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Abstract

Both the Saglek and Hopedale sedimentary basins, respectively located on the northern and southern offshore Labrador margins, attracted hydrocarbon exploration in the 1970s and early 1980s. Two significant wells were Corte Real P-85 in the Hopedale Basin and Pothurst P-19 in the Saglek Basin. To determine the ages and paleoenvironments of the sediments in these wells, I undertook analyses of the organic-walled microfossils (dinocysts, miospores, acritarchs, chitinozoa), which are collectively termed palynomorphs. Both wells encountered only Tertiary sediments, with Corte Real P-85 being in the Ypresian at total depth and Pothurst P-19 being in the Lutetian at total depth. In both wells I identified a thick Lutetian section, an unusual occurrence in Labrador Shelf wells. One pleasant surprise was the flood of small pollen grains in the Plio-Pleistocene of Corte Real P-85, which holds promise for subdividing this time interval in Labrador Shelf wells. Reworking trends occur in both wells, with Carboniferous spores and Cretaceous spores and dinocysts common in Corte Real P-85, whereas in Pothurst P-19 only Cretaceous palynomorphs are reworked. Presumably the specimens were transported from the west and northwest. Significant breaks in the section are the apparent absence of Bartonian and Middle Miocene and the attenuated Priabonian sediments in Pothurst P-19. Neither well discovered oil nor natural gas.

Introduction

In the 1970s and early 1980s, there was extensive hydrocarbon exploration on the Canadian margin of the Labrador Sea, with about 30 wells being drilled if we include Davis Strait. Some of the wells are potential natural gas producers but the remoteness of the area has discouraged development. However, data from the wells have been invaluable in enabling lithostratigraphic and biostratigraphic determinations on the rocks underlying the Labrador Shelf. Two of these wells are Petro-Canada et al. Corte Real P-85 and Petro-Canada et al. Pothurst P-19, which were drilled on the Labrador Shelf in 1981-82 and 1982-83 respectively. Corte Real P-85 is in the Hopedale Basin; Pothurst P-19 is in the more northerly Saglek Basin (Figure 1). The Corte Real well was drilled to test the hydrocarbon potential of the Kenamu Formation, including the Leif Member, within a large, structurally closed, Tertiary listric fault. A secondary

objective was an upper Paleocene seismic marker in the Gudrid Formation (Petro-Canada et al. 1984). Pothurst P-19 targeted the Eocene Leif Member in a rollover sequence resulting from growth faulting (Petro-Canada et al. 1982). Neither well discovered oil or natural gas. At Corte Real P-85, the water depth was 438 m and the total depth was 4551 m, and at Pothurst P-19, the water depth was 195 metres and the total depth was 3992 metres. Both wells were completed in Tertiary rocks at total depth.

My study is based exclusively on the palynological analysis of cuttings samples, representing ten-metre composites over a thirty metre interval. Unfortunately, there were no conventional cores from either well and the sidewall cores from Corte Real P-19 were taken to destruction by the operators.

Methodology

Figure 2 provides a summary of my biostratigraphic and paleoenvironmental conclusions for the Corte Real P-85 well plotted against the lithostratigraphy and well logs. This figure denotes a series of bioevents generally representing Last Occurrences (a Last Occurrence is the highest or youngest occurrence of a taxon in a well or surface section and is commonly denoted by the acronym LO). First Occurrences (LOs) are not reliable indicators when deriving data from cuttings so I have not included any in Figure 2. I include a quantitative plot of the relative abundances of the palynomorph groups in this well in Figure 3. This plot is based on the analysis of dinoflagellate cysts (dinocysts), miospores (spores and pollen), acritarchs (organic microfossils of unknown origin) and other microfossils

I show stratigraphic ranges of palynomorphs for Corte Real P-85 in Figures 4 and 5. In Pothurst P-19, the poor recovery of palynomorphs precluded a quantitative plot of the data, although Figure 6 shows the LO of palynomorph taxa. To provide more data on the palynomorph occurrences' in Pothurst P-19, I include Figure 7, which represents a stratigraphic range plot of dinocyst taxa. Plates 1-5 illustrate specimens from the Corte Real P-85 well, and Plate 6 illustrates specimens from the Pothurst P-19 well.

Age interpretations for the two wells are based primarily on the known stratigraphic ranges of dinocysts in European sections (Powell, 1992; Bujak et al., 1980; Bujak, 1994; Stover et al., 1996; Williams et al., 1999, 2004) and from older wells and coreholes from offshore

eastern Canada and onshore and offshore western Greenland (Williams, 1975; Williams and Brideaux, 1975; Williams and Bujak, 1977; Barss et al., 1979; Williams et al., 1990; Sónderholm et al., 2003; Nøhr-Hansen, 2003, 2004; Nøhr-Hansen et al., in press; and Fensome et al., in press). The papers by Nøhr-Hansen et al. (in press) and Fensome et al. (in press) have been particularly informative since they collate the palynological data from 17 wells in the Labrador Sea and Davis Strait to derive an events plot, which has regional applicability.

Throughout this study, I have adhered to the time scale proposed by Gradstein et al. (2012). This has been also used in the transposing of ages given for individual dinocyst species but derived from other sources.

Samples processed for palynomorphs from Corte Real P-85 had previously been chips retained on the +60 micron screen. The results had been extremely disappointing with few palynomorphs recovered, most of which were not helpful for age determinations. Consequently, I decided to have the -60 micron fraction processed at GSC Calgary. In Corte Real P-85, palynomorph counts were initially conducted on every sample going down the well. But then, because of time constraints and often paucity of recovered specimens, I counted every other sample only. In Pothurst P-19, the extremely poor assemblages ruled out any possibility of undertaking counts.

Corte Real P-85

Biostratigraphy

The interval from total depth at 4551 to 4060 metres contains the LOs of several age-diagnostic dinocyst species including: *Vallodinium nigeriaense* (4080 metres), *Deflandrea oebisfeldensis* (4110 metres), *Wilsonidium edwardsii* (4470 metres) and *Eatonicysta furensis* (4500 metres). Williams et al. (2004) considered all these species apart from *Vallodinium nigeriaense*, which was not plotted, to have their LOs in the Ypresian. Jan du Chêne and Adediran (1985) described *Vallodinium nigerianese* from a roadside outcrop in Nigeria, which they considered to be Paleocene to Early Eocene. Based on the morphology of the species (Williams et al., 2015), I believe the outcrop is, at least in part Early Eocene (Ypresian). And I

consider the age of the interval 4551-4060 metres in Corte Real P-85 to be Ypresian. Within this interval is the consistent presence of the fresh-water fern *Azolla* between 4470 and 4230 metres, with its LO at 3990 metres. Brinkhuis et al. (2006) stated there is an *Azolla* abundance just above the Ypresian-Lutetian boundary in the sediments of Nordic seas. Although *Azolla* is not abundant in any of the Corte Real samples, I consider it's LO at 3990 metres to be significant and to be just within the Lutetian. This supports my placing the top of the Ypresian at 4060 metres.

Azolla is a small moss-like, freshwater fern famous for its nitrogen-fixing capability. Its modern distribution indicates that it prefers much warmer temperatures than occur today in the Labrador-Baffin Seaway (Brinkhuis *et al.*, 2006). Accordingly, its presence in Corte Real P-85 suggests the possibility of freshwater lakes feeding rivers, which transported the *Azolla* to the sea and hence out into deeper water during the Ypresian. Massive concentrations of dead *Azolla* accumulating at the bottom of the lakes could be preserved in sediment, giving rise to source rocks rich in type I kerogen. Given the right combination of time and temperature, such rocks would be major sources of oil. The occurrences of *Azolla* in Labrador Sea-Davis Strait wells are restricted to a narrow time interval at the top of the Ypresian (Nøhr_Hansen et al., in press).

According to palynological studies reported in Bujak-Davies Group (1987), the interval 4550-4005 metres is Ypresian. This is at variance with the findings of the micropaleontological studies in the same report, in which the interval 4550-4165 metres is considered to be Paleocene.

The Ypresian is overlain by a thick Lutetian section that extends from 4050 to 2910 metres. Dinocyst species having their LOs in this interval include *Glaphyrocysta divaricata* (consistent LO starting at 3660 metres), *Schematophora speciosa* (3540 metres), *Chiropteridium gilbertii* (3360 metres), *Areoligera undulata* (2940 metres), *Glaphyrocysta divaricata* (2940 metres), *Glaphyrocysta spineta* (2910 metes) and *Phthanoperidinium distinctum* (2910 metres). Bujak (1994) placed the LO of *Phthanoperidinium distinctum* just below the top of the Lutetian. Bujak et al. (1980) considered the LOs of *Areoligera undulata*, *Glaphyrocysta divaricata* and *Glaphyrocysta spineta* to be close to or on the Bracklesham/Bartonian boundary, which is generally considered to be close to the top of the Lutetian.

There is a marked increase in fungal spores at 3330 metres. This agrees with the findings of Nøhr-Hansen et al. (in press), who noted a Lutetian peak of fungal spores on their bioevents chart for the Labrador-Baffin Seaway region.

One surprising aspect of the Lutetian section in Corte Real P-85 is the high degree of reworked Late Cretaceous miospores and dinocysts. These include the spores *Cicatricosisporites minutaestriatus*, and *Appendicisporites jansonii*; pollen such as various species of *Aquilapollenites*, *Mancicorpus*, *Wodehouseia spinata*, *Wodehouseia octospinosa*, and *Rugubivesiculites reductus*; and the dinocysts *Cerodinium diebelii*, *Trichodinium castanea*, *Oligosphaeridium complex*, *Isabelidinium cretaceum*, *Odontochitina costata*, *Chatangiella ditissima*, *Heterosphaeridium difficile*, *Dinogymnium heterocostatum* and *Chatangiella granulifera*. There are also several Carboniferous spores.

Based on my analyses, Bartonian rocks extend from 2880 to 2220 metres. The top is picked on the LOs of the pollen *Extratriporopollenites* and *Pistillipollenites* at 2220 metres. Nøhr-Hansen et al. (in press) and Fensome et al. (in press) note that the LOs of the two pollen taxa occur within the Bartonian. Also having it's LO in this sample is the dinocyst *Deflandrea eocenica.*

In the Bartonian of Corte Real P-85 other significant LOs are: *Cicatricososporites* (2550 metres), *Phthanoperidinium geminatum* (2580 m), *Heteraulacacysta pustulosa* (2610 metres), *Cleistosphaeridium elegantulum* (2700 metres), *Phthanoperidinium alectrolophum* (2730 metres), *Enneadocysta arcuata* (2820 metres), *Eocladopyxis peniculata* (2820 metres) and *Heteraulacacysta porosa* (2820 metres). Bujak (1994) placed the LO of *Heteraulacacysta porosa* at the top of the Bartonian, and Fensome et al. (in press) considered the LO of *Cleistosphaeridium elegantulum* to be Lutetian-Bartonian.

Bujak Davies Group (1987), using palynological data, assigned the following ages to the designated intervals: Middle Eocene (3985-3165 metres), Middle-Late Eocene (3145-2605 metres), Late Eocene-Early Oligocene (2585-2325 metres), Early Oligocene (2305-2005 metres) and Late Oligocene (1985-1845 metres). These are somewhat at odds with their micropaleontological data, which gave the breakdown: Paleocene to Early Eocene (4550-4165 metres), Early Eocene (4145-3245 metres), Middle Eocene (3225-2565 metres), and Late Eocene

(2545-1565 metres). Combining the two, Bujak Davies Group (1987) came up with the following ages and associated intervals: Paleocene to Early Eocene (4550-4165 metres), Early Eocene (4145-3245 metres), Middle Eocene (3225-2565 metres), late Eocene (2545-1565 metres), Early Oligocene (1545-1045 metres), and Miocene or younger (1025-775 metres). My results appear to be intermediate between the palynological and micropaleontologica data of the Bujak-Davies Group (1987).

I am assigning from 2190 to 1830 metres to the Late Eocene (Priabonian). This is based on the presence of *Svalbardella* sp. at 1830 metres, *Svalbardella cooksoniae* sensu Eldrett *et al*. (2004) at 1860 metres, and *Svalbardella* cf. *cooksoniae* at 1920 metres. There is some contention over the age of the LO of *Svalbardella cooksoniae* sensu Eldrett et al. (2004). Costa *et al*. (1988) reported it from the early Oligocene of northeast Europe. Head and Norris (1989) placed the LAD within the nannofossil zone NP 22, which is early Oligocene (Rupelian). In two ODP holes in the Norwegian Sea, Williams and Manum (1999) placed the LAD within the Rupelian at 31.9 Ma, based on the time scale of Goll (1989). Brinkuis and Biffi (1993) and Brinkhuis (1994), by correlation with the magnetostratigraphy, determined the LAD to equate with Chron 12r, which again is Rupelian. Eldrett *et al*. (2004), based on the occurrence of the taxon in ODP Hole 913B, correlate the LAD with Chron 13r at 33.6 Ma, almost at the Priabonian-Rupelian boundary. Accordingly, I shall use the LO of *Svalbardella cooksoniae* to indicate the top of the Priabonian.

The occurrence of *Svalbardella cooksoniae* at 1860 metres disputes the palynological findings of the Bujak Davies Group (1987), who considered this to be Late Oligocene (Chattian). It shows closer agreement with their micropaleontological data, which indicates a Late Eocene age.

I assign the interval from 1800 to 1680 metres to be Rupelian. This is based on the LO of *Phthanoperidinium coreoides* in the sample at 1680 metres. According to Fensome et al. (in press) this species has it's LO in the Rupelian. Other taxa having their LOs in the Rupelian of Corte Real P-85 include the dinocysts *Cleistosphaeridium diversispinosum* and *Cordosphaeridium cantharellus* and the acritarch *Tritonites*.

I did not record any Chattian index species above 1680 metres, suggesting that sediments of this age are absent in the Corte Real well, signifying a major hiatus. But in the sample from 1590 metres are the pollen *Tiliaepollenites* sp. A of Fensome et al. (in press) and the spore *Osmundacidites wellmannii*. According to Fensome et al. (in press), the former has its LO in the Early Miocene, the latter has its LO in the Burdigalian (late Early Miocene). However, Williams and Bujak (1977) considered *Osmundacidites wellmannii* (as *Osmundacidites claytonensis*) to have its LO in the middle to late Miocene on the Labrador Shelf. And Williams (1975) gave a middle Miocene LO for *Tiliaepollenites* sp A (as *Bombacacidites* sp. A). Although I am assigning only the interval 1650-1590 metres to the Early Miocene (probably Burdigalian), the thickness (less than 65 metres) suggests that the Lower Miocene is condensed. The absence of Aquitanian index taxa adds support to the non-deposition or subsequent erosion of sediments of this age.

A distinctive acritarch termed Acritarch sp. 1 by Head et al. (1989) occurs in the sample at 1620 metres. Head et al. (1989) recorded this taxon from the Miocene of ODP Site 645 in Baffin Bay. Acritarch sp. 1 is most abundant in the Middle Miocene, but can occur occasionally in the Early and Late Miocene.

Bujak Davies Group (1987) placed the top of the Late Eocene at 1565 metres, based on a study of the foraminifera. The palynological data indicated that Miocene or older sediments extended from 1825 to 1645 metres.

The interval 1560 to 1140 metres appears to be Middle Miocene. I base this interpretation on the presence of the dinocyst *Trinovantedinium*? *xylochoporum* in the sample at 1140 metres. This species was originally described by de Verteuil and Norris (1992) from the Middle Miocene of Maryland. Another species that occurs in this interval and whose LO does not extend above the Middle Miocene is *Unipontidinium aquaeductum*. Williams et al. (2004), placed the LO of this species in Northern Hemisphere mid-latitudes at 13.2 Ma, that is within the Serravallian. Reworked Early Cretaceous spores and Late Cretaceous dinocysts are common in most of the samples.

Spinifertes ovatus, a dinocyst, is present in the sample at 1110-1120 metres. According to Fensome et al. (in press), the LO of this species occurs in the Messinian. Thus I am assigning

this one sample to the Late Miocene. Other palynomorphs in the sample include several reworked Cretaceous spores and dinocysts. The thinness of the Upper Miocene sediments seems to indicate that there is a major hiatus within this time interval in Corte Real P-85.

Bujak Davies Group (1987) was somewhat vague in their interpretations of the interval 1545-1045 metres: according to the foraminiferal data, the age is Early Oligocene. This contrasts with the palynology, which indicated an age for the interval 1545-775 metres of Plio-Pleistocene or older.

A characteristic feature of the interval from 1080 to 780 metres, the latter being the highest sample in the well, is the high abundance of *Pinuspollenites* and other pollen, especially small specimens of *Betulaepollenites*. The spore *Sphagnumsporites* is also common. dee Vernal and Mudie (1989), in a palynological study of the Late Pliocene to Holocene of ODP Site 645 in Baffin Bay, recorded similar trends, but only in the Late Pliocene-earliest Pleistocene. That would indicate that from 1080 to 780 metres is Pliocene, since similar abundances would presumably occur in the Early Pliocene. Reworked palynomorphs are common in this interval, especially Late Cretaceous dinocysts.

Foraminiferal assemblages according to the Bujak Davies Group (1987) indicate an age of Miocene or younger for from 1025 to 775 metres. As noted above, the palynomorphs give an age of Plio-Pleistocene or older up to 775 metres. Both determinations show some agreement with my results.

There appear to be two major hiatuses in Corte Real P-85 that can be related to the regional unconformities recognized in the Labrador Shelf and more northerly areas by McWhae et al. (1980) and McWhae (1981). The older, the Baffin Bay Unconformity, was dated by McWhae et al. (1980) as early Oligocene. In Corte Real P-85, it is primarily Late Oligocene (Chattian), with Lower Miocene sediments directly overlying the Rupelian. But from the thicknesses it also appears that some of the Rupelian and most of the Early Miocene (Aquitainian-Burdigalian) is missing, presumably through erosion. Although the unconformity in Corte Real P-85 is somewhat younger than postulated by McWhae et al. (1980), it agrees with the age of a hiatus in the South Labrador N-79 well identified by Williams (2007b). As that

author concluded, I regard the hiatus in Corte Real P-85 as compatible with the Baffin Bay Unconformity.

The second hiatus appears to be within the Late Miocene (Tortonian-Messinian) but also probably includes part of the Middle Miocene. McWhae et al. (1980) defined the Beaufort Unconformity, which they considered Late Miocene. This correlates with the missing section in Corte Real P-85.

Paleoenvironments

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

How does one do this and what are the known problems? Since the vast majority of samples are drill cuttings, both qualitative and quantitative data have disadvantages. Because of caving and contamination from drilling mud, the major concern is to determine which specimens are in place. This applies to both qualitative and quantitative data. For qualitative analyses, we rely on LOs or last occurrences going down the hole, which still has potential for inaccuracies. Quantitative analyses are more speculative. However, species counts will show the more obvious trends and permit larger groupings. Thus for dinocysts, the gonyaulacacean/peridiniacean/ceratiacean ratio, as used by Lister and Batten (1988), is one possible option.

One major advantage of palynomorphs is the diversity of paleoenvironments they denote. Spores and pollen yield information on terrestrial paleoenvironments, while dinocysts provide a key to the aqueous domains from freshwater to open ocean. But there are caveats. One is that dinocysts represent the encysted stage of the motile dinoflagellate, which is a planktonic organism. Consequently, it has been widely accepted that dionocyst distribution patterns exhibit a minimal relationship to water depths. In a literal sense this is correct. But, dinoflagellates and hence the corresponding dinocysts, do show distinct environmental preferences, especially when

related to salinity and/or nutrient availability. Thus some dinocysts are restricted to (or more abundant in) non-marine, lagoonal, coastal, inshore, offshore or open-ocean settings. This means that it is feasible to make paleoenvironmental interpretations. For example, open ocean can be equated with a deeper water or bathyal environment.

Using control provided by other fossil groups and lithostratigraphy will ultimately lead to the development of a sophisticated paleoenvironmental model for dinocyst species, providing it is based on both quantitative and qualitative data at the species level. This concept is not new, as demonstrated by the pioneering research, based primarily on qualitative data, of Gocht (1969), Downie et al. (1971) and Köthe (1990). The early results soon highlighted the need for quantitative data to obtain reproducible and predictive results. Thus, the model presented by Brinkhuis (1992, 1994), which represented a major advancement in dinocyst paleoenvironmental studies, must be keyed to quantitative studies.

Brinkhuis (1992, 1994) in his study of the Priabonian illustrated lateral changes in dinocyst assemblages across a transect from lagoonal to open ocean environments. I have used the modified version of this model, as presented in Sluijs et al. (2005), in my paleoenvironmental interpretations for the South Labrador N-79 well and shall, where possible, duplicate it here. Because of the relative sparseness of dinocysts in the assemblages, however, I have had difficulty in interpreting paleoenvironmental settings for some of the samples.

A plot showing the relative percentages of dinocysts, miospores, acritarchs and other organic-walled dinocysts is given in Fig 3. This plot reveals the dominance of miospores throughout the section, with values exceeding 87% and sometimes attaining 100%. However, all the samples contain some dinocysts, even though this is not reflected in the counts. The explanation for this apparent anomaly is that the counts are undertaken on unsieved fractions of each sample. Sieving, which is a routine procedure, concentrates the dinocysts, which are generally larger than the miospores with the exception of the bivesiculates. Another bias is that the counts were done on samples from the -63 micron fraction, thus further reducing the possibility of having abundant dinocysts on the count slides.

Allowing for the above concerns, what conclusions can be drawn from the quantitative data? The dominance of the miospores could indicate one of three possibilities: that the section

is predominantly non-marine, that it is middle neritic or that it is open ocean. The presence of what I consider in situ dinocysts and the high degree of reworked dinocysts and miospores indicate that most if not all of the section is marine. From 4500 to 4140 metres, mainly Early Eocene in age, specimens of *Impagidinium* occur in about one-third of the samples. Based on these occurrences I consider 4500-4140 metres to represent a time of deeper water, open ocean deposition in the vicinity of the Corte Real well. This is surprising in view of the persistent occurrence of the fresh-water fern *Azolla* in the samples between 4470 and 3990 metres. The most likely explanation for this is that specimens of this genus were transported from nearby fresh-water sites. Since *Azolla* is found in lower latitudes today, its presence in the Ypresian-Lutetian of Corte Real indicates that the region was much warmer during the Early Eocene than it is today.

Impagidinium is one of the few dinocyst genera, which appear to be restricted to open ocean, deeper water environments. Wall et al. (1977) were the first to recognize that *Impagidinium* species (then included in *Leptodinium*) were indicative of oceanic realm environments. Brinkhuis (1992) incorporated this concept into his Priabonian model and Dale (1996) confirmed the validity of *Impagidinium* dominance among organic-walled dinocysts in the oceanic realm. The *Impagidinium* signal has been used to indicate open water or deeper water paleoenvironments in studies of other Labrador Sea wells, for example South Labrador N-79 (Williams, 2007b).

Bujak Davies Group (1987) and Miller & d'Eon (1987) have published paleoenvironmental interpretations of Corte Real P-85. Whereas Bujak-Davies Group (1987) based their conclusions on the distribution patterns of benthic foraminifera taxa, d'Eon-Miller and Associates Ltd (1987) relied on lithologic analyses. In both papers, the interval 4550-4100 metres was interpreted as bathyal.

As noted above, the Lutetian extends from 4050 to 2910 metres. Within the lower part of this interval, from 4050 to 3750 metres, I did not record any specimens of *Impagidinium*. But there were a few dinocysts, most apparently reworked. Pollen, especially *Pinuspollenites*, were common. *Pinuspollenites* is often over-represented in deep-sea sediments off eastern Canada (Mudie, 1982; and de Vernal and Mudie, 1989). Such abundances reflect the adaptability of the pollen grains of this genus to be transported over long distances, either by wind or oceanic

currents. My observed results suggest that deposition over this interval was deeper water, farther offshore in the vicinity of Corte Real P-85.

The only other paleoenvironmental interpretations of the interval 4050-3750 metres in the Corte Real well are again those of Bujak-Davies (1987) and Miller & d'Eon (1987). According to these authors, deposition was in a bathyal paleoenvironment. This would confirm the significance of the high percentages of *Pinuspollenites*.

Between 3720 and 2910 metres, *Impagidinium* occurs intermittently and relative percentages of *Pinuspollenites* vary from 12 to 27%. Dinocysts are rare but small angiosperm pollen ae frequent to common. I consider this denotes open ocean, deeper water conditions. The findings of Bujak-Davies (1987) and Miller & d'Eon (1987) also agree with a bathyal setting in the vicinity of Corte Real P-85 during the later Lutetian.

Above the Lutetian sediments, the Bartonian extends from 2820 to 2220 metres, the Priabonian from 2190 to 1830 metres, the Rupelian from 1800 to 1680 metres and the early Miocene from 1650 to 1590 metres. Between 2850 and 2700 metres, the water depths were bathyal, based on the presence of *Impagidinium* . From 2700 to 1980 metres, depths were more variable, with *Impagidinium* occurring infrequently but *Deflandrea phosphoritica* being present in most samples. I am assuming that the specimens of *Deflandrea phosphoritica* are in place but they could have been transported in. If in place, what do they signify regarding the paleoenvironment? Downie et al. (1971) considered the species to be more abundant closer to shore.

Deciphering the dinocyst data regarding paleoenvironments between 2700 and 1980 metres is somewhat of a conundrum. I would interpret the paleoenvironment as neritic but this is at variance with the findings of Bujak-Davies Group (1987) and Miller & d'Eon (1987). The former authors concluded from the foraminiferal data that 3225-1565 metres represented deposition in bathyal to outer neritic paleoenvironments, whereas the latter considered 2973-1788 metres to represent bathyal deposition. If the conclusions of Bujak-Davies Group (1987) and Miller & d'Eon (1987) are correct, then the specimens of *Deflandrea phosphoritica* are either washed in or the species could tolerate a wide range of paleoenvironments. The persistently high counts of *Pinuspollenites* support a more a more offshore location.

From 1950 to the uppermost sample at 780 metres, there are only four specimens of *Impagidinium*. Since reworking is high in this interval, it would seem reasonable to assume that these four specimens should be included in that category. There appear to be few dinocysts that are in situ so it is difficult to use these to determine the paleoenvironment. However the pollen and spores are more helpful. Above 1650 m, *Sphagnumsporites* is frequent to common. de Vernal and Mudie (1989) recorded high abundances of *Sphagnumsporites* (as *Sphagnum*) in upper Pliocene-lowermost Pleistocene sediments from ODP Site 645 in Baffin Bay. They interpreted this as indicating extensive peatlands in the source area, sign of a humid, cool-temperate to subarctic climate. Further, these authors considered the high pollen counts to indicate influxes from a nearby source. The samples in the Corte Real well show high counts of small pollen above 1800 metres and common *Sphagnumsporites* above 1620 metres. Consequently, I am taking these signals to indicate deposition in the interval from 1800 to the uppermost sample at 780 metres to have been neritic, with shallowing upwards.

