3.

TERTIARY SUBSURFACE CORRELATIONS USING PYRITIZED DIATOMS, OFFSHORE EASTERN CANADA

Project 740004

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Abstract

Ditch cutting samples from 16 offshore wells in Eastern Canada have been analyzed for the presence of pyritized diatoms. Four different species, all informally assigned to the genus **Coscinodiscus** *and designated* **C.** *spp. 1, 2, 3 and 4 are described and illustrated, with comparison to descriptions in European literature.*

Numerical peaks of diatoms occur in Labrador Shelf and Grand Banks well at various stratigraphic levels, and are composed largely of **C.** *spp. 1, 3 and 4. No abundance peaks are present in wells on the Scotian Shelf.*

Some conclusions regarding these peaks are as follows: On the Labrador Shelf **Coscinodiscus** *spp. 3 and 4 occur abundantly below the Middle Eocene while above this* **C.** *sp. 1 is generally the most common form. In the northern Grand Banks area two distinct frequency peaks occur at different stratigraphic levels. In the southern Grand Banks and Scotian Shelf areas, diatoms are much less common in Tertiary strata. The Late Paleocene-Early Eocene abundance peak of* **C.** *spp. 3 and 4 noted in Labrador Shelf and Grand Banks wells is also present in strata of similar age in various northern European localities. Peaks of diatom abundance occur in sediments from both bathyal and neritic environments.*

Introduction

Discoid diatoms are a common constituent of the Tertiary microfossil assemblages of many wells of offshore Eastern Canada, particularly on the Labrador Shelf and Grand Banks. These diatoms are, with few exceptions, completely pyritized and appear to represent the internal mold of the space between the two silicious frustules comprising the test of a whole specimen. This contrasts with the remains of discoid diatoms found in recent sediments which usually occur as single, disjointed frustules.

This paper describes these occurrences and defines their areal and temporal extent by comparing the diatom assemblages found in 16 wells located on the Labrador Shelf, the Grand Banks, and the Scotian Shelf. These wells are; Karlsefni H-13, Gudrid H-55, Indian Harbour M-52, Bonavista C-99, Cumberland B-55, Dominion O-23, Egrit N-46, Egret K-36, Heron H-73, Petrel A-62, Kittiwake P-11, Puffin B-90, Hermine E-94, Sable Island C-67, Sable Island E-48 and Triumph P-50 (Fig. 3.1).

The samples examined were taken from ditch cuttings; each sample representing a 10 m composite interval, and sample spacing being approximately 30 m.

The combined 10 m samples were disintegrated and washed through a standard 75 μ sieve; four picking trays of each sample residue were examined and all the shelly microfossils found were mounted in 60 hole slides. The slides represent to a reasonable extent the microfossil assemblages encountered in the composite samples.

Counts were made of the number of diatoms present in each slide and the geographic/stratigraphical distribution of the different types observed were compiled from these.

Correlation of the relative numerical peaks in each well conforms to a large extent to broad chronostratigraphical correlation based on foraminifera. Tentative interpretations are offered for the relative frequency fluctuations observed.

