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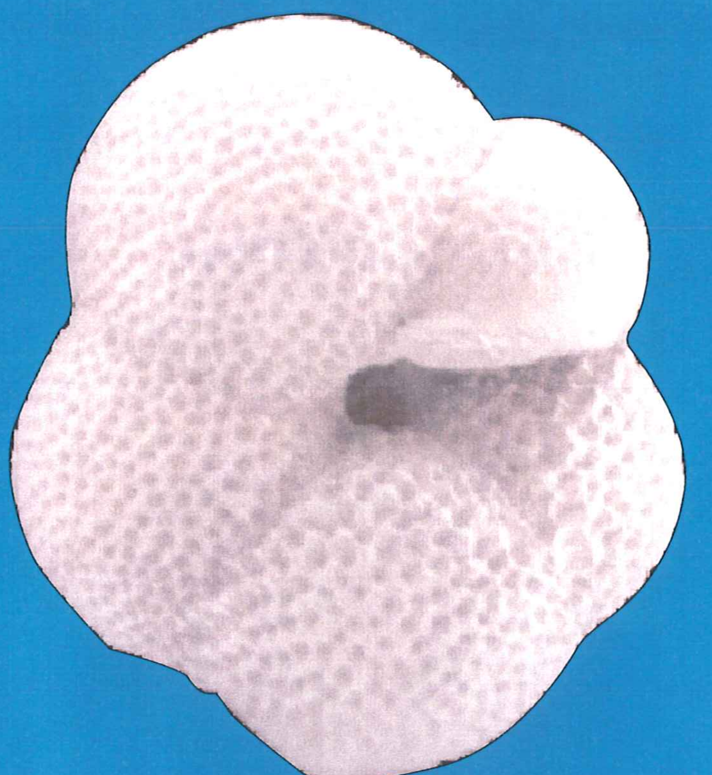
Cenozoic Micropaleontology of Three Wells, Scotian Shelf and Slope

F.C. Thomas



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Cenozoic micropaleontology of three wells, Scotian Shelf and Slope

by

F.C. Thomas
Geological Survey of Canada (Atlantic)
P.O. Box 1006
Dartmouth, NS B2Y 4A2

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ABSTRACT

The Cenozoic biostratigraphy of three exploration wells, Acadia K-62, Shubenacadie H-100 and Eagle D-21, Scotian Basin, offshore Nova Scotia is based primarily on their rich planktic and benthic foraminiferal assemblages. Acadia and Shubenacadie, lying some 36 km apart, were drilled in relatively deep water on the upper Scotian Slope. Eagle D-21 is located in shallow water near the shelf break some 300 km to the northeast. In the Paleocene to the Early Miocene, all three sites had typically deep-water benthic assemblages, while later in the Miocene the foraminiferal suite at Eagle D-21 changed rapidly to one reflecting a marked decrease in water depth. Several breaks in deposition occur at both the Shubenacadie H-100 and Eagle D-21 locations, particularly between the Middle Eocene and Early Miocene. The stratigraphic section at Acadia K-62 appears to be somewhat more complete. At Shubenacadie H-100, foraminifera indicate a Campanian-Maastrichtian to Paleocene age for a seismically-defined turbidite fan.

INTRODUCTION

The Scotian Shelf, offshore Eastern Canada, has been the site of intensive hydrocarbon exploration for more than thirty years, with over 160 wells drilled. Only five wells have been drilled on the upper slope, however, in water depths exceeding 500 m.

Micropaleontological studies of the Cenozoic sections of many of the shelf wells have been published, and more have been described in internal Geological Survey of Canada reports. With the exception of a few industry studies available at the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) office in Halifax, Nova Scotia, there have been no publications on the micropaleontology of the slope wells.

The impetus for this paper is the renewed oil company interest in the Cenozoic sedimentary history of the upper slope, as recorded in wells such as Acadia K-62 and Shubenacadie H-100 and certain near-slope shelf wells, especially Eagle D-20.

Chevron Pex Shell Acadia K-62 was spudded in the summer of 1978 as an exploratory well in 866.3 m of water on the upper Scotian Slope some 200 km southwest of Sable Island (Figure 1). Forty-three samples were available for study from the Cenozoic section of the well. These are ditch cuttings and represent sediments from the 1200-2508 m below rotary table height. More information about Acadia K-62 is available in the company's well history report (Lewis and Pandachuk, 1978), available from CNSOPB.

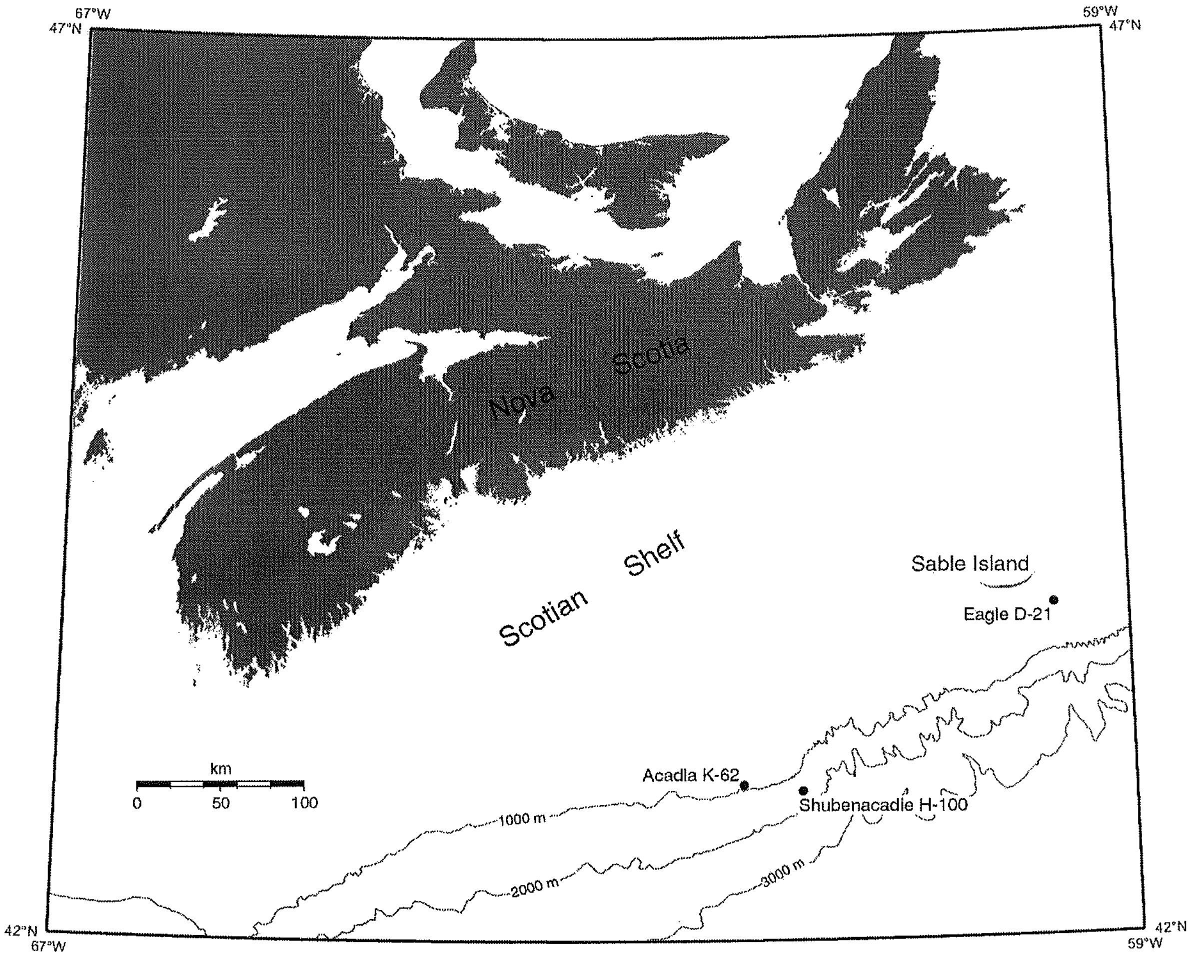

Figure 1. Location map showing three wells.

Shell *et al.* Shubenacadie H-100 was spudded November 5, 1982 as a new field wildcat well on the upper Scotian Slope in 1476.5 m of water some 260 km southeast of Halifax, Nova Scotia, and just 36 km west of Acadia K-62. Forty-two samples of ditch cuttings were available for study from this well, representing depths from 2140 m to 3830 m below rotary table height. Samples represent 10 m sections, usually with 30 m gaps. Further information about this well is contained in the company's well history report (Shell Canada Resources Ltd., 1983).

Shell Mobil Tetco Eagle D-21 was spudded April 22, 1972 as a new field wildcat well some 20 km southeast of Sable Island, in 51.2 m water depth on the Scotian Shelf, and some 300 km to the northeast of Acadia K-62. Since this well was drilled prior to metrification, all samples were collected and labelled in Imperial units. To facilitate interpretation, data from this well is given in both metric and Imperial units. For the purposes of this study, some 40 samples from the interval 1680' (512 m) to 5310' (1618.5 m) below rotary table height were examined. The samples from Eagle D-21 were ditch cuttings, derived from discrete 30' (10 m) intervals, usually separated by unsampled 30' (10 m) gaps. More data on this well can be found in the company's well history report (Shell Canada Resources Ltd., 1974).

Exact locations and drilling data for these three wells are given in Table 1. Lists of all samples used are provided in Table 2.

This is the first publication outlining the Cenozoic micropaleontology of the three wells, although there are internal reports (Thomas, 1994, 2000a, 2000b).

		Acadia K-62	**Eagle D-21***	**Shubenacadie H-100**
GSC locality number		D171	D80	D219
Location	latitude	42 51' 44"	43 50' 06.73"	42 49' 28.4"
	longitude	61 55' 02"	59 34' 09.21"	61 28' 42.8"
Elevation: Sea level to R.T.		12.8 m	29.9 m (98')	25 m
Water depth		866.3 m	51.2 m (168')	1476.5 m
Total depth		5287.4 m	4660.4 m (15,290')	4200 m
Sampled interval		1200-5287 m	512-4639 m 1680-15,220')	2140-4200 m
Interval studied		2430-3448 m	512-1618.5 m (1680-5310')	2140-3830 m
Casing points		928 m 1182.9 m 1785.2 m 2786.3 m	265.2 m (870') 996.7 m (3270') 2213.5 m (7262')	468 m 2107.4 m 2532 m 3476.8 m

Table 1. Locality numbers and drilling data.

*Eagle D-21 was drilled prior to metrification, and all depths were originally recorded in feet.

METHODS

All samples were soaked in a solution of water and Quaternary O, a commercial surfactant, for at least 24 hours, then boiled for about an hour. If necessary, individual samples were buffered with calcium carbonate to preserve a neutral or slightly alkaline pH condition.

Treated samples were wet sieved using a 63 micron mesh and the residues were oven dried. Each sample was then dry sieved, using 850-, 250- and 180-micron meshes.

Portions from each mesh size and often from the catch pan, were examined under binocular microscopes in standard 5x9 cm picking trays. For each mesh size, two trays were picked clean of all recognizable microfossils and microfossil fragments, usually using a fine artists' paint brush. All picked material was then placed in labelled 60-grid micropaleontological slides.

Picking of all samples was carried out under contract at Bedford Institute of Oceanography (BIO) by staff of Atlantic Paleo Services (APS), Dartmouth, Nova Scotia or by Harding Scientific and Technical Services, Halifax, Nova Scotia.

Two slides were normally made from each sample, one for use and storage by Geological Survey of Canada (Atlantic) at BIO and one for archival purposes for the appropriate regulatory agency. These archive slides are now held by CNSOPB at their Core Storage and Laboratory Facility in Dartmouth, Nova Scotia.

In the studies of all three wells, age determinations of microfossil assemblages were based primarily on index planktic foraminiferal species as outlined by Caron, (1985), Kennett and Srinivasan (1983) and Toumarkine and Luterbacher (1985). The regional benthic/planktic foraminiferal assemblage zonation of Gradstein and Agterberg (1982) was also useful.

Water depths and other environmental parameters for the sections studied are estimated from the relative numbers of *in situ* planktic and benthic foraminifera, the nature of the benthic species and assemblages (as reviewed in Gradstein *et al.*, 1994; Tjalsma and Lohmann, 1983; and van Morkhoven *et al.*, 1986) and in some cases, the nature of other microfossils present.

Acadia K-62 (in metres)
1200-1210, 1230-1240, 1260-1270, 1290-1300, 1320-1330, 1350-1360, 1380-1390, 1410-1420, 1440-1450, 1470-1480, 1500-1510, 1530-1540, 1560-1570, 1590-1600, 1620-1630, 1650-1660, 1680-1690, 1710-1720, 1740-1750, 1770-1780, 1812-1824, 1842-1854, 1872-1884, 1902-1914, 1932-1944, 1962-1974, 1992-2004, 2022-2034, 2052-2064, 2082-2094, 2112-2124, 2142-2154, 2172-2154, 2172-2184, 2202-2214, 2232-2244, 2262-2274, 2292-2304, 2322-2334, 2352-2364, 2382-2394, 2412-2424, 2430-2448, 2466-2478, 2490-2508, 2532-2550.

Shubenacadie H-100 (in metres)
2140-2150, 2180-2190, 2220-2230, 2260-2270, 2300-2310, 2340-2350, 2380-2390, 2420-2430, 2460-2470, 2500-2510, 2540-2550, 2580-2590, 2620-2630, 2660-2670, 2700-2710, 2740-2750, 2780-2790, 2815-2825, 2860-2870, 2900-2910, 2940-2950, 2980-2990, 3020-3030, 3060-3070, 3100-3110, 3140-3150, 3180-3190, 3220-3230, 3260-3270, 3300-3310, 3340-3350, 3380-3390, 3420-3430, 3460-3470, 3495-3505, 3535-3545, 3620-3630, 3660-3670, 3700-3710, 3740-3750, 3780-3790, 3820-3830.

Eagle D-21 (in feet)
1680-1710, 1740-1770, 1830-1860, 1920-1950, 2010-2040, 2100-2130, 2190-2220, 2280-2310, 2370-2400, 2460-2490, 2550-2580, 2640-2670, 2730-2760, 2790-2820, 2880-2910, 2940-2970, 3030-3060, 3120-3150, 3210-3240, 3270-3330, 3360-3420, 3480-3510, 3570-3600, 3660-3690, 3750-3780, 3840-3870, 3930-3960, 4020-4050, 4110-4140, 4200-4230, 4290-4320, 4380-4410, 4470-4500, 4560-4590, 4650-4680, 4740-4770, 4830-4860, 4920-4950, 5010-5040, 5110-5130.

Table 2. Samples analysed in this study.

GEOLOGICAL SETTING

All the Tertiary sediments of the Scotian Basin are included in the Banquereau Formation, a sequence of clastic sediments up to 1.5 km thick (Wade and MacLean, 1990). Deposition of the Banquereau Formation began in the Campanian-Maastrichtian, immediately following deposition of the chalky Wyandot Formation. The Wyandot represents the culmination of a transgressive sequence begun in the mid-Cretaceous as the clastic Logan Canyon Formation.

During the Paleogene, seaward tilting of the Scotian margin resulted in extensive erosion and reworking of inner shelf Cretaceous facies and the deposition of deep-water marine facies beneath what is now the present-day outer shelf (Grant, McAlpine and Wade, 1986). Subsequent regression and progradation in the later Tertiary and Quaternary formed the present Shelf.

In some parts of the outer shelf and slope, local erosion in Late Paleocene and Early Eocene time produced chalky fans on the upper rise (Swift, 1987) and resulted in local-scale hiati on the shelf, as reported by several workers (Doeven, 1983; Thomas, unpublished data). An extensive erosional event of Late Eocene age occurred on the shelf, possibly caused by widespread subaerial exposure. Subsequent Oligocene and Miocene deposition on the shelf is largely confined to paleotopographic lows, as seen in shelf wells and environments are generally considered to reflect inner to outer neritic conditions. Swift (1987) provides a detailed summary and synthesis of seismic interpretations of the Tertiary of shelf sites.

The Banquereau Formation is roughly wedge-shaped, thinning towards the Nova Scotian coast and being thickest under the present Scotian Slope (Jansa and Wade, 1974). The formation is predominantly composed of marine shales, mudstones, siltstones and sandstones, with occasional limy intervals. Consolidation varies, increasing more or less with depth, although nowhere can the formation be described as well indurated. Hardy (1974, p.173) divided the Banquereau Formation into four informal subunits on the basis of age and lithology. These are:

(i) Maskonomet Beds. The argillaceous mudstones of Campanian to Maastrichtian age that rest conformably on the Wyandot Formation (chalk) and are succeeded by the Nashwauk Beds.

(ii) Nashwauk Beds. The argillaceous glauconitic sandstones and mudstones of Paleocene to Eocene age that overlie the Maskonomet and are succeeded by the Manhasset Beds.

(iii) Manhasset Beds. The argillaceous, glauconitic sandstones of Oligocene age that overlie the Nashwauk and are succeeded by the Esperanto Beds.

(iv) Esperanto Beds. The unconsolidated sandstones and interbedded claystones of Miocene to Pliocene age, that overlie the Manhasset Beds and are succeeded unconformably by Pleistocene sediments.

DISCUSSION

Acadia K-62

Most Scotian Margin wells contain similar, and well-known, shallow-water benthic foraminiferal assemblages, particularly in their Miocene sections. Acadia K-62, by contrast, represents much more pelagic conditions, with many familiar benthic markers environmentally excluded. However, abundant planktic foraminifera throughout most of the Cenozoic section of this well permit biostratigraphic interpretation with some degree of confidence. The Cenozoic stratigraphic succession for Acadia K-62 is given in Figure 2 and a complete listing of taxa in each section is provided in Appendix 1.

Maastrichtian/Campanian (2532+ m)

The sample at 2532 m contains a large number of caved Tertiary taxa, but there are also siubstantial numbers of Campanian-Maastrichtian planktic foraminifera such as heterohelicids, suggesting that deposition may have been more or less uninterrupted across the K/T boundary at the Acadia K-62 site.

