, 2003a, b, c, d, in press a, b, c).

In Grand Falls H-09, the deepest drill cuttings samples processed for palynomorphs are from 1572.8-1581.9 m. The predominantly spore-pollen assemblage has a Jurassic aspect but there are no precise age indicators, since the dinocyst taxa present also occur in higher samples. The interval 1581.9-1563.6 m appears to be Bathonian, however, based on the last appearance datums (LADs) of several dinocysts in the cuttings sample from 1572.8-1563.6 m. Dinocyst taxa with LADs at this level include *Ctenidodinium* "*delicatum* subps. *brevispinum*", *Ctenidodinium cornigerum*, *Ctenidodinium sellwoodii* and *Mendicodinium groenlandicum*. Williams (2003c) placed the LADs of *Mendicodinium groenlandicum* and *Ctenidodinium cornigerum* in the Bathonian, which substantiates my conclusions for the interval 1572.7-1563.6 m. The presence of *Ctenidodinium* "*delicatum* subsp. *brevispinosum*" in the Bathonian of Cormorant N-83 (Williams, in press a) is further confirmation. As in other Grand Banks wells (e.g. Williams, 2003c, in press), the Bathonian in Grand Falls H-09 has a diverse dinocyst assemblage.

The overlying Callovian extends from 1563.6 to 1517.9 m. As in other Grand Banks wells (Williams, 2003c), I use the LAD of *Gonyaulacysta adecta* subsp. *adecta* var. *adecta* to place the top of the

Callovian in the cuttings sample at 1527.1-1517.9 m. Sarjeant (1982) described *Gonyaulacysta jurassica* subsp. *adecta* var. *adecta* from the Callovian of Scotland. In southwest Germany, the LAD of the variety is mid Oxfordian (Feist-Burkhardt and Wille, 1992). This probably reflects climatic control. Other dinocysts with LADs in this interval are *Dissiliodinium baileyi* and *Valensiella ovulum*. Bujak and Williams (1977) defined the Callovian *Valensiella vermiculata* Zone, which was characterized by the LADs of several dinocysts including *Valensiella ovulum* and *Ctenidodinium pachydermum*.

I regard 1517.9-1362.5 m as Oxfordian, with the LAD of the dinocyst *Ctenidodinium ornatum* being in the uppermost sample at 1371.6-1362.5 m. Williams *et al*. (1999) placed the LAD of *Ctenidodinium ornatum* at 154.1 Ma. According to Gradstein and Ogg (1996), 154.1 Ma marks the Oxfordian-Kimmeridgian boundary. The dinocyst species *Pareodinia* "*bilobata*", *Rhynchodiniopsis cladophora* and *Sentusidinium verrucosum* also have their LADs in the Oxfordian of Grand Falls.

The LAD of *Gonyaulacysta jurassica* is generally taken as early Kimmeridgian, if one is using the "long" Kimmeridgian. In southern England, the type Kimmeridgian extends from the top of the Oxfordian at 143.1 Ma to the base of the Portlandian at 145.6 Ma. This contrasts with the Tethyan Realm, where the top of the Kimmeridgian is placed at 150.7 Ma, the base of the Tithonian. Thus, the English Kimmeridgian is termed the long Kimmeridgian. Williams *et al*. (1999) placed the LAD of *Gonyaulacysta jurassica* at 149.36 Ma, which is close to the Kimmeridgian-Tithonian boundary. In Grand Falls H-09, the LAD of *Gonyaulacysta jurassica* is in the cuttings sample at 1252.7-1261.9 m. Thus, I consider the sample 1252.7-1261.9 m to approximate with the top of the early Kimmeridgian. Other dinocyst taxa with their LADs in the early Kimmeridgian of the Grand Falls well are *Gochteodinia mutabilis*, *Occisucysta balios* and *Senoniasphaera jurassica*.

Upper Kimmeridgian-Portlandian extend from 1243.6 to 1143 m. *Amphorula metaelliptica* has its LAD in the cuttings sample at 1143-1152 m. Williams *et al*. (1999) gave the LAD of *Amphorula metaelliptica* as 138.8 Ma, within the Berriasian. In several Jeanne d'Arc wells and in the St. George J-55 well (Williams, 2003b), however, the LAD of this species seems to equate with the top of the Jurassic. Supporting evidence for my conclusion is the presence of *Ctenidodinium culmulum* in the cuttings sample at 1179.6-1188.7 m. Williams *et al*. (1999) gave a stratigraphic range of 145.6-137 Ma for this species, which is equivalent to the Portlandian-Berriasian. Williams (1975) erected the Portlandian *Ctenidodinium panneum* Zone and noted that the LAD of *Ctenidodinium culmulum* marks the top of this zone. Thus, it seems reasonable to include the interval 1243.6-1143 m at least partly in the Portlandian.

I cannot exclude the possibility of some of the above interval being late Kimmeridgian, although I did not observe any diagnostic Kimmeridgian species. Spores, pollen and dinocysts occur from 1362.4-1316.7 m but they are either long-ranging or caved.