Bujak-Davies Group (1987) determined the following paleoenvironments: middle neritic (1535-1325 metres), inner to middle neritic (1295-1045 metres), inner neritic (1015-1005 metres), transitional to inner neritic (975-845 metres) and inner neritic (815-775 metres). Miller and d'Eon (1987) provided the following breakdown: outer shelf to bathyal, prodelta? (1788-1396 metres), inner to middle shelf, prograding delta slope and prodelta turbiditic (1396-993 metres), inner to middle shelf, prograding delta slope and prodelta turbiditic (993-830 metres), and marginal marine, deltaic distributary channel (830-770 metres). The general trend, as in my findings, is that the section is shallowing upwards.

Other indicators of paleoenvironments or the nature of the hinterland can be determined from some of the reworked taxa in the samples. The dominant reworked specimens are Late Cretaceous dinocysts, especially species of *Chatangiella* that are most common above 1950 metres. This may reflect considerable erosion of Upper Cretaceous rocks in the Early Oligocene to Pliocene. There are several possible explanations for this: one being that there was considerable uplift in the region, another being climate cooling with the onset of cooler-water conditions. The latter would have resulted in an increased formation of ice in higher latitudes and hence a fall in sea level. Both would cause greater erosion of rocks lying updip to the Corte Real location, more likely on the shelf but possibly also on land. Reworked pollen and spores

also occur in considerable numbers, with the most abundant being the Late Cretaceous *Aquilapollenites*, which occurs primarily above 2300 metres. But there are also some Carboniferous spores and Early Cretaceous spores and pollen. The reworked Carboniferous spores are most abundant between 3750 and 3240 metres, suggesting that Carboniferous rocks were eroded and the material transported earlier than the Cretaceous rocks. This is not what one would expect, but may reflect a much more complicated history than uplift and subsequent erosion.

Correlation of Palynology and Lithostratigraphy

The lithostratigraphic interpretations presented in Fig. 2 are derived from Moir (1987) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (2008). According to Moir (1987), the sediments from total depth at 4551 to 4060 metres in Corte Real P-85 are assignable to the Markland Formation. The Canada-Newfoundland and Labrador Offshore Petroleum Board (2008), in designating the interval 4395-4060 metres as Markland, essentially came to the same conclusion as Moir. Williams et al. (1985) gave an age for this formation as Albian-Cenomanian to Paleocene. Thus the designated age of the Markland does not agree with my findings, since I consider from 4551 to 4080 metres to be Early Eocene (Ypresian).

McWhae et al. (1980) formally proposed the Markland Formation for a sequence of shales, siltstone, sandstone and thin dolomitic limestone of Cenomanian-Turonian to Danian age on the Labrador Shelf. According to McWhae et al. (1980) and McWhae (1981), there are five regional unconformities in the Labrador Sea. These are from oldest to youngest: the Labrador Unconformity; the Avalon Unconformity; the Bylot Unconformity; the Baffin Bay Unconformity; and the Beaufort Unconformity. One and possibly two of these can be identified in Corte Real P-85.

In the interval 4050-2910 metres, which I have included in the Lutetian, Moir (1987) provided the following breakdown: Gudrid Formation (4060-4041 metres), Cartwright Formation (4041-3379 metres), and Kenamu Formation (3379-3082 metres). Moir placed the top of the overlying Mokami Formation at 1355 metres. The Newfounland Labrador Offshore Petroleum Board (2008) agreed in total with Moir's findings.

McWhae et al. (1980) elevated the Gudrid to formation status, the unit originally being named the Gudrid Sand Member of the Cartwright Formation by Umpleby (979), who characterized it as a quartz and feldspar-rich sand. The Gudrid is only 19 metres thick in Corte Real P-85 indicating that most of it was not deposited or if so was eroded away. Umpleby (1979) defined the Cartwright Formation, which overlies the Gudrid in Corte Real P-85, as a mudstone grading to siliceous 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 Bjarni O-82 (Williams, 2006a) and Gilbert F-53 (Williams, 2006c) the paleoenvironments are outer shelf to neritic, as in Corte Real. Dafoe (pers. comm.) considers that the Gudrid Formation is absent and the Cartwright Formation is attenuated in Corte Real P-85.

According to Williams et al. (1985), the Gudrid Formation is conformably overlain by the Kenamu Formation. The Kenamu was defined by McWhae et al. (1980) as an Eocene shale, siltstone, and sandstone sequence, which is in part glauconitic and calcareous: these sediments were deposited in outer shelf to upper slope environments.

Barss et al. (1979) considered the age of the Gudrid and the Cartwright formations to be Paleocene to Early Eocene, somewhat older than I found. However, the same authors dated the Kenamu Formation as Early Eocene to Early Oligocene, thus in part confirming my age determination for the interval 3082-2910 metres in Corte Real P-85.

Overlying the Kenamu is the Mokami Formation, the thickest unit in Corte Real P-85. McWhae et al. (1980) defined the Mokami as a predominantly claystone and soft shale unit. According to these authors the age is possibly Late Eocene to Middle Miocene; the paleoenvironment was neritic. Barss et al. (1979) gave an age of Late Eocene to Plio-Pleistocene for the formation. In Corte Real P-85, both Moir (1987) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (2008) considered the interval 3082-1355 metres to be Mokami, which would imply that the formation in this well is Lutetian-Middle Miocene. But much of the Mokami appears to be missing. I could not recognize any Chattian and there was a major gap in the Middle to Upper Miocene. I interpret the absence of the Chattian to denote the Baffin Bay Unconformity of McWhae et al. (1980) and McWhae (1981). And the gap in the Middle to Upper Miocene sequences presumably represents the Beaufort Unconformity.

In Corte Real P-85, the youngest lithologic unit is the Saglek Formation, which extends from 1355 to 600 metres (Moir, 1987; Canada-Newfoundland and Labrador Offshore Petroleum Board, 2008). Umpleby (1979) erected the Saglek Formation for a sequence of poorly sorted, fine- to coarse-grained or conglomeritic clastics with abundant pelecypod fragments, lignite and glauconite. Originally the age of the formation was Eocene to Miocene. In their redefinition, McWhae et al. (1980) included only the uppermost pre-Quaternary part of the Saglek Formation, however, and dated it as mid-Late Miocene to Pliocene. This age range shows good agreement with my findings that 1560-1140 metres is Middle Miocene, 1110 metres is Late Miocene and 1080-780 metres is Late Pliocene to earliest Pleistocene.

Summary

Corte Real P-85 was drilled to test the hydrocarbon potential of the Eocene Kenamu Formation in a Tertiary listric fault and to intersect an upper Paleocene seismic marker in the Gudrid Formation. But the well was only in Eocene (Ypresian) sediments at total depth of 4551 metres. Age control is based primarily on dinocysts, although the spores and pollen are useful especially in the Miocene and Pliocene.

One surprise in Corte Real P-85 is the thickness of the Lutetian-Bartonian section, which extends from 4050 to 2220 metres, the Lutetian alone being 1170 metres. In several other Labrador Shelf wells, there appears to be a hiatus in the Lutetian (Dickie et al., 2011) and none have a comparable thickness for this stage. The high degree of reworked Late Cretaceous dinocysts in the Lutetian could indicate that a major river system was bringing in considerable volumes of sediment which was either deposited in a delta front or transported south by a proto-Labrador Current to be deposited in the vicinity of Corte Real P-85.

Sequentially overlying the Bartonian are sediments of Priabonian, Rupelian, Miocene, and Pliocene age. There are several hiatuses in this interval, the most significant appearing to be that between the Rupelian and the upper part of the Early Miocene. I am equating this with the Baffin Bay Unconformity of McWhae et al. (1980) and McWhae (1981), even though in the former paper the age was given as Early Oligocene. In other wells in the Hopedale Basin (e.g. South Labrador N-79: Williams, 2007b), this unconformity is younger than Early Oligocene,

possibly reflecting findings from the analysis of more wells than were available to McWhae et al. (1980) or McWhae (1981).

Within the Middle and Upper Miocene interval, there is obviously at least one significant hiatus, which appears to correlate with the Beaufort Unconformity of McWhae et al. (1980) and McWhae (1981).

Paleoenvironments in Corte Real P-85 ranged from open ocean, that is probably bathyal, throughout the Eocene, then gradually shallowing in the Oligocene. Neritic conditions prevailed in the Neogene, becoming more prevalent upwards.

Initially, palynomorph recovery in the Eocene, especially of dinocysts, was good. But this fell off dramatically in the Oligocene and Neogene. Reprocessing all the sample and not just the portion retained on a +63 micron screen led to considerable improvement in recovery of the smaller palynomorphs and provided many of the specimens needed for age control.

Pothurst P-19

Biostratigraphy

All the palynology slides, which I analyzed from Pothurst P-19, were processed in the early 1980s when techniques were somewhat rudimentary. An additional problem is the generally coarse-grained nature of the sequences. Combined, these two factors meant that recovery of palynomorphs was extremely poor in this well, making it impossible to conduct counts and, in many instances, to record index palynomorphs. This should be borne in mind when reading my summary of the results below.

Total depth in Pothurst P-19 was 3992 metres. The interval from 3985 to 3180 metres contains the LOs of several age diagnostic dinocyst species including: *Glaphyrocysta spineta* at 3820-3810 metres; *Glaphyrocysta divaricata* at 3790-3780 metres; *Enneadocysta* "*annulus*" and *Trithyrodinium conservatum* at 3760-3750 metres; *Cordosphaeridium gracile*, *Alterbidinium*? *bicellulum* and *Glaphyrocysta ordinata* at 3730-3720 metres; *Platycaryapollenites* at 3610-3600 metres; *Heteraulacacysta leptalea* at 3520-3510 metres; *Cleistosphaeridium elegantulum* at

3460-3450 metres; *Deflandrea* sp. B sensu Williams and Brideaux, 1975 at 3400-3390 metres; *Extratriporopollenites* at 3340-3330 metres; *Hystrichostrogylon membraniphorum* at 3310-3300 metres; *Diphyes colligerum* at 3220-3210 metres; and *Hystrichosphaeridium tubiferum* at 3190-3180 metres. Since Williams et al. (2004) placed the LO of *Hystrichosphaeridium tubiferum* in the Early Lutetian in the Northern Hemisphere's mid-latitudes, I place the top of the early Lutetian at 3190-3180 metres, even though being in higher latitudes may affect the stratigraphic range of this species. Supporting evidence is provided by *Trithyrodinium conservatum* and *Alterbidinium? bicellulum*, which according to Fensome et al. (in press) both have LOs in the Lutetian.

My interpretation that the Pothurst P-19 is in lower Lutetian sediments at total depth is at odds with the findings of other biostratigraphers. In the most recent study by Riley Geoscience Limited (Ainsworth et al., 2014), they considered the well to bottom in Ypresian sediments, which extended from 3985 to 3695 metres. Bujak-Davies Group (1987) also came to a similar conclusion but included in the Ypresian the interval from 3972 to 3450 metres. However, Petro-Canada (1984) agreed with me that Pothurst P-19 reached total depth in Middle Eocene sediments but only extended these up to 3635 metres.

Overlying the lower Lutetian is a thin wedge of Priabonian, represented by the one sample, which covers the interval 3160-3150 metres. Present in this sample is the dinocyst *Glaphyrocysta* sp. A of Williams and Brideaux, 1975 (recorded by these authors as *Cyclonephelium* sp. A). Williams and Brideaux (op. cit.) placed the LO of this taxon at the top of the Priabonian.

Bujak-Davies Group (1987) considered 3430-3180 metres to be Middle Eocene, not attempting to subdivide it into Lutetian and Bartonian. Ainsworth et al. (2014) also took this approach, terming the interval 3685-3195 metres as Lutetian-Bartonian.

The top of the Early Oligocene or the Rupelian appears to be in the sample from 3080 to 3070 metres. This is based on the LO of *Phthanoperidinium coreoides*. According to Fensome et al. (in press) this species has it's LO in the Rupelian. Thus, the Rupelian is only about 80 metres thick in the vicinity of the Pothurst P-19 well. Other species with their LOs in this interval include *Operculodinium multispinosum* and *Thalassiphora fenestrata*.

Above about 3150 metres, there are some significant differences in interpretations. Bujak-Davies Group (1987) dated 3160 to 2350 m as Middle to Late Eocene, whereas Ainsworth et al. (2014) recognized Rupelian between 3185 and 3055 metres and Chattian from 3045 to 2785 metres. As the previous and following paragraphs show, the latter age determinations are more in line with mine.

The Chattian is about twice the thickness of the Rupelian, extending from 3040 to 2860 metres. *Deflandrea phosphoritica* has it's LO in the sample at 2870-2860 metres. Williams et al. (2004) placed the LO of *Deflandrea phosphoritica* in mid latitudes of the Northern Hemisphere within the Aquitainian, but I consider this close enough to the Chattian top to be used to pick the Chattian-Aquitainian boundary. Also having it's LO in the Chattian interval in Pothurst P-19 is *Chiropteridium galea*. According to Williams et al. (2004), *Chiropteridium galea* also has it's LO in the Aquitainian in mid latitudes of the Northern Hemisphere, just below that of *Deflandrea phosphoritica*. But Nøhr-Hansen et al. (in press) plot the LO of *Deflandrea phosphoritica* just below the Chattian-Aquitainian boundary and the LO of *Chiropteridium galea* on the boundary. However, one cannot exclude the possibility that the upper part of the interval 2870-2860 metres is in part early Aquitainian.