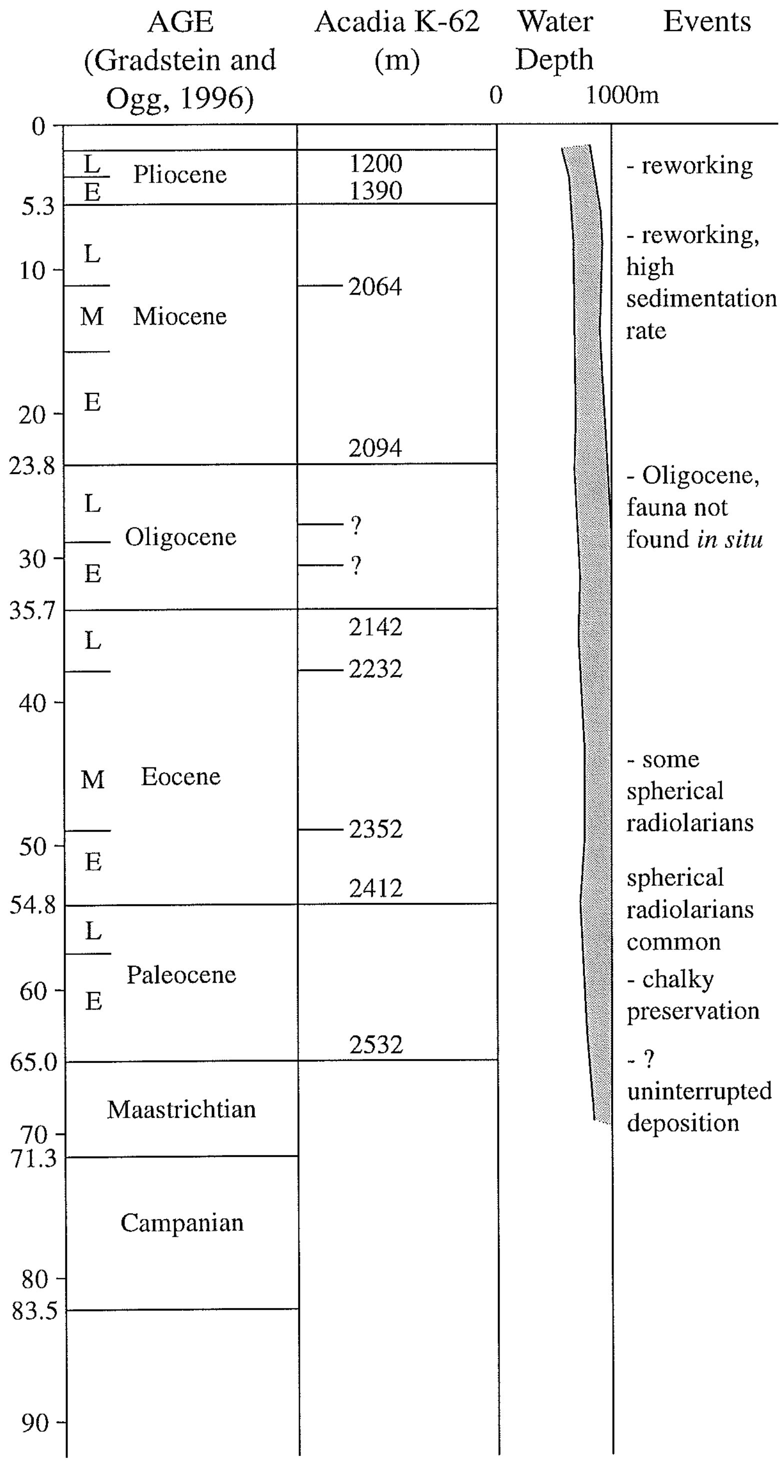

Figure 2. Cenozoic ages, depths and environments of Acadia K-62.

This sample would probably represent the Maskonomet Beds of Hardy's (1974) classification.

Paleocene (2412-2508 m)

Planktic foraminifera are abundant and form about 90% of the microfossils in the Paleocene. Preservation is generally good, though many specimens appear to have been encased in chalk, with two distinct modes of preservation, some microfossils showing contamination of buff-coloured chalk, whereas others are much whiter.

Rich planktic foraminiferal assemblage in this interval contain a number of diagnostic Paleocene species (see Appendix 1). There are even one or two Late Cretaceous planktics. These are heterohelicids, taxa known to persist in younger sediments in many parts of the Nova Scotian offshore: the author has encountered them reworked in Pleistocene deposits from the lower Scotian Slope (Thomas, 1990). There are also small numbers of radiolarians, including spherical, lenticular, and spindle-shaped taxa.

Although no species is abundant, the benthic assemblage is diverse. The most common taxa are buliminids such as *Bulimina tuxpamensis* and *Bulimina bradbury.* Most are calcareous and well-preserved, with agglutinated forms comprising less than 10% of the benthic total. A few species, such as *Rzehakina epigona* and *Gavelinella beccariiformis* are well-documented benthic markers for the Paleocene in East Coast wells (Gradstein and Agterberg, 1982). Most of the others are known to range from Paleocene to at least Early or early Middle Eocene in many Atlantic sites (Tjalsma and Lohmann, 1983).

Apart from the radiolarians, the only non-foraminiferal taxa are a few specimens of indeterminate, smooth-walled ostracodes.

The relative abundance of planktic foraminifera, the nature of the benthic species, and the common radiolarians all suggest a bathyal environment of deposition for this assemblage and the regional setting suggests a lower slope location, even in the early Paleogene. Whatever the exact water depth during deposition, it was clearly above CCD.

In terms of Hardy's (1974) classification, this material and all the overlying Eocene section would be defined as Nashwauk Beds.

Early Eocene (2352-2394 m)

The Early Eocene is recognized by the presence of such planktic markers as *Acarinina pentacamerata*, *Morozovella caucasica* and *Turborotalia cerooazulensis frontosa*. These and other planktics make up about 90% of the *in situ* biota. The benthic assemblage is rich and diverse, with a few agglutinated taxa. Preservation remains generally good in most cases, although many specimens exhibit a chalky coating. Spherical and ovoid radiolarians are present in substantial numbers.

Spherical radiolarians are found in substantial numbers in the lowermost Cenozoic of some Jeanne d'Arc Basin wells to the northeast (Thomas, 1995) and in at least one other Scotian Shelf well, Intrepid L-80 (A. MacRae, pers. comm., 2000), beside the two other sites in this study. It may be that such radiolarian assemblages be locally useful as ecostratigraphical markers in deep-water sites on the Scotian Shelf, as they have been shown to be in the Jeanne d'Arc Basin (Thomas, 1995).

The environment of deposition was apparently lower slope, although the thinness of the section (if complete) suggests a reasonably low sedimentation rate. The common calcareous benthics and well-preserved planktic assemblage clearly suggest a location well above the CCD.

Middle Eocene (2232-2334 m)

The rich Middle Eocene section contains several distinctive marker planktics including some, such as *Globogerinatheks mexicana* gr. and *Hantkenina alabamensis,* which were originally described from lower-latitudes (Toumarkine and Luterbacher, 1985). There is only one other record of *Hantkenina alabamensis* on the Canadian Atlantic Margin, in Freydis B-87 on the Labrador Shelf (Gradstein and Agterberg, 1982). The benthic assemblage of this section includes small numbers of agglutinated taxa, although the biota is still largely calcareous. Some spherical radiolarians are also present. Preservation of most forms is fairly good.

The thin Middle Eocene (if complete) suggests a low sedimentation rate and the relatively high P:B ratio (10:1) suggests a deep, probably lower slope, environment, though still obviously well above the carbonate compensation depth (CCD).

Middle/Late Eocene (2142-2214 m)

Two planktic foraminiferal markers for the Middle-Late Eocene, *Turborotalia cerroazulensis pomeroli* and *Globigerinatheka* aff. *conglobata,* have their highest occurrence at 2142 m. Other typical Eocene forms, such as *Globigerina eocaena*, occur just below this. A diagnostic Eocene benthic, *Cibicidoides eocaena*, also appears here.

The preservation of the microfossils in this section is remarkably good, although a few of the larger planktic specimens tend to be flattened. The ratio of planktic to benthic foraminifera (P:B) seems to have been gradually decreasing going up the well, although in some intervals extensive cavings may alter the composition of some samples. This gradual decrease confirms that the environment would have been deeper before the deposition of the overlying sections.

Oligocene?

Although no samples contain a distinct Oligocene assemblage, Acadia K-62 may have penetrated sediments of this age, since several specimens of a diagnostic Oligocene planktic foraminifera, *Catapsydrax* aff. *dissimilis*, occur in a sample from 2202-2214 m, in a Middle-Late Eocene assemblage. The environment of deposition is unknown.

Early and Middle Miocene (2084-2094 m)

The single sample contains two diagnostic planktic foraminiferal species, *Globigerina praebulloides* and *Globorotalia praemenardi*. Otherwise, the planktic and benthic assemblages are similar to higher up, with numerous caved specimens. Preservation of the *in situ* assemblage is generally good and the environment of deposition was probably similar to the overlying sections.

Late Miocene (1410-2064 m)

The Late Miocene age is based on the few specimens of the planktic foraminifera *Globorotalia plesiotumida* and Gradstein and Agterberg's (1982) age-diagnostic benthic taxon *Asterigerina gurichi*. Otherwise, much of the benthic assemblage is somewhat similar to that in the Pleistocene (Pliocene?), although some of the specimens are probably caved, as evidenced by the numbers of Plio-Pleistocene planktics. A few fish teeth, some radiolarians and other non-foraminiferal microfossils also occur, along with a few reworked Eocene and Late Cretaceous foraminifera (Appendix 1).

Preservation is variable, ranging from near-pristine to abraded, to heavily stained or encrusted. In many cases the more poorly preserved specimens may be reworked from older material, but belong to long-ranging or unidentifiable forms. In a few samples some minor pyritization of occasional specimens seems to have taken place.