There appears to be a major gap across the Jurassic-Cretaceous boundary in Grand Falls H-09. Although there is a sample gap between 1143 and 1088.1 m, I do not see any evidence for Berriasian to Barremian sediments above 1088 m. I place the interval 1088.1-1051.6 m in the Aptian, based on the LAD of the pollen *Parvisaccites amplus* in the cuttings sample at 1060.7-1051.6 m. Davies in Williams *et al*. (1990) presented an informal zonation for the late Jurassic to late Cretaceous of the Hibernia wells in the Jeanne d'Arc Basin. In this zonation, Davies included a *Parvisaccites amplus* zone of late Aptian age. Substantiation of an Aptian age is the LAD of *Cribroperidinium sepimentum* at 1069.9-1079 m. Williams *et al*. (1999) gave the LAD of *Cribroperidinium sepimentum* as 112.18 Ma. According to Gradstein and Ogg (1996), the Aptian-Albian boundary is at 112.2 Ma. This is almost identical to the LAD of *Cribroperidinium sepimentum*, which I regard as a good Aptian marker.

I include the interval 1042.4-896.1 m in the Albian. The LAD of the dinocyst *Chichaouadinium vestitum* and the spore *Appendicisporites problematicus* are in the cuttings sample from 896.1-905.3 m. Williams

(1975) erected the *Chichaouadinium* (as *Spinidinium*) cf. *vestitum-Eucommiidites minor* Zone, which he considered Albian. *Chichaouadinium* cf. *vestitum* differs from *Chichaouadinium vestitum* only in having the accessory archeopyle sutures more developed. Bujak and Williams (1978) redefined the zone and noted that species of *Appendicisporites* were common in the zone but rare or absent in overlying zones. Williams *et al*. (1999) gave the LAD of *Chichaouadinium vestitum* as 98.5 Ma. According to Gradstein and Ogg (1996), the Albian-Cenomanian boundary is at 98.9 Ma. Thus, I consider the LAD of *Chichaouadinium vestitum* to mark the Albian-Cenomanian boundary. Species with their LADs within the Albian of Grand Falls H-09 are the dinocysts *Kiokansium williamsii* and *Histiocysta palla* and the spores *Impardecispora apiverrucata* and *Concavissimisporites variverrucatus*.

Only one sample, from 880 to 877.8 m, appears to be Cenomanian. The contained dinocyst assemblage has abundant *Epelidosphaeridia spinosa* and common *Cleistosphaeridium huguoniotii*. Williams (1975) gave the LAD of *Epelidosphaeridia spinosa* as being in his *Cleistosphaeridium polypes* (now *Kiokansium unituberculatum*) Zone of Cenomanian age. Bujak and Williams (1978) gave the LAD of *Epelidosphaeridia spinosa* as Turonian but stated that its highest consistent occurrence or abundance was in the *Cleistosphaeridium polypes* Zone. Williams *et al*. (1999) placed the LAD of *Epelidosphaeridia spinosa* at 94.85 Ma. The Cenomanian-Turonian boundary is at 93.5 Ma (Gradstein and Ogg, 1996), so it seems reasonable to regard the LAD of *Epelidosphaeridia spinosa* as the top of the Cenomanian.

Supporting evidence for a Cenomanian age is the presence of *Litosphaeridium siphoniphorum*. Williams *et al*. (1999) gave the LAD of this species as 92 Ma, just within the Turonian. In Terra Nova K-18 in the Jeanne d'Arc Basin, the LAD of *Litosphaeridium siphoniphorum* and *Cleistosphaeridium huguoniotii* was taken as indicative of a Cenomanian age (Williams, 2003d).

The interval from 877.8-731.5 m contains a mixed dinocyst assemblage, with several Albian taxa that I consider reworked. Throughout this interval, there are several dinocyst taxa with LADs. These include *Canningia colliveri*, *Cerbia* cf. *tabulata*, *Cyclonephelium vannophorum*, *Heterosphaeridium difficile*, *Odontochitina porifera*, *Oligosphaeridium pulcherrimum* and *Xenascus sarjeantii*. Some of these taxa are useful stratigraphic markers. Williams (1975) erected the *Oligosphaeridium pulcherrimum* Zone, which he recognized in several Scotian Shelf wells. He considered the index species to have its LAD in the Coniacian in offshore eastern Canada. Williams (2003d) recorded *Oligosphaeridium pulcherrimum* and *Xenascus sarjeantii* from an interval he regarded as Turonian-Coniacian in the Terra Nova K-18 well. The LAD of *Cyclonephelium vannophorum*, according to Williams *et al*. (1999) is 89 Ma, which is the Turonian-Coniacian boundary (Gradstein and Ogg, 1996). I regard the above as confirming a Turonian-Coniacian age for the interval 877.8-731.5 m.

