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# **STRATIGRAPHY OF THE AMOCO IOE A-1 PUFFIN B-90 WELL, GRAND BANKS OF NEWFOUNDLAND**

W.A.M. JENKINS  
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L.F. JANSA  
G.L. WILLIAMS



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## ABSTRACT

The Amoco IOE A-1 Puffin B-90 well, drilled to a total depth of 15,425 feet, penetrates a thick sequence of Cenozoic strata which, at 7,480 feet, rests unconformably on a Cretaceous succession almost 8,000 feet thick. The lithostratigraphic succession on the southwestern Grand Banks in the vicinity of Puffin compares closely with that on the Scotian Shelf, and all six formations recognized in the well are referred to units having their type sections on the Scotian Shelf: in ascending stratigraphic order these are the Verrill Canyon, Mississauga, Logan Canyon, Dawson Canyon, Wyandot and Banquereau formations.

The Puffin succession is referred to two biostratigraphic zonations, the constituent zones of which are defined and dated by, respectively, dinoflagellates and spores, and foraminifers. The relationship between the lithostratigraphy (formations) and the biostratigraphy (zones) is discussed.

Most of the Cretaceous stages and all the Tertiary series are represented in the Puffin succession. Only two significant depositional hiatuses have been detected. One is at approximately 8,960 feet between the Logan Canyon Formation (Albian) and the lower part (Coniacian) of the Dawson Canyon Formation, where rocks of the Cenomanian and Turonian Stages apparently are missing. The other (placed by paleontology at 7,480 feet, by lithology and mechanical logs at 7,418 feet) is at the top of the Cretaceous between the Wyandot Formation (lower Maastrichtian) and the basal beds (lower Paleocene) of the Banquereau Formation. The well bottoms in the Verrill Canyon Formation of Berriasian-early Valanginian age.

Lower Cretaceous deposits (15,425 to 8,950 feet) accumulated in a progressively shallowing neritic environment. Upper Cretaceous depositional environments range from outer neritic to upper slope. In latest Cretaceous or earliest Tertiary time, deep marine slope conditions were established; these prevailed until the Miocene from which time on depositional environments became progressively shallower. Pliocene to Pleistocene deposits accumulated in a very shallow nearshore marine environment.

## RÉSUMÉ

Le puits A-1 Puffin B-90 de l'Amoco et IOE, foré jusqu'à une profondeur totale de 15,425 pieds, traverse une épaisse série de couches du Quaternaire et du Tertiaire qui repose, en discontinuité à 7480 pieds, sur une série crétacée de près de 8000 pieds d'épaisseur. En ce qui concerne la lithologie et la stratigraphie, la série qu'on trouve au sud-ouest des Grands Bancs, à proximité de Puffin, est tout à fait comparable à celle du Plateau continental de la Nouvelle-Ecosse, à telles enseignes que les six formations qui ont été identifiées dans ce puits ont pu être rattachées à des unités dont le type a été pris dans la série du Plateau continental de la Nouvelle-Ecosse; il s'agit, du plus ancien au plus récent, de: la Formation Verrill Canyon, la Formation Mississauga, la Formation Logan Canyon, la Formation Dawson Canyon, la Formation Wyandot et la Formation Banquereau.

La série de Puffin relève, quant à la biostratigraphie, de deux écosystèmes, dont les zones biologiques sont définies et datées par des dinoflagellés et des spores, et par des foraminifères, respectivement. Le propos de cet article est d'étudier les relations qui existent entre la lithologie stratigraphique (formations) et la biostratigraphie (zones).

La plupart des étages du Crétacé et toutes les séries du Tertiaire sont représentés dans la série de Puffin. On n'observe que deux solutions de continuité de quelque importance dans la sédimentation. L'une se situe vers 8960 pieds, entre la Formation Logan Canyon (Albien) et la partie inférieure (Coniacien) de la Formation Dawson Canyon; il semble bien que le Cénomaniens et le Turonien soient absents. L'autre (située par la paléontologie à 7480 pieds et par la lithologie et la diagraphie à 7418 pieds) se trouve au sommet du Crétacé, entre la Formation Wyandot (Maestrichtien inférieur) et les couches de base (Paléocène inférieur) de la Formation Banquereau. Le fond du puits est dans la Formation Verrill Canyon, qui date du début du Valanginien.

Les sédiments du Crétacé inférieur (de 15,425 pieds à 8950 pieds) se sont accumulés dans un milieu néritique dont la profondeur diminuait progressivement. Pour le Crétacé supérieur, la sédimentation a eu lieu dans des milieux qui allaient de la partie externe de la zone néritique à la partie supérieure du talus continental. Aux tout derniers moments du Crétacé ou au tout début du Tertiaire, se sont établies des conditions de mer profonde et de talus continental; ces conditions ont prévalu jusqu'au Miocène, époque à partir de laquelle la sédimentation s'est faite dans un milieu progressivement de moins en moins profond. Du Pliocène au Pléistocène, les sédiments se sont accumulés dans un milieu marin très peu profond et proche du rivage.

## STRATIGRAPHY OF THE AMOCO IOE A-1 PUFFIN B-90 WELL, GRAND BANKS OF NEWFOUNDLAND

### INTRODUCTION

This paper describes the stratigraphy of the Amoco IOE A-1 Puffin B-90 well located at the southwestern edge of the Grand Banks approximately 200 miles south-southwest of St. John's, Newfoundland at 44° 39' 12.73"N, 53° 42' 28.35"W (Fig. 1). The well was spudded September 29, 1971 in 350 feet of water and drilled to a total depth of 15,425 feet, with casing set at 528 feet, 869 feet, 2,558 feet and 8,856 feet. Puffin was the third deep exploratory well (after Eider M-75 and Murre G-67) drilled on the Grand Banks by Amoco Canada Petroleum Company Ltd. and Imperial Oil Enterprises Ltd. Its purpose was to test for the accumulation of hydrocarbons in a deep-seated anticline. No significant accumulations were found, however, and the well was abandoned December 30, 1971. The stratigraphy described here (Fig. 2) is based upon studies of lithology (Jansa), dinoflagellates and spores (Jenkins and Williams), and foraminifers and ostracods (Ascoli and Gradstein) in cuttings from 1,030 to 15,425 feet and one hundred sidewall cores taken at approximately fifty-foot intervals between 5,900 and 12,300 feet. All footages were measured from the rotary table standing 98 feet above sea level and 448 feet above the sea bed.

### ACKNOWLEDGMENTS

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### LITHOSTRATIGRAPHY

The lithostratigraphic succession on the southwestern Grand Banks in the vicinity of Puffin compares closely with that on the Scotian Shelf. All six formations recognized in the well are referred to units having their type sections on the Scotian Shelf. In ascending stratigraphic order, these are the Verrill Canyon, Mississauga, Logan Canyon, Dawson Canyon, Wyandot and Banquereau formations.\* The succession has been interpreted from ditch cuttings, and from spontaneous potential, resistivity,

\*It is not everywhere clear in McIver's (1972) original descriptions whether unit names were intended to end with rank terms (Member Formation) or descriptive lithologic terms (Chalk, Shale), and the original lithologic designations are not everywhere applicable (Art. 15, Code of American Commission on Stratigraphic Nomenclature). In this paper, therefore, formal names of lithostratigraphic units end in rank terms, not descriptive lithologic terms; thus Wyandot Formation, not Wyandot Chalk.

gamma ray, sonic and dipmeter logs. Nomenclature is essentially that of McIver (1972). Lithostratigraphic units are described below in ascending stratigraphic order.

#### Verrill Canyon Formation (15,425 to 12,336 feet):

The description of this formation is based solely on cuttings since mechanical logs are not available below 12,000 feet. The Verrill Canyon Formation is a mudstone sequence containing minor quantities of siltstone and fine-grained sandstone, and lacks porosity. Its contact with the overlying Mississauga Formation is gradational. The mudstone is medium grey, generally non-calcareous, with rare subangular quartz grains dispersed in an argillaceous matrix. Glauconite, pyrite, fragmentary molluscs and ostracods are rare. A few calpionellids occur between 13,460 and 13,060 feet. Epistominid foraminifers are common to abundant from 14,200 to 12,670 feet. Finely divided organic matter and coalified plant material were found throughout the formation.