A Lower Miocene sequence can be recognized between 2840 and 2800 metres. In the sample from 2810-2800 metres is the LO of the spore *Osmundacidites wellmannii*. Fensome et al. (in press) designated the LO of this species as Early Miocene. In the sample below is the LO of the pollen *Tiliaepollenites* sp. A of Fensome et al. (in press); these authors also considered this taxon to have its LO in the Early Miocene. But Williams and Bujak (1977), in a study of Tertiary palynomorphs from Labrador Shelf wells, recorded the taxon in the *Operculodinium centrocarpum* assemblage of possible middle to late Miocene age.

I assign the interval 2780 to 2050 metres to the Late Miocene, with the Middle Miocene either having been eroded away or not deposited. The top of the Late Miocene is based on the LO of *Spiniferites ovatus*, which according to Fensome et al. (in press) has it's LO in the Messinian. From 2030 to 1360 metres, I include in the Early Pliocene or Zanclean, basing the top of this interval on the LO of the pollen *Betulaepollenites*. de Vernal and Mudie (1989) observed an increase in the abundance of *Betulaepollenites* (as *Betula*) in the Early Pliocene as opposed to the Late Pliocene and Pleistocene. Other pollen taxa having their LOs between 2030

and 1360 metres include: *Zonalapollenites igniculus*, *Artimesia*, *Gramineae* and *Corylus*. There appear to be no in-situ dinocysts, possibly a reflection of the poor processing. Above 1360 metres appears to be late Pliocene-Pleistocene.

Ainsworth et al. (2014) assigned 2775-2415 metres to the Early Pliocene or Zanclean and 2405 to 555 metres to the Late Pliocene to Pleistocene. Bujak-Davies Group (1987) determined the following ages: Late Eocene (2330 to 1960 metres); Early Oligocene (1940 to 1720 metres); Late Oligocene (1700 to 1660 metres); Early to Middle Miocene (1640-1480 metres); Miocene or older (1460-610 metres); and Late Miocene to Pleistocene (590 to 550 metres). These determinations show no agreement either with Ainsworth et al. (2014) or my findings.

Paleoenvironments

Paleoenvironmental data for Pothurst P-19 are scarce, since palynomorph counts could not be undertaken because of the sparse assemblages. But some settings are indicated by individual taxa and the reworking depicts a changing scenario. The occasional occurrence of the dinocyst *Impagidinium* in samples at 3860-3850 metres and 3550-3540 metres indicates open-ocean, probably bathyal paleoenvironments. This agrees with the interpretations of Ainsworth et al. (2014), who considered the sediments in the interval 3992-3184 metres to be bathyal. The presence of *Nematosphaeropsis balcombiana* in the sample from 2360-2350 metres would indicate continuing deeper-water conditions, either outer shelf or bathyal. Other evidence is lacking except for the absence of in situ dinocysts above 2060-2030 metres. Normally, this would indicate either a non-marine or an open-ocean setting. But the high number of reworked palynomorphs suggests a delta front, with sediment transported in from the west or northwest.

The reworking in Pothurst P-19 is extremely high and shows some interesting fluctuations. Reworked Late Cretaceous dinocysts occur sporadically in the lower and upper part of the well, but are much more persistent between 2950 and 1660 metres. From 2660 to 1330 metres and 1160 to 970 metres, both Cretaceous dinocysts and miospores are found in many of the samples. One unusual occurrence is the continuing presence of the Early Cretaceous dinocyst *Nyktericysta* in the interval 2530-1480 metres. *Nyktericysta* favoured lagoonal or

coastal environments; the delicate nature of its wall suggests that it may not have been transported over great distances before being deposited in the vicinity of the Pothurst well.

The diversity and abundance of reworked palynomorphs is highest in the interval 1310-550 metres and is surprisingly variable. The most frequent are species of *Veryhachium*, an acritarch genus common in Paleozoic rocks. What the age of the specimens is in Pothurst P-19 is debatable but there are some clues in the composition of other reworked species in this interval. Chitinozoans, which are present in occasional samples from 1310 to 550 metres, are known only from the Early Paleozoic. This supports my conclusion that Lower Paleozoic rocks were being eroded in the hinterland, with the reworked sediments being deposited in the Pothurst vicinity during the Plio-Pleistocene.

Correlation of Palynology and Lithostratigraphy

The lithostratigraphic interpretations presented in **Figure**. 6 are derived from Moir (1989), the Canada-Newfoundland and Labrador Offshore Petroleum Board (2008), and Ainsworth et al. (2014). It is surprising how much variation there is between the lithostratigraphic picks in these three papers. Moir (1989) was the only author to recognize the Gudrid Formation, which extended from total depth at 3992 to 3976 metres. The overlying Kenamu covers the interval 3976-3184 metres, with the Leif Member between 3272 and 3184 metres. The Canada-Newfoundland and Labrador Offshore Petroleum Board (2008) disagreed with Moir (1989) in considering the Kenamu Formation to represent the bottommost 16 metres in the well, from 3992 to 3976 metres, and they considered this interval to be part of the Leif Member of the Kenamu. From 3976 to 1449 metres was assigned, by the The Canada-Newfoundland and Labrador Offshore Petroleum Board (2008), to the Mokami Formation. Ainsworth et al. (2014) categorized 3992-3976 metres as an unnamed sandstone and included the interval 3992-3184 metres in the Kenamu, which shows close agreement with Moir (1989).

Biostratigraphic data may resolve some of the confusion. The Gudrid Formation is overlain by the Kenamu Formation, which was defined by McWhae et al. (1980) 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) considered the age of the Gudrid to be Paleocene to Early Eocene. I did not identify an Early Eocene section in Pothurst P-19, so am inclined to the opinion that Gudrid sediments are not present in the well. According to Barss et al. (1979), the Kenamu Formation was Early Eocene to Early Oligocene. Thus my age assignment of early Lutetian for the interval 3985 to 3180 metres appears to fit the lithostratigraphic data.

Ainsworth et al. (2014) questionably identified an unconformity at 3184 metres. My data indicate that lower Lutetian sediments are overlain by Priabonian sediments between 3180 and 3160 metres. This hiatus must represent that unconformity.

McWhae et al. (1980) defined the overlying Mokami Formation as a predominantly claystone and soft shale unit. According to these authors the age is possibly Late Eocene to Middle Miocene; the paleoenvironment was neritic. Barss et al. (1979) gave an age of Late Eocene to Plio-Pleistocene for the formation. If we accept the interpretation of Moir (1989) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (2008), then the top of the Mokami is at 1449 metres. Thus it would span the Priabonian to Zanclean in Pothurst P-19. My findings agree with Barss et al. (1979). Ainsworth et al. (2014) plotted a second unconformity at 2785 metres. I recorded Lower Miocene sediments in the interval 2810-2800 metres and Upper Miocene sediments in the sample from 2780-2770 metres. I am assuming that this hiatus equates with the unconformity plotted by Ainsworth et al. (2014).

Both Moir (1989) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (2008) considered the interval 1449 to 362 metres to be assignable to the Saglek Formation. This differs markedly from Ainsworth et al. (2014), who placed the base of the Saglek at 2785 metres. If they are correct that would mean that the age of this formation is Middle Miocene to Plio-Pleistocene. McWhae et al. (1980) stated that the Saglek "is probably mid-Late Miocene to Pliocene…." Barss et al. (1979) dated the Saglek, as defined by McWhae et al. (1980) as Pliocene-Pleistocene in the Labrador Shelf wells Bjarni H-81 and Snorri J-90, both of which are in the Hopedale Basin. I concluded that in Pothurst P-19, if we take the base of the Saglek as at 1449 metres, its age is Plio-Pleistocene.

Summary

Petro-Canada et al. drilled Pothurst P-19 to test the Eocene Leif Member in a rollover sequence resulting from growth faulting. The well reached total depth at 3992 metres and penetrated a section ranging from early Lutetian to Plio-Pleistocene. Although recovery of dinocysts and miospores was poor, the former were more useful for determining ages in the Paleogene, whereas the latter often provided control or support in the Neogene.

As in Corte Real P-85, the Lutetian is relatively thick, extending from 3985 to 3180 metres and this represents only the early part of the stage. The hiatus at about 3180 metres shows agreement with several other Labrador Shelf wells (Dickie et al., 2011). But in Pothurst P-19, the Bartonian is also missing. Overlying the lower Lutetian sediments is a thin wedge of Priabonian (one sample at 3160-3150 metres) sequentially overlain by about 300 metres of Rupelian sediments. The top of the Rupelian approximates with a hiatus.

Within the sequences of Priabonian, Rupelian, Miocene, and Pliocene age is a major hiatus between Lower and Upper Miocene sediments. I am equating this with the Beaufort Unconformity, which McWhae (1980) considered to be Middle to Late Miocene.

A thick Upper Miocene-Lower Pliocene section contains high numbers of Cretaceous dinocysts and miospores, with Early Paleozoic acritarchs and chitinozoans being present from 1310 to 550 metres. These two signals indicate that somewhere in the hinterland, Cretaceous rocks and subsequently Lower Paleozoic rocks were being eroded, with the sediments being transported into the vicinity of the Pothurst well by rivers and then the Labrador Sea Current or its precursor.

Paleoenvironmental data are not robust but do indicate open-ocean, bathyal conditions in much of the well, with shallowing in the Plio-Pleistocene.

The difficulty of drawing definitive conclusions for the Pothurst P-19 well relate to the poor quality of the processed samples and the coarse-grained nature of much of the section. It would be worth the time and effort to resample the well and undertake some reprocessing using some of the new techniques.

Conclusions

Although the sections in the two wells Corte Real P-85 and Pothurst P-19 encountered sediments often of similar ages, comparison of the assemblages is difficult reflecting the differences in processing for palynomorphs.

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References

Ainsworth, N.R., Riley, A., Bailey, H.W. and Gueinn, K.J., 2014: Cretaceous – Tertiary stratigraphy of the Labrador Shelf. Riley Geosicence Ltd., 56p.

Barss, M.S., Bujak, J.P. & Williams, G.L. 1979: Palynological zonation and correlation of sixty-seven wells, eastern Canada. Geological Survey of Canada Paper 78 (24), p.1–118.

Brinkhuis, H. 1992: Late Eocene to early Oligocene dinoflagellate cysts from central and northeast Italy, 169p. Unpublished Ph.D. thesis, University of Utrecht.

Brinkhuis, H. 1994: Late Eocene to early Oligocene dinoflagellate cysts from the Priabonian type-area (northeast Italy) — biostratigraphy and paleoenvironmental interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology, 107(1–2), p.121–163.

Brinkhuis, H. and Biffi, U. 1993: Dinoflagellate cyst stratigraphy of the Eocene/Oligocene transition in central Italy. Marine Micropaleontology, 22, p.131-183.

Brinkhuis, H. et al. 2006: Episodic fresh surface waters in the Eocene Arctic Ocean. Nature, 441 (7093) p.606-609.

Bujak, J.P. 1994: New dinocyst taxa from the Eocene of the North Sea. Journal of Micropalaeontology, 13, p.119–131.

Bujak–Davies Group, 1987: Biostratigraphy and maturation of 17 Labrador and Baffin Shelf wells. Volume 1: Scope, methodology, format and recommendations. Geological Survey of Canada, Open File 1929, 95p.

Bujak, J.P., Downie, C., Eaton, G.L. and Williams, G.L. 1980: Dinoflagellate cysts and acritarchs from the Eocene of southern England. Special Papers in Palaeontology, no.24, 100 p.

Canada Newfoundland & Labrador Offshore Petroleum Board, 2008: Schedule of wells: Newfoundland and Labrador offshore area.

Costa, L.I., Manum, S.B. and Meyer, K.-J. 1988: The regional distribution of dinoflagellates; correlation of the interregional zonation with the local zones and regional lithostratigraphy. Great Britain/Norway. The Viking Graben. In: Vinken, R.C. (Ed.). The Northwest European Tertiary

Basin Results of the International Geological Correlation Programme, Project No. 124. Geologisches Jahrbuch. Reihe A., 100, p.30-332.

Dale, B. 1996: Dinoflagellate cyst ecology: modelling and geological applications. In: Jansonius, J. & McGregor, D.C. (eds): Palynology: principles and applications, 3, p.1249–1275. Dallas: American Association of Stratigraphic Palynologists Foundation.

de Vernal, A. and Mudie, P.J. 1989: 24. Pliocene and Pleistocene palynostratigraphy at ODP Sites 646 and 647, eastern and southern Labrador Sea. Ocean Drilling Program, Proceedings, Scientific Results, Leg 105, College Station, Texas, p.401-422.

de Verteuil, L. and Norris, G. 1992: Miocene protoperidiniacean dinoflagellate cysts from the Maryland and Virginia coastal plain. In: Head, M.J. and Wrenn, J.H. (editors), Neogene and Quaternary Dinoflagellate Cysts and Acritarchs, p.391-430. American Association of Stratigraphic Palynologists Foundation, Dallas, U.S.A.

Dickie, K., Keen, C.E., Williams, G.L. & Dehler, S.A. 2011: Tectonostratigraphic evolution of the Labrador margin, Atlantic Canada. Marine & Petroleum Geology, 28, p.1663–1675.

Downie, C., Hussain, M. & Williams, G.L. 1971: Dinoflagellate cyst and acritarch associations in the Paleogene of southeast England. Geoscience and Man, 3, p. 29–35.