It is always difficult to subdivide the Late Cretaceous using dinocysts. This mainly reflects the common prevalence of chalky facies and the more offshore locations. In Grand Falls H-09, much of the Upper Cretaceous section is shaly, so dinocyst recovery is reasonable. This has let me recognize the Santonian, based on the LAD of *Raetiaedinium truncigerum* in the cuttings sample at 685.8-676.8 m. Williams and Brideaux (1975) noted that *Raetiaedinium* (as *Hystrichosphaeridium*) *truncigerum* had an LAD in the Santonian. And Williams (1975) erected a *Raetiaedinium* (as *Hystrichosphaeridium*) *truncigerum* Zone, which he considered Santonian. This agrees with my including 685.8-676.7 m in the Santonian.

I subdivide the Campanian which extends from 667.5-457.2 m into early (667.5-603.5 m) and late (603.5-493.8 m). My early Campanian top is based on the LAD of *Surculosphaeridium longifurcatum* and *Surculosphaeridium* cf. *longifurcatum*. According to Williams *et al*. (in press), *Surculosphaeridium longifurcatum* has an LAD of 81.68 Ma. Gradstein and Ogg (1996) gave the age of the Campanian as 83.5 to 71.3 Ma. Thus 81.68 Ma falls within the early Campanian.

The late Campanian (603.5-493.8 m) is characterized by the LAD of the dinocysts *Aldorfia deflandrei* and *Palaeohystrichophora infusorioides* in the cuttings sample at 493.8-502.9 m. Williams *et al*. (1999) gave an LAD of 68.8 Ma for *Aldorfia* (as *Apteodinium*) *deflandrei* and an LAD of 69.6 Ma for *Palaeohystrichophora infusorioides*. Gradstein and Ogg (1996) placed the Campanian-Maastrichtian boundary at 71.3 Ma. I regard the LADs of *Aldorfia deflandrei* and *Palaeohystrichophora infusorioides* to be close enough to the Campanian-Maastrichtian boundary to be considered as marking it. The LADs of these two species is taken as confirmation of my late Campanian designation for the interval 603.5-493.8 m.

Other dinocysts with their LADs in the late Campanian of Grand Falls H-09 are *Odontochitina operculata* and *Xenascus ceratioides*. Williams (1975) defined the top of his *Odontochitina operculata* Zone on the LADs of several dinocyst species, including *Odontochitina operculata* and *Xenascus ceratioides*. Williams *et al*. (1999) gave the LAD of *Odontochitina operculata* as 70.5 Ma and the LAD of *Xenascus ceratioides* as 68.8 Ma. The Campanian-Maastrichtian boundary at 71.3 Ma is just below the LAD of *Odontochitina operculata*.

Grand Falls H-09 is one of the few Grand Banks wells, which appears to have a Maastrichtian section. I take the LAD of *Cannosphaeropsis utinensis* in the cuttings sample at 411.5-402.3 m as denoting the top of this stage. Williams *et al*. (1999) gave the LAD of *Cannosphaeropsis utinensis* as 66.3 Ma. Gradstein and Ogg (1996) placed the top of the Maastrichian at 65 Ma. So, it seems reasonable to equate the two events.

Between 393.2-347.5 m are three cuttings samples which cannot be more precisely dated than Paleocene. The samples contain common *Areoligera* cf. *medusettiformis* and *Areoligera* cf. *senonensis*, with frequent *Thalassiphora* "*nuda*". In other Grand Banks wells such as Skua E-41 and Terra Nova K-18, Williams (2003c,d) noted high abundances of *Areoligera* cf. *medusettiformis* and *Areoligera* cf. *senonensis* in the late Paleocene. The undescribed species *Thalassiphora* "*nuda*" and the several specimens of *Hafniasphaera* may denote an early rather than a late Paleocene age but there are none of the usual Danian markers.

Higher in the well in the cuttings sample at 338.3-329.2 m, there are some reliable late Paleocene markers. The dinocyst species *Areoligera gippingensis* and *Cerodinium* "*glabrum*" have their LADs in this sample, thus denoting a probable Thanetian age. Williams *et al*. (1999) gave a stratigraphic range of 58-57 Ma for *Areoligera gippingensis*. Thus, this species straddles the Selandian-Thanetian boundary, which Gradstein and Ogg (1996) placed at 57.9 Ma. The genus *Cerodinium glabrum*, previously known as *Cerodinium speciosum* subsp. *glabrum* was described by Gocht (1969) from the late Paleocene. Subsequent studies (e.g. Heilmann-Clausen, 1985) have confirmed this age.

The Ypresian can be subdivided into early and late. The early Ypresian extends from 320 to 256 m. Several dinocyst taxa have their LADs in this interval, including *Dapsilidinium simplex*, *Deflandrea oebisfeldensis*, *Dracodinium condylos, Dracodinium varielongitudum*, *Spiniferella cornuta* and *Cerodinium denticulatum*. Williams *et al*. (1999) gave the LAD of *Deflandrea oebisfeldensis* as 52.5 Ma, and of *Dracodinium condylos* as 51.5 Ma. The Ypresian extends from 54.8 to 49 Ma (Gradstein and Ogg, 1996), so the LADs of both the above species seem a reasonable choice for indicating the top of the early Ypresian.