The environment of deposition was upper slope. The thickness of this interval suggests a relatively high rate of sedimentation; this may have been caused to some extent by spillover from the shelf. There are a few samples where the assemblages are sparse; these may represent debris flow deposits. Lithologically, these sediments and the early and Middle Miocene section below would be part of Hardy's (1974) Esperanto Beds.

Pleistocene (Pliocene?) (1200-1390 m)

In these sediments, planktic foraminiferal numbers constitute about half of the rich foraminiferal assemblages, and most samples contain diagnostic Pleistocene taxa such as *Neogloboquadrina pachyderma* and *Globigerina bulloides*. Most specimens are dwarfed, similar to those from Pleistocene surficial sediments in piston cores on the Scotian Slope (Thomas *et al.*, 1990). Both *Neogloboquadrina pachyderma* and *Globigerina bulloides* are considered cold-temperate indicators (Kennett and Srinivasan, 1983). Towards the bottom of this interval, however, warmer-water taxa such as *Globorotalia crassaformis* and *Orbulina universa* become prevalent. It is not possible to determine if this change represents an interglacial cycle or Pliocene sedimentation, since their ranges extend down into the Pliocene. The benthic foraminifera are abundant and diverse, including many species found in modern slope environments. In some samples, there are small numbers of discoid radiolarians, as well as occasional echinoid fragments. Some reworked foraminiferal taxa of Tertiary and rarely, Late Cretaceous age also occur sporadically.

Preservation of this material is generally good, with many specimens appearing quite "fresh". The environment of deposition was probably upper slope. Some samples have a much "colder" appearance than others because of the preponderance of dwarfed planktics, presumably from the Pleistocene levels. There may have been a certain amount of downslope transport of material from older sediments eroding, perhaps at the shelf break; this would account for the small numbers of reworked Tertiary and Cretaceous taxa. In Hardy's (1974) classification, this section may contain some Esperanto Beds, although the Pleistocene material is included in the Laurentian Formation, the designation given to all Quaternary units on the Nova Scotia Atlantic margin (Grant, McAlpine and Wade, 1986).

Shubenacadie H-100

The Cenozoic section of Shubenacadie H-100 differs from previously studied East Coast wells, in part due to its relatively deep-water setting (based on microfossil evidence) and because of local stratigraphic features described below.

Seismic evidence (J. Wade, pers. comm., 2000) suggests the presence of a large "turbidite fan" in the Paleogene, ostensibly composed of sediments slumped down from shallower localities. This may be an upslope expression of one of Swift's (1987) "chalky fans". The reworked microfossils in such material tend to obscure stratigraphic successions.

Figure 3 summarizes the ages and stratigraphic picks in this well, and Appendix II presents a listing of the taxa encountered in each section.

Late Cretaceous (Campanian-Maastrichtian 3495-3830+ m)

The Upper Cretaceous interval is readily identifiable by the abundance of diagnostic Campanian-Maastrichtian planktic forms, particularly heterohelids and rugoglobigerinids. Generally, the preservation of these taxa is not particularly chalky (as seen in the ?Lower Eocene section), but is more typical of normal, fine clastic deposition. In many upslope East Coast wells, the uppermost Cretaceous is the chalky Wyandot Formation and usually contains large numbers of globotruncanids. However Shubenacadie H-100 was a much deeper, more pelagic site and thus contains a different suite of planktic forms, without the chalky appearance. The relative scarcity of benthic taxa at Shubenacadie H-100 may be in part due to the rapid deposition of clastics from upslope areas, making it difficult for diverse benthic assemblages to become established. Fragments of the large mollusc *Inoceramus* occur at 3820 m. It is common geological practice to correlate the top of the Cretaceous with the uppermost occurrence of this marker, although Ward *et al.* (1991) have demonstrated that the actual extinction of the genus occurs at the end of the Early Maastrichtian. This species may have been environmentally excluded from its upper range in this deep-water environment.

In Hardy's (1974) scheme, this interval would be assigned to the Maskonomet Beds.

Paleocene (3460-3470 m)

The single Paleocene sample contains some age diagnostic planktics, and a few benthic species which are associated with Paleocene sediments in other East Coast wells (Gradstein and

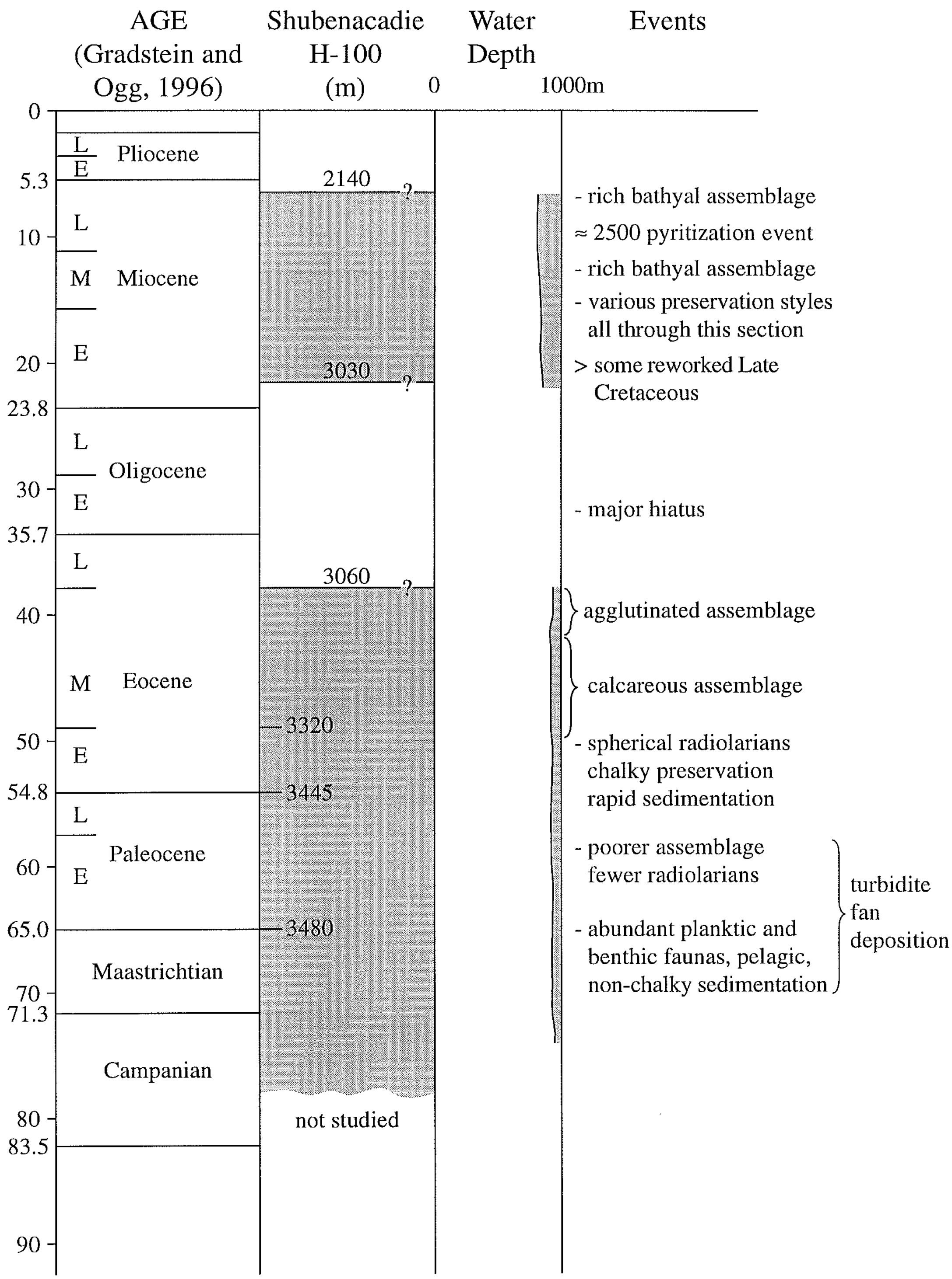

Figure 3. Cenozoic ages, depths and environments of Shubenacadie H-100.

Agterberg, 1982). The preservation is quite good, although the assemblage is not as rich as the overlying ?Lower Eocene section. Spherical and ovoid radiolarians are present in small numbers. A few reworked Upper Cretaceous planktics also occur. The depositional setting during the Paleocene was in deep water.

The Paleocene to Middle Eocene sediments would appear to correspond to Hardy's (1974) Nashwauk Beds.

?Early Eocene (3340 - 3430 m)

The few planktic species that appear only in this interval in Shubenacadie H-100 are long-ranging forms known to extend up into the Middle Eocene. However, there are numerous spherical radiolarians, very similar to forms known only from the Lower Eocene and, in a few instances, the Paleocene, of some East Coast wells, notably in the Jeanne d'Arc Basin off Newfoundland (Thomas, 1995). These radiolarians are an open-water, pelagic indicator but, because of the unstable nature of their opaline silica tests, are usually only preserved when sedimentation rates are rapid, as in the fan sequence at this site. From 3340m down, the preservation of the microfossil suites also becomes much whiter and more chalky, though still generally good. This type of preservation is also seen in sediments of Early Eocene age in the Jeanne d'Arc Basin. The chalkiness of this material again suggests an upslope extension of one of Swift's (1987) "chalky fans".

Obviously, the depositional setting in this section of the well is similar in depth to the Paleocene sediments, probably with rapid clastic sedimentation.