Eldrett, J.S., Harding, I.C., Firth, J.V. & Roberts, A.P. 2004: Magnetostratigraphic calibration of Eocene-Oligocene dinoflagellate cyst biostratigraphy from the Norwegian-Greenland Sea. Marine Geology, 204, p.91–127.

Fensome, R.A., Nøhr-Hansen, H. & Williams, G.L. in press: Cretaceous and Cenozoic dinoflagellate cysts and other palynomorphs from the western and eastern margins of the Labrador-Baffin Seaway. Grønlands Geologiske Undersøgelse Bulletin.

Gocht, H. 1969: Formengemeinschaften alttertiären Mikroplanktons aus Bohrproben des Erdölfeldes Meckelfeld bei Hamburg. Palaeontographica, Abt. B, 126, p. l–100.

Goll, R.M. 1989: A synthesis of Norwegian-Greenland Sea biostratigraphies: ODP Leg 104 on the Vöring Plateau. In: Eldholm, O., Thiede, J., Taylor, E., Barton, C., Bjørklund, K., Bleil, U., Ciesielski, P., Desprairies, A., Donnally, D., Froget, C., Goll, R., Henrich, R., Jansen, E., Krissek, L., Kvenvolden, K., Letturay, A., Love, D., Lynse, P., McDonald, T., Mudie, P.,

Osterman, L., Parson, L., Phillipps, J.D.., Pittenger, A., Qvale, G., Schönharting, G., Viereck, L. (Eds.), Proceedings ODP, Scientific Results 104, Ocean Drilling Program, College Station, Texas, p.777-826.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. 2012: The geologic time scale 2012. Elsevier, 1176 p.

Grant, A.C. 1980: Problems with plate tectonics: the Labrador Sea. Bulletin of Canadian Petroleum Geology, 28, p.252-278.

Head, M.J. and Norris, G. 1989: 28. Palynology and dinocyst stratigraphy of the Eocene and Oligocene in ODP Leg 105, Hole 647A, Labrador Sea. Ocean Drilling Program, Proceedings, Scientific Results, Leg 105, p.515-550

Head, M.J., Norris, G. and Mudie, P.J. 1989: 25. Palynology and dinocyst stratigraphy of the Upper Miocene and lowermost Pliocene, ODP Leg 105, Site 646, Labrador Sea. Ocean Drilling Program, Proceedings, Scientific Results, Leg 105, p.423-451.

Jan du Chêne, R.E. and Adediran, S.A. 1985: Late Paleocene to Early Eocene dinoflagellates from Nigeria. Cahiers de micropaléontologie, Centre nationale de la recherche scientifique, no.1984-3, p.5-38. (Cover date 1984, issue date 1985, according to p.2 of publication.)

Köthe, A. 1990: Paleogene Dinoflagellates from northwest Germany — biostratigraphy and paleoenvironment. Geologisches Jarhrbuch Reihe A, 118, p.3–111.

Lister, J.K. and Batten, D.J. 1988: Stratigraphic and palaeoenvironmental distribution of Early Cretaceous dinoflagellate cysts in the Hurlands Farm Borehole, West Sussex, England. Palaeontographica, Abteilung B, 210, p.9-89.

McWhae, J.R.H. 1981: Structure and spreading history of the northwestern Arctic region from the Scotian Shelf to Baffin Bay. In: Kerr, J.W. & Fergusson, A.J. (eds): Geology of the North Atlantic Borderlands. Canadian Society of Petroleum Geologists, Memoir **7**, p. 299–332.

McWhae, J.R.H., Elie, R., Laughton, D.C. & Gunther, P.R. 1980: Stratigraphy and petroleum prospects of the Labrador Shelf. Bulletin of Canadian Petroleum Geology, 28 (4), p. 460–488.

Miller, P.E. & d'Eon, G.J. 1987: Labrador Shelf palaeoenvironments. Geological Survey of Canada, Open File 1722, 186p.

Moir, P.N. 1987: Stratigraphic picks, Eastcan et al Roberval K-92. Geological Survey of Canada, Atlantic Geoscience Centre, Report No. EPGS-Strat. 14-87 PNM, 2p.

Moir, P.N. 1989: Lithostratigraphy 1. Review and type sections. In Geological Survey of Canada, Atlantic Geoscience Centre, East Coast Basin Atlas Series, Labrador Shelf, p. 26.

Mudie, P.J. 1982: Pollen distribution in recent marine sediments, eastern Canada. Canadian Journal of Earth Sciences, 4: 709-724.

Nøhr-Hansen, H. 2003: Dinoflagellate cyst stratigraphy of the Palaeogene strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Greenland. Marine and Petroleum Geology, 20, p. 987–1016.

Nøhr-Hansen, H. 2004: Dinoflagellate cyst stratigraphy of the North Leif I-05 well, Hopedale Basin, Labrador Shelf, offshore eastern Canada. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2004/109, 117p, 2 Enclosures.

Nøhr-Hansen, Williams, G.L. & H., Fensome, R.A. in press: Biostratigraphic correlation of the western and eastern margins of the Labrador-Baffin Seaway and implications for the regional geology. Grønlands Geologiske Undersøgelse Bulletin.

Petro-Canada et al. 1982: Well history report Petro-Canada et al. Pothurst P-19. Petro-Canada Exploration Inc, Calgary, Alberta, 88p.

Petro-Canada et al. 1982: Well history report Petro-Canada et al. Corte Real P-85. Petro-Canada Exploration Inc, Calgary, Alberta, 87p.

Powell, A.J. 1992: Stratigraphic Index of Dinoflagellate Cysts. In: British Micropalaeontological Society Series. Chapman and Hall, London, 290p.

Sluijs, A., Pross, J. & Brinkhuis, H. 2005: From greenhouse to icehouse; organic-walled dinoflagellate cysts as paleoenvironmental indicators in the Paleogene. Earth-Science Reviews, 68 (3–4), p. 281–315.

Sluijs, A., Schouten, S., Pagani, M., Woltering, M., Brinkhuis, H., Sinninghe Damsté, J.S., Dickens, G.R., Huber, M., Reichart, G.-J. Stein, R., Matthiessen, J., Lourens, L.J., Pedentchouk,

N., Backman, J., Moran, K. & the Expedition 302 Scientists. 2006: Subtropical Arctic Ocean temperatures during the Palaeocene/Eocene thermal maximum. Nature, 441, p.610–613.

Sønderholm, M., Nøhr-Hansen, H., Bojesen-Koefoed, J.A., Dalhoff, F. & Rasmussen, J.A. 2003: Regional correlation of Mesozoic–Palaeogene sequences across the Greenland-Canada boundary. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2003/25, 175 p.

Stover, L.E., Brinkhuis, H., Damassa, S.P., de Verteuil, L., Helby, R.J., Monteil, E., Partridge, A.D., Powell, A.J., Riding, J.B., Smelror, M. and Williams, G.L. 1996: Chapter 19. Mesozoic–Tertiary dinoflagellates, acritarchs and prasinophytes. In Jansonoius, & McGregor (eds): Palynology: principles and applications. Volume 2, p.641–750. American Association of Stratigraphic Palynologists Foundation, Dallas.

Total C.F.P. 1980: Petrographic study (TS, SEM-Dolomite unit). Total

Umpleby, D.C. 1979: Geology of the Labrador Shelf. Geological Survey of Canada Paper 79-13**,** 34p.

Wall, D., Dale, B., Lohmann, G.P. & Smith, W.K. 1977: The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic Oceans and adjacent areas. Marine Micropaleontology, 2, p.121–200.

Williams, G.L. 1975: Dinoflagellate and spore stratigraphy of the Mesozoic–Cenozoic, offshore eastern Canada. In: van der Linden, W.J.M. & Wade, J.A. (eds): Offshore Geology of Eastern Canada Volume 2, Regional Geology. Geological Survey of Canada Paper 2, p.107–161.

Williams, G.L. 2007a: Palynological analysis of Total Eastcan *et al*. Bjarni O-82, Hopedale Basin, Labrador Shelf. Geological Survey of Canada Open File Report 5439, 19p.

Williams, G.L. 2007b: Palynological analysis of Chevron *et al*. South Labrador N-79, Hopedale Basin, Labrador Basin. Geological Survey of Canada Open File Report 5446, 26p.

Williams, G.L. 2007c: Palynological analysis of Total Eastcan *et al*. Gilbert F-53, Saglek Basin, Labrador Shelf. Geological Survey of Canada Open File Report 5450, 22p.

Williams, G.L. and Brideaux, W.W. 1975: Palynological analysis of upper Mesozoic and Cenozoic Rocks of the Grand Banks, Atlantic Continental Margin. Geological Survey of Canada Bulletin 236, 163 p.

Williams, G.L. and Bujak, J.P. 1977: Cenozoic palynostratigraphy of offshore eastern Canada. American Association of Stratigraphic Palynologists Contribution Series 5A, p.14–47.

Williams, G.L. and Manum, S.B. 1999: 7. Oligocene-Early Miocene dinocyst stratigraphy of Hole 985A (Norwegian Sea). . Ocean Drilling Program, Proceedings, Scientific Results, Leg 162, p.99-109

Williams, G.L., Fyffe, L.R., Wardle R.J., Colman-Sadd, S.P., & Boehner, R.C: 1985. Lexicon of Canadian Stratigraphy: Volume VI, Atlantic Canada. Canadian Society of Petroleum Geologists, 572p.

Williams, G.L., Ascoli, P., Barss, M.S., Bujak, J.P., Davies, E.H., Fensome, R.A. & Williamson, M.A. 1990: Biostratigraphy and related studies. In: Keen, M.J. & Williams, G.L. (eds): Geology of the continental margin of eastern Canada. Geology of Canada 2, p.87–137. Geological Survey of Canada.

Williams, G.L., Bujak, J.P., Brinkhuis, H., Fensome, R.A. & Weegink, J.W. 1999: Mesozoic–Cenozoic dinoflagellate cyst course, Urbino, Italy, May 17–22, 1999. (Unpublished short course manual),

Williams, G.L., Brinkhuis, H., Pearce, M.A., Fensome, R.A. & Weegink, J.W. 2004: Southern Ocean and global dinoflagellate cyst events compared: index events for the Late Cretaceous–Neogene. In: Exon, N.F. *et al.* (eds) : Proceedings of the Ocean Drilling Program, Scientific Results 189, p.1–98.

Williams, G.L., Damassa, S.P., Fensome, R.A. and Guerstein, G.R., 2015: *Wetzeliella* and its allies — the 'hole' story; a taxonomic revision of the Paleogene subfamily Wetzelielloideae. Palynology, 39, p.289-344. (Published online 2015, hard copy 2016)

Species Citations

Alterbidinium? *bicellulum* (Islam 1983a) Lentin & Williams 1985

Appendicisporites jansonii Pocock 1962

Aquilapollenites Rouse 1957

Areoligera undulata Eaton 1976

Azolla Lamarck in Lamarck et al. 1783

Betulaepollenites Potonié 1960

Bombacacidites Couper 1960.

Cerodinium diebelii. (Alberti 1959) Lentin & Williams 1987

Chatangiella Vozzhennikova 1967

Chatangiella ditissima (McIntyre 1975) Lentin & Williams 1976

Chatangiella granulifera (Manum 1963) Lentin & Williams 1976

Chiropteridium galea (Maier 1959) Sarjeant 1983

Chiropteridium gilbertii Fensome et al. in press

Cicatricosisporites minutaestriatus (Bolkhovitina 1961) Pocock 1964

Cicatricososporites Pflug & Thomson in Thomson & Pflug 1953

Cleistosphaeridium elegantulum Fensome et al. in press

Cordosphaeridium cantharellus (Brosius 1963) Gocht 1969

Cordosphaeridium gracile (Eisenack 1954) Davey & Williams 1966b

Deflandrea eocenica Balteş1969

Deflandrea oebisfeldensis Alberti 1959

Deflandrea phosphoritica Eisenack 1938

Deflandrea sp. B sensu Williams and Brideaux 1975

Dinogymnium heterocostatum (Deflandre 1936b) Evitt et al. 1967

Diphyes colligerum (Deflandre & Cookson 1955) Cookson 1965a

Eatonicysta furensis (Heilmann-Clausen in Heilmann-Clausen & Costa 1989) Stover & Williams 1995

Enneadocysta "annulus" informal species name

Enneadocysta arcuata (Eaton 1971) Stover & Williams 1995

Eocladopyxis peniculata Morgenroth 1966a

Extratriporopollenites Pflug in Thomson & Pflug 1952 ex Pflug in Thomson & Pflug 1953