I included the single cuttings sample at 246.9-237.7 m in the late Ypresian. In this sample are the LADs of *Areoligera* cf. *medusettiformis* and *Areoligera* cf. *senonensis*. Williams (1975) erected an *Areoligera senonensis* senus Gocht, 1969, Assemblage Zone, which he considered early Eocene or Ypresian. *Areoligera senonensis* sensu Gocht, 1969 is the same taxon as *Areoligera* cf. *senonensis*. Williams *et al*. (1999) gave an LAD for *Areoligera* cf. *medusettiformis* of 48 Ma. *Areoligera* cf. *medusettiformis* was the basis for the LAD of 48 Ma given by Williams *et al*. (op.cit.) for *Areoligera medusettiformis*. The Ypresian-Lutetian boundary is at 48 Ma, so both *Areoligera* taxa are useful for determining the Ypresian-Lutetian boundary.

The highest sample at 228.6-219.5 m appears to be early Lutetian. I base this on the presence of *Diphyes ficusoides*, which has an LAD of 45.2 Ma. Gradstein and Ogg (1996) gave the age of the Lutetian as 49 to 41.3 Ma. Thus, 45.2 Ma is close to the top of the early Lutetian. Other dinocyst taxa with LADs in this sample include *Adnatosphaeridium multispinosum* (common), *Batiacasphaera compta* and *Wilsonidium echinosuturatum*.

Paleoenvironments

In Grand Falls H-09, the only samples available for paleoenvironmental studies are composite cuttings samples covering 10 m. To generate a viable paleoenvironmental plot, it is best to have quantitative data, which is of questionable value when based on cuttings. But since other samples are not available, I have done counts on cuttings slides down to 384.1-393.2 m. I did not do counts below 393.2 m because of the low numbers of in situ specimens and the high numbers of caved material. This has posed some restrictions on paleoenvironmental intepretations, which perforce are based more on qualitative data. But it is possible to develop an overview.

The paleoenvironmental curve shows the Grand Falls location is neritic for most of the mid Jurassic to early Tertiary. The interval from the bottommost sample at 1581.9-1572.8 m to 1362.5-1371.6 m represents an inner neritic setting. The sparse dinocyst assemblages often contain *Ctenidodinium* specimens. Smelror and Leereveld (1989), in a study of Bathonian-Oxfordian rocks of the Rhône Valley, defined a *Ctenidodinium combazii*-*Cleistosphaeridium varispinosum* assemblage that they considered indicative of shallow marine deposition. From this and his findings in the Skua E-41 well, located in the Carson Basin, Williams (2003c) concluded that *Ctenidodinium* is an indicator of closer to shore, neritic environments.

Within the interval 1581.9-1362.5 m, the assemblages are dominated by spores and pollen, especially the taxodiacean pollen *Perinopollenites elatoides*. Frequent pollen in a few samples are *Callialasporites monoalasporus* and *Vitreisporites* sp. Singh, 1971. The trilete spore genera *Leiotriletes* and *Cyathidites* become more abundant higher up. From the assemblages, I conclude that the Grand Falls location was inner neritic, close to shore in the Bathonian-Oxfordian.

A surprise in the early Kimmeridgian is the absence or sparsity of dinocysts in the interval 1353-1316 m. In the absence of other evidence, I am concluding that this is marginal marine. Dinocysts reappear in the sample at 1289.3-1280.2 m but again are sparse or absent from 1243-1140 m. This, I assume, denotes a marginal marine milieu with occasional deepening to inner neritic.

There is a gap in the sampling from 1143 to 1088.1 m. From 1088 to 859.5 m, the paleoenvironments appear to have been relatively stable inner to possibly mid neritic. The three samples between 1060 and 1014 m contain abundant cuticles. In the cuttings sample at 960-950 m, *Camarozonosporites* increases in abundance and stays common up to 914 m. This suggests a closer to shore, shallower environment.

Farther offshore conditions prevailed from 905 to 749 m, although there were fluctuations. The cuttings sample at 880-877 m contains abundant *Epelidosphaeridia spinosa* and common *Cleistosphaeridium huguoniotii*. Little is known about the paleoenvironmental preferences of these two species. Both are small cysts with thin walls. *Epelidosphaeridia spinosa* is a peridinialean. *Cleistosphaeridium huguoniotii* is a gonyaulacalean. Cookson and Hughes (1964) described *Epelidosphaeridia spinosa* from the Cambridge Greensand, which has a high glauconitic content. Glauconite generally indicates an open marine, shallow environment, which I am interpreting for *Epelidosphaeridia spinosa*. Presumably, the environment was not too high energy and the waters were relatively calm.

The cuttings sample from 877 to 868 m contains frequent *Palaeohystrichophora infusorioides*. From its delicate structure, I would consider this species to favour the same environments as *Epelidosphaeridia spinosa*. Dinocysts dominate the palynomorph assemblages in the upper Cretaceous-Paleogene samples but recovery is often poor. The sparse assemblages from 868-749 m are often dominated by caved specimens. The few taxa which appear to be in situ suggest a mid neritic environment.

I cannot draw any conclusions for the interval 749 to 402 m, so show a dashed line which spans much of the late Cretaceous. This reflects the low numbers of in situ dinocysts recovered due to the small samples and the absence of quantitative data.

In situ palynomorph abundances increase markedly in the Paleogene. From 393-219 m there is little change, with the topmost sample at 227.6-219.5 m still representative of open marine conditions. Throughout this interval, the dinocysts are dominant and there are very few spores and pollen. I have not observed the floods of *Areoligera* that were recorded at Skua E-41 (Williams, 2003c), St. George J-55 (Williams, 2003b) or Terra Nova K-18 (Williams, 2003d). And I have not seen the *Apectodinium* peaks that occur in Skua E-41 (Williams, 2003c) and Terra Nova K-18 (Williams, 2003d). This may be due to sampling intervals or reflect different environments.

Correlation of Palynology and Lithology

The lithostratigraphy of Grand Falls H-09 was first described by Bartlett and Smith (1971). These authors defined seven lithostratigraphic sequences, which were numbered sequentially from oldest (one) to youngest (seven). These unconformity-bounded sequences were given the ages: one - mid to upper Jurassic; two - Neocomian; three - ?Aptian to Cenomanian; four - Turonian to mid Maastrichtian; five - late Danian to mid Thanetian; six - early Cuisian to early Lutetian; seven - Aquitanian to Sarmatian.

Although detailed, the breakdown of Bartlett and Smith (1971) has not been followed. This primarily reflects the impact of two papers: McIver (1972) formalized the lithostratigraphy of the Scotian Basin and McAlpine (1990), rather than adopting McIver's terminology as others had done (e.g. Jansa and Wade, 1975), formally erected several lithostratigraphic units of Jurassic-early Cretaceous age.

Wade and Sherwin (1987) published the terminology and lithostratigraphy of Grand Falls H-09 using primarily the formations defined by McIver (1972). The first attempt to apply the terminology of McAlpine (1990) was by Moir (1989, pers.comm.). Unfortunately, Moir (1989, BASIN) is not a formal publication but, I use his formation tops, as shown in Figure 1.

The Voyager Formation is the oldest lithostratigraphic unit that Moir recognizes in Grand Falls H-09. Its age, based on palynology, is Bathonian-Oxfordian. Sequentially overlying the Voyager are the Rankin Formation, of Oxfordian-early Kimmeridgian age, and the Jeanne d'Arc Formation (or its equivalent), of late Kimmeridgian-Portlandian age. According to McAlpine (1990), the age of the Voyager in the type section is late Bathonian-Oxfordian. He considered the Rankin Formation to be early Oxfordian to early Kimmeridgian at the type section and the Jeanne d'Arc Formation to be Kimmeridgian-Tithonian. The Egret Member of the Rankin Formation has not been identified in Grand Falls H-09, perhaps because the environment was too shallow or too oxic. This is disappointing since the Egret is the source rock in the Jeanne d'Arc Basin.

Unconformably overlying the Jeanne d'Arc is the Fortune Bay Shale (equivalent), which is conformably overlain by the Hibernia Formation (equivalent). In Grand Falls, I consider the Fortune Bay Shale to be Aptian and the Hibernia Formation to be Albian. These ages disagree with the ages of the Fortune Bay

Shale in its type section (mid to late Kimmeridgian) and the Hibernia Formation in its reference section (Tithonian-Berriasian). This discrepancy probably results from the time gap, which is much greater than originally thought.

The Eider Formation (994.6-896.6 m) unconformably overlies the Hibernia Formation (equivalent). McAlpine (1990) gave the age of the Eider Formation as late Albian to late Cenomanian. In Grand Falls H-09 it is Albian. Apparently sequentially overlying the Eider Formation are the Dawson Canyon Formation (896.6-318.6 m) and the Banquereau Formation (318.6-1 m). The Petrel Member of the Dawson Canyon Formation extends from 878-867 m. Based on my data, I consider the Dawson Canyon Formation to be Cenomanian-Early Eocene. This is unlikely, indicating that the top of the Dawson Canyon Formation should be lower. The Petrel Member appears to be Turonian, as on the Scotian Shelf.

Summary
Grand Falls H-09 has attenuated Jurassic, Cretaceous and Tertiary sections, with one major unconformity and a possible hiatus. A Bathonian to Portlandian sequence is unconformably overlain by a Aptian-Maastrichtian sequence just above 1143 m. Maastrichtian sediments appear to be separated by a hiatus from upper Paleocene sediments, but it is not possible to confirm this. The uppermost sample is early Lutetian. This is considerably older than expected and probably reflects the location of the well high on the margin of the Whale Basin.