Regional Stratigraphy and Depositional Environments

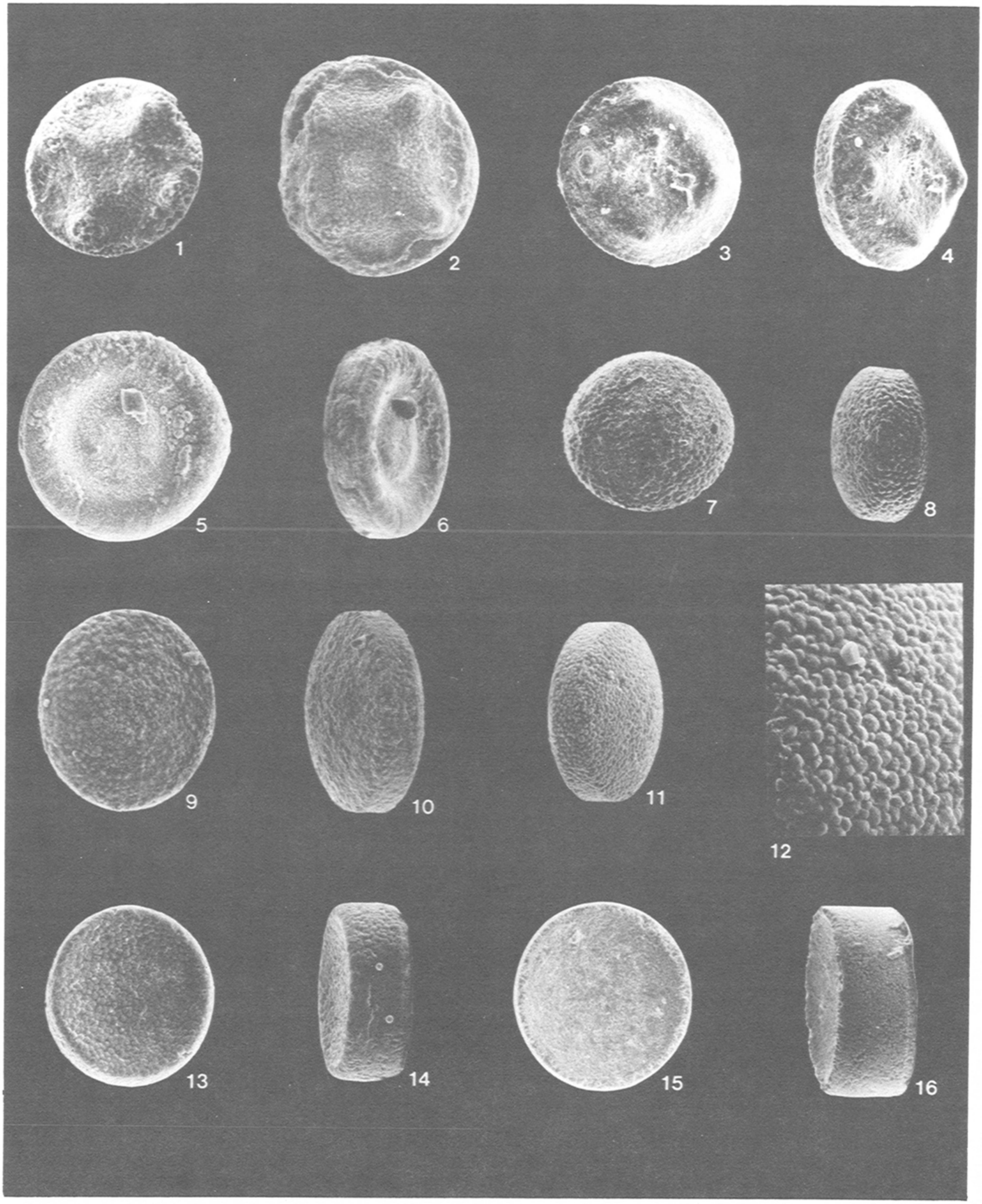
The Canadian Atlantic margin, commonly divided into the Scotian Shelf, Grand Banks and Labrador Shelf, spans the mid to high latitudinal realm (north of 42°). Cenozoic sediments in excess of 3000 m thickness were encountered in exploratory wells; foraminifera abound in the majority of Cenozoic drilling samples. These microfossils provide a 7 to 12 fold stratigraphic subdivision based on a latitudinally differentiated zonation which employs stratigraphic exits (tops) (Gradstein and Agterberg, in press).

Planktonic foraminifera are most useful in the southern Grand Banks and Scotian Shelf were 12 zones have been recognized based on species of standard zonations (Stainforth et al., 1975) which are common enough to be of practical value in correlation. Similarly, on the northern Grand Banks and Labrador Shelf a sevenfold subdivision of the Cenozoic sediments based on planktonics is possible. In this northern area the regional application of the planktonics zonation is limited due to the patchy distribution of taxa and their relatively rare occurrence, but the zonation improves chronostratigraphic calibration for the benthonic foraminifera zones.

The benthonic foraminiferal zonation is based on optimum sequences and optimum groupings methods discussed by Gradstein and Agterberg (in press). It provides a relatively conservative zonation based on all of the exits of benthonic (and planