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Palynological analysis of Canterra PCI St. George J-55 Carson Basin, Grand Banks of Newfoundland

G.L. Williams

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G.S.C. Locality No.: D-298

Location: 45°44'45"N, 48°38'46"W

Elevation Sea level to R.T.: 23.5 m

Water Depth: 104.5 m

Total Depth: 4100.2 m

Spud Date: 9 April 1986

Interval Studied: 595-4100 m

Casing Points: 762 mm at 188 m; 508 mm at 572.7 m; 340 mm at 1717 m

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Introduction

Canterra PCI St. George J-55 is in the northern part of the Carson Basin, the Grand Banks of Newfoundland. My study is based on the palynological analysis of 137 cuttings samples covering the interval 595-4100 m and 77 sidewall core samples from 1142.1-4080 m. All the slides are the property of the Geological Survey of Canada (GSC) and were processed at GSC Atlantic.

Biostratigraphy

Figure 1 gives the stratigraphic breakdown for St. George J-55 based on the dinoflagellate cysts (dinocysts), spores and pollen. I have determined the ages from the known stratigraphic 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 and Brideaux, 1975; Barss *et al.*, 1979; Bujak-Davies Group, 1987; Williams *et al.*, 1990; Williams, in press a and b).

The deepest sample in the well is a cuttings sample at 4090-4100 m, for which I cannot give a definitive age. There is a sidewall at 4080 m, however, which contains the dinocysts *Amphorula metaelliptica* and *Lanterna bulgarica* and the spore *Pilosisporites* sp.A Bujak and Williams 1977. Williams *et al.* (1999) gave the first appearance datum (FAD) for *Amphorula metaelliptica* as 152.18 Ma, that's within the Kimmeridgian. Bujak and Williams (1977) considered *Pilosisporites* sp.A to have a stratigraphic range of Oxfordian-Portlandian, but Davies *in* Bujak-Davies Group (1987) disagreed. He restricted *Pilosisporites* sp.A to the Kimmeridgian. Regardless, the age of 4080 m cannot be older than Kimmeridgian, but what part.

Based on samples higher up, I include the interval 4100-3755 m in the mid Kimmeridgian, because of the last appearance datum (LAD) of the dinocyst *Epiplosphaera areolata* at 3725-3735 m. In wells in the

Jeanne d'Arc Basin, this and other species of *Epiplosphaera* have an LAD in the Kimmeridgian (Williams, in press a). The dinocyst *Leptodinium subtile* occurs in the cuttings samples at 3995-4005 m and 3975-3975 m. Williams *et al.* (1999) placed the LAD of *Leptodinium subtile* at 144.88 Ma, the uppermost Tithonian. Other authors, including Williams and Bujak (1985) considered the LAD as within the Kimmeridgian. In St. George J-55, the LAD of *Leptodinium subtile* would appear to be mid Kimmeridgian.

The late Kimmeridgian, from 3730-3195 m, is denoted by the LAD of the dinocysts *Perisseiasphaeridium insolitum* and *Epiplosphaera reticulata* in the cuttings sample at 3195-3205 m. These taxa have their LAD in the late Kimmeridgian of several wells in the Jeanne d'Arc Basin. Confirming the late Kimmeridgian age is the frequent occurrence of the dinocyst *Muderongia simplex* in the sidewall core at 3661 m. Riding *et al.* (2001) noted that *Muderongia simplex* is present consistently in the middle Volgian from the *Rotunda* to *Okuseusis/Kerberus* zones, which crosses the Kimmeridgian-Portlandian boundary. Elsewhere in the Jeanne d'Arc Basin the LAD of the consistent occurrence of *Muderongia simplex* (as *Muderongia* sp.A Davey 1979) approximates with the top of the Kimmeridgian.

I consider from 3192-2715 m to be Portlandian. The top of the Portlandian is marked by the LADs of the dinocyst species *Amphorula delicata* and *Amphorula metaelliptica* in the cuttings sample at 2715-2725 m. Williams *et al.* (1999) gave the LADs of *Amphorula delicata* and *Amphorula metaelliptica* respectively as 140.6 and 138.8 Ma, within the Berriasian. In several Jeanne d'Arc wells, however, the LADs of these species appear to equate with the top of the Jurassic. One concern about my placement of the Jurassic-Cretaceous boundary is the occurrence of the dinocyst species *Phoberocysta neocomica* and *Pseudoceratium pelliferum* in the sidewall core at 3239 m. Furthermore, *Pseudoceratium pelliferum* occurs consistently in sidewall cores above 3239 m. Williams *et al.* (1999) gave the FAD of *Phoberocysta neocomica* as 138.33 Ma and the FAD of *Pseudoceratium pelliferum* as 138.2 MA. Therefore, the possibility exists that from 3239-2779 m is basal Berriasian.

Supporting my placement of the top of the Portlandian at 2715-2725 m is the occurrence of the dinocyst *Lanterna sportula* in the sidewall core at 2779 m. Williams *et al.* (1999) gave a LAD of 141.3 Ma for *Lanterna sportula*. This is just within the Berriasian. Stover *et al.* (1996), however, considered the genus *Lanterna* to have its LAD at the top of the Portlandian. I follow Stover *et al.* (op cit.) in using this species as a boundary marker. The closely related species *Lanterna bulgarica* occurs in the cuttings sample at 2745-2755 m, providing further evidence that this interval is close to the Jurassic-Cretaceous boundary.

In St. George J-55, the Berriasian extends from 2722.5-2265 m. The cuttings sample at 2265-2275 m contains a rich assemblage, including the LADs of the spores *Cicatricosisporites* EM, *Cicatricosisporites* EQ, *Kraeuselisporites* EB and *Striatella* EAB, all taxa erected by Davies *in* Bujak-Davies Group (1987). Other spores are *Aequitriradites baculatus* and *Trilobosporites aornatus*. Davies (op.cit.) gave the LADs of *Cicatricosisporites* EQ, *Striatella* #EAB and *Trilobosporites aornatus* as Berriasian in the Jeanne d'Arc Subbasin. I take the LADs of the above species at 2265-2275 m as good evidence of Berriasian. Further confirmation is the presence of the dinocyst *Phoberocysta neocomica* subsp. *cruciformis.*

The Berriasian is overlain by Valanginian sequence extending from 2245-1888 m. In the sidewall core at 1888 m are the dinocysts *Achomosphaera neptuni, Phoberocysta "ahorna "* and *Spiniferites speciosus.* Williams *et al.* (1999) gave the LAD for *Achomosphaera neptuni* as 113.96 Ma, which is late Aptian. But Williams (1975) considered the *Phoberocysta neocomica* Zone to be Berriasian-Valanginian. And one of his index species is *Achomosphaera neptuni*, wich rarely occurs above this zone on the Scotian Basin. *Cassiculosphaeridia magna*, present in the sidewall core at 2033.5 m, has a consistent LAD in the Valanginian in Jeanne d'Arc wells.

Spores are common in the Valanginian but are generally long ranging. In St. George J-55, species with LADs in this stage are *Coronatispora valdensis, Aequitriradites spinulosus* and *Aequitriradites baculatus*. In other Jeanne d'Arc wells, the LAD of *Aequitriradites spinulosus* appears to be consistently in the Valanginian.

I have recognized the Hauterivian section in St. George J-55 from 1885 to 1785 m. This is based on the LAD of the dinocyst *Occisucysta* sp.A of Bujak and Williams (1978). These authors gave the LAD of this species as Hauterivian or within their *Ctenidodinium elegantulum* Zone. Other taxa with LADs in this zone are the spores *Rubinella major* sensu Norris, 1969 and *Trilobosporites hannonicus*. The interval 1785-1568.5 m I include in the Barremian. The sidewall core at 1568.5 m contains the LAD for consistent *Callialasporites dampieri* and *Subtilisphaera perlucida*. Davies *in* Williams *et al.* (1990) had a *Subtilisphaera terrula* Zone of Late Hauterivian-Barremian age. As I have found in wells in the Jeanne d'Arc Basin, Davies placed the LAD of *Subtilisphaera* at the top of the Barremian. And the spore *Callialasporites dampieri* also rarely occurs in post-Barremian sediments. Other spores with LADs in the Barremian are *Cerebropollenites mesozoicus, Cicatricosisporites versiformis* and *Klukisporites pseudofurcatus*.

One of the most frequently encountered marker species in the Cretaceous of offshore eastern Canada is the dinocyst *Cerbia tabulata*. This species, whose LAD consistently marks the top of the Aptian, occurs in the cuttings sample at 1485-1495 m. Therefore, I include from 1555-1485 m in the Aptian. Spores with LADs in the Aptian of St. George J-55 are *Plicatella potomacensis* and *Densoisporites velatus*.

An Albian assemblage is restricted to the sidewall core at 1478 m. From this sample, I recorded the dinocysts *Epelidosphaeridia spinosa* and *Kiokansium williamsii* and the spores *Cicatricosisporites hughesii, Klukisporites pseudoreticulatus* and *Trilobosporites apiverrucatus*. Davies *in* Bujak-Davies (1987) gave a LAD of Albian for *Trilobosporites apiverrucatus*. Williams *et al.* (in press) give a LAD of 93.81 Ma for *Epelidosphaeridia spinosa* and Williams *et al.* (1999) gave an LAD of 96.2 Ma for *Kiokansium williamsii*, which places them within the Cenomanian. Since I have not identified the Cenomanian in St. George J-55, I regard these species as further support of an Albian age.

From the overlying interval, I have a cuttings sample from 1455-1465 m and sidewall cores of 1465.5 and 1429 m. The cuttings sample is dominated by Paleocene-Eocene caved specimens but contains *Canningia reticulata*. In several wells in the Jeanne d'Arc Basin, this dinocyst has its LAD in the early Campanian. Possibly, this is the age of 1455-1465 m. The sidewall cores at 1465.5 and 1429 m contain mixed assemblages of early Cretaceous and Tertiary palynomorphs. I cannot comment on the age but obviously there was reworking.

The cuttings sample at 1425-1435 m further confuses the interpretation. This contains a rich dinocyst assemblage, with several Selandian index species including *Palaeocystodinium bulliforme* and *Palaeoperidinium pyrophorum*. According to Williams *et al.* (in press), the LAD of *Palaeocystodinium bulliforme* is 57.9 Ma and that of *Palaeoperidinium pyrophorum* is 58.04 Ma. This is at or close to the Selandian-Thanetian boundary, which is at 57.9 Ma. A third species, *Spinidinium densispinatum*, indicates a slightly older age. Willams *et al.* (1999) considered the LAD of this species at 59.38 Ma, just above the Danian-Selandian boundary. Perhaps the solution is to regard the interval 1425-1435 m as Selandian.

The overlying cuttings sample from 1395-1405 m appears to be early Eocene or Ypresian. It has a diverse palynomorph assemblage with the dinocysts *Adnatosphaeridium multispinosum,* frequent *Apectodinium homomorphum, Cordosphaeridium gracile,* common *Cyclonephelium* sp.A Williams and Brideaux 1975, *Spiniferella cornuta* and *Wilsonidium echinosuturatum*. Williams *et al.* (1999)

considered the LAD of *Apectodinium homomorphum* to be 38.7 Ma, that's within the Bartonian. But *Apectodinium homomorphum* occurs rarely in the Lutetian and Bartonian. *Wilsonidium echinosuturatum* is a good Lutetian marker, having its LAD at 42.0 Ma in Southern Hemisphere higher latitudes (Williams *et al.*, in press), which is close to the Lutetian-Bartonian boundary. *Areoligera* cf. *senonensis* and *Areoligera* cf. *medusettiformis*, both of which occur in this sample, have their LADs in the Ypresian. Single specimens of *Areoligera* cf. *medusettiformis* occur in cuttings samples above 1395 m but I consider these to be reworked.

Middle Eocene sediments extend from 1375-915 m and can be subdivided into early and late Lutetian and Bartonian. The early Lutetian from 1375-1275 m is characterized by the LAD of the dinocysts *Glaphyrocysta divaricata, Glaphyrocysta ordinata, Hystrichostrogylon clausenii* and *Diphyes pseudoficusoides*. Williams *et al.* (1999) gave the LAD of *Glaphyrocysta ordinata* as 45.8 Ma and the LAD of *Glaphyrocysta divaricata* as 44.5 Ma. Gradstein and Ogg (1996) gave the age of the Lutetian as 49-41.3 Ma. Therefore, I feel justified in considering 1365-1275 m to be early Lutetian. This is supported by Bujak (1994), who placed the LAD of *Hystrichostrogylon clausenii* in the early Lutetian and the LAD of *Diphyes pseudoficusoides* at about the boundary between the early and late Lutetian.

From 1255-1035 m, which I consider late Lutetian, is marked by the LAD of *Glaphyrocysta exuberans* and *Glaphyrocysta intricata* in the cuttings sample at 1035-1045 m. Other species with LADs in this interval are the dinocysts *Deflandrea eocenica, Deflandrea hialina* and *Phthanoperidinium powellii*. In Jeanne d'Arc wells I have studied, species of *Glaphyrocysta* do not extend into the late Eocene and rarely into the Bartonian. Species with their FADs in the late Lutetian of St. George J-55 are the dinocysts *Heteraulacacysta stoveri, Operculodinium microtrianum* and *Phthanoperidinium comatum*. Williams *et al.* (1999) gave the FAD of *Phthanoperidinium comatum* as 49.79 Ma, that's close to the Ypresian-Lutetian boundary.

Samples from the overlying Bartonian contain rich assemblages of pollen and dinocysts. I include from 1015 to 915 m in this stage. The dinocyst *Heteraulacacysta porosa* has its LAD in the cuttings sample at 945-955 m. Bujak (1994) gave the LAD of this species as the top of the Bartonian. Williams *et al.* (in press) place the LAD at 36.4 Ma, which is basal Priabonian. In the Jeanne d'Arc Basin, *Heteraulacacysta* does not usually occur in post-Bartonian sediments, although in a few wells there is a strong influx in the Rupelian. Other dinocysts with their LADs in the Bartonian of St. George J-55 are *Charlesdownia proserpina, Enneadocysta "annulata"* and *Hystrichostrogylon membraniphorum*. The pollen *Sequoiapollenites* has its LAD in the cuttings sample at 975-985 m.

In both the late Lutetian and the Bartonian, there is a high percentage of Late Cretaceous dinocysts. I assume this reflects extensive erosion and transportation of Upper Cretaceous sediments, either submarine or subaerial.

Upper Eocene or Priabonian sediments extend from 895-765 m, based on the LAD of the dinocyst *Lentinia serrata* in the cuttings sample at 765-775 m. Williams *et al.* (in press) give the LAD for *Lentinia serrata* as 33.5 Ma, which is close to the top of the Priabonian. The dinocyst *Areosphaeridium diktyoplokum*, which has a LAD of 33.3 Ma (Williams *et al.*, in press), is in the cuttings samples at 855-865 and 795-805 m. This further confirms the Priabonian age for the interval 765-895 m. Other dinocysts with LADs in the Priabonian are *Phthanoperidinium eocenicum, Phthanoperidinium levimurum, Phthanoperidinium multispinum, Corrudinium reticulatum* and *Eocladopyxis peniculata.*

I have assigned the youngest sediments I analysed to the Rupelian or early Oligocene, which is from 715-595 m. The informal dinocyst species *Enneadocysta "cingulomagna"* occurs in the highest sample at 595-605 m. This has its LAD in the Rupelian in several wells in the Jeanne d'Arc Basin. Other dinocysts occurring in the Rupelian of St. George J-55 are *Wetzeliella gochtii, Chiropteridium galea* and *Membranophoridium aspinatum.*

Paleoenvironments

The paleoenvironmental interpretations I present for St. George J-55 are based primarily on the sidewall cores, although the cuttings samples can be used for general observations. In sidewall cores that contain at least 50 palynomorphs, I have counted the number of spores and pollen versus the number of dinocysts. The plot is shown in Figure 2. Where possible, I counted 200 specimens. The spore-pollen to dinocyst ratio provides useful information on paleoenvironments and, sometimes, on the sequence stratigraphy.

The deepest sample examined, a cuttings sample at 4090-4100 m, contains an impoverished assemblage with both pollen and dinocysts. There is a high percentage of carbonized organic matter. Dinocysts indicate an open marine environment, with the absence of schizeaceous spores perhaps suggesting open marine, well offshore. A sidewall core at 4080 m has spores, pollen, dinocysts and microforaminifera. From the high spore-pollen to dinocyst ratio in this and cores up to 4008 m, I interpret the environment as inner neritic, closer to shore.

There is a significant decrease in the spore-pollen to dinocyst ratio in the sidewall cores at 3975 and 3945 m, presumably denoting more offshore, open marine conditions. The same sidewalls also contain common to abundant specimens of the dinocyst *Dingodinium*, which thus may be indicative of the middle to outer neritic milieu.

A sidewall core at 3920 m has a high abundance of *Corollina torosus* and a dominance of spores and pollen, with occasional dinocysts such as *Gochteodinia mutabilis* and *Geiselodinium paeminosum.* I interpret this as very close to shore, marine to brackish water.

From 3880 to 1687.5 m is predominantly closer to shore, inner neritic, with several nonmarine and an occasional more offshore interlude. Spore-pollen to dinocyst ratios for most of this interval are high. From 3880 to 3845-3855 m appears to be farther from shore, open marine, with occasional specimens of *Leptodinium.* The interval 3820-3470 m is close to shore, inner marine to brackish water. There are few dinocysts in the sidewall cores but much better recovery from the cuttings samples. This I presume indicates fluctuating environments with more offshore episodes.

A more offshore interlude occurs at 3415 m, which contains a single specimen of the dinocyst *Leptodinium.* This is based on my belief that *Leptodinium*, like the morphologically similar *Impagidinium*, reflects an offshore, open marine environment. The spore-pollen to dinocyst ratio remains high. From 3363 to 2994 m, where I have several sidewall cores, but only one cuttings sample, there are only minor fluctuations in the environment. Microforaminiferal linings are consistent but rare. And dinocyst concentrations are low. I interpret this interval as close to shore, inner neritic.

The sparse numbers of dinocysts in the sidewalls from 2960-2844 m, mostly indicate nonmarine to, at most, brackish water deposition. More open, offshore marine conditions return at 2779 m and persist almost unbroken to 2161.5 m. The sidewall core at 2548 m contains a much richer dinocyst assemblage, with species of *Systematophora, Pseudoceratium, Muderongia* and *Cribroperidinium.* I interpret this a marine transgressive episode. This is continued at 2336, 2222.5 and 2192 m.

A return to closer to shore, neritic environments occurs at 2108.5 m, which persists to 2053 m. The sidewall at 2033.5 m marks a return to more open marine conditions, with presumably deeper water. This sample contains numerous dinocysts, with several specimens of *Spiniferites, Phoberocysta* and

Gonyaulacysta. *Phoberocysta* has been regarded as more inshore or littoral and *Muderongia* as open marine (Contu and Monteil *in* Monteil, 1990). *Spiniferites* and *Gonyaulacysta*, however, predominate in more open marine, oligotrophic regimes.

The sidewall cores at 2010 and 1972 m give mixed signals. Dinocysts are rare or absent but there is an occasional microforaminiferal lining. I interpret the cores as representing a marine environment but in a more oligotrophic setting. There is a nonmarine interlude at 1918 m and a return to a neritic setting at 1888 m, where the sidewall core contains *Phoberocysta* and a microforaminiferal lining. From 1888-1687 m, the signal is mixed. Dinocyst recovery is low or absent, indicative of a marginal marine setting. But interpretation is difficult because of some Tertiary caved material in the cuttings samples. This Tertiary cave becomes dominant in the cuttings samples from 1675-1485 m.

I have difficulty in interpreting 1643.5 to 1465.6 m. The sidewall at 1643.5 m contains two specimens, both bivesiculate pollen. Such pollen can be windborne for hundreds of miles offshore. A sidewall at 1600.5 m is more informative, containing several specimens of the peridinialean dinocyst *Subtilisphaera*. This should be indicative of inner neritic deposition. If it was a phagotroph, however, it could indicate more offshore environments. Sidewalls at 1568.5, 1478 and 1465.5 m are equally ambiguous. The high percentage of bivesiculate pollen at 1478 m may denote an outer shelf or even deeper water in an oligotrophic zone not conducive to dinocysts.

Two sidewall cores at 1465.5 and 1429 m are contaminated with caved Tertiary pollen and dinocysts. The indigenous assemblages, if identified correctly, are mainly *Corollina* pollen. *Corollina*, according to Traverse (1988) is produced by coniferous plants, specifically of the Cheirolepidiaceae. Hughes (1976) noted that *Corollina* is dominant in shales and limestones deposited offshore from the coal swamps where they flourished. Presumably the pollen could be blown far out to sea if prevailing winds were southeasterlies.

There is a significant change in the cuttings sample at 1425-1435 m. Although this is 4 m below the Cretaceous-Tertiary unconformity, the assemblage is dominated by Paleocene dinocysts, with no Cretaceous taxa. In this interval, there is an abundance peak of *Areoligera* cf. *medusettiformis*. In other wells on the Grand Banks, including Terra Nova K-18 in the Jeanne d'Arc Basin and Skua E-41 in the Carson Basin, *Areoligera* acmes have been characteristic of the Thanetian. In St. George J-55, because of the co-occurrence of *Palaeoperidinium pyrophorum* and *Palaeocystodinium bulliforme*, I consider 1425-1435 m as Selandian or possibly Danian. Powell *et al.* (1996) described *Areoligera* dominated assemblages from the type Thanetian of southern England. In the Pegwell Bay section, there are three levels where *Areoligera* is superabundant and three where it is abundant. According to Powell *et al.* (op. cit.), such horizons denote restricted, high-energy, marginal marine settings typical of a transgressive regime, although the species *Areoligera gippingensis* is considered indicative of offshore marine environments (Heilmann-Clausen, 1994). These authors believed the richest samples were close to the most condensed interval or maximum flooding surface.

I interpret 1435-1005 m as an offshore, open marine environment, presumably often an area of upwelling with a rich nutrient supply. An abundance of *Pinuspollenites* in the cuttings sample at 1304-1315 m indicates a more distant from shore location. At 1035-1045 m, there is an influx of pollen, which I am assuming indicates a closer to shore, inner to middle neritic environment. This interpretation seems to be confirmed by the high relative abundances of the dinocyst *Eocladopyxis peniculata* in the cuttings samples at 975-985, 915-925 and 885-895 m. Closely related dinocyst genera, such as *Homotryblium* and *Polysphaeridium*, are indicative of warmer water, lagoonal to brackish water environments (Brinkhuis, 1992). Thus, I interpret the interval 915-925 m especially as closer to shore and marking warmer climatic conditions.

This trend presumably continues in the interval 855-867 m in which the acritarch *Epicephalopyxis indentata* is common. Brinkhuis and Schiøler (1996) regarded a dominance of this species to denote very shallow marine environments, based on the findings of Elsik (1977). Although it must be allochthonous in St. George J-55, its presence indicates a shallower water environment.

I interpret the cuttings samples from 835-735 m as representing a neritic but more offshore milieu, with common taxa being *Phthanoperidinium* and *Deflandrea phosphoritica.* A more offshore setting is indicated for the uppermost samples from 735-605 m, with *Pinus* becoming abundant and in 625-635 m, *Spiniferites* being frequent.

The Tertiary section in St. George J-55, that's from 1421-595 m, contains rich dinocyst assemblages. These predominantly comprise indigenous taxa but reworked Cretaceous taxa are common from 1065 to 595 m. Most of the reworked taxa are Late Cretaceous. Obviously, Upper Cretaceous rocks were being eroded to the west or northwest and the sediments transported to the vicinity of St. George J-55. One reworked species, *Chatangiella decorosa*, is known only from the Late Cretaceous of higher latitudes (Lentin and Williams, 1980), so may denote long distance transport from arctic Canada.

Correlation of Palynology and Lithostratigraphy

The only published study of the lithostratigraphy of St. George J-55 is that by the Canada Newfoundland Offshore Petroleum Board (1998). In my comparison with the palynology, however, I shall use data provided by K.D. McAlpine of GSC Atlantic (Fig.2). McAlpine (pers. comm.) assigned the sediments from 4100-3902 m to the Fortune Bay Shale, a unit formalized in McAlpine (1990). This is a shale and siltstone unit with thin sandstones developed locally. According to my data, the Fortune Bay is mid Kimmeridgian. McAlpine (1990) gave the age as mid to late Kimmeridgian, according to the Bujak-Davies Group (1988d). Like me, these authors use the "long' Kimmeridgian and the Portlandian terminology for the two youngest Jurassic stages. McAlpine (1990) preferred using the "short" Kimmeridgian and the Tithonian for the same interval. Therefore, he regarded the age of the Fortune Bay Shale as Tithonian.

The Whiterose Shale - the basinal equivalent of the Hibernia, Cataline and Eastern Shoals formations - extends from 3902-3006 m. I consider this interval to be mid Kimmeridgian to Portlandian. The Bujak-Davies Group (1988c) considered the formation to be late Kimmeridgian to Barremian; McAlpine (1990) interpreted it as late Tithonian to Barremian.

In St. George J-55 the Whiterose Shale is attenuated, presumably due to a shallowing of the environments and a corresponding change in lithology. McAlpine (pers. comm.) labels the sandstone-shale sequences from 3006-1857 m as "unnamed Lower Cretaceous sandstones and shales". From my palynological analysis, I consider this interval to be Portlandian-Hauterivian.

McAlpine (pers. comm.) includes 1857-1479 m in the Nautilus Shale. According to McAlpine (1990), the shale is early Aptian to late Albian-Cenomanian at the type section in Nautilus C-92. This age is based on the micropaleontology (Williamson, 1987). I consider 1857-1479 m to be Hauterivian to Aptian. If the Nautilus Shale does indeed extend down to 1857 m, I cannot reconcile my palynological data with the age for the type section. I place the base of the Barremian at 1785 m and the base of the Hauterivian at 1885 m, perhaps more logical but still not satisfactory depths for the base of the Nautilus Shale. There is certainly an attenuated Hauterivian and Barremian in St. George J-55 and overlying Aptian and Albian sequences are very condensed. To add to the uncertainties, CNOPB (1998) marked an Aptian unconformity at 1840 m. This would lie close to my Hauterivian-Barremian boundary. The only solution is to resample the interval from 2000-1550 m and re-evaluate both the lithostratigraphy and biostratigraphy.

McAlpine (pers. comm.) and CNOPB (1998) both recognized an unconformity at 1479 m. According to McAlpine, this separates the Nautilus Shale from the Wyandot. CNOPB stated that the unconformity is Albian. The CNOPB interpretations best fits my palynological data. I consider the sidewall core at 1478 m as Albian and recognize a Campanian sliver at 1455-1465 m.

There is a base Tertiary unconformity at 1421 m, according to McAlpine (pers.comm.). My data are not as precise, since I consider the cuttings sample at 1425-1435 m to be Selandian. This results from the massive Tertiary caving in this sample, which obscures any Campanian signal. Based on the lithostragraphy, I interpret the Selandian as immediately overlying the unconformity at 1421 m. McAlpine (pers. comm.) includes all the Tertiary section in the Banquereau Formation. As I have stated in other well history reports, this formation needs to be subdivided. Deptuck *et al.* (in press) are proposing a formal subdivision of the lowermost part of the Banquereau. This is a promising start on a long overdue task.

Summary

St. George J-55 contains a more or less complete Upper Jurassic section, an attenuated and incomplete Cretaceous sequence above the Berriasian-Valanginian, and a condensed Paleogene section in the Paleocene and early Eocene. Age control is primarily from dinocysts in the Kimmeridgian-Portlandian, dinocysts, spores and pollen in the Berriasian-Barremian, and dinocysts in the Aptian-Albian, Campanian and early Tertiary. By using the dinocysts as control, I have determined the stratigraphic range of several pollen and spore species. These will provide invaluable control in other wells in the Carson and Jeanne d'Arc basins.

The sediments in St. George J-55 were deposited in non-marine to open ocean environments, with deeper water conditions in much of the Paleogene. I have insufficient date to draw conclusions on the paleoenvironments in the late Cretaceous. In the Paleogene, correlation with data from other areas, however, is demonstrating the value of dinocysts as paleoenvironmental and paleoclimatic indicators. By extending such concepts to the Jurassic and Cretaceous, I should be able to develop a model that will provide paleoenvironmental control throughout the Mesozoic-Cenozoic of the Grand Banks.

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Figure 1. Stratigraphy and paleoecology of Canterra PCI St. George J-55. The lithostratigraphic picks are provided by K.D. McAlpine (pers. comm.).

Appendix A

References for dinoflagellate citations are from Williams *et al.* (1998). References for spore and pollen citations are from Dettmann (1963), Norris (1969) and Singh (1971).

Achomosphaera alcicornu (Eisenack, 1954b) Davey and Williams, 1966a
Achomosphaera neptuni (Eisenack, 1958a) Davey and Williams, 1966a
Achomosphaera "procerus"
Adnatosphaeridium filiferum (Cookson and Eisenack, 1958) Williams and Downie, 1969
Adnatosphaeridium multispinosum Williams and Downie, 1966c
Adnatosphaeridium vittatum Williams and Downie, 1966c
Aequitriradites baculatus Doring, 1964
Aequitriradites spinulosus (Cookson and Dettmann, 1958) Cookson and Dettmann, 1961
Aequitriradites verrucosus (Cookson and Dettmann, 1958) Cookson and Dettmann, 1961
Alisogymnium euclaense (Cookson and Eisenack, 1970a) Lentin and Vozzhennikova, 1990
Alisporites grandis (Cookson, 1953) Dettmann, 1963
Amphorula delicata van Helden, 1986
Amphorula metaelliptica Dodekova, 1969
Apectodinium homomorphum (Deflandre and Cookson, 1955) Lentin and Williams, 1977b
Appendicisporites jansonii Pocock, 1962
Araneosphaera araneosa Eaton, 1976
Areoligera semicirculata (Morgenroth, 1966b) Stover and Evitt, 1978
Areoligera sentosa Eaton, 1976
Areoligera cf. *medusettiformis* O. Wetzel, 1933b
Areoligera cf. *senonensis* Lejeune-Carpentier, 1938a
Areosphaeridium diktyoplokum (Klumpp, 1953) Eaton, 1971
Areosphaeridium michoudii Bujak, 1994
Auritulinasporites deltaformis Burger, 1966
Baltisphaeridium "scalenofurcatum"
Bourkedinium granulatum Morgan, 1975
Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961
Callialasporites monoalasporus Sukh Dev, 1961
Callialasporites obrutus Norris, 1969
Callialasporites segmentatus (Balme, 1957) Sukh Dev, 1961
Canningia reticulata Cookson and Eisenack, 1960b
Cassiculosphaeridia magna Davey, 1974
Cassidium Drugg, 1967
Cerbia tabulata (Davey and Verdier, 1974) Below, 1981a
Cerebropollenites macroverrucosus (Thiergart) Schultz, 1967
Cerebropollenites mesozoicus (Couper, 1958) Nilsson, 1958
Cerodinium speciosum (Alberti 1959b) Lentin and Williams, 1987
Charlesdowniea coleothrypta (Williams and Downie, 1966b) Lentin and Vozzhennikova, 1989
Charlesdowniea proserpina van Mourik *et al.*, 2001
Chatangiella decorosa (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella tripartita (Cookson and Eisenack, 1960a) Lentin and Williams, 1976
Chiropteridium galea (Maier, 1959) Sarjeant, 1983
Chlamydophorella nyei Cookson and Eisenack, 1958
Cicatricosisporites #EAD Davies *in* Bujak-Davies, 1987
Cicatricosisporites #EM Davies *in* Bujak-Davies, 1987
Cicatricosisporites #EQ Davies *in* Bujak-Davies, 1987
Cicatricosisporites #ES Davies *in* Bujak-Davies, 1987

Cicatricosisporites australiensis (Cookson, 1953) Potonié, 1956
Cicatricosisporites hallei Delcourt and Sprumont, 1955
Cicatricosisporites hughesii Dettmann, 1963
Cicatricosisporites magnus Doring, 1965
Cicatricosisporites notabilis Doring, 1965
Cicatricosisporites pseudotripartitus (Bolkhovitina, 1961) Dettmann, 1963
Cicatricosisporites purbeckensis Norris, 1969
Cicatricosisporites subrotundus Brenner, 1963
Cicatricosisporites versiformis Doring, 1965
Cingutriletes Pierce, 1961
Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986
Cleistosphaeridium "diversielegantulum"
Cleistosphaeridium huguoniotii (Valensi, 1955a) Davey, 1969a
Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978
Contignisporites fornicatus Dettmann, 1963
Contignisporites glebulentus Dettmann, 1963
Contignisporites major Doring, 1965
Cordosphaeridium gracile (Eisenack, 1954b) Davey and Williams, 1966b
Cordosphaeridium cf. *eoinodes* (Eisenack, 1958a) Eisenack, 1963b
Corollina echinata (Burger, 1965) Dörhöfer, 1979
Corollina torosus (Reissinger) Klaus, 1960
Coronatispora valdensis (Couper, 1958) Dettmann, 1963
Corrudinium reticulatum Grabowska *in* Malinowskiej and Piwockiego, 1996
Costatoperforosporites foveolatus Deák, 1962
Cribroperidinium "aculeatum"
Cribroperidinium cf. *boreas* (Davey, 1974) Helenes, 1984
Ctenidodinium culmulum (Norris, 1965) Lentin and Williams, 1973
Ctenidodinium elegantulum Millioud, 1969
Ctenidodinium ornatum (Eisenack, 1935) Deflandre, 1939a
Cyclonephelium sp. A Williams and Brideaux, 1975
Cyclonephelium sp. B Williams and Brideaux, 1975
Cyclonephelium vannophorum Davey, 1969a
Cymososphaeridium validum Davey, 1982b
Deflandrea denticulata Alberti, 1959b
Deflandrea eocenica Balteş, 1969
Deflandrea hyalina Balteş, 1969
Deflandrea phosphoritica Eisenack, 1938b
Densoisporites velatus Weyland and Krieger, 1953
Dichadogonyaulax pannea (Norris, 1965) Sarjeant, 1969
Dingodinium cerviculum Cookson and Eisenack, 1958
Dingodinium "endocornum"
Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965a
Diphyes pseudoficusoides Bujak, 1994
Dissiliodinium globulum Drugg, 1978
Dissiliodinium sp. Drugg, 1978
Enneadocysta "annulata"
Enneadocysta "cingulomagna"
Enneadocysta multicornuta (Eaton, 1971) Stover and Williams, 1995
Eocladopyxis "brevispinosa"
Eocladopyxis peniculata Morgenroth, 1966a
Eocladopyxis "verrucosa"
Epelidosphaeridia spinosa Cookson and Hughes, 1964

Epiplosphaera areolata Klement, 1960
Epiplosphaera bireticulata Klement, 1960
Epiplosphaera gochtii (Fensome, 1979) Brenner, 1988
Epiplosphaera ornata (Courtinat *in* Courtinat and Gaillard, 1980) Brenner, 1988
Epiplosphaera reticulata (Valensi, 1953) Courtinat, 1989
Eucommiidites sp.
Fibrocysta axialis (Eisenack, 1965b) Stover and Evitt, 1978
Foraminisporis wonthaggiensis (Cookson and Dettmann, 1958) Dettmann, 1963
Galeacornea clavis Stover, 1963
Gardodinium trabeculosum (Gocht, 1959) Alberti, 1961
Geiselodinium paeminosum Drugg, 1978
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
Glaphyrocysta pastielsii (Deflandre and Cookson, 1955) Stover and Evitt, 1978
Glaphyrocysta "preordinata"
Glaphyrocysta spineta (Eaton, 1976) Stover and Evitt, 1978
Glaphyrocysta sp. "Y"
Gochteodinia mutabilis (Riley *in* Fisher and Riley, 1980) Fisher and Riley, 1982
Gochteodinia villosa (Vozzhennikova, 1967) Norris, 1978
Gonyaulacysta diutina Duxbury, 1977
Gonyaulacysta jurassica (Deflandre, 1939a) Norris and Sarjeant, 1965
Gothanipollis Krutzsch, 1959
Hafniasphaera hyalospinosa Hansen, 1977
Hemiplacophora semilunifera Cookson and Eisenack, 1965a
Heteraulacacysta campanula Drugg and Loeblich Jr., 1967
Heteraulacacysta leptalea Eaton, 1976
Heteraulacacysta porosa Bujak *in* Bujak *et al.*, 1980
Heteraulacacysta pustulosa Jan du Chêne and Adediran, 1985
Heteraulacacysta "stoveri"
Heterosphaeridium difficile (Manum and Cookson, 1964) Ioannides, 1986
Hystrichodinium voigtii (Alberti, 1961) Davey, 1974
Hystrichodinium voigtii subsp. *brevispinum*
Hystrichokolpoma cinctum Klumpp, 1953
Hystrichokolpoma salacium Eaton, 1976
Hystrichostrogylon clausenii Bujak, 1994
Hystrichostrogylon membraniphorum Agelopoulos, 1964
Hystrichostrogylon "procerus"
Imbatodinium kondratjevii Vozzhennikova, 1967
Impagidinium victoriense (Cookson and Eisenack, 1965a) Stover and Evitt, 1978
Impardecispora #A Dörhöfer, 1977
Impardecispora apiverrucata (Couper, 1958) Venkatachala, Kar and Razi, 1968
Impardecispora splendens (Kara-Murza, 1954) Davies *in* Bujak-Davies, 1987
Januasporites tumulosus Norris, 1969
Kiokansium williamsii C. Singh, 1983
Kleithriasphaeridium fasciatum (Davey and Williams, 1966b) Davey, 1974
Klukisporites foveolatus Pocock, 1964
Klukisporites pseudoreticulatus Couper, 1958
Kraeuselisporites #EA Davies *in* Bujak-Davies, 1987
Kraeuselisporites #EB Davies *in* Bujak-Davies, 1987
Lanterna bulgarica Dodekova, 1969

Lanterna sportula Dodekova, 1969
Lentinia serrata Bujak *in* Bujak *et al.*, 1980
Leptodinium eumorphum (Cookson and Eisenack, 1960b) Sarjeant *in* Davey *et al.*, 1969
Leptodinium regale Gocht, 1970b
Leptodinium subtile Klement, 1960
Leptolepidites #EQ Davies *in* Bujak-Davies, 1987
Leptolepidites major Couper, 1958
Leptolepidites psarosus Norris, 1969
Lithodinia cf. *arcanitabulata* Brenner, 1988
Lycopodiacidites cerniipites (Ross, 1949) Norris, 1969
Maghrebinia perforata (Clarke and Verdier, 1967) Below, 1981a
Meiourogonyaulax bejuii Zotto *et al.*, 1987
Meiourogonyaulax deflandrei Sarjeant, 1968
Meiourogonyaulax stoveri Millioud, 1969
Membranophoridium aspinatum Gerlach, 1961
Mendicodinium sp. B Brenner 1988
Mendicodinium "rugulatum"
Microreticulatisporites diatretus Norris, 1969
Muderongia sp.A Cookson and Eisenack, 1958
Muderongia simplex Alberti, 1961
Occisucysta balios Gitmez, 1970
Occisucysta "distincta"
Occisucysta tentoria Duxbury, 1977
Oligosphaeridium asterigerum (Gocht, 1959) Davey and Williams, 1969
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966b
Oligosphaeridium perforatum (Gocht, 1959) Davey and Williams, 1969
Operculodinium divergens (Eisenack, 1954b) Stover and Evitt, 1978
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983a
Palaeocystodinium bulliforme Ioannides, 1986
Palaeohystrichophora infusorioides Deflandre, 1935
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967b
Pareodinia ceratophora Deflandre, 1947d
Parvisaccites amplus Brenner, 1963
Parvisaccites radiatus Brenner, 1963
Perinopollenites elatoides subsp. *"major"*
Perisseiasphaeridium sp. "Y"
Phoberocysta "ahorna"
Phoberocysta neocomica (Gocht, 1957) Millioud, 1969
Phthanoperidinium "atabulatum"
Phthanoperidinium comatum (Morgenroth, 1966b) Eisenack and Kjellström, 1972
Phthanoperidinium eocenicum (Cookson and Eisenack, 1965a) Lentin and Williams, 1973
Phthanoperidinium "hibernium"
Phthanoperidinium multispinum Bujak *in* Bujak *et al.*, 1980
Phthanoperidinium powellii Bujak, 1994
Pilosisporites verus Delcourt and Sprumont, 1955
Pilosisporites sp. A Bujak and Williams, 1977
Pilosisporites #EB Davies *in* Bujak-Davies, 1987
Pilosisporites trichopapillosus (Thiergart) Delcourt and Sprumont, 1955
Plicatella #ES Davies *in* Bujak-Davies, 1987
Plicatella #EQ Davies *in* Bujak-Davies, 1987
Plicatella bilateralis (Singh, 1971) Dörhöfer, 1977
Plicatella potomacensis (Brenner, 1963) Davies, 1985