There is no marked change in the inner neritic setting throughout the mid and late Jurassic and into the early Cretaceous, although there are episodes of shallowing, with marginal to possibly nonmarine conditions. Deeper water prevails in the late Cretaceous and into the early Tertiary, with slight shallowing in the uppermost part.

One major concern in Grand Falls H-09 must be the question of source rocks. Where is the Egret Member and what is the potential for generating hydrocarbons?

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<u>Appendix A</u>
References for dinoflagellate citations are given in Williams *et al*. (1998). References for spore and pollen citations are from PALYNODATA. Informal taxa will be illustrated in a forthcoming Palyatlas.

Achomosphaera alcicornu (Eisenack, 1954b) Davey and Williams, 1966a
Adnatosphaeridium caulleryi (Deflandre, 1939a) Williams and Downie, 1969
Adnatosphaeridium multispinosum Williams and Downie, 1966c
Adnatosphaeridium vittatum Williams and Downie, 1966c
Aequitriradites spinulosus (Cookson and Dettmann, 1958) Cookson and Dettmann, 1961
Alisogymnium euclaense (Cookson and Eisenack, 1970a) Lentin and Vozzhennikova, 1990
Alisporites grandis (Cookson, 1953) Dettmann, 1963
Alterbidinium? *bicellulum* (Islam, 1983b) Lentin and Williams, 1985
Amphorula metaelliptica Dodekova, 1969
Apectodinium homomorphum (Deflandre and Cookson, 1955) Lentin and Williams, 1977b
Apectodinium quinquelatum (Williams and Downie, 1966b) Costa and Downie, 1979
Appendicisporites erdtmannii Pocock, 1964
Appendicisporites jansonii Pocock, 1962
Appendicisporites problematicus Burger, 1966
Apteodinium deflandrei (Clarke and Verdier, 1967) Lucas-Clark, 1987
Areoligera gippingensis Jolley, 1992
Areoligera medusettiformis O. Wetzel, 1933b
Areoligera cf. *medusettiformis* O. Wetzel, 1933b
Areoligera cf. *senonensis* Lejeune-Carpentier, 1938a
Areoligera sentosa Eaton, 1976
Areosphaeridium michoudii Bujak, 1994
"*Axiodinium*" *articulatum*
"*Axiodinium*" *simile*
Batiacasphaera compta Drugg, 1970b
Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961
Callialasporites infrapunctatus (Lantz) Pocock, 1970
Callialasporites obrutus Norris, 1969
Callialasporites segmentatus (Balme, 1957) Sukh Dev, 1961
Camarozonosporites insignis Norris, 1967
Canningia reticulata Cookson and Eisenack, 1960b
Canningia reticulata sensu Williams and Brideaux, 1975
Cannosphaeropsis utinensis O. Wetzel, 1933b
Cerbia cf. *tabulata* (Davey and Verdier, 1974) Below, 1981a
Cerebrocysta bartonensis Bujak in Bujak et al., 1980
Cerebropollenites macroverrucosus (Thiergart) Schultz, 1967
Cerebropollenites mesozoicus (Couper, 1958) Nilsson, 1958
Cerodinium denticulatum (Alberti, 1959b)
Cerodinium "*glabrum*"
Charlesdowniea coleothrypta (Williams and Downie, 1966b) Lentin and Vozzhennikova, 1989
Charlesdowniea crassiramosa (Williams and Downie, 1966b) Lentin and Vozzhennikova, 1989
Chatangiella biapertura (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella tripartita (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Chichaouadinium vestitum (Brideaux, 1971) Bujak and Davies, 1983
Chlamydophorella? *grossa* Manum and Cookson, 1964
Chlamydophorella nyei Cookson and Eisenack, 1958
Chytroeisphaeridia chytroides (Sarjeant, 1962a) Downie and Sarjeant, 1965
Cicatricosisporites augustus Singh, 1971

Cicatricosisporites australiensis (Cookson, 1953) Potonié, 1956
Cicatricosisporites hallei Delcourt and Sprumont, 1955
Cicatricosiporites reticicatricosus Doring, 1965
Circulodinium colliveri (Cookson and Eisenack, 1960b) Helby, 1987
Cleistosphaeridium huguoniotii (Valensi, 1955a) Davey, 1969a
Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978
Contignisporites cooksoniae (Balme, 1957) Dettmann, 1963
Contignisporites glebulentus Dettmann, 1963
Converrucosisporites variverrucatus (Couper, 1958) Norris, 1969
Cordosphaeridium gracile (Eisenack, 1954b) Davey and Williams, 1966b
Corollina torosus (Reissinger) Klaus, 1960
Corollina vignollensis (Reyre, 1970)
Coronifera oceanica Cookson and Eisenack, 1958
Corrudinium reticulatum Grabowska in Malinowskiej and Piwockiego, 1996
Cribroperidinium sepimentum Neale and Sarjeant, 1962
Ctenidodinium continuum Gocht, 1970b
Ctenidodinium cornigerum (Valensi, 1953) Jan du Chêne et al., 1985b
Ctenidodinium culmulum (Norris, 1965) Lentin and Williams, 1973
Ctenidodinium "*delicatum*" subsp. "*brevispinum*"
Ctenidodinium ornatum (Eisenack, 1935) Deflandre, 1939a
Ctenidodinium pachydermum (Deflandre, 1939a) Gocht, 1970b
Ctenidodinium sellwoodii (Sarjeant, 1975a) Stover and Evitt, 1978
Cyclonephelium vannophorum Davey, 1969a
Cymososphaeridium validum Davey, 1982b
Dapsilidinium? *simplex* (White, 1842) Bujak et al., 1980
Deflandrea oebisfeldensis Alberti, 1959
Deflandrea truncata Stover, 1974
Deltoidospora hallii Miner, 1935
Densoisporites microrugulatus Brenner, 1963
Densoisporites triradiatus Delcourt and Sprumont, 1955
Densoisporites velatus Weyland and Krieger, 1953
Dinogymnium heterocostatum (Deflandre, 1936b) Evitt et al., 1967
Diphyes brevispinum Bujak, 1994
Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965a
Diphyes ficusoides Islam, 1983b
Dissiliodinium baileyi Feist-Burkhardt and Monteil, 2001
Dissiliodinium cf. *baileyi*
Dorocysta sp.
Dracodinium condylos (Williams and Downie, 1966b) Costa and Downie, 1979
Dracodinium varielongitudum (Williams and Downie, 1966b) Costa and Downie, 1979
Eatonicysta ursulae (Morgenroth, 1966a) Stover and Evitt, 1978
Ellipsodinium rugulosum Clarke and Verdier, 1967
Elytrocysta sp.
Enneadocysta arcuata (Eaton, 1971) Stover and Williams, 1995
Eocladopyxis "*brevispinosa*"
Epelidosphaeridia spinosa Cookson and Hughes, 1964
Epiplosphaera gochtii (Fensome, 1979) Brenner, 1988
Exochosphaeridium bifidum (Clarke and Verdier, 1967) Clarke et al., 1968
Exochosphaeridium striolatum (Deflandre, 1937b) Davey, 1969a
Fibrocysta axialis (Eisenack, 1965b) Stover and Evitt, 1978
Florentinia buspina (Davey and Verdier, 1976) Duxbury, 1980

Florentinia cooksoniae (Singh, 1971) Duxbury, 1980
Florentinia ferox (Deflandre, 1937b) Duxbury, 1980
Florentinia mantellii (Davey and Williams, 1966b) Davey and Verdier, 1973
Florentinia radiculata (Davey and Williams, 1966b) Davey and Verdier, 1973
Foraminisporis wonthaggiensis (Cookson and Dettmann, 1958) Dettmann, 1963
Geiselodinium sp.
Glaphyrocysta divaricata (Williams and Downie, 1966c) Stover and Evitt, 1978
Glaphyrocysta "*preordinata*"
Glaphyrocysta spineta (Eaton, 1976) Stover and Evitt, 1978
Gochteodinia mutabilis (Riley in Fisher and Riley, 1980) Fisher and Riley, 1982
Gonyaulacysta jurassica (Deflandre, 1939a) Norris and Sarjeant, 1965
Gonyaulacysta jurassica subsp. *adecta* var. *adecta* Sarjeant, 1982b
Heterosphaeridium difficile (Manum and Cookson, 1964) Ioannides, 1986
Heterosphaeridium "*grandfallsii*"
Heterosphaeridium heteracanthum (Deflandre and Cookson, 1955) Eisenack and Kjellström, 1972
Histiocysta palla Davey, 1969a
Histiophora ornata Klement, 1960
Homotryblium tenuispinosum Davey and Williams, 1966b
Hystrichodinium pulchrum Deflandre, 1935
Hystrichokolpoma cinctum Klumpp, 1953
Hystrichosphaeridium bowerbankii Davey and Williams, 1966b
Hystrichosphaeridium salpingophorum Deflandre, 1935
Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937b
Hystrichosphaeridium tubiferum subsp. "*perforatum*"
Impardecispora apiverrucata (Couper, 1958) Venkatachala, Kar and Razi, 1968
Impardecispora sp.A Dörhöfer, 1977
Isabelidinium acuminatum (Cookson and Eisenack, 1958) Stover and Evitt, 1978
Isabelidinium belfastense (Cookson and Eisenack, 1961a) Lentin and Williams, 1977a
Ischyosporites amplireticosus Doring, 1973
Januasporites sp.
Kiokansium williamsii C. Singh, 1983
Kleithriasphaeridium loffrense Davey and Verdier, 1976
Kleithriasphaeridium readei (Davey and Williams, 1966b) Davey and Verdier, 1973
Klukisporites areolatus Singh, 1971
Klukisporites pseudoreticulatus Couper, 1958
Laciniadinium arcticum (Manum and Cookson, 1964) Lentin and Williams, 1980
Leptolepidites psarosus Norris, 1969
Litosphaeridium arundum (Eisenack and Cookson, 1960) Davey, 1979b
Litosphaeridium siphoniphorum (Cookson and Eisenack, 1958) Davey and Williams, 1966b
"*Lunaria*" *articulata*
Maghrebinia sp.
"*Megaspora grandis*"
Melitasphaeridium pseudorecurvatum (Morgenroth, 1966a) Bujak et al., 1980
Mendicodinium groenlandicum (Pocock and Sarjeant, 1972) Davey, 1979c
Microdinium veligerum (Deflandre, 1937b) Davey, 1969a
Muratodinium fimbriatum (Cookson and Eisenack, 1967b) Drugg, 1970b
Occisucysta balios Gitmez, 1970
Occisucysta "*distincta*"
Odontochitina operculata (O. Wetzel, 1933a) Deflandre and Cookson, 1955
Odontochitina porifera Cookson, 1956
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966b

Oligosphaeridium "*complex/pulcherrimum*"
Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955)
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983a
Operculodinium multispinosum Ashraf, 1979
Palaeohystrichophora infusorioides Deflandre, 1935
Palaeoperidinium cretaceum (Pocock, 1962) Lentin and Williams, 1976
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967b
Pareodinia "*bilobata*"
Pareodinia ceratophora Deflandre, 1947d
Pareodinia ceratophora (with kalyptra)
Parvisaccites amplus Brenner, 1963
Parvisaccites radiatus Brenner, 1963
Perinopollenites elatoides Couper, 1958
Perinopollenites elatoides subsp. "*major*"
Plicatella #ES Davies in Bujak-Davies, 1987
Podocarpidites tricocca (Maljavkina) Bolchovitina
Pseudoceratium eisenackii (Davey, 1969a) Bint, 1986
Pterodinium cingulatum (O. Wetzel, 1933b) Below, 1981a
Raetiaedinium truncigerum (Deflandre, 1937b) Kirsch, 1991
Rhynchodiniopsis cladophora (Deflandre, 1939a) Below, 1981a
Rubinella major (Couper, 1958) Norris, 1969 sensu Norris, 1969
Rugubivesiculites reductus Pierce, 1961
Rugubivesiculites rugosus Pierce, 1961
Scortea sp.
Scriniodinium crystallinum (Deflandre, 1939a) Klement, 1960
Senoniasphaera jurassica (Gitmez and Sarjeant, 1972) Lentin and Williams, 1976
Senoniasphaera protrusa Clarke and Verdier, 1967
Senoniasphaera rotundata Clarke and Verdier, 1967
Sentusidinium rioultii subsp. "*minispinum*"
Sentusidinium verrucosum (Sarjeant, 1968) Sarjeant and Stover, 1978
Spinidinium echinoideum (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Spiniferella cornuta (Gerlach, 1961) Stover and Hardenbol, 1994
Spiniferites porosus (Manum and Cookson, 1964) Harland, 1973
Spiniferites "*procerus*"
Spiniferites "*ramuliferus*"
Surculosphaeridium longifurcatum (Firtion, 1952) Davey et al., 1966
Surculosphaeridium cf. *longifurcatum*
Systematophora ancyrea Cookson and Eisenack, 1965a
Systematophora orbifera Klement, 1960
Systematophora penicillata (Ehrenberg, 1843b) Sarjeant, 1980a
Systematophora turonica (Alberti, 1961) Downie and Sarjeant, 1965
Systematophora vestita (Deflandre, 1939a) Davey, 1982b
Tanyosphaeridium regulare Davey and Williams, 1966b
Tanyosphaeridium variecalamum Davey and Williams, 1966b
Tenua hystrix Eisenack, 1958a
Thalassiphora "*nuda*"
Thalassiphora pelagica (Eisenack, 1954b) Eisenack and Gocht, 1960
Triblastula nuda O. Wetzel, 1961
Trichodinium castanea Deflandre, 1935
Trigonopyxidia ginella Cookson and Eisenack, 1960a
Trithyrodinium evittii Drugg, 1967

Trithyrodinium "*granulatum*"
Trithyrodinium "*scabratum*"
Turbiosphaera galatea Eaton, 1976
Uvaesporites glomeratus Doring, 1965
Valensiella ovulum (Deflandre, 1947d) Eisenack, 1963a
Vitreisporites pallidus (Reissinger) Potonié, 1960
Wilsonidium echinosuturatum (Wilson, 1967c) Lentin and Williams, 1976
Wilsonidium tabulatum (Wilson, 1967c) Lentin and Williams, 1976
Xenascus ceratioides (Deflandre, 1937b) Lentin and Williams, 1973
Xenascus sarjeantii (Corradini, 1973) Stover and Evitt, 1978

Figure 1. D26 PAN AM-IMPERIAL GRAND FALLS H-09