Glaphyrocysta divaricata (Williams & Downie 1966b) Stover & Evitt 1978

Glaphyrocysta ordinata (Williams & Downie 1966b) Stover & Evitt 1978

Glaphyrocysta spineta (Eaton 1976) Stover & Evitt 1978

Heteraulacacysta leptalea Eaton 1976

Heteraulacacysta porosa Bujak in Bujak et al. 1980

Heteraulacacysta pustulosa Jan du Chêne & Adediran 1985

Heterosphaeridium difficile (Manum & Cookson 1963) Ioannides 1986

Hystrichosphaeridium tubiferum (Ehrenberg 1838) Deflandre 1937

Hystrichostrogylon membraniphorum Agelopoulos 1964

Impagidinium Stover & Evitt 1978

Isabelidinium cretaceum (Cookson 1956) Lentin & Williams 1977a

Leptodinium Klement 1960

Mancicorpus Mchedishvili in Samoilovitch et al. 1961

Nematosphaeropsis balcombiana Deflandre & Cookson 1955

Nyktericysta Bint 1986

Odontochitina costata Alberti 1961

Oligosphaeridium complex (White 1842) Davey & Williams 1966b

Operculodinium multispinosum Ashraf 1979

Osmundacidites wellmannii Couper 1953

Phthanoperidinium alectrolophum Eaton 1976

Phthanoperidinium coreoides (Benedek 1972) Lentin & Williams 1976

Phthanoperidinium distinctum Bujak 1994

Phthanoperidinium geminatum Bujak in Bujak et al. 1980

Piladinium edwardsii (Wilson 1967) Williams et al. 2015

Pinuspollenites Raatz 1938

Pistillipollenites Rouse 1962

Platycaryapollenites

Rugubivesiculites reductus Pierce 1961

Schematophora speciose Deflandre & Cookson 1955

Sphagnumsporites Raatz 1956

Spiniferites ovatus Matsuoka 1983

Svalbardella Manum 1960

Svalbardella cooksoniae Manum 1960

Thalassiphora fenestrata. Liengiarern et al. 1980

Tiliaepollenites Potinié 1931

Trichodinium castanea Deflandre 1935

Trinovantedinium? xylochoporum de Verteuil & Norris 1992

Trithyrodinium? *conservatum* Fensome et al. in press

Tritonites.Marshall & Partridge 1988

Unipontidinium aquaeductum (Piasecki 1980) Wrenn 1988

Vallodinium nigeriaense (Jan du Chêne & Adediran 1985) Williams et al. 2015

Veryhachium Deunff 1954

Wodehouseia octospinosa

Wodehouseia spinata Stanley 1961

Zonalapollenites igniculus (Potonié 1931) Thomson & Pflug 1953

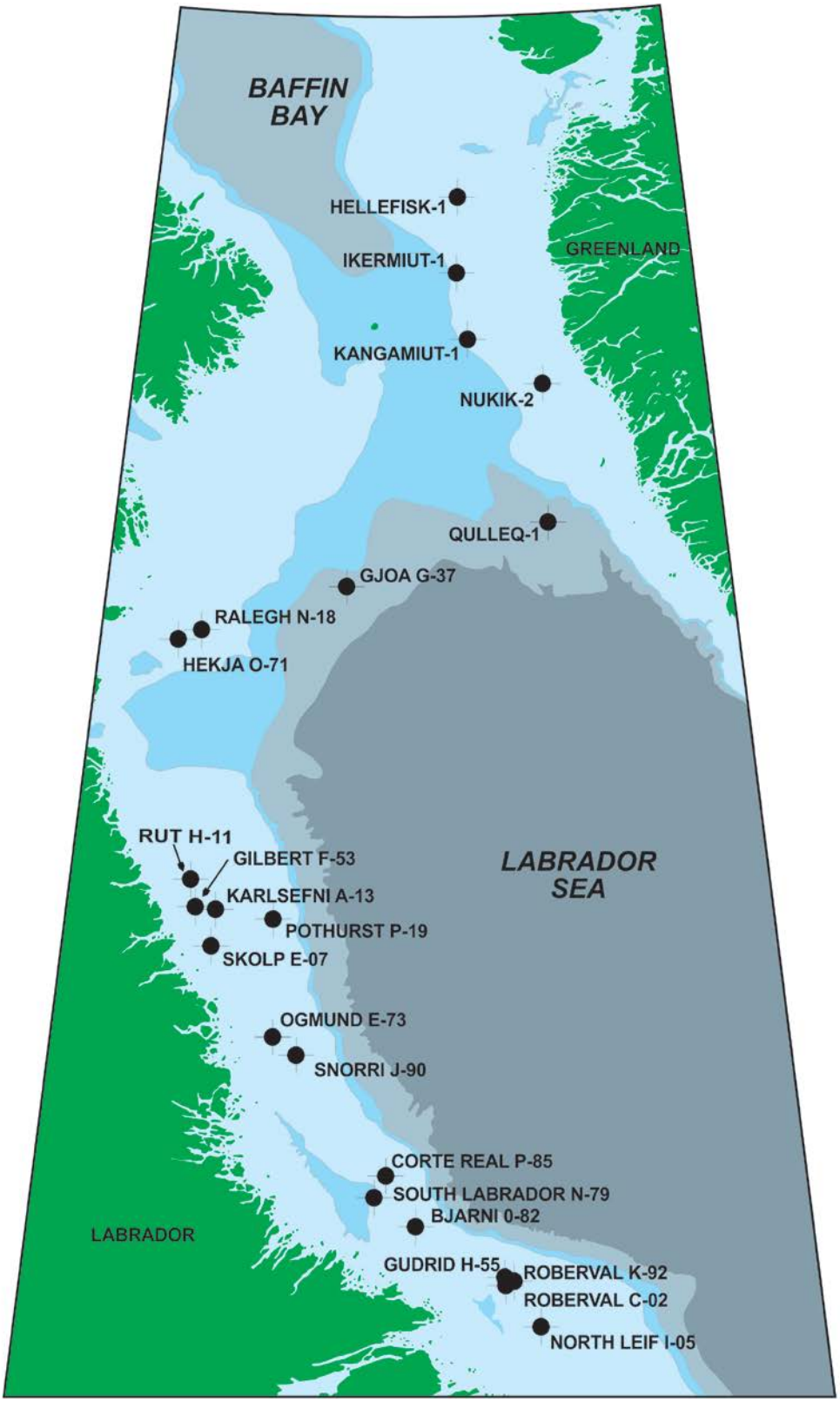


Figure 1. Map of Labrador Sea showing the location of the Corte Real P-85 and Pothurst P-19 wells.

Figure Captions

Figure 2. Well log, lithology, and formation and biostratigraphic picks for the Corte Real P-85 well. The information other than my age determinations is taken from the BASIN database. The ages shown for the Bujak-Davies (1987) analyses are based respectively on palynology, micropaleontology and the combined ages for the two disciplines.l.

Figure 3. Relative abundances of miospores, bisaccates, others (*Palambages*, *Pediastrum*, etc.), acritarchs and dinocysts in the Corte Real P-85 well. These data are the basis for the paleoenvironmental conclusions that I draw about this well.

Figure 4. Plot showing the stratigraphic ranges and abundances of dinocysts in Corte Real P-85.

Figure 5. Plot showing the stratigraphic ranges and relative abundances of miospores, acritarchs and other palynomorphs in Corte Real P-85.

Figure 6. Well log, lithology, and formation and biostratigraphic picks for the Pothurst P-19 well. The information other than my age determinations is taken from the BASIN database. The ages shown for the Bujak-Davies (1987) analyses are based respectively on palynology and micropaleontology.

Figure 7. Plot showing the stratigraphic ranges of dinocysts in Pothurst P-19.

PLATE 1

Miospores are from the Corte Real P-85 well. Scale bar represents 30 microns

1. "*Acaryapollenites*". Informal genus characterized by one equatorial and two sub-equatorial pores. 1680 metres. P532131-AD.
2. *Appendicisporites erdtmanii*. 1710 metres. P532132-BF.
3. *Appendicisporites jansonii*. 3360 metres. P532187AD
4. *Aquilapollenites trialatus*. 960 metres. P53217-BF.
5. *Aquilapollenites* sp. 3240 metres. P5321-83B.
6. *Araleacioipollenites* sp. 2760 metres. P321-67BF.
7. *Betulaepollenites* sp. 2550 metres. P5321-60BD.
8. *Carpinus* sp. 2370 metres. P532154-BF.
9. *Caryapollenites inelegans*. 1680 metres. P532131-AD.
10. *Caryapollenites veripites*. 4440 metres. P321-122BF.
11. *Chenopodipollis*. 990 metres. P53218-BD.
12. *Cicatricosisporites ornatus*. 2730 metres. P5321-66BD.
13. *Cicatricososporites eocenicus*. 3210 metres. P5321-82BD.
14. *Corsinipollenites oculusnoctis*. 1470 metres. P532124-BD.
15. *Corylus*. 3990 metres. P5321-108BG.
16. *Cupanieidites*. 4020 metres. P5321-109AG.
17. *Densosporites*. 1230 metres. P532116-BD -63.
18. *Extratriporopollenites*. 3000 metres. P5321-75BB.
19. *Extratriporopollenites*. 3960 metres. 5321-107AG.
20. *Gothanipollis*. 3060 metres. P5321-77AE.

Corte Real P-85 Plate 1

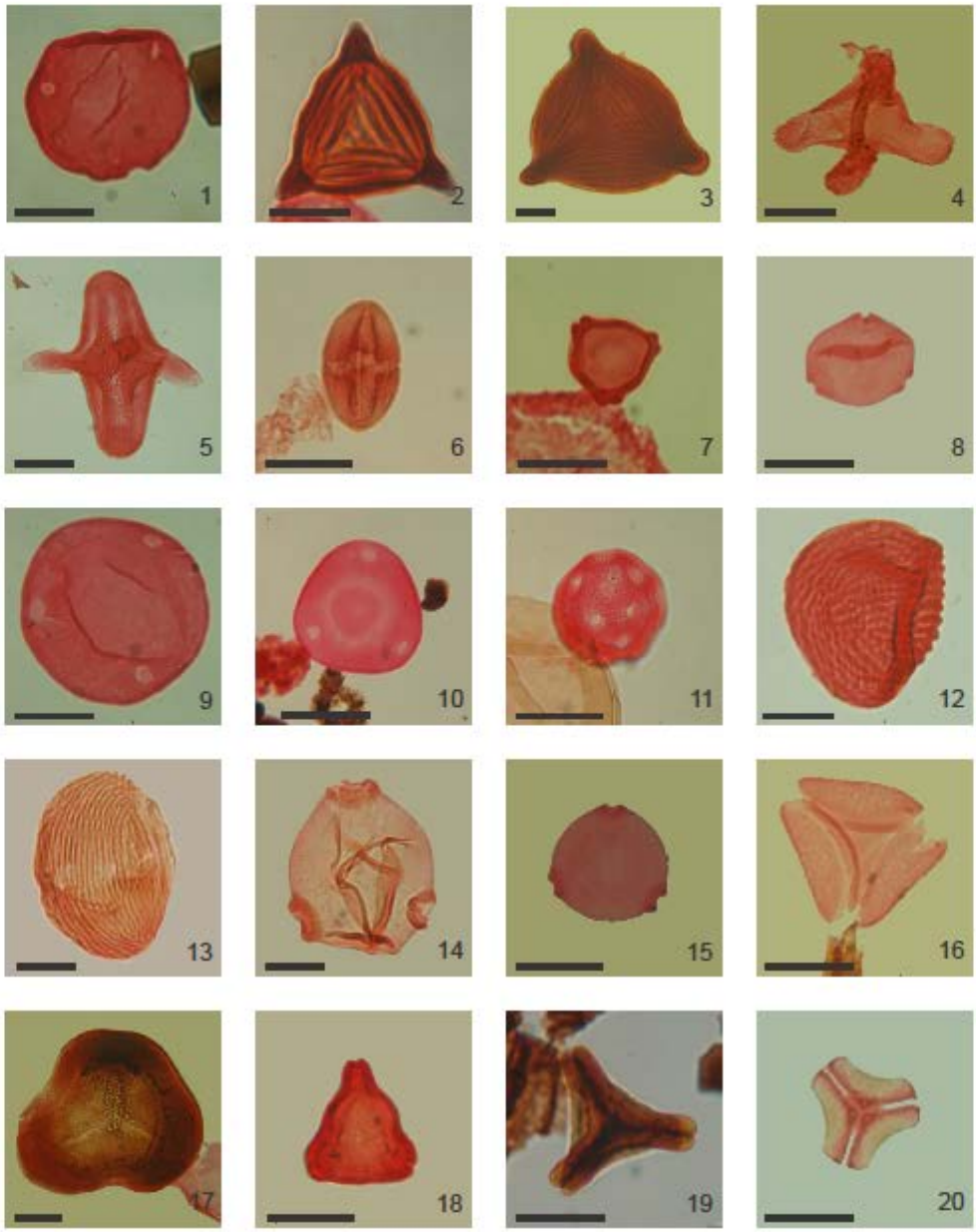


PLATE 2

Miospores from the Corte Real P-85 well. Scale bar represents 30 microns

1. "*Granatriporites*" sp. 3330 metres. P5321-86BF.
2. *Ilexpollenites* tetrad. 2850 metres. P5321-70BD.
3. *Juglanspollenites* sp. 2700 metres. P5321-65AB.
4. *Liquidambarpollenites* sp. 2100 metres. P523145-BF
5. *Momipites annellus*. 3570 metres. P5321-94AB.
6. *Momipites ventifluminus*. 3570 metres. P5321-94AB.
7. *Momipites wyomingensis*. 780 metres. P5321-1AB.
8. *Nyssapollenites* sp. 3060 metres. P5321-77AE.
9. *Pterocaryapollenites* sp. 2700 metres. P5321-65BF.
10. *Pinuspollenites* sp. 1050 metres. P532110_!B.
11. *Pistillipollenites mcgregorii*. 2220 metres. P532149-BF.
12. *Platycaryapollenites* sp. 3000 metres. P5321-75BB.
13. *Podocarpus* sp.4500 metres. P5321-125AD.
14. *Porosipollis porosus*. 1050 metres. P532110-BB.
15. *Pterocaryapollenites* sp. 2370 metres. P532154-BF.
16. *Quercoidites* sp. A of Williams 1986. 1740 metres. P532133-AB.
17. *Tricolpites micromunus*. 840 metres. P5231-3BB.
18. *Sapotaceoidaepollenites* sp. 2850 metres. P5321-70BE.
19. *Acanthotriletes* sp. 1260 metres. P532117-BF -63.
20. *Symplocoipollenites* sp. A Williams 1986. 4110 metres. P5321-112AG.