Podocarpidites herbstii Burger, 196
Podocarpidites tricocca (Maljavkina) Bolchovitina
Pseudoceratium pelliferum Gocht, 1957
Pterocaryapollenites sp.
Rhynchodiniopsis cladophora (Deflandre, 1939a) Below, 1981a
Rouseisporites sp.
Rubinella major (Couper, 1958) Norris, 1969 sensu Norris, 1969
Rugubivesiculites reductus Pierce, 1961
Samlandia chlamydophora Eisenack, 1954b
Scriniodinium inritibile Riley *in* Fisher and Riley, 1980
Sentusidinium rioultii (Sarjeant, 1968) Stover and Sarjeant, 1978
Sentusidinium rioultii subsp. "*minispinum*"
Sentusidinium verrucosum (Sarjeant, 1968) Sarjeant and Stover, 1978
Sequioapollenites sp.
Spinidinium densispinatum Stanley, 1965
Spiniferella cornuta (Gerlach, 1961) Stover and Hardenbol, 1994
Spiniferites sp. "W"
Spiniferites dentatus (Gocht, 1959) Lentin and Williams, 1973
Spiniferites "duplifurcatus"
Spiniferites "procerus"
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970
Spiniferites pseudofurcatus subsp. "*brevispinum*"
Spiniferites scabrosus (Clarke and Verdier, 1967) Lentin and Williams, 1975
Spiniferites speciosus (Deflandre, 1937b) Sarjeant, 1970
Spongodinium delitiense (Ehrenberg, 1838) Deflandre, 1936b
Striatella #EAB Davies *in* Bujak-Davies, 1987
Striatella #EF Davies *in* Bujak-Davies, 1987
Striatella #ET Davies *in* Bujak-Davies, 1987
Subtilisphaera perlucida (Alberti, 1959b) Jain and Millepied, 1973
Svalbardella cf. cooksoniae Manum, 1960
Systematophora areolata Klement, 1960
Systematophora complicata Neale and Sarjeant, 1962
Systematophora complicata Neale and Sarjeant, 1962, sensu Duxbury
Systematophora orbifera Klement, 1960
Systematophora palmula Davey, 1982b
Systematophora penicillata (Ehrenberg, 1843b) Sarjeant, 1980a
Systematophora schindewolfii (Alberti, 1961) Downie and Sarjeant, 1965
Systematophora turonica (Alberti, 1961) Downie and Sarjeant, 1965
Systematophora valensii (Sarjeant, 1960a) Sarjeant, 1961b
Systematophora vestita (Deflandre, 1939a) Davey, 1982b
"Talladinium" coleothryptum
"Tallidinium" variabile
Tectatodinium grande Williams *et al.*, 1993
Tehamadinium dodekovae Jan du Chêne *et al.*, 1986b
Thalassiphora patulum (Williams and Downie, 1966c) Stover and Evitt, 1978
Thalassiphora pelagica (Eisenack, 1954b) Eisenack and Gocht, 1960
Thalassiphora reticulata Morgenroth, 1966b
Trilobosporites #EC Davies *in* Bujak-Davies, 1987
Trilobosporites aequiverrucatus Dörhöfer, 1977
Trilobosporites aornatus Doring, 1965
Trilobosporites apiverrucatus Couper, 1958
Trilobosporites bernissartensis (Delcourt and Sprumont, 1959) Potonié, 1956

Trilobosporites canadensis Pocock, 1962
Trilobosporites domitus Norris, 1969
Trilobosporites hannonicus (Delcourt and Sprumont, 1955) Potonié, 1956
Trilobosporites marylandensis Brenner, 1963
Trilobosporites obsitus Norris, 1969
Trilobosporites "tuberculiformis"
Trilobosporites valanginensis (Kara-Murza) Dörhöfer, 1977
Trilobosporites weylandii Doring, 1965
Uvaesporites glomeratus Doring, 1965
Valensiella ovulum (Deflandre, 1947d) Eisenack, 1963a
Vitreisporites sp. Singh, 1972
Wallodinium luna (Cookson and Eisenack, 1960a) Lentin and Williams, 1973
Wetzeliella gochtii Costa and Downie, 1976
Wetzeliella ovalis Eisenack, 1954b
Wetzeliella symmetrica Weiler, 1956
Wilsonidium sp. Lentin and Williams, 1976
Wilsonidium echinosuturatum (Wilson, 1967c) Lentin and Williams, 1976

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D298 Canterra PCI ST. GEORGE J-55

KB: 23.0 m; WD: 104.5 m; TD: 4100.2 m

Figure 1. Stratigraphy and paleoecology of Canterra PCI St. George J-55. The lithostratigraphic picks are provided by McAlpine (pers. comm.)

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