Middle Eocene (3060-3310 m)

The Miocene/Middle Eocene unconformity is marked by an abrupt change at 3060-3070 m to a predominantly agglutinated benthic suite, with planktic forms including a few age-diagnostic taxa such as *Acarinina* cf. *densa*, *Morozovella spinulosa* and *Truncorotalites rohri* occurring only rarely. There are some caved Miocene planktics but most calcareous benthics and planktics are absent. Further down calcareous forms again predominate, and planktics become fairly common in most samples.

The environment of deposition was probably nearly as deep as in the Early Eocene. The levels where calcareous fossils are rare may indicate a shallowing of the CCD, possibly a response to some variation in the oceanic circulation patterns.

Miocene (2140-3030 m)

In general, the Miocene assemblage contains abundant planktic foraminifera, which often outnumber benthic forms by as much as 20:1. At certain intervals, absolute numbers of all specimens drop off to much lower values, and at 2460-2510 m, there is evidence of pyritization in the much-diminished foraminiferal suite. Below 2510 m preservation is again generally good and the assemblages are richer.

The styles of preservation of individual microfossils throughout the Miocene tend to vary substantially even within individual samples. Some specimens may be white and "fresh" in appearance, whereas others are stained buff or reddish to varying degrees, as in the Late Miocene section of Acadia K-62.

The environment of deposition is fairly deep, probably representing lower bathyal conditions (1000-2000 m water depth). This is confirmed by the predominance of planktic foraminifera and the nature of most of the benthic suite (van Morkhoven *et al.,* 1986). The lower 200 m of the Miocene contain occasional reworked Late Cretaceous benthic and planktic foraminifera, suggesting at least some clastic input in the form of downslope transport from an eroding upslope source, again similar to the Late Miocene of the Acadia site.

Lithostratigraphically, this section of the well would appear to be an offshore equivalent of Hardy's (1974) Esperanto Beds.

That the entire Oligocene and Upper Eocene appear to be missing is not unusual in East Coast wells; seismic records indicate many widespread unconformities in the Tertiary of the outer margin (Swift, 1987).

<u>Shubenacadie H-100: Implications for local seismic stratigraphy</u>

Wade (1987) and MacLean and Wade (1993), when defining the formation tops for Shubenacadie H-100, as based in part on seismic sections, identified a 'turbidite fan". Such fans are common in the Tertiary sediments of much of the Scotian Slope (Swift, 1987), but are usually local in nature, perhaps measuring a few kilometres or tens of kilometres in length or breadth. At Shubenacadie H-100, the top of this particular fan was at 3436 m and its base at 3784 m, overlying questionable Dawson Canyon Formation. According to Grant *et al.* (1986), this formation may include material of Cenomanian to Maastrichtian age.

Wade (1987) assumed that the turbidite fan was Tertiary, although the age was unknown.

However, the top of this sedimentary fan appears to coincide more or less with the top of the Paleocene (3460 m - this report). And, more significantly, it includes Maastrichtian and possible Campanian sediments. Thus, although the fan lies unconformably above the ?Dawson Canyon, (J. Wade, pers. comm., 2000), sedimentation may be more or less complete. Further biostratigraphic studies of this well may clarify this situation.

Another possible explanation for the preponderance of Late Cretaceous microfossils in the lower half of the fan is to ascribe them to reworking; ostensibly derived from some eroding upslope source, and assuming an actual Paleocene age for the interval. While possible, this scenario does not seem likely given the excellent condition of the specimens and the lack of indigenous Paleocene taxa in that part of the section. Furthermore, the paucity of benthic forms there strongly suggests *in situ* pelagic deposition.

Eagle D-21

The Cenozoic foraminiferal assemblages in Eagle D-21 show two distinct facies. The first is a deep-water, largely planktic assemblage extending from the Paleocene to the Early Miocene, where it grades into the second, a rich, benthic-dominated, neritic foraminiferal biotope that extends into the Early Pliocene (Figure 4). Sedimentation does not seem to have been continuous, however; minor hiati appear to exist between each series, and in some cases, within series.

Preservation of the foraminiferal suites in this well is generally quite good and the chalky appearance of lower Paleogene material seen in the other two wells is also evident.

Appendix III contains the faunal listing for each section of this well.

Early-Middle Paleocene (1444.8-1563.6 m; 4740-5130')

This section has no diagnostic planktic foraminifera, but contains several Paleocene benthic markers including *Rzehakina epigona*, one of Gradstein and Agterberg's (1982) Paleocene indicators.

Together the Eocene and Paleocene strata at Eagle D-21 correspond in age to Hardy's (1974) Nashwauk Beds.

Below 1563.6 m (5130'), samples contain rich Late Cretaceous assemblages dominated by planktic forms, with chalky preservation, and suggesting at least an outer neritic to upper bathyal environment (Hardy's, 1974 Maskonomet Beds).

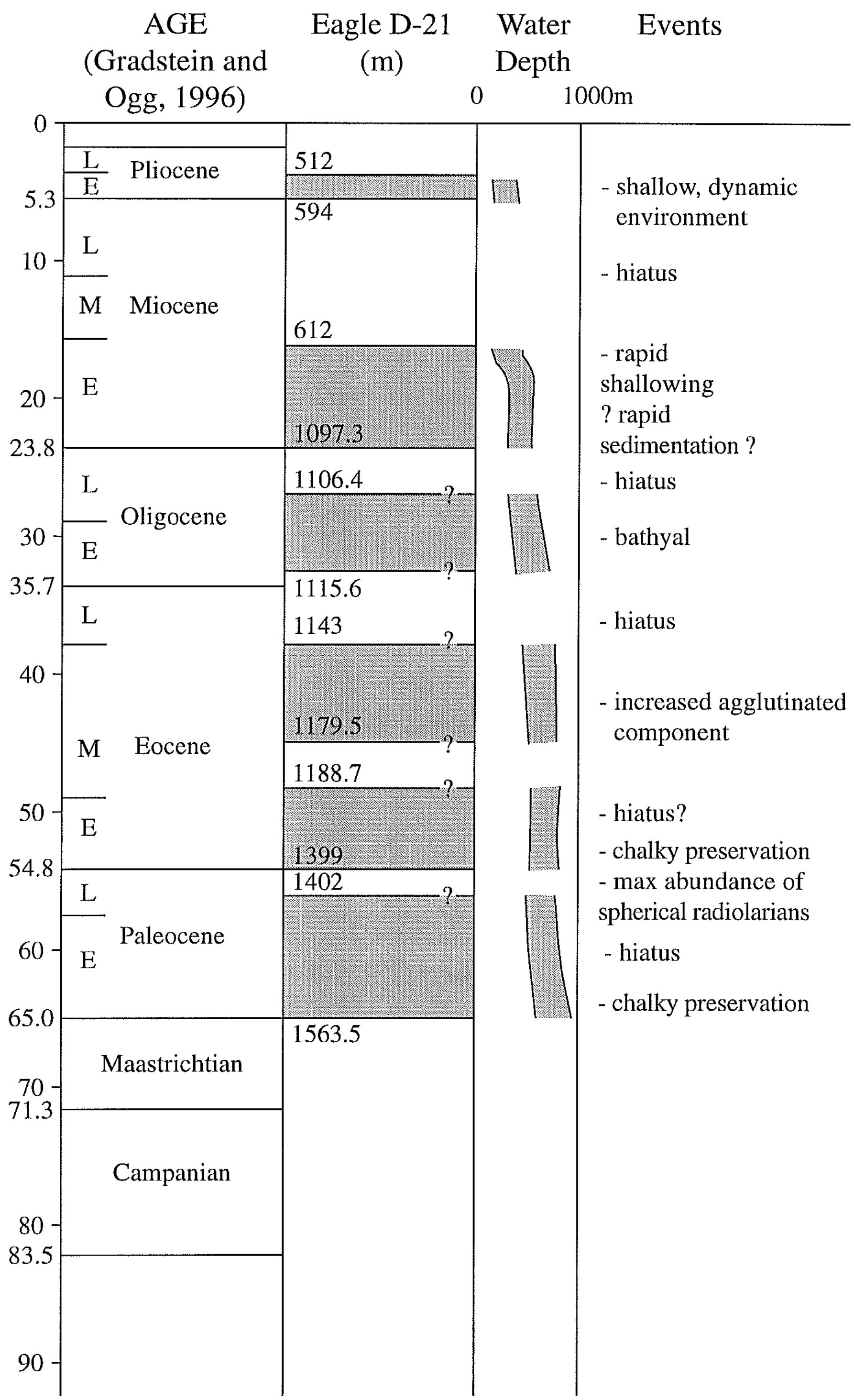

Figure 4. Cenozoic ages, depths and environments of Eagle D-21.

Middle Paleocene 1402.1-1426.5 m; 4600-4680')

This thin, rich interval contains two Middle Paleocene planktic markers and three age-diagnostic benthic ones (Gradstein and Agterberg, 1982; Tjalsma and Lohmann, 1983). Benthic forms make up about half of the total foraminiferal assemblage and spherical radiolarians are common.

earliest Eocene (1316.7-1399 m; 4320-4590')

This interval contains common diagnostic planktic foraminifera such as the Morozovellids and the agglutinated benthic *Spiroplectammina spectabilis,* an Early Eocene marker in offshore eastern Canada (Gradstein and Agterberg, 1982). Some other agglutinated forms are also present, comprising perhaps 40% of the benthic assemblage. At least some of the planktics may be caved. Spherical radiolarians are abundant in most samples.

The presence of the radiolarians suggests, as explained above, some enhancement of the rate of deposition.

late Early Eocene (1188.7-1310.6 m; 3900-4300')

This section is similar to the overlying upper Middle Eocene, with abundant planktic foraminifers. Agglutinated forms make up nearly half of the benthic foraminiferal suite, both in numbers and species. Small numbers of spherical radiolarians, as in the other two wells in this study, are also present. Many, though not all the microfossils, have chalky coatings.

The larger numbers of agglutinated species and specimens in the benthic component, compared to the underlying lying section, may be a function of changing bottom water conditions during the time of deposition, since water depths had probably not changed dramatically. Variations in bottom water characteristics may have also diminished the "chalkiness" of some of the fossil assemblage.

late Middle Eocene (1143-1179.5 m; 3750-3870')

In this interval, as below, planktic foraminifera make up some 90% of the microfossil assemblages, and readily allow age determinations. Bathyal conditions are indicated by the high planktic:benthic ratio in the Paleocene-Eocene.

Middle Oligocene (1106.4-1115.6 m; 3630-3660')

The single sample contains the planktic *Globorotalia opima opima,* a diagnostic middle Oligocene taxon. Otherwise the interval is similar to the lower part of the overlying Lower Miocene, with a bathyal environment.

Since this sample is Oligocene, it should be included in Hardy's (1974) Manhasset Beds.

Early Miocene (612-1097.3 m; 2008-3600')

The upper few samples have similar assemblages to the overlying Pliocene, except for a few diagnostic Early Miocene planktics. From about 760 m down the numerically rich and diverse assemblages diminish, so that at 945-975 m the few microfossils are mostly discoid radiolarians. Below this level benthic foraminifera are again more common, but the species indicate deeper, lower neritic to upper bathyal conditions.

In this section the foraminiferal assemblages show a shallowing trend upwards. The impoverished interval at 945-975 m may represent a sudden increase in deposition rates, inhibiting normal benthic productivity and allowing the preservation of the chemically, relatively unstable radiolarians.

This section and the overlying Pliocene sediments would represent Hardy's (1974) Esperanto Beds.

Early Pliocene (512-594 m; 1680-1950')

The Lower Pliocene section at the top of the sampled interval contains a rich benthic assemblage dominated by large lenticulinids, marginulinids and rectuvigerinids. A few other benthics are present, including a few agglutinated species. There are small numbers of planktics some of which are age-diagnostic, such as *Globoquadrina altispira* and *Globoquadrina dehiscens*. The preservation is generally good, although the larger forms usually show some abrasional damage.

A neritic environment is indicated for this interval. The abrasional damage on most of the larger benthics suggests some post-depositional transport in a hydrodynamically active setting.

SYNTHESIS

Correlation of the three wells (Figure 5) is difficult because of the distance of Eagle D-21 from the other two and the absence of seismic correlation. However, the micropaleontological

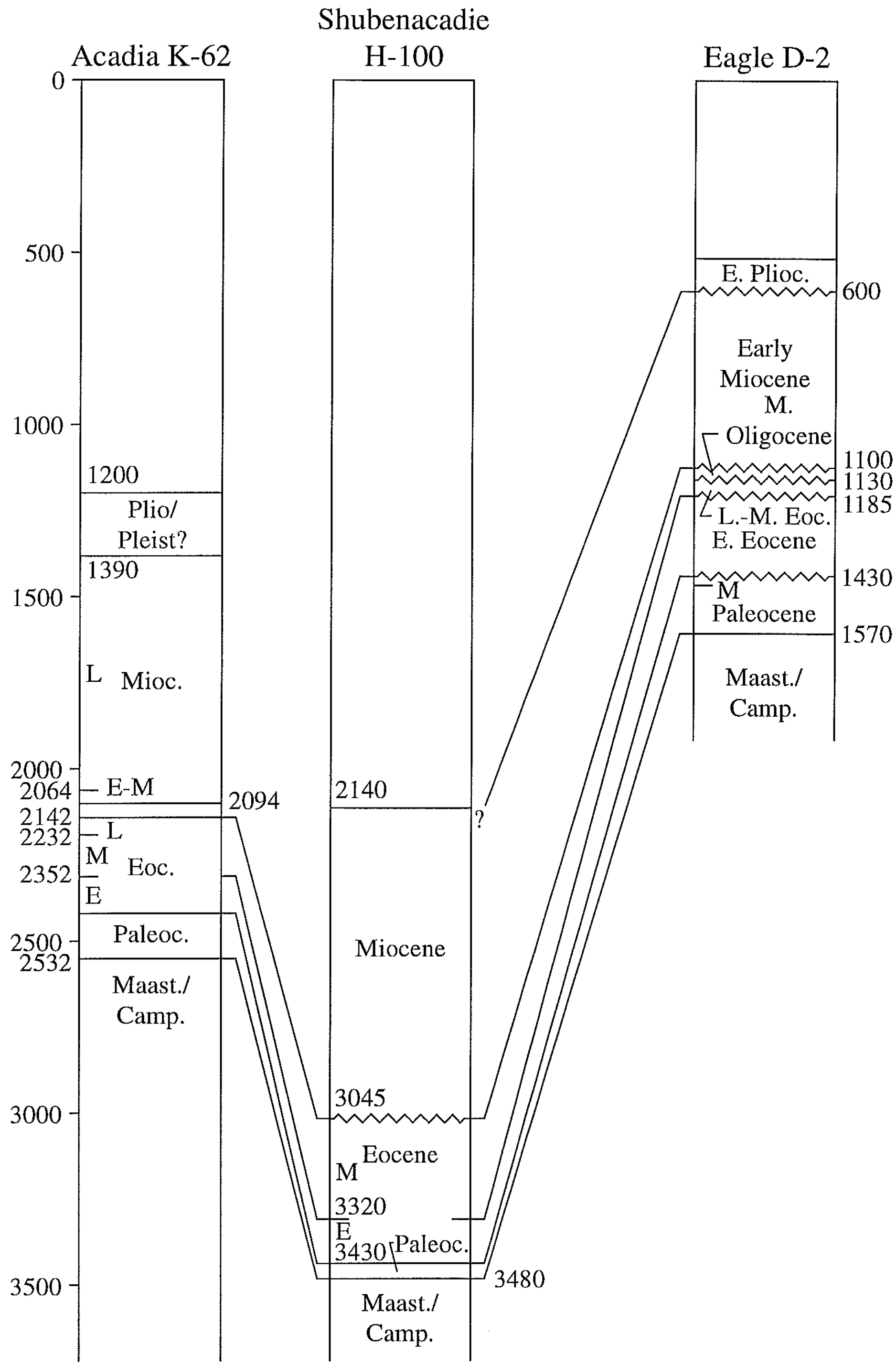

Figure 5. Cenozoic correlations of Acadia K-62, Shubenacadie H-100 and Eagle D-21.

Datum is rotary table height for each well.

analyses of these three wells provide useful information on the biostratigraphy and paleoenvironments of parts of the shelf edge and upper Scotian slope during much of the Cenozoic. This can be summarized as follows:

Paleocene - There was deep-water, pelagic sedimentation at all three locations. At Shubenacadie H-100 and possibly Acadia K-62, the two upper slope sites, some of this sedimentation was in the form of chalk-rich fan deposits. Such deposits are less common at Eagle D-21, which was further upslope. The samples from Acadia K-62 contain the richest Paleocene benthic and planktic foraminiferal assemblages in any of the three wells, suggesting highest local biological productivity. The spherical radiolarians found at all three sites probably make their first appearance in the Paleocene. At the shallower Eagle D-21 site, there is a Late Paleocene hiatus.

Early Eocene - This interval is marked by the maximum abundance of spherical radiolarians in all three sites. The chalky preservational style continued in all three sites and deposition was in a deep-water environment. The end of the Early Eocene in Eagle D-21 may be marked by a hiatus.

Middle Eocene - Benthic foraminiferal assemblages included more agglutinated species and numbers at Eagle D-21 and Shubenacadie H-100, though the early part of the Middle Eocene is missing at Eagle D-21. At Acadia K-62, agglutinated forms increased in number only slightly. For unknown reasons, the spherical radiolarians disappeared at all three sites. Water depth remained bathyal.

Late Eocene - Sediments of this age are probably present in Acadia K-62, but can not be clearly differentiated because of extensive caving. Upper Eocene sediments can not be identified in either of the other two wells.

Oligocene - The only unequivocally Oligocene sample, from Eagle D-21, was deposited in a bathyal environment. There may be an unrecognized section of this age at the Acadia site.

Miocene - At the upper slope Shubenacadie H-100 and Acadia K-62 sites, rich planktic assemblages with differing preservational styles and reworked older material suggest a dynamic, active environment with relatively high biological productivity, possibly related to upwelling. Though still bathyal, the sites was possibly subjected to sediment reworking by contour currents or other hydrodynamic phenomena. Some pyritization of microfossils occurred sporadically at the Shubenacadie H-100 location, presumably attributable to changing bottom water chemistry. This indicates instability of oceanic water stratification; possibly an intensification of upwelling occurred, with larger amounts of carbonate-poor bottom water brought to the Shubenacadie H-100 site. During the Early Miocene, the more nearshore Eagle D-21 site was characterized by rapid shoaling towards neritic conditions. Late Miocene erosion resulted in this time period being unrepresented in Eagle D-21. There appears to be a relatively thick Late Miocene section at Acadia K-62, presumably representing spillover sediments from the shelf edge; however, extensive caving of younger material hinders analysis.

Pliocene - The Eagle D-21 site is characterized by a neritic, dynamic environment, as water depths decreased substantially. Sediments of this age are probably present in Acadia K-62, although diagnostic species restricted to the Pliocene were not found. The environment of deposition in the Acadia K-62 section appears to be upper slope, with a reduced P:B ratio relative to older sections. This epoch was not encountered in Shubenacadie H-100, although sediments of this age may occur in higher, unsampled levels.

Pleistocene - Encountered only in Acadia K-62, but clearly identifiable by cold-water, modern planktics and typically high-latitude benthics indicating a shelf or upper slope environment.

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APPENDIX I

Biostratigraphic Sucession and Faunal Lists, Acadia K-62

Pleistocene (Pliocene?) 1200-1390 m

Planktic foraminifera
Globigerina bulloides
Globigerinoides sp.
Globorotalia crassaformis
Globorotalia inflata
Globorotalia truncatulinoides
Neogloboquadrina pachyderma
Orbulina universa
Sphaeroidinella dehiscens

Benthic foraminifera
Biloculina sp.
Bolivina earlandi
Bolivina cf. *quadrilata*
Bolivina subaenariensis
Bucella frigida
Bulimina costata
Bulimina exilis
Bulimina marginata
Cassidulina reniforme
Cibicides lobatulus
Cribroelphidium excavatum
Cribroelphidium groenlandicum
Dentalina advena
Eggerella bradyi
Eponides umbonatus
Globobulimina auriculata
Gyroidina sp.
Hoeglundina elegans
Islandiella teretis
Lenticulina sp.
Neoconorbina sp.
Nodosaria lamnulifera
Nodosaria sp.
Nonion barleeanum
Nonionellina labradoricum
Oolina sp.
Oridorsalis tenera
Parafrondicularia advena
Planulina wuellerstorffi
Protelphidium orbiculare
Pullenia bulloides
Sigmoilinopsis schlumbergeri
Stilostomella bradyi
Stilostomella sp.
Uvigerina peregrina
Uvigerina spinicostata
Uvigerina sp.

Other microfossils
Echinoid plates
Echinoid spines
Radiolarians (discoid)

Reworked taxa
1200 m *Heterohelix* sp. (Maastrichtian)
1230 m *Gavelinella* sp. (Late Cretaceous)
1230 m Gastropod fragments (stained, eroded, Tertiary)
1230 m *Marginulina* aff. *decorata* (Tertiary)
1260 m *Coscinodiscus* sp.2 (diatom, Tertiary)
1260 m *Globoquadrina* sp. (Miocene)
1260 m *Globorotalia scitula-praescitula* (Miocene)
1260 m Pyritized tubes (?Miocene)
1230 m *Uvigerina miozea-nuttalli* (Miocene)
1350 m *Globotruncana* sp. (Late Cretaceous)
1390 m *Catapsydrax parvulus* (Early Miocene)

Late Miocene 1410-2064 m

Planktic foraminifera
Globigerinoides spp.
Globorotalia plesiotumida
Neogoloboquadrina acostaensis

Benthic foraminifera
Asterigerina gurichi
Bulimina sp.
Cassidulina subglobosa
Cyclammina cf. *cancellata*
Eggerella bradyi
Fissurina marginata
Gyroidina sp.
Karreriella atlantica
Lagena sp.
Laticarinina pauperata (caved to 2490 m)
Lenticulina calcarata
Lenticulina iota
Lenticulina sp.
Martinotiella sp.
Nodosaria sp.

Oolina melo
Ophthalmidium sp.
Pulleniatina obliqueloculata
Pyrgo sp.
Pyrulina sp.
Quinqueloculina seminulum
Spiroplectammina sp.
Trochammina sp.

<u>Other microfossils</u>
Fish teeth, otoliths
Limacina sp. (pteropod)
Radiolarians (spherical and discoid)
Ostracode
Selachian denticles
Sponge spicules

<u>Reworked taxa</u>
1410 m *Globotruncana* sp. (Late Cretaceous)
1812 m *Globigerina umbilicata* (Eocene)
1812 m *Haplophragmoides* aff. *kirki* (Eocene)

Early and Middle Miocene 2082-2094 m

<u>Planktic foraminifera</u>
Globigerina praebulloides
Globigerinatella cf. *insueta*
Globorotalia praemenardi

Oligocene (?)

<u>Planktic foraminifera</u>
Catapsydrax aff. *dissimilis* (caved to 2202 m)

Middle/Late Eocene 2142-2214 m

<u>Planktic foraminifera</u>
Acarinina spinuloinflata-bulbrooki gr.
Globigerina eocaena
Globigerinatheka conglobata gr.
Globoquadrina venezuelana
Orbulinoides beckmanni
Turborotalia cerroazulensis pomeroli

<u>Benthic foraminifera</u>
Cibicides eocaena

Middle Eocene 2232-2334 m

<u>Planktic foraminifera</u>
Globigerina linaperta
Globigerinatheka mexicana gr.
Hantkenina alabamensis
Morozovella lehneri
Planorotalites pseudoscitula
Pseudohastigerina micra
Pseudohastigerina wilcoxensis
Truncorotalites rohri
Truncorotalites topilensis
Turborotalia cerooazulensis cerroazulensis

<u>Benthic foraminifera</u>
Ammodiscus latus
Bathysiphon aff. *eocaena*
Bulimina sp.
Bulimina trinitatensis
Cyclammina amplectens
Dorothia cf. *trochoides*
Epistomina eocaena
Glomospira charoides
Gyroidinoides aff. *quadratus*
Karreriella horrida
Karreriella subglabra
Lenticulina whitei
Marginulinopsis cf. *decorata*
Neoeponides lunata
Osangularia velascoensis
Plectina nuttalli
Pyramidina rudita
Saracenaria sp.
Stilostomella cf. *aculeata*
Tritaxia sp.
Uvigerina cf. *rippensis*

<u>Other microfossils</u>
Radiolarians (spherical - common)

Early Eocene 2352-2394 m

<u>Planktic foraminifera</u>
Acarinina pentacamerata
Acarinina cf. *primitiva*
Acarinina sp.
Morozovella caucasica
Turborotalia cerroazulensis frontosa

<u>Benthic foraminifera</u>
Anomalinoides rubiginosus
Aragonia semireticulata (caved to 2490 m)
Bulimina semicostata

Cibicidoides grimsdalei (caved to 2490 m)
Cibicidoides aff. *subspiratus*
Hyperammina sp.
Pyramidina sp.
Recurvoides sp.
Spiroplectammina navarroana
Stilostomella gracillima (caved to 2466 m)
Stilostomella cf. *subspinosa*
Vulvulina spinosa

Other taxa
Radiolarians (spherical, abundant)

Paleocene 2412-2508 m

Planktic foraminifera
Acarinina broedermanni
Acarinina mckannai
Globigerina eocaena
Globigerina linaperta
Globigerina sp.
Globigerinatheka sp.
Globoquadrina aff. *venezuelana* (caved)
Heterohelix sp. (reworked)
Morozovella acuta
Morozovella aequa
Morozovella aragonensis-caucasica gr.
Morozovella sp.
Planorotalites compressa
Pseudohastigerina micra

Benthic foraminifera
Alabamina sp.
Ammodiscus planatus
Anomalina spissiformis
Anomalinoides acuta
Bulimina bradbury
Bulimina tuxpamensis
Cibicidoides sp.
Cibicidoides tuxpamensis
Cibicidoides cf. *ungerianus*
Cyclammina latidorsata
Cyclammina sp.
Gavelinella beccariiformis
Gaudryina laevigata
Gaudryina pyramidata
Karreriella sp.
Lenticulina cf. *whitei*
Nonion sp.
Recurvoides sp.
Reophax sp.
Reticulophragmium sp.
Rzehakina epigona
Spiroplectammina spectabilis
Stilostomella sp.
Tritaxia paleocenica
Trochamminoides sp.
Uvigerina sp.

Other microfossils
Ostracodes (rare)
Radiolarians (spherical, discoid, spindle-shaped; common)

Reworked taxa
2490 m *Globotrunca* spp. (Late Cretaceous)
2490 m *Heterohelix* spp. (Late Cretaceous)

Maastrichtian/Campanian 2532 m

Gavelinella sp.
Globotruncana spp.
Heterohelix spp.