Corte Real P-85 Plate 2

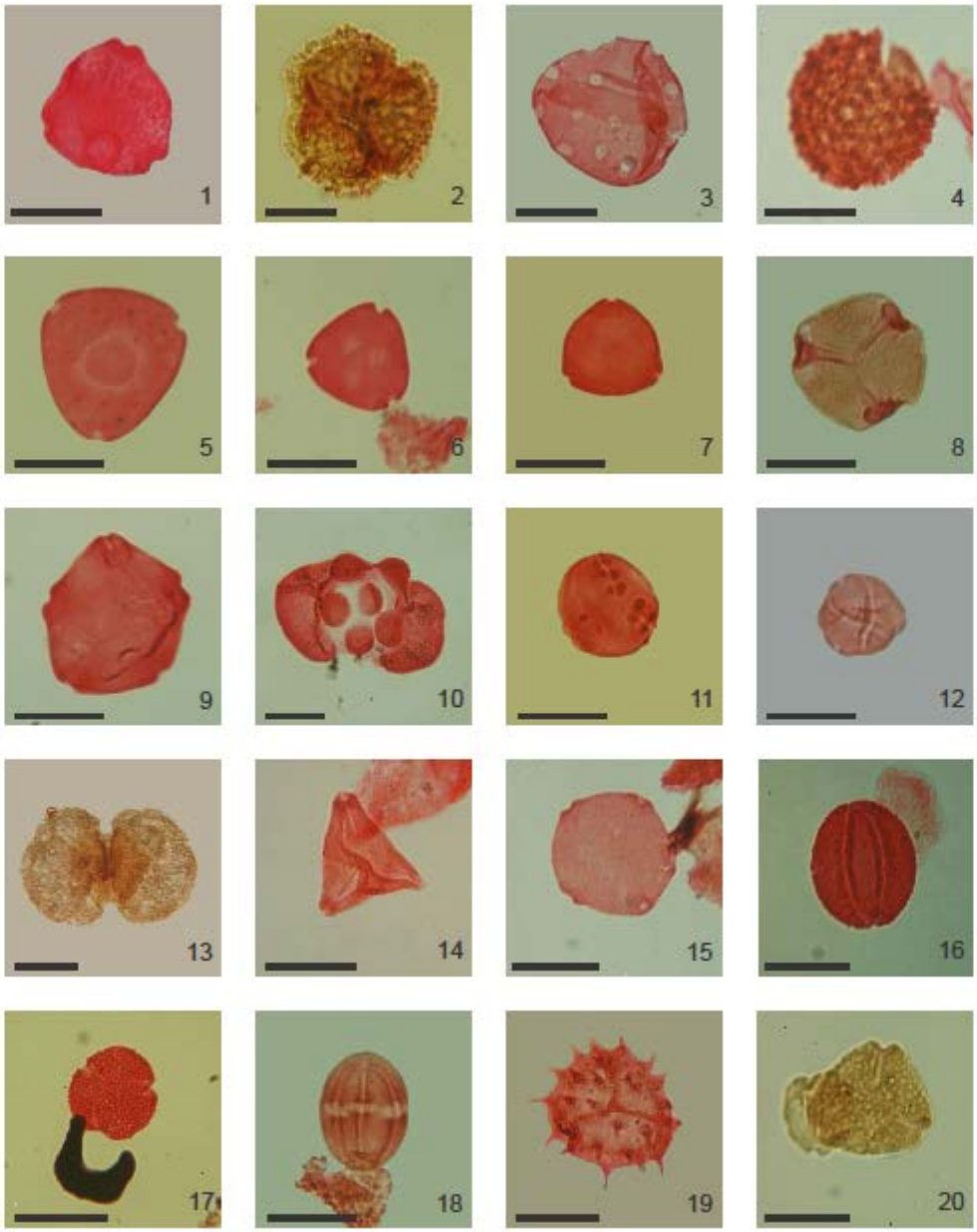


PLATE 3

Miospores and dinocysts from the Corte Real P-85 well. Figs. 1-12 are pollen: figs. 13-20 are dinocysts. Scale bar represents 30 microns

1. *Tiliaepollenites crassipites*. 1800 metres. P523135-AB. Miospore.
2. *Tiliaepollenites* sp. A. Fenome et al. (in press). 3300 metres. P5321-85AF. Miospore.
3. *Trudopollis* sp. 2220 metres. P532149-BB. Miospore.
4. *Triatriopollenites* sp. 3060 metres. P5321-77AE. Miospore.
5. *Tricolporopollenites* sp. 3630 metres. P5321-97AF. Miospore.
6. *Tricolporopollenites* sp. 1650 metres. P532130-BD. Miospore.
7. *Trilobosporites apiverrucatus*. 1290 metres. P532118-BD.
8. *Trudopollis* sp. 2070 metres. P523144-BF. Miospore.
9. *Verrutricolpites* sp. 3750 metres. P5321-100BC. Miospore.
10. *Wodehousiea octospina*. 3990 metres. P5321-108AE .Miospore.
11. *Zlivisporis* sp. 1590 metres. P532128-BD. Miospore.
12. *Zonalapollenites igniculus*. 1650 metres. P532130-BD. Miospore.
13. *Alisogymnium euclaense*. 870 metres. P53214-BB. Dinocyst.
14. *Alterbidinium minor*. 1680 metres. P532131-AD. Dinocyst.
15. *Areoligera senonensis*. 2760 metres. P5321-67BD. Dinocyst.
16. *Areoligera undulata*. 2820 metres. P5321-69BD. Dinocyst.
17. *Canningia* sp. 1020 metres. P53219-BD. Dinocyst.
18. *Cerebrocysta magna*. 4440 metres. P5321-123AD. Dinocyst.
19. *Chatangiella granulifera*. 3900 metres. P5321-105BF. Dinocyst.
20. *Chiropteridium galea*. 2040 metres. P523143-AB. Dinocyst.

Corte Real P-85 Plate 3

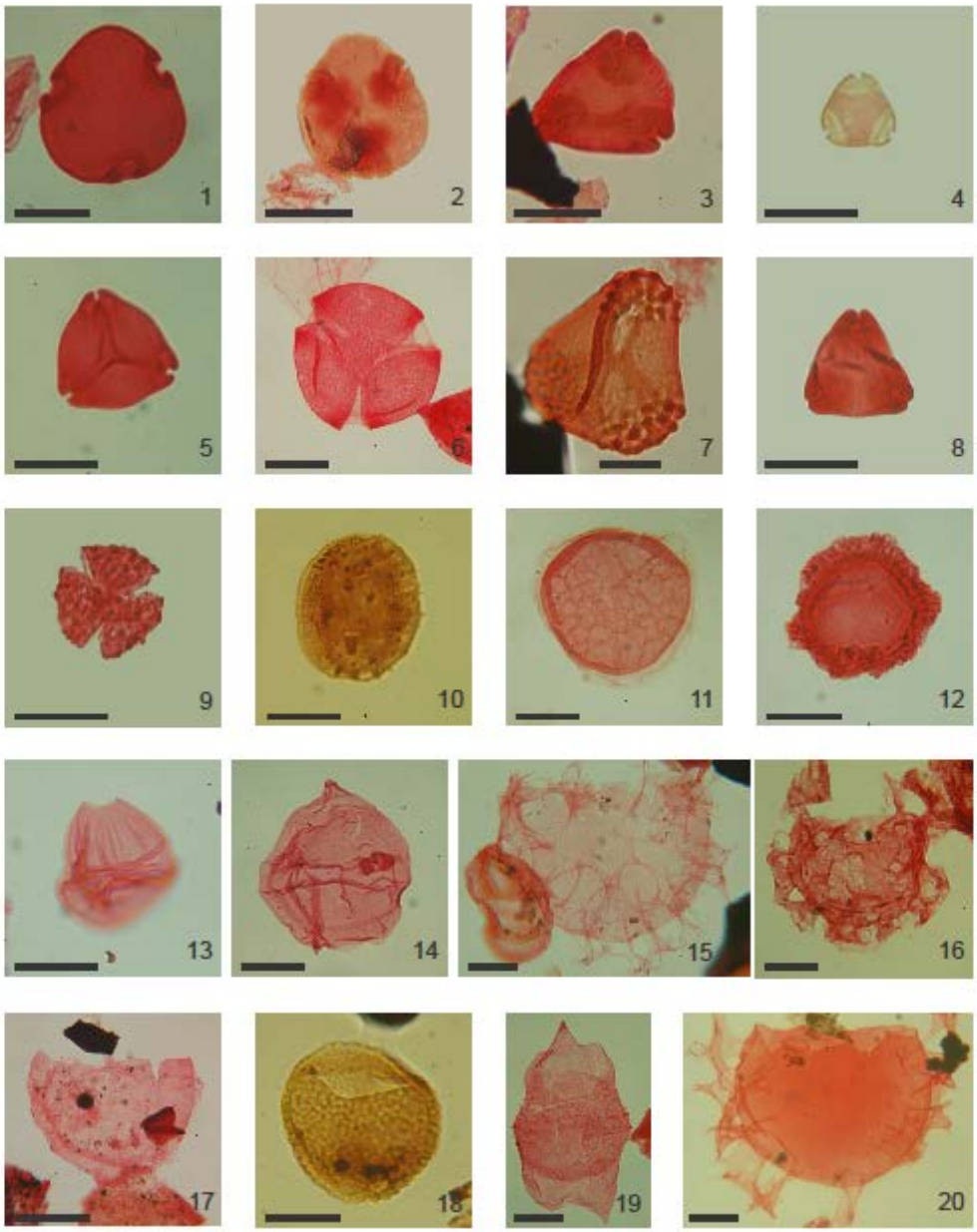


PLATE 4

Dinocysts from the Corte Real P-85 well. Scale bar represents 30 microns

1. *Danea* sp. 4140 metres. P5321-13AD.
2. *Deflandrea eocenica*. 2220 metres. P532149-BB.
3. *Deflandrea* sp. B Williams and Bujak 1977. 3630 metres. P5321-96AD.
4. *Elytrocysta druggii*. 1080 metres. P532111-AD.
5. *Eocladopyxis peniculata*. 2760 metres. P5321-67BD.
6. *Glaphyrocysta spineta*. 2910 metres. P5321-72BD.
7. *Glaphyrocysta vicina*. 4140 metres. P5321-13AD.
8. *Glaphyrocysta vicina*. 4140 metres. P5321-13AD.
9. *Glaphyrocysta vicina*. 4140 metres. P5321-13AD.
10. *Heterosphaeridium* sp. 1140 metres. P5321-13BD.
11. *Impagidinium* sp. Ventral view of ventral surface. 1740 metres. P532133-BD.
12. *Impagidinium* sp. Ventral view of dorsal surface. 1740 metres. P532133-BD.
13. *Laciniadinium williamsii*. 810 metres. P5231-2AD.
14. *Lingulodinium multivirgatum*. 1140 metres. P532113-A +63.
15. *Microdinium* sp. 990 metres. P53218-BB.
16. *Minisphaeridium latirictum*. 2820 metres. P5321-69BB.
17. *Phthanoperidinium alectrolophum*. 2760 metres. P321-67BF.
18. *Phthanoperidinium geminatum*. 2610 metres. P5321-62BF.
19. *Phthanoperidinium levimurum*. 960 metres. P53217-BD.
20. *Phthanoperidinium regale*. 2580 metres. P5321-61BF.

Corte Real P-85 Plate 4

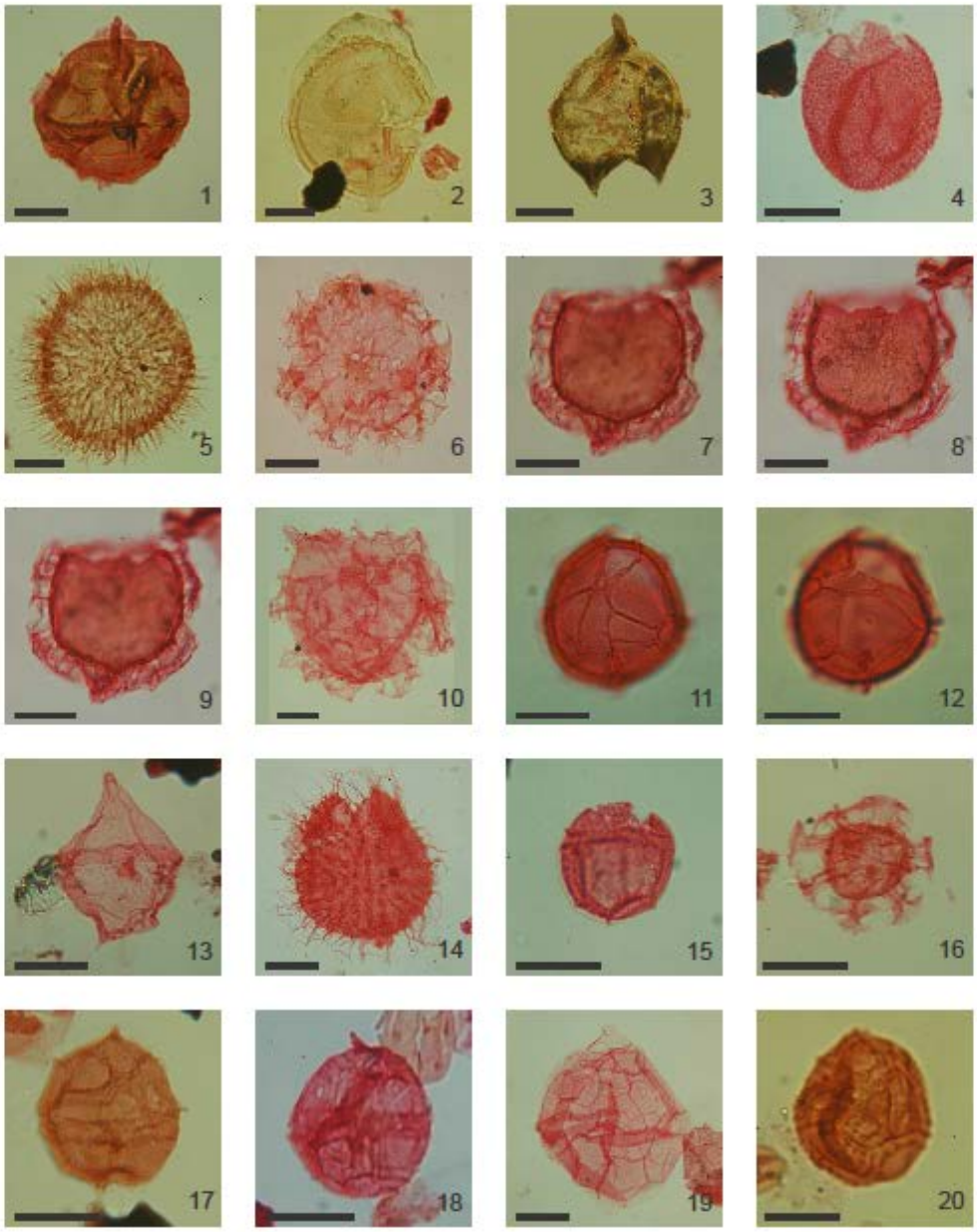


PLATE 5

Dinocysts from the Corte Real P-85 well. Scale bar represents 30 microns

1. *Phthanoperidinium*. 3060 metres. P5321-77AE. Dinocyst
2. *Samlandia chlamydophora*. 2820 metres. P5321-69BD. Dinocyst
3. *Senoniasphaera protrusa*. 780 metres. P5231-1BE. Dinocyst
4. *Spiniferella cornuta*. 3780 metres. P5321-101AE. Dinocyst
5. *Spongodinium* sp. 900 metres. P53215-BC. Dinocyst
6. *Svalbardella* cf. *cooksoniae*. 1860 metres. P523137-AB. In this specimen, the apical horn is acuminate and the antapical horn is rounded. Dinocyst
7. *Svalbardella* sp. 3300 metres. P5321-85BD. Dinocyst
8. *Svalbardella* sp. 3900 metres. P5321-105BF. Dinocyst
9. *Trinovantedinium xylochoporum*. 1230 metres. P532116-AB. Dinocyst
10. *Unipontidinium aquaeductum*. 1290 metres. P532118-BD. Dinocyst
11. Acritarchs p. 1 of Head et al. (1989). 1680 metres. P532131-AE. Acritarch
12. *Comasphaeridium* sp. 2880 metres. P5321-71BE. Acritarch
13. *Leiofusa jurassica*. 1410 metres. P532122-BB. Acritarch
14. *Tritonites* cf. *bilobus*. 1590 metres. P532128-BF. Acritarch
15. *Tritonites* sp. 3750 metres. P5321-100BC. Acritarch
16. *Tytthodiscus* sp. 870 metres. P53214-BD.
17. Fungal element: *Diporicellaesporites*.3000 metres. P5321-76BB
18. Fungal element: *Pluricellaesporites*. 3360 metres. P532187AD
19. Fungal element: *Pluricellaesporites*. 3360 metres. P532187AD
20. Fungal element: *Pluricellaesporites*. 3540 metres. P5321-93AD

Corte Real P-85 Plate 5

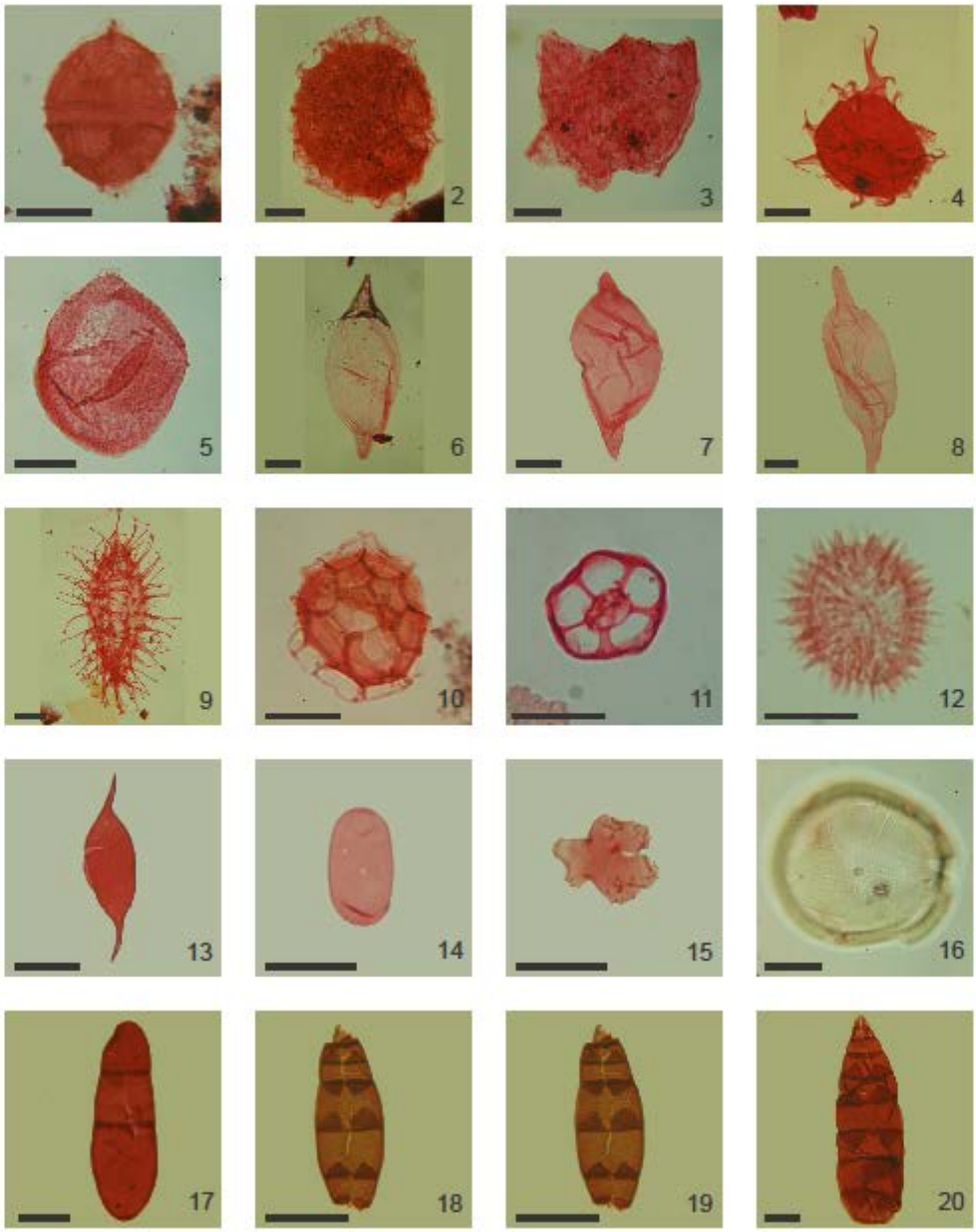
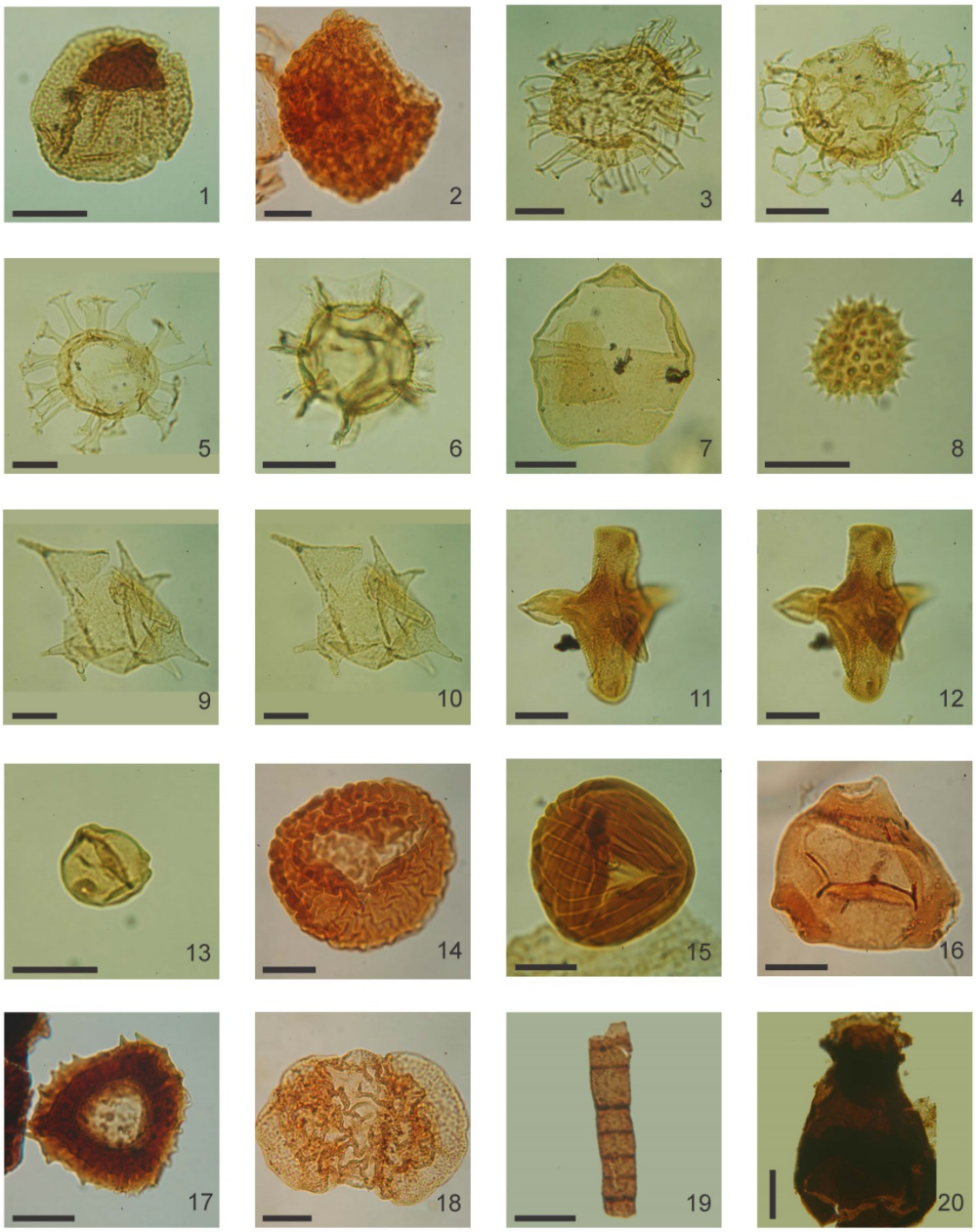


PLATE 6

Dinocysts, miospores and chitinozoans from the Pothurst P-19 well. Scale bar represents 30 microns

1. *Canningia* sp. 2560-2570 metres. P23986-01. Dinocyst
2. *Cerebrocysta magna*. 3750-3760 metres. P24026-01. Dinocyst
3. *Cleistosphaeridium diversispinosum*. 1960-1970 metres. P23966-01. Dinocyst
4. *Enneadocysta* sp. 3750-3760 metres. P24026-01. Dinocyst
5. *Hystrichosphaeridium tubiferum*. 3180-3190 metres. P24007-01. Dinocyst
6. *Impagidinium strialatum*. 1030-1040 metres. P23935-01. Dinocyst
7. *Luxadinium propatulum*. 1750-1760 metres. P23959-01. Dinocyst
8. *Nyktericysta davisii*. 1480-1490 metres. P23950-01. Dinocyst
9. *Nyktericysta davisii*. 1480-1490 metres. P23950-01. Dinocyst
10. *Ambrosia* sp. 1840-1850 metres. P23962.01. Miospore.
11. *Aquilapollenites trialatus*.. 2590-2600 metres. P23987-01. Miospore.
12. *Aquilapollenites trialatus*.. 2590-2600 metres. P23987-01. Miospore.
13. *Betulaepollenites*. 2710-2720 metres. P23991-01. Miospore.
14. *Camarozonosporites insignis*. 3810-3820 metres. P24028-01. Miospore.
15. *Cicatricosisporites subrotundus*. 2050-2060 metres. P23969-01. Miospore.
16. *Corsinipollenites oculusnoctis*. 1720-1730 metres. P23958-01. Miospore.
17. *Densosporites* sp. 2560-2570 metres. P23986-01. Miospore.
18. *Rugubivesiculites rugosus*. 3130-3140 metres. P24005-01. Miospore.
19. *Svalbardella* sp. 3210-3220 metres. P24008-01. Dinocyst
20. Chitinozoan, reworked from Lower Paleozoic rocks. 1300-1310 metres. P23944-01

Pothurst P-19 Plate 6