The siltstone is similar in composition to the mudstone, in which it occasionally forms thin laminae. Clastic particles in both show little preferred orientation and the internal fabric appears chaotic. Bioturbation is rare. Moderately sorted protoquartzite-type siltstones containing common opaque minerals and echinoderm fragments occur near the top of the formation. Feldspar and chlorite are rare. A few beds of argillaceous micritic limestone are present.

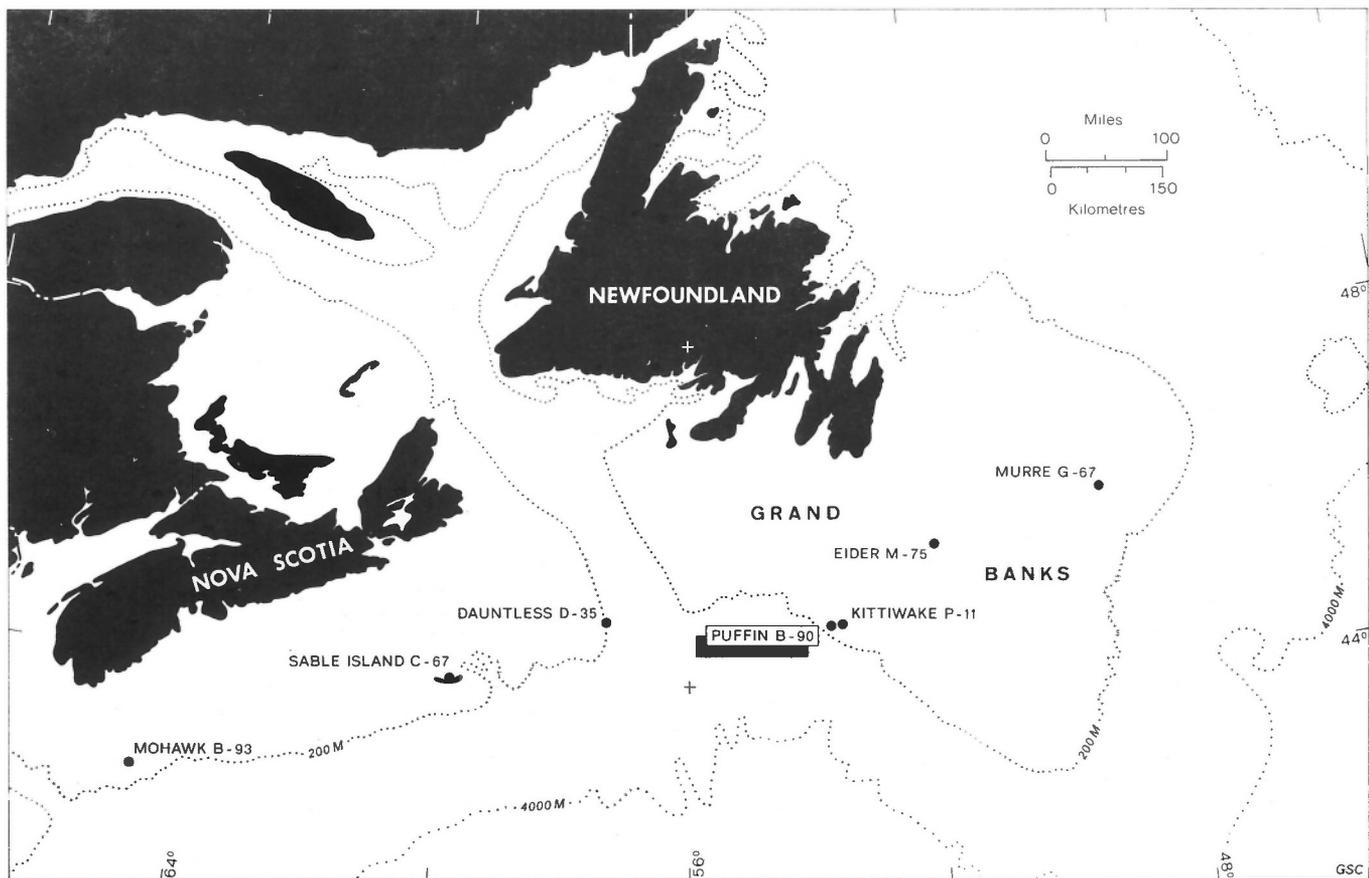
Poor sorting and random orientation of clastic particles in the mudstone and siltstone suggest that the Verrill Canyon Formation was deposited rapidly, below wave base. The frequent occurrence of finely divided opaque carbonaceous fragments and translucent structureless organic matter in mudstone is indicative of river-born detritus deposited on an open shelf.

The Verrill Canyon Formation corresponds to the dinoflagellate/spore Zone of *Phoberocysta neocornica* and the informal foraminifer zone of *Buccicrenata italica*.

#### Mississauga Formation (12,336 to 9,836 feet):

The Mississauga Formation\* in Puffin is mainly a sandstone sequence which can be subdivided into two units. The lower unit (12,336 to 11,840 feet) is approximately 40 per cent sandstone and 60 per cent siltstone and silty shale. Sandstone beds are ten to twenty feet thick and consist of very fine grained greywacke (some beds contain up to 40 per cent basaltic and rhyolitic grains of volcanic origin), protoquartzite, volcanic sandstone and calcareous

\*The spelling "Mississauga", given to the Scotian Shelf well and the formation named after it (McIver, 1972), has little general currency and probably is based ultimately in orthographic error. In view of this and the term's short life in the geological literature priority does not prevent adoption of the orthodox spelling.



sandstone. Grains are subangular to subrounded and are poorly sorted. The lower unit was laid down in a delta front environment that grades up into an environment of distributary mouth bars and distributary channel deposits. The shallowing of the environment is interpreted to be a result of delta progradation.

The upper unit (11,840 to 9,836 feet) is over 80 per cent sandstone and nearly 20 per cent siltstone and shale, with several limestone beds between 10,060 and 9,836 feet. Its contact with the overlying "Naskapi Shale" is sharp. Sandstone beds are thirty to seventy feet thick. Limestones and sandstones of this upper unit were laid down in a shallow marine, nearshore environment.

The formation corresponds to the dinoflagellate/spore Zones of *Ctenidodinium elegantulum* and *Tenua anaphrissa*, and to the informal foraminifer zones of *Planularia crepidularis* and *Choffatella decipiens*.

**"Naskapi Shale" (9,836 to 9,515 feet):** The informally named "Naskapi Shale" is a medium grey to greenish grey silty shale containing thin (up to ten feet thick) beds of siltstone, and rare limestone. Its contact with the Logan Canyon Formation is gradational.

The siltstone is argillaceous, poorly sorted and medium grey. Near the base of the member the shale is brownish grey with some reddish brown beds. The lowest fifty feet of the member consists of limestones made up of foraminifer-mollusc quartz sand wackestone and packstone, containing *Choffatella*, smaller foraminifers, gastropods, annelids, echino-

derms and algae. The "Naskapi Shale" was laid down in a shallow marine environment.

The "Naskapi Shale" is referred to the dinoflagellate/spore Zone of *Deflandrea perlucida*-*Systematophora schindewolfi*.

**Logan Canyon Formation (9,515 to 8,960 feet):**

This sequence was named the Eider unit by Amoco Canada and Imperial Oil (1973). It consists of almost equal parts of sandstone and siltstone-shale, with less than 1 per cent limestone. Microfossils indicate that a hiatus exists between this formation and the overlying Dawson Canyon Formation at approximately 8,960 feet.

The sandstone beds are ten to eighty feet thick, light grey, quartzose, with variable quantities of argillaceous matrix. Sandstone near the base of the formation is medium grained; sandstone in the upper part is fine grained. Grains are subangular to subrounded. Feldspars form less than 5 per cent of the detrital particles, while glauconite and heavy minerals are accessory components. Coal fragments are common in the sandstone at about 9,400 feet.

Siltstone-shale beds generally are medium grey and micaceous; coalified plant fragments are common on bedding planes. Limestone beds are up to ten feet thick and consist of light brownish grey biomicrite, skeletal wackestone and oolitic pack stone; quartz grains occur in some. Bioclasts consist of abraded fragmentary foraminifers, molluscs, bryozoans and echinoderms. Ferroan calcite has replaced the mollusc fragments, and siderite occasionally replaces

the micritic matrix. In the oolitic packstones, foraminifers form the nuclei of the oolites.

Microfossils indicate that the Logan Canyon Formation is a marginal marine deposit with intertonguing marine and nonmarine sediments, and that the marine influence increased during deposition of the formation. An oolitic packstone in the upper part of the formation indicates that the depositional environment remained relatively shallow and that occasional high energy conditions led to local reworking of bottom sediments.

The formation corresponds to the dinoflagellate/spore Zone of *Spinidinium* cf. *vestitum*-*Eucommiidites minor* and to the informal foraminifer zone of *Lenticulina gaultina*.

Dawson Canyon Formation (8,960 to 7,510 feet): This formation is a shale containing rare siltstone beds and several limestones. Contact between this formation and the overlying Wyandot Formation is gradational.

Dark grey siltstones and thin limestone beds occur near the base of the formation. The siltstones contain yellowish limonitic glauconite grains; some are protoquartzitic, well sorted and cemented by silica, ferroan calcite and granular siderite. The limestones at the base of the formation consist of skeletal wackestone and packstone. Worn fragmentary annelids, bryozoans, echinoderms and *Inoceramus* are present and, in some beds, have thick micritic coats and faint oolitic laminations. Molluscs are replaced by coarse, sometimes iron-rich, sparry calcite. In the limestones glauconite and quartz grains are rare. The limestones have a micritic matrix locally replaced by siderite and dolomite. The occurrence in these basal beds of oxidized glauconite, siderite and rare reddish shale with colour changes suggests that these sediments accumulated in an oxidizing environment, and would support the fossil evidence for a hiatus at the base of the formation.

The "Petrel Member"\* overlies these basal beds at 8,800 to 8,610 feet. It is a light grey, dense foraminiferal coccolith wackestone and packstone lacking visible porosity. Planktonic foraminifers comprise as much as one third of the rock. Coccoliths occur in the micrite. Sand-size fragments of molluscs and *Inoceramus* are minor constituents.

The shale which overlies the "Petrel Member" and comprises most of the Dawson Canyon Formation is medium dark grey to medium grey, slightly fissile and generally calcareous. It contains foraminifers and fragments of *Inoceramus*. Silt-size material, muscovite and glauconite are scarce. The shale generally lacks porosity and some fragments are strongly mylonitized.

The lower part of the formation, comprising the "Petrel Member" and the basal beds of the formation, corresponds to the dinoflagellate/spore Zone of *Oligosphaeridium pulcherrimum* and to the informal foraminifer zone of *Globotruncana renzi*. The remainder of the formation above the "Petrel Member" corresponds to the dinoflagellate/spore Zones of *Hystriosphraeridium truncigerum*, *Odontochitina operculata* and *Dinogymnium euclaensis*; and to the informal foraminifer zones of *Globotruncana coronata*, *G. ventricosa* and the lower part of *G. arca*.

\*The unit was informally named the Petrel Limestone by Amoco Canada Petroleum Company Ltd. and Imperial Oil Limited (1973).

Wyandot Formation (7,510 to 7,418 feet): The Wyandot Formation is a white foraminiferal coccolith wackestone in its lower part, grading upward into soft chalk. Its contact with the overlying Banquereau Formation is sharp. Skeletal material in the limestone is silt-sized and composed of fragments of planktonic foraminifers, rare echinoderms and *Inoceramus*. In thin sections, coccoliths were observed in a micritic matrix. The Wyandot Formation and "Petrel Member" of the Dawson Canyon Formation resemble each other closely in thin section and show no porosity.

The lower part of the formation (7,510 to 7,480 feet) corresponds to the upper part of the informal foraminifer zone of *Globotruncana arca*.

Banquereau Formation (7,418 to 1,090 feet): This formation is a mudstone-shale sequence with subordinate sandstone, siltstone and chalk. A thin sequence of pale red and greenish grey marl with a siderite or dolomite bed overlies the Wyandot Formation; these rocks correspond to the dinoflagellate/spore Zone of *Palaeoperidinium pyrophorum*-*Ceratiopsis diebeli*. Chalk (7,376 to 7,260 feet) overlying the marl is a white foraminiferal wackestone containing planktonic foraminifers, coccoliths, and rare radiolarians all in a micritic matrix. The chalk grades upward into a thin bed of calcareous foraminiferal mudstone which in turn is overlain by a shale. The latter is brownish grey, silty, and rich in fine organic matter and coalified plant fragments; frequently it is calcareous with occasional beds of siltstone and fine-grained sandstone. Foraminifers, glauconite, rare mica and pyrite occur in the shale.

Thin beds of siltstone and very fine grained glauconitic sandstone occur from 5,500 to 5,180 feet and correspond to the dinoflagellate/spore Zone of *Apteodinium* sp. B. Other siltstone beds occur at 4,120 to 3,950 feet and belong to the dinoflagellate/spore Zone of *Pentadinium laticinctum*. Argillaceous sediments above 4,550 feet are unconsolidated.

Between 2,012 and 1,090 feet (the highest sample examined lithologically) beds of quartz sandstone, ten to forty feet thick, are interbedded with brownish grey mudstone. These fall within the upper part of the dinoflagellate/spore Zone of *Carnosphaeropsis* sp. A and the dinoflagellate/spore Zone of *Artemisia-Taraxacum*. Grain size of the sand increases upward, becoming coarse at the top. The grains are well rounded and moderately sorted; polished grains occur in the upper sands. Also, there occur volcanic grains of basaltic and rhyolitic composition similar to grains described from the Mississauga Formation. The finer grained sand occasionally contains foraminifers, fragmentary molluscs and echinoderm spines, and is cemented by sparry calcite.

#### BIOSTRATIGRAPHY

The Puffin succession is referred to two biostratigraphic zonations: the formal zonation proposed by Williams (in prep.) for the Mesozoic-Cenozoic succession of eastern Canada based on dinoflagellates and spores (15,425 to 1,030 feet) and an informal Mesozoic zonation based on foraminifers (15,435 to 6,460 feet). In the Tertiary some plank-

tonic foraminiferal extinction levels are given. Some information is from sidewall cores taken between 12,300 and 5,900 feet, but most is from cuttings between 15,425 and 1,030 feet. Consequently, both zonations are defined to a considerable extent in terms of a succession of fossil "tops" or extinction points. The species diagnostic of a given zone with few exceptions do not occur in a younger zone. It is by means of the biostratigraphic zones, whose ages are known with varying degrees of precision, that wells on Canada's Atlantic continental margin are correlated. The zonal succession is discussed below in ascending stratigraphic order.

The oldest rocks penetrated by Puffin B-90 belong to the dinoflagellate/spore Subzone of *Biorbifera johnewingi* of the *Phoberocysta neocomica* Zone. The *B. johnewingi* Subzone is defined by the vertical range of *B. johnewingi* Habib and is of very early Cretaceous age. On the southwestern Grand Banks, where it has also been found in Amoco Imperial A-1 Kittiwake P-11 (44° 40'N, 53° 31'W), it is provisionally dated Berriasian-early Valanginian. In Puffin it extends from 15,425 to 14,500 feet and occupies the lowest third of the Verrill Canyon Formation. *Biorbifera johnewingi* ranges through most of the Berriasian type section in France; through most of the Berriasian and lower Valanginian at JOIDES site 105 in the North Atlantic, 380 miles east of Cape Hatteras; and from the base of the Berriasian to middle Valanginian in the Sacramento Valley of California (Habib and Warren, 1973). It first occurs at or close to the Jurassic-Cretaceous boundary in all three localities but has not been recorded in the Jurassic. It is associated in Puffin B-90 with *Wanaea spectabilis* (Deflandre and Cookson) Cookson and Eisenack and *Prolixosphaeridium* sp., which are confined to the subzone. The presence of the foraminifer *Saracenaria valanginiana* Bartenstein and Brand at 15,060 feet, suggesting an early Valanginian age from the horizon, is consistent with the evidence that the range of *Biorbifera johnewingi* in this area is Berriasian-early Valanginian.

On the Scotian Shelf the diagnostic fossils of the *Biorbifera johnewingi* Subzone commonly are missing and the subzone has not been recognized in Shell A-1 Mohawk B-93, Shell A-1 Naskapi N-30, Shell A-1 Oneida O-25 or Mobil Tetco A-1 Dauntless D-35. The subzone is not absent everywhere on the Scotian Shelf, however, for it occurs in a thin sequence (300 feet thick) of strata near the bottom of Mobil A-1 Sable Island C-67 (Williams, in prep.). This distribution would suggest either that some areas of the Scotian Shelf lay outside the lateral ranges of the species that characterize the *Biorbifera johnewingi* Subzone on the southwestern Grand Banks or that basal Cretaceous rocks are missing in some parts of the Scotian Shelf and attenuated in others.

The *Biorbifera johnewingi* Subzone is included in the *Phoberocysta neocomica* Zone which extends from 15,425 to 12,160 feet. Fossils diagnostic of this zone are *Phoberocysta neocomica* (Gocht) Millioud, *Achomosphaera neptuni* (Eisenack) Davey and Williams and *Systematophora orbifera* Klement. The zone is dated Berriasian-Valanginian (Williams, in prep.). In Puffin B-90 it occupies the same vertical interval as the informal foraminifer zone of *Buccicrenata italica* (15,425 to 12,160 feet) and approximately the same vertical interval as the Verrill Canyon Formation (15,425 to 12,336 feet). The informal foraminifer zone is characterized by *Buccicrenata*

*italica* Dieni and Massari, *Conorboides valendisensis* (Bartenstein and Brand) and *Saracenaria valanginiana* and is considered here to be Berriasian-Valanginian. A Berriasian-Valanginian age for this interval, is consistent with the abundance of the ostracod *Paracypris* ex gr. *acuta* (Cornuel).

Considerable numbers of Upper Jurassic microfossils occur between 13,490 and 12,248 feet in upper Valanginian deposits at the top of the Verrill Canyon Formation and in Hauterivian beds at the base of the Mississauga Formation. Oxfordian-Kimmeridgian dinoflagellates and spores make up as much as 3 per cent of the organic microfossils in this interval. They include *Chytroesphaeridia chytrooides* (Sarjeant) Downie and Sarjeant (12,470 feet), *Concentrisporites* spp. (12,380 feet), *Endosporites jurassicus* Pocock (13,260 to 12,760 feet), *Gonyaulacysta cladophora* (Deflandre) Dodekova (13,490 to 13,460 feet), *Hexagonifera jurassica* Gitmez and Sarjeant (13,280 to 13,250 feet) and *Leptodinium norrisi* Pocock (12,290 to 12,260 feet). A few Kimmeridgian-Tithonian ostracods occur between 13,160 and 12,260 feet, and include *Galliaecytheridea* sp. and *Schuleridea* aff. *triebeli oblonga* Donze. The distribution of these Jurassic fossils is sporadic within an otherwise orderly succession of Lower Cretaceous fossil assemblages and the evidence at hand points to their being reworked.

The dinoflagellate/spore Zone of *Ctenidodinium elegantulum* (12,090 to 10,760 feet), provisionally dated Hauterivian (Williams, in prep), spans the lower part of the Mississauga Formation. It is characterized by *Broomea jaegeri* Alberti and *Gonyaulacysta serrata* (Cookson and Eisenack) Sarjeant. It corresponds very closely to the informal *Planularia crepidularis* zone (12,160 to 10,950 feet) which is here considered to be Hauterivian on the basis of the Hauterivian foraminifer marker *Lenticulina ouachensis bartensteini* Moullade and the ostracod Hauterivian markers *Protocthere hechti* Triebel and *Cythereis* cf. *senckenbergi* Triebel. *Planularia crepidularis* (Roemer), which ranges throughout the Neocomian, has not been encountered in the *P. crepidularis* zone of Puffin B-90 but was encountered in residues from the underlying *Buccicrenata italica* zone.

The dinoflagellate/spore peak Zone of *Tenua anaphrissa* (10,700 to 9,850 feet), which is based on sidewall core, is dated Barremian (Williams, in prep.) and corresponds to the upper part of the Mississauga Formation. Diagnostic species are *Cerebropollenites mesozoicus* (Couper) Nilsson, *Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner, *Deflandrea perlucida* Alberti (common), *Dingodinium cerviculum* Cookson and Eisenack, *Muderongia simplex* Alberti (common) and *Pseudoceratium pelliferum* Gocht. The zone occupies much the same interval as the informal zone of *Choffatella decipiens* (10,950 to 9,800 feet), which is here considered Barremian-Aptian.

The overlying dinoflagellate/spore Zone of *Deflandrea perlucida*-*Systematophora schindewolfi* extends from 9,759 to 9,460 feet. It contains *D. perlucida*, *Callialasporites trilobatus* (Balme) Sukh Dev, *Cordosphaeridium eoinodes* (Eisenack) Eisenack, *Cyclonephelium attadalicum* Cookson and Eisenack, *C. cf. attadalicum* Cookson and Eisenack and is dated Aptian (Williams, in prep.). The oldest part of the zone, containing the dinoflagellates *Tenua anaphrissa* and *Pareodinia ceratophora* Deflandre emend. Gocht and

the spore *Pilososporites trichopapillosus* (Thiergart) Delcourt and Sprumont at 9,759 feet, is provisionally dated early Aptian (Williams, in prep.). This zone corresponds approximately to the "Naskapi Shale", which extends from 9,836 to 9,515 feet.

The dinoflagellate/spore Zone of *Spinidinium* cf. *Vestitum-Eucommiidites minor* overlies the Zone of *Deflandrea perlucida* and extends from 9,422 to 8,950 feet. It is characterized in this well by *Eucommiidites minor* Groot and Penny, *Appendicisporites jansonii* Pocock, *Trilobosporites apiverrucatus* Couper and *Vitreisporites pallidus* (Reissinger) Nilsson and is dated Albian by Williams (in prep.). It corresponds to the informal foraminifer zone of *Lenticulina gaultina* which is here considered to be Albian; and to the Logan Canyon Formation which extends from 9,515 to 8,960 feet. The presence of the ostracod *Schuleridea* aff. *jonesiana* (Bosquet), which has its highest occurrence in the Albian, confirms the age of this interval.

No conclusive evidence has been found in Puffin B-90 for rocks of Cenomanian or Turonian age, and a depositional hiatus exists between the Logan Canyon and Dawson Canyon formations. Organic microfossil evidence indicates a substantial hiatus in deposition between 8,950 and 8,890 feet, where the dinoflagellate/spore Zone of *Oligosphaeridium pulcherrimum*, dated Coniacian (Williams, in prep.) rests on the Albian dinoflagellate/spore Zone of *Spinidinium* cf. *vestitum-Eucommiidites minor*. Closely supporting the dinoflagellate and spore evidence, the informal foraminifer zone of *Globotruncana renzi*, here considered Coniacian, rests at 8,960 feet upon the informal foraminifer zone of *Lenticulina gaultina* here referred to the Albian. It is significant that no caved material of Cenomanian-Turonian age has been found in cuttings below the top of the Albian. Lithostratigraphy would support the fossil evidence for the existence of a hiatus at the base of the Dawson Canyon Formation (see p. 3).

The dinoflagellate/spore Zone of *Oligosphaeridium pulcherrimum* (8,890 to 8,660 feet) and the informal foraminifer zone of *Globotruncana renzi* (8,960 to 8,560 feet) occupy much the same vertical interval and correspond approximately to the "Petrel Member" (8,800 to 8,610 feet), of the Dawson Canyon Formation. The former zone is characterized by *Areoligera* sp. A (Williams, in prep.) and *Cyclonephelium varnophorum* Davey, the latter by *Globotruncana renzi* Gandolfi, *G. sigali* Reichel and *G. marginata* (Reuss).