APPENDIX II

Biostratigraphic Succession and Faunal Lists, Shubenacadie H-100

Miocene (undifferentiated) 2140- 3030 m

<u>Planktic foraminifera</u>
Catapsydrax aff. *dissimilis*
Dentoglobigerina aff. *altispira*
Globigerina bulloides
Globigerina cf. *decorapta*
Globigerina praebulloides
Globigerina sacculifer
Globigerina spp.
Globigerinoides triloba
Globorotalia cf. *cibaoensis*
Globorotalia crassaformis
Globorotalia inflata
Globorotalia aff. *limbata*
Globorotalia scitula-praescitula gr.
Globorotalia siakensis
Neogloboquadrina aff. *acostaensis*
Neogloboquadrina continuosa
Orbulina sp.
Orbulina cf. *suturalis*
Sphaeroidinellopsis aff. *seminulum*

<u>Benthic foraminifera</u>
Anomalina cf. *globulosa*
Anomalina sp.
Bulimina cf. *aculeata*
Bulimina cf. *alsatica*
Bulimina marginata
Bulimina mexicana
Bulimina sp.
Cassidulina sp.
Cassidulina subglobosa
Cibicides sp.
Cibicidoides cf. *incrassatus*
Cibicidoides robertsonianus
Clavulina sp.
Coarse agglutinated spp.
Cyclammina cancellata
Dentalina sp.
Elphidium cf. *advena*
Elphidium spp.
Ehrenbergina spp.
Eponides sp.
Fissurina marginata
Glomospira sp.
Gyroidina aff. *girardana*
Gyroidina spp.
Gyroidina soldanii
Haplophragmoides sp.
Hoeglundina elegans
Karreriella bradyi
Laticarinina pauperata
Lenticulina aff. *americana*
Lenticulina angulata
Lenticulina spp.
Marginulina sp.
Martinotiella communis
Miliolinella aff. *subrotunda*
Nonion barleeanum
Planulina aff. *renzi*
Planulina sp.
Planulina wuellerstorfi
Plectofrondicularia spp.
Pullenia bulloides
Pyrgo lucernula
Pyrgo aff. *murrhina*
Pyrgo sp.
Quinqueloculina aff. *seminulum*
Rectoglandulina rotundata
Rectoglandulina cf. *torrida*
Rotalia sp.
Saccammina sp.
Sigmoilinopsis schlumbergeri
Stilostomella sp.
Triloculina trihedra
Uvigerina miozea-nuttalli
Uvigerina peregrina
Uvigerina spp.
Vulvulina sp.

<u>Other microfossils</u>
Coscinodiscus sp.3 (Diatom)
Echinoid spines
Fish otoliths
Fish teeth
Ostracodes
Pyritized tubes
Radiolarians

Reworked taxa
2740 m ?Turrilina alsatica (Oligocene) - bad specimen, ID questionable
2860 m *Marginotruncana* sp. (Turonian-Santonian)
2980 m *Morozovella* sp. (Eocene)
3020 m *Heterohelix* sp. (Campanian-Maastrichtian)

Middle Eocene 3060-3310 m

Planktic foraminifera
Acarinina cf. *densa*
Globigerina eocaena
Morozovella spinulosa
Morozovella spp.
Subbotina frontosa
Truncorotalites rohri
Turborotalia cf.*cerroazulensis cocoaensis-cunialensis* (caved?)

Benthic foraminifera
Ammodiscus latus
Ammodiscus planus
Anomalina cf. *acuta*
Bathysiphon sp.
Bulimina impendens
Bulimina pupoides
Bulimina cf. *semicostata*
Cibicidoides cf. *grimsdalei*
Cyclammina amplectens
Cyclammina latidorsata
Cyclammina rotundidorsata
Cyclammina sp.
Cystammina pauciloculata
Epistomina eocaena
Gaudryina pyramidata
Glomospira corona
Guttulina sp.
Haplophragmoides kirki
Hyperammina sp.
Lenticulina whitei
Melonis pompiloides (fat)
Nuttalinella florealis
Planulina cf. *costata*
Pullenia quinqueloba
Spiroplectammina cf. *navarroana*
Spiroplectammina sp.
Stilostomella subspinosa
Uvigerina spinicostata

Other microfossils
Fish teeth

?Early Eocene 3340-3430 m

Planktic foraminifera
Acarinina pentacamerata
Acarinina primitiva
Morozovella cf. *acuta*
Morozovella caucasica-aragonensis gr.
Morozovella spp.

Benthic foraminifera
Bulimina tuxpamensis
Dorothia trochoides
Cibicidoides sp.
Gavelinella sp.
Karreriella horrida
Osangularia sp.
Planulina cf. *costata*

Other microfossils
Spherical radiolarians

Reworked taxa
3380 m *Heterohelix* sp. (Campanian-Maastrichtian)

Paleocene 3460-3470 m

Planktic foraminifera
Globoconusa daubjergensis
Morozovella trinidadensis
Planorotalites pseudomenardi
Planorotalites sp.

Benthic foraminifera
Glomospira corona
Nuttalites truempyi
Rzehakina epigona

Reworked taxa
Gavelinella sp. (Late Cretaceous)
Globotrunca spp. (Late Cretaceous)
Heterohelix sp. (Campanian-Maastrichtian)

Late Cretaceous-Campanian-Maastrichtian 3495-3830+ m

Globotruncanita cf. *conica*

Pseudotextularia elegans
Racemiguembelina fructosa
Rugoglobigerina rugosa

Various unidentified benthics, and *Inoceramus* (mollusc) fragments at 3820-3830 m.

APPENDIX III

Biostratigraphic Succession and Faunal Lists, Eagle D-21

Early Pliocene 1680-1950'

Planktic foraminifera
Globigerinoides ruber
Globoquadrina altispira
Globoquadrina dehiscens
Globorotalia hirsuta-praehirsuta
Globorotalia aff. *margaritae*

Benthic foraminifera
Astacolus sp.
Bolivina floridana
Bulimina sp.
Caucasina elongata
Cibicides sp.4
Florilus pizzarense
Guttulina sp.
Hormosina ovula
Lenticulina alatolimbata
Lenticulina calcarata
Lenticulina spp.
Marginulina bachei
Marginulina sp.
Martinotiella cylindrica
Nodosaria sp.
Pseudonodosaria sp.
Quinqueloculina cf. *seminulum*
Rectuvigerina transversa
Spiroplectammina sp.
Stilostomella cf. *aculeata*
Textularia agglutinans
Triloculina sp.
Uvigerina peregrina
Uvigerina proboscidea
Uvigerina spp.

Other taxa
Diatoms
Echinoid spines
Gastropods
Radiolarians

Early Miocene 2008-3600'

Planktic foraminifera
Catapsydrax sp.
Globigerinoides primordius-sicanus
Globigerinoides sp.
Globoquadrina dehiscens
Globigerina sp.
Globorotalia continuosa
Globorotalia mayeri-continuosa
Globorotalia sp.
Praeorbulina glomerosa

Benthic foraminifera
Ammodiscus sp.
Asterigerina gurichi
Bathysiphon discreta gr.
Bolivina sp.
Bulimina sp.
Cassidulinoides sp.7
Cibicidoides sp.
Cyclammina cancellata
Cyclammina sp.
Eponides umbonatus
Gaudryina sp.
Globulina sp.
Haplophragmoides sp.
Hormosina sp.
Kalamopsis sp.
Karreriella conversa
Karreriella sp.
Lenticulina iota
Nodosaria sp.1
Nodosaria sp.14
Nodosaria sp.20
Nodosaria spp.
Plectofrondicularia sp.
Polymorphina sp.
Pullenia sp.
Rectuvigerina cf. *banneri*
Reophax sp.
Robulus cf. *vortex*
Sigmomorphina sp.
Siphonina cf. *danvillensis*
Sphaeroidina bulloides
Spirillina sp.
Stilostomella sp.
Uvigerina aff. *canariensis*

Other taxa
Diatoms
Radiolarians
Scaphopod sp.

Middle Oligocene 3630-3660'

Planktic foraminifera
Globigerina ciperoensis anguliofficinalis (caved to 3930')
Globorotalia opima opima

Benthic foraminifera
Ceratobulimina contraria

late Middle Eocene 3750-3870'

Planktic foraminifera
Acarinina densa
Globigerina eocaena
Globigerina linaperta
Globigerina ouachitaensis
Globoquadrina venezuelana
Planorotalites sp.
Pseudohastigerina micra
Truncorotalites rohri
Turborotalia cerroazulensis cocoaensis
Turborotalia cerroazulensis pomeroli

Benthic foraminifera
Cibicidoides truncanus

late Early Eocene 3900-4300'

Planktic foraminifera
Acarinina pentacamerata
Acarinina soldadoensis
Globigerina senni
Globigerinatheka cf. *subconglobata*
Morozovella sp.
Morozovella wilcoxensis-intermedia
Pseudohastigerina wilcoxensis
Subbotina patagonica
Subbotina sp.

Benthic foraminifera
Bulimina cf. *tuxpamensis*
Cibicidoides sp.
Cibicidoides ungerianus
Globocassidulina subglobosa
Hanzawai sp.
Ophthalmidium sp.
Reticulophragmium sp.

Other taxa
Radiolarians

earliest Eocene 4300-4590'

Planktic foraminifera
Acarinina mckannai
Acarinina soldadoensis
Morozovella aequa
Morozovella subbotinae

Benthic foraminifera
Anomalinoides grosserugosa
Bathysiphon sp.
Bulimina sp.
Cibicidoides aff. *subspiratus*
Cibicidoides tuxpamensis
Gaudryina pyramidata
Gavelinella danica
Haplophragmoides spp.
Karreriella subglabra
Lenticulina spp.
Marginulina sp.
Matanzia sp.
Nuttalides truempyi
Reticulophragmium sp.
Spiroplectammina spectabilis
Vulvulina spinosa

Other taxa
Radiolarians

Middle Paleocene 4600-4680'

Planktic foraminifera
Globigerina triloculinoides
Planorotalites pseudomenardii

Benthic foraminifera
Bigenerina sp.
Coryphystoma cf. *midwayensis*
Gavelinella cf. *beccariformis*
Glomospira corona

Early/Middle Paleocene 4740-5130'

Benthic foraminifera
Ammodiscus sp.
Gaudryina sp.
Recurvoides sp.
Rzehakina epigona
Spirillina sp.
Spiroplectammina navarroana
Tritaxia aspera

Other taxa
Sponge spicules

Maastrichtian 5280'

Abundant Globotruncanids etc.