The dinoflagellate/spore Zone of *Hystriosphæridium truncigerum* (8,590 to 7,950 feet), dated Santonian (Williams and Brideaux, in press; Williams, in prep.) and the informal foraminifer zone of *Globotruncana coronata* (8,560 to 7,960 feet) occupy the same interval in the middle of the Dawson Canyon Formation. They are characterized by the dinoflagellates *Hystriosphæridium truncigerum* Deflandre and *Hystriosphæropsis ovum* Deflandre, and the foraminifers *Globotruncana coronata* Bolli, *G. carinata* Dalbiez and *G. concavata* (Brotzen).

The dinoflagellate/spore Zone of *Odontochitina operculata* (7,900 to 7,555 feet), which includes the *Trichodinium castanea* informal subzone, contains *Odontochitina operculata* (O. Wetzel) Deflandre and Cookson, *Australiella tripartita* (Cookson and Eisenack) Vozzhennikova, *Gardodinium deflandrei* Clarke and Verdier, *Hystriosphæridium stellatum* Maier and *Xenascus ceratioides* (Deflandre) Lentin and Williams, and is dated Campanian (Williams, in prep.).

It corresponds to the uppermost part of the Dawson Canyon Formation, which "tops" at 7,510 feet.

The *Trichodinium castanea* subzone (7,900 to 7,770 feet), and the informal foraminifer zone of *G. ventricosa* (7,960 to 7,780 feet) occupy the same interval in the upper Dawson Canyon Formation. Characteristic fossils are the dinoflagellates *Trichodinium castanea* (Deflandre) Clarke and Verdier, *Deflandrea echinoidea* Cookson and Eisenack and *Palaeohystriosphæridium infusorioides* Deflandre, and the foraminifers *Globotruncana ventricosa* White, *Archeoglobigerina cretacea* (d'Orbigny) and *Bolivinoidea draco miliaris* Hiltermann and Koch. The dinoflagellate/spore subzone and the foraminifer zone are here considered early Campanian. These ages are supported by the ostracod *Brachyocythere rhomboidalis* (Berry) which ranges up into Campanian.

The youngest Cretaceous zones recognized are the dinoflagellate/spore Zone of *Dinogymnium euclaensis* (7,520 feet) in the Dawson Canyon Formation ten feet below the base of the Wyandot Formation; and the informal foraminifer zone of *Globotruncana arca* (top at 7,480 feet) in the upper 45 feet of the Dawson Canyon Formation and the lower part of the Wyandot Formation. Characteristic fossils are the dinoflagellates *Ceratiopsis diebeli* (Alberti) Vozzhennikova, *Dinogymnium acuminatum* Evitt, Clarke and Verdier, *D. euclaensis* Cookson and Eisenack, *Gillinia hymenophora* Cookson and Eisenack and *Hystriosphæridium recurvatum* (White) Davey and Williams, and the foraminifers *Globotruncana arca* (Cushman), *Bolivinoidea decoratus delicatulus* Cushman and *Globotruncana stuarti* (de Lapparent), which are here provisionally considered early Maastrichtian.

The oldest Tertiary strata in Puffin B-90 are referred to the dinoflagellate/spore Zone of *Palaeoperidinium pyrophorum-Ceratiopsis diebeli* (7,410 to 7,390 feet), which contains *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant, *Ceratiopsis diebeli* and *Svalbardella australina* (Cookson) Malloy, and is provisionally dated early Paleocene (Williams, in prep.). A sidewall core at 7,474 feet contains the dinoflagellates *Ceratiopsis diebeli*, *Spiniferites cingulatus* (O. Wetzel) Sarjeant, *S. scabrosus* Clarke and Verdier, *Subtilidinium minutum* Morgenroth and *Achomosphaera tridactylites* (Valensi) Deflandre and Sarjeant. This assemblage is Maastrichtian-early Paleocene in age. In the interval 7,390 and 7,360 feet immediately overlying the Paleocene dinoflagellate/spore Zone occur the foraminifers *Globorotalia pseudobulloides* (Plummer), *G. pseudomenardi* Bolli and the *G. uncinata/angulata* group, which may be dated Paleocene (Berggren, 1971). A diastem probably exists at or about 7,418 feet between the base of the Banquereau Formation and the Wyandot Formation. Biostratigraphy has not permitted this diastem to be more closely dated than late Maastrichtian-early Paleocene.

In Puffin B-90 the Eocene succession includes lower, middle and upper Eocene strata. The lower and middle Eocene deposits like the Paleocene, are remarkably thin. The dinoflagellate/spore Zone of *Areoligera senonensis* is characterized by the peak abundance of *Cordosphaeridium gracilis* (Eisenack) Davey and Williams. The zone is recognized in sidewall cores 7,300 and 7,246 feet and is dated early Eocene (Williams, in prep.). It corresponds very closely to the interval 7,300 and 7,270 feet containing the foraminifers *Globotalia rex* Martin and *G. aragonensis* Nuttall which also indicate an early

Eocene age (Postuma, 1971). These lower Eocene rocks are chalk beds (7,376 to 7,260 feet) near the base of the Banquereau Formation.

The middle Eocene dinoflagellate/spore Zone of *Adnatosphaeridium reticulense* has been recognized at only one horizon (7,207 feet) where it contains *Cordosphaeridium gracilis* and *Spiniferites* sp. A rich assemblage of foraminifers from 7,210 to 7,120 feet contains *Globorotalia spinuloinflata* (Bandy) (syn. *G. bulbrookii* Bolli), *G. broedermanni* Cushman and Bermudez and *Globigerina linaperta* Finlay of middle Eocene age (Postuma, 1971).

The dinoflagellate/spore Zone of *Diphyes colligerum* (6,933 to 6,648 feet) is dated late Eocene (Williams, in prep.). It contains *Areosphaeridium diktyoplokus* (Klumpp) Eaton, *Diphyes colligerum* (Deflandre and Cookson) Cookson, *Leptodinium incompositum* (Drugg) Lentin and Williams and *Rhombodinium draco* (Gocht) Vozzhennikova. The highest occurrence of *Globorotalia cerroazulensis* (Cole) at 6,850 to 6,820 feet is the highest foraminiferal evidence for the top of the upper Eocene. Above 6,820 feet the foraminifers in Puffin B-90 have been studied solely with a view to interpreting depositional environments.

One thousand feet of strata in Puffin B-90 (6,545 to 5,560 feet) are referred to two Oligocene dinoflagellate/spore zones. The lower *Deflandrea heterophlycta* Zone, dated early Oligocene (Williams, in prep.), is divided into two subzones. The *Areosphaeridium arcuatum* informal peak subzone (6,545 to 6,025 feet), based on sidewall cores and characterized by common *Areosphaeridium arcuatum* Eaton, *Adnatosphaeridium reticulense* (Pastiels) De Coninck, *Cordosphaeridium inodes* (Klumpp) Eisenack, and *Samlandia chlamydophora* Eisenack, is here provisionally dated early Oligocene A. The *Cordosphaeridium funiculatum* informal subzone (5,950 to 5,620 feet), characterized by *Cordosphaeridium funiculatum* Morgenroth, *Areosphaeridium arcuatum*, *Deflandrea heterophlycta* Deflandre and Cookson, *Thalassiphora pelagica* (Eisenack) Eisenack and Gocht, and *Wetzeliella coleothrypta* Williams and Downie, is here provisionally dated early Oligocene B. The upper of the two Oligocene zones, the *Chiropteridium dispersum* Zone (5,590 to 5,560 feet) containing *Chiropteridium dispersum* Gocht, *Cordosphaeridium cantharellum* (Brosius) Gocht, *Deflandrea phosphoritica* Eisenack and *D. spinulosa* Alberti, is middle-late Oligocene.

Three dinoflagellate/spore zones are recognized in a 3,600 foot thick succession (5,500 to 1,870 feet) here dated Miocene. The *Apteodinium* sp. B Zone (5,500 to 5,200 feet), containing *Apteodinium* sp. B Williams and Brideaux (in press), *Cyclopsiella elliptica* Drugg and Loeblich and *Lejeunia aechmophora* Benedek, is here considered early Miocene. The *Pentadinium laticinctum* Zone (5,140 to 3,670 feet), characterized by *Pentadinium laticinctum* Gerlach, *Lejeunia fallax* Morgenroth, *L. paratenella* Benedek and *Polysphaeridium pastielsi* Davey and Williams, is here included in the middle Miocene. The *Cannosphaeropsis* sp. A Zone (3,610 to 1,870 feet), with *Cannosphaeropsis* sp. A Williams and Brideaux (in press), *Nematosphaeropsis* sp. B Williams and Brideaux (in press) and *Tiliaepollenites* sp. A Williams and Brideaux (in press), is here referred to the late Miocene.

The youngest strata sampled in the Puffin B-90 well are referred to the *Artemisia-Taraxacum* dinoflagellate/spore Zone. This is subdivided into the *Hystriochosphaeridium pseudorecurvatum* informal subzone (1,810 to 1,150 feet), containing *H. pseudorecur-*

*vatum* Morgenroth, *Thalassiphora delicata* Williams and Downie and *Xenicodinium hispidum* Drugg, and provisionally dated Pliocene by Williams (in prep.); and the *Spiniferites scabratus* informal subzone (1,060 to 1,030 feet), containing *S. scabratus* (Wall) Sarjeant and *Tectatodinium pellitum* Wall, and here considered Pleistocene. Samples were not taken between 1,030 feet and the seabed at 448 feet.

#### ENVIRONMENTS OF DEPOSITION IN PUFFIN B-90

Sediments between 15,425 and 8,960 feet, consisting of the entire Lower Cretaceous succession penetrated in Puffin, were laid down in a progressively shallowing neritic environment. The Berriasian-Valanginian silts and mudstones between 15,425 and 12,336 feet which comprise the Verrill Canyon Formation contain a diverse foraminiferal assemblage with common epistominids, lenticulinids and arenaceous taxa. Rare calpionellids are present between 13,460 and 13,060 feet. The fauna suggests an open marine shelf environment. The frequent occurrence of fine plant fragments and sapropel in the mudstones indicates river born detritus.

In Puffin B-90 the Mississauga Formation between 12,336 and 9,836 feet is of Hauterivian-Barremian age. It is essentially a sandstone sequence with common siltstone and limestone intercalations near the top. It is interpreted as a higher energy deposit than the Verrill Canyon Formation, and as having been laid down in a delta front environment that graded upwards into distributary mouth bars and distributary channels. The shallowing of the environment is believed to be a result of delta progradation. The interpretation of an inner neritic and nearshore environment on the basis of lithostratigraphy is supported by a less diverse foraminifer assemblage in these rocks than in the underlying Verrill Canyon Formation.

The "Naskapi Shale" at 9,836 to 9,515 feet, of Aptian age, is characterized by microfaunal and microfloral assemblages of very limited diversity. Larger foraminifers such as *Choffatella* and *Orbitolina* characterize some beds. The environment was shallow and nearshore.

In Puffin B-90 the Logan Canyon Formation is Albian and extends from 9,515 to 8,960 feet. It is a nearshore marine deposit with intertonguing nonmarine beds. Foraminifers are generally absent; coal fragments are common at 9,400 feet. Thin oolitic limestone intercalations with abraded skeletal material suggest high energy conditions that occasionally led to the local reworking of bottom sediments.

The Upper Cretaceous sediments in Puffin are of deeper, more open marine character than the underlying Lower Cretaceous deposits. The Senonian Dawson Canyon Formation is a shale, with rare siltstone beds and several micritic limestones, extending from 8,960 to 7,510 feet. From 8,950 to 8,660 feet the microfauna is impoverished. Above 8,660 feet, however, foraminifers, especially planktonic ones, and coccoliths are abundant. The environment deepens rapidly above 8,660 feet where outer neritic, open marine conditions were established. The overlying Wyandot Formation (7,510 to 7,418 feet), a foraminiferal-coccolith wackestone, shows that relatively deep, open marine conditions continued into early Maastrichtian time.

The Paleocene to Pleistocene mudstone-shale sequence with subordinate sand, siltstone beds and chalks between 7,418 and 1,090 feet, comprises the Banquereau Formation. It is a deep marine, slope deposit which shallows progressively from Miocene time onward.

The Paleogene microfauna is largely pelagic, composed of planktonic foraminifers, coccoliths and radiolarians, with some arenaceous (*Spiroplectammina*) and calcareous benthos. Late Eocene to Miocene faunas (below 4,000 feet) show rich arenaceous assemblages with large specimens of *Cyclammina* (including *C. cancellata* Brady), *Haplophragmoides*, *Bathysiphon*, *Trochammina* and calcareous benthos such as *Melonis* aff. *pompiloides* (Fichtel and Moll), hispid uvigerinids and stilostomellids. This Paleogene-Miocene fauna is interpreted as of deep marine, slope character.

Above 4,000 feet the microfauna consists largely of calcareous benthonics and depositional environments become progressively more shallow. Less diverse faunas, with *Cassidulina*, *Lenticulina*, *Elphidium*, *Uvigerina* and some miliolids, make up the youngest Puffin assemblages and indicate a return to shallow marine, probably inner neritic conditions during the Pliocene and Pleistocene.

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## APPENDICES I - II

## BIOSTRATIGRAPHIC ZONES AND THEIR MICROFOSSIL CONTENT IN PUFFIN B-90

The biostratigraphic zones recognized in Puffin B-90 are listed below in two separate appendices. Appendix I deals with the dinoflagellate/spore zonation and Appendix II with the foraminifer zonation and ostracod occurrences. Species of biostratigraphic significance or numerical importance are indicated for each zone. Because they are based largely on cuttings' samples, each of the two zonations is actually a succession of fossil "tops" or local extinction points. They are listed below in descending stratigraphic order. The species listed within each zone with few exceptions do not occur in younger zones higher up the well.

## APPENDIX I

## SELECTED SPECIES IN THE DINOFLAGELLATE/SPORE ZONES OF PUFFIN B-90

- 1030'-1060': *Spiniferites scabratus* informal subzone (Pleistocene) of the *Artemisia-Taraxacum* Zone  
Species: *Spiniferites membranaceus* (Rossignol) Sarjeant; *Spiniferites scabratus* (Wall) Sarjeant; *Tectatodinium pellitum* Wall.
- 1150'-1810': *Hystriichosphaeridium pseudorecurvatum* informal subzone (Pliocene) of the *Artemisia-Taraxacum* Zone  
Species: *Hystriichosphaeridium pseudorecurvatum* Morgenroth; *Operculodinium israelianum* (Rossignol) Wall; *Thalassiphora delicata* Williams and Downie; *Xenicodinium hispidum* Drugg.
- 1870'-3610': *Cannosphaeropsis* sp. A Zone (late Miocene)  
Species: *Cannosphaeropsis* sp. A Williams and Brideaux (in press); *Cyclopsiella* sp. A Williams and Brideaux (in press); *Leptodinium patulum* Wall; *Lingulodinium machaerophorum* (Deflandre and Cookson) Wall; *Nematosphaeropsis balcombiana* Deflandre and Cookson; *Nematosphaeropsis* sp. B Williams and Brideaux (in press); *Operculodinium* cf. *israelianum* (Rossignol) Wall; *Spiniferites nodosus* (Wall) Sarjeant; *Spiniferites* sp.; *Tiliaepollenites* sp. A Williams and Brideaux (in press); *Tuberculodinium vancampoeae* (Rossignol) Wall.
- 3670'-5140': *Pentadinium laticinctum* Zone (middle Miocene)  
Species: *Hemicystodinium* sp. B; *Hystriichokolpoma rigaudae* Deflandre and Cookson; *Hystriichosphaeropsis obscura* Habib; *Lejeunia fallax* Morgenroth; *Lejeunia paratenella* Benedek; *Lejeunia* sp. A; *Lingulodinium* sp. B Williams and Brideaux (in press); *Operculodinium giganteum* Wall; *Palaeocystodinium golzowense* Alberti; *Pentadinium laticinctum* Gerlach; *Polysphaeridium pastielsi* Davey and Williams; *Spiniferites crassipellis* (Deflandre and Cookson) Sarjeant; *Spiniferites pseudofurcatus* (Klumpp) Sarjeant; *Tanyosphaeridium* sp. A Williams and Brideaux (in press); *Xenikoon* sp. A Williams and Brideaux (in press).
- 5200'-5500': *Apteodinium* sp. B Zone (early Miocene)  
Species: *Apteodinium* sp. B Williams and Brideaux (in press); *Apteodinium* sp. Gocht, 1969; *Cyclopsiella elliptica* Drugg and Loeblich; *Lejeunia aechmophora* Benedek.
- 5560'-5590': *Chiropteridium dispersum* Zone (late-middle Oligocene)  
Species: *Chiropteridium dispersum* Gocht; *Cordosphaeridium cantharellum* (Brosius) Gocht; *Deflandrea phosphoritica* Eisenack; *Deflandrea spinulosa* Alberti.
- 5620'-5950': *Cordosphaeridium funiculatum* subzone of the *Deflandrea heterophlycta* Zone (early Oligocene B)  
Species: *Areosphaeridium arcuatum* Eaton; *Ascostomocystis potane* Drugg and Loeblich; *Chiropteridium aspinatum* (Gerlach) Brosius; *Cordosphaeridium funiculatum* Morgenroth; "*Cyclonephelium exuberans*"; *Cyclonephelium* sp. A; *Deflandrea heterophlycta* Deflandre and Cookson; *Dinopterygium cladoides* Deflandre sensu Morgenroth, 1966; *Eocladopyxis peniculatum* Morgenroth; *Homotryblium plectilum* Drugg and Loeblich; *Perissetasphaeridium* sp. A Williams and Brideaux (in press); *Thalassiphora pelagica* (Eisenack) Eisenack and Gocht; *Wetzeliella coleothrypta* Williams and Downie; *Wetzeliella* sp. A Williams and Brideaux (in press).
- 6025'-6545': *Areosphaeridium arcuatum* peak subzone of the *Deflandrea heterophlycta* Zone (early Oligocene A)  
Species: *Adnatosphaeridium reticulense* (Pastiels) De Coninck; *Areosphaeridium arcuatum* (common); *Cordosphaeridium inodes* (Klumpp) Eisenack; *Cyclonephelium intricatum* Eaton; *Deflandrea wardenensis* Williams and Downie; *Samlandia chlamy-dophora* Eisenack; *Tsugaepollenites igniculus* (Potonie) Potonie and Venitz (base 6520 feet); *Wetzeliella ovalis* Eisenack.
- 6648'-7137': *Diphyes colligerum* Zone (late Eocene)

- Species: *Areosphaeridium diktyoplokus* (Klumpp) Eaton; *Diphyes colligerum* (Deflandre and Cookson) Cookson; *Leptodinium incompositum* (Drugg) Lentin and Williams; *Pentadinium laticinctum* subsp. *granulatum* Gocht; *Pentadinium taeniagerum* Gerlach; *Phthano-peridinium* sp. B; *Rhombodinium draco* (Gocht) Vozzhennikova; *Spiniferites cornutus* (Gerlach) Sarjeant.
- 7207': *Adnatosphaeridium reticulense* Zone (middle Eocene)
- Species: *Cordosphaeridium gracilis* (Eisenack) Davey and Williams; *Spiniferites* sp.
- 7246'-7300': *Areoligera senonensis* Zone (early Eocene)
- Species: *Comasphaeridium* cf. *cometes* (Valensi) Staplin, Jansonius and Pocock; *Cordosphaeridium gracilis* (peak abundance); *Wetzeliella symmetrica* Weiler.
- 7390'-7410': *Palaeoperidinium pyrophorum-Ceratiopsis diebeli* Zone (early Paleocene)
- Species: *Ceratiopsis diebeli* (Alberti) Vozzhennikova; *Deflandrea leptodermata* Cookson and Eisenack; *Exochosphaeridium bifidum* (Clarke and Verdier) Clarke et al. *forma* P Evitt, 1961; *Microdinium* sp. A; *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant; *Svalbardella australina* (Cookson) Malloy.
- 7520': *Dinogymnium euclaensis* Zone (Maastrichtian)
- Species: *Ceratiopsis diebeli* (base); *Dinogymnium acuminatum* Evitt et al.; *Dinogymnium euclaensis* Cookson and Eisenack; *Diphyes colligerum* (base); *Gillinia hymenophora* Cookson and Eisenack; *Heliodinium voigti* Alberti; *Hystrichosphaeridium recurvatum* (White) Davey and Williams; *Microdinium veligerum* (Deflandre) Davey; *Odontochitina operculata* (O. Wetzel) Deflandre and Cookson (one specimen); *Spiniferites wetzeli* (Deflandre) Sarjeant; *Svalbardella australina* (base); *Tanyosphaeridium magdali* (Drugg) Heisecke; *Trigonopyxidia ginella* (Cookson and Eisenack) Downie and Sarjeant; *Xenascus ceratioides* (Deflandre) Lentin and Williams (one specimen).
- 7555'-7900': *Odontochitina operculata* Zone (Campanian)
- Species: *Australiella tripartita* (Cookson and Eisenack) Vozzhennikova; *Cannosphaeropsis utinensis* O. Wetzel; *Deflandrea sverdrupiana* Manum; *Dinogymnium digitus* (Deflandre) Evitt et al.; *Gardodinium deflandrei* Clarke and Verdier; *Hewagonifera chlamydata* Cookson and Eisenack; *Hystrichosphaeridium stellatum* Maier; *Impletosphaeridium whitei* (Deflandre and Courteville) Morgenroth; *Microdinium veligerum* (Deflandre) Davey sensu Wilson, 1971; *Odontochitina operculata* (common); *Oligosphaeridium complex* (White) Davey and Williams; *Senoniasphaera rotundata* Clarke and Verdier; *Xenascus ceratioides* (common).
- 7770'-7900': *Trichodinium castanea* informal subzone of the *Odontochitina operculata* Zone (early Campanian)
- Species: *Chlamydophorella nyei* Cookson and Eisenack; *Deflandrea echinoidea* Cookson and Eisenack; *Dinogymnium undulosum* Cookson and Eisenack; *Exochosphaeridium striolatum* (Deflandre) Davey; *Odontochitina costata* Alberti; *Oligosphaeridium dictyophorum* (Cookson and Eisenack) Davey and Williams; *Palaeohystriochophora infusorioides* Deflandre; *Trichodinium castanea* (Deflandre) Clarke and Verdier.
- 7950'-8590': *Hystrichosphaeridium truncigerum* Zone (Santonian)
- Species: *Cannosphaeropsis utinensis* (base); *Cyclonephelium distinctum* Deflandre and Cookson; *Deflandrea sverdrupiana* (base); *Dinogymnium acuminatum* (base); *Dinogymnium heterocostatum* (Deflandre) Evitt et al.; *Dinogymnium undulosum* (base); *Dinopterygium cladoides* Deflandre; *Hystriochokolpoma ferox* (Deflandre) Davey; *Hystrichosphaeridium truncigerum* Deflandre; *Hystrichosphaeropsis ovum* Deflandre; *Polysphaeridium laminaspinosum* Davey and Williams; *Rugubivesiculites reductus* Pierce; *Senoniasphaera protrusa* Clarke and Verdier; *Stephodinium coronatum* Deflandre; *Surculosphaeridium longifurcatum* (Firtion) Davey et al.
- 8660'-8890': *Oligosphaeridium pulcherrimum* Zone (Coniacian)
- Species: *Areoligera* sp. A; *Cyclonephelium varnophorum* Davey.
- 8950'-9422': *Spinidinium* cf. *vestitum-Eucommiidites minor* Zone (Albian)
- Species: *Appendicisporites jansonii* Pocock; *Appendicisporites problematicus* (Burger) Singh; *Ascodinium pontis-mariae* (Deflandre) Deflandre; *Cicatricosisporites augustus* Singh; *Cicatricosisporites hallei* Delcourt and Sprumont; *Classopollis classoides* Pflug, emend. Pocock and Jansonius; *Cleistosphaeridium polypes* (Cookson and Eisenack) Davey; *Cleistosphaeridium polypes* subsp. A; *Cribroperidinium intricatum* Davey; *Cribroperidinium orthoceras* (Eisenack) Davey; *Eucommiidites minor* Groot and Penny; *Oligosphaeridium albertense* (Pocock) Davey and Williams; *Tigrisporites* sp.; *Trilobosporites apiverrucatus* Couper; *Vitreisporites pallidus* (Reissinger) Nilsson.

9460'-9759': *Deflandrea perlucida*-*Systematophora schindewolfi* Zone (Aptian)

Species: *Appendicisporites unicus* (Markova) Singh; *Astrocysta cretacea* (Pocock) Davey; *Callialasporites trilobatus* (Balme) Sukh Dev; *Canningia colliveri* Cookson and Eisenack; *Contignisporites cooksonii* (Balme) Dettmann; *Cordosphaeridium eoinodes* (Eisenack) Eisenack; *Cyclonephelium attadalicum* Cookson and Eisenack; *Cyclonephelium* cf. *attadalicum*; *Deflandrea perlucida* Alberti; *Pareodinia ceratophora* Deflandre (at 9759 feet); *Pilosisporites trichopapillosus* (Thiergart) Delcourt and Sprumont (9759 feet); *Tenua anaphrissa* (Sarjeant) Benedek (at 9759 feet). The sample at 9759 feet is dated early Aptian.

9850'-10,700': *Tenua anaphrissa* peak Zone (Barremian)

Species: *Cerebropollenites mesozoicus* (Couper) Nilsson; *Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner; *Ctenidodinium* sp.; *Deflandrea perlucida* (common); *Dingodinium cerviculum* Cookson and Eisenack; *Imbatodinium* sp.; *Muderongia simplex* Alberti (common); *Muderongia tomaszowensis* Alberti; *Pareodinia ceratophora* with kalyptra; *Polystephanephorus sarjeantii* Gitmez; *Pseudoceratium dettmannae* Cookson and Hughes; *Pseudoceratium pelliferum* Gocht.

10,760'-12,090': *Ctenidodinium elegantulum* Zone (Hauterivian)

Species: *Appendicisporites bifurcatus* Singh (base); *Appendicisporites problematicus* (base); *Broomea jaegeri* Alberti; *Cyclonephelium varnophorum* (base); *Gonyaulacysta serrata* (Cookson and Eisenack) Sarjeant; *Lanterna sportula* Dodekova.

12,160'-15,425': *Phoberocysta neocomica* Zone (Valanginian-Berriasian)

Species: *Achomosphaera neptuni* (Eisenack) Davey and Williams; *Aequitriradites spinulosus* (Cookson and Dettmann) Cookson and Dettmann; *Appendicisporites potomacensis* Brenner (base at 12,216 feet); *Cribroperidinium sepimentum* Neale and Sarjeant; *Endosporites jurassicus* Pocock (12,760 to 12,790 feet); *Gonyaulacysta cladophora* (Deflandre) Dodekova (13,460 to 13,490 feet); *Hexagonifera jurassica* Gitmez and Sarjeant (13,250 to 13,280 feet); *Oligosphaeridium anthophorum* (Cookson and Eisenack) Eisenack and Kjellstrom (base at 12,216 feet); *Phoberocysta neocomica* (Gocht) Millioud; *?Pseudoceratium nudum* Gocht; *?Spiniferites dentatus* Gocht; *Systematophora orbifera* Klement.

14,500'-15,425': *Biorbifera johnewingi* Subzone (early Valanginian-Berriasian)

Species: *Biorbifera johnewingi* Habib; *Prolixosphaeridium* sp.; *Wanaea spectabilis* (Deflandre and Cookson) Cookson and Eisenack.

## APPENDIX II

### SELECTED FORAMINIFER AND OSTRACOD SPECIES IN THE INFORMAL FORAMINIFER ZONES OF PUFFIN B-90

7480'-7555': *Globotruncana arca* zone (early Maastrichtian)

Species: *Bolivinooides decoratus delicatulus* Cushman; *B. draco miliaris* Hiltermann and Koch; *B. granulatus* Hofker; *Gavelinella clementiana* (d'Orbigny); *G. danica* (Brotzen); *Globigerinelloides multispina* (Lalicker); *Globotruncana arca* (Cushman); *G. gansseri* Bolli; *G. stephensoni* Pessagno; *G. stuarti* (de Lapparent); *G. stuartiformis* Dalbiez; *Heterohelix* spp.; *Loxostomum gemmum* (Cushman); *Stensioina pommerana* Brotzen.

7780'-7960': *Globotruncana ventricosa* zone (Campanian)

Species: *Archeoglobigerina cretacea* (d'Orbigny); *Bolivinooides draco miliaris* Hiltermann and Koch; *B. strigillatus* (Chapman); *Globigerinelloides multispina* (Lalicker); *Globotruncana arca* (Cushman); *G. bulloides* Vogler; *G. formicata* Plummer; *G. lapparenti* Brotzen; *G. linneiana* (d'Orbigny); *G. stuartiformis* Dalbiez; *G. ventricosa* White; *Neoflabellina rugosa* (d'Orbigny);

*Stensioina pommerana* Brotzen; *Brachycythere rhomboidalis* (Berry).

7960'-8560': *Globotruncana coronata* zone (Santonian)

Species: *Archeoglobigerina cretacea* (d'Orbigny); *Arenobulimina americana* Brotzen; *Gavelinella clementiana* (d'Orbigny); *G. pertusa* (Marsson); *Globigerinelloides prairehillensis* Pessagno; *Globotruncana angusticarinata* Gandolfi; *G. carinata* Dalbiez; *G. concavata* (Brotzen); *G. coronata* Bolli; *G. elevata* (Brotzen); *G. formicata* Plummer; *G. globigerinoides* Brotzen; *G. linneiana* (d'Orbigny); *Brachycythere rhomboidalis* (Berry); *Cythereis* sp.

8560'-8960': *Globotruncana renzi* zone (Coniacian)

Species: *Globotruncana carinata* Dalbiez; *G. concavata* (Brotzen); *G. coronata* Bolli; *G. lapparenti* Brotzen; *G. marginata* (Reuss); *G. renzi* Gandolfi; *G. sigali* Reichel; *Hedbergella bosquensis* Pessagno; *H. delrioensis* (Carsey); *Trochamminoides* spp.; *Cythereis* spp.

8960'-±9500': *Lenticulina gaultina* zone (Albian)

Species: *Ammobaculites subcretaceus* Cushman and Alexander; *Epistomina cretosa* Ten Dam; *Globigerinelloides bentonensis* (Morrow); *G. caseyi* (Bolli, Loeblich and Tappan); *Lenticulina gaultina* (Berthelin); *L. nodosa* (Reuss); *Marssonella trochus* (d'Orbigny); *Schuleridea* aff. *jonesiana* (Bosquet); *Asciocythere* sp.; *Neocythere* spp.

9800'-10,950': *Choffatella decipiens* zone (Aptian-Barremian)

Species: *Ammobaculites reophacoides* Bartenstein; *Choffatella decipiens* Schlumberger; *Lenticulina nodosa* (Reuss); *Reophax minuta* Tappan; *Trocholina infragranulata* Noth; *Paracypris* ex gr. *acuta* (Cornuel); *Neocythere* aff. *vanveeni* Mertens; *Schuleridea* sp.

10,950'-12,160': *Planularia crepidularis* zone (Hauterivian)

Species: *Choffatella decipiens* Schlumberger; *Conorboides?* sp.; *Lenticulina ouachensis bartensteini* Moulade; *Trocholina infragranulata* Noth; *Protoocythere hechti* Triebel; *Cythereis* cf. *senckenbergi* Triebel; *Asciocythere* sp.

12,160'-15,425': *Buccicrenata italica* zone (Valanginian-Berriasian)

Species: *Buccicrenata italica* Dieni and Massari; *Conorboides hofkeri* Bartenstein and Brand; *C. valendisensis* (Bartenstein and Brand); *Dorothia praehauteriviana* Moulade; *Epistomina caracolla* (Roemer); *E. hechti* Bartenstein, Bettenstaedt and Bolli; *E. ornata* (Roemer); *E. tenuicostata* Bartenstein and Brand; *Marssonella praeoxycona* Moulade; *Planularia crepidularis* (Roemer); *Saracenaria valanginiana* Bartenstein and Brand (15,060 feet); *Paracypris* ex gr. *acuta* (Cornuel); *Dolocytheridea* sp.; ?*Cardiobairdia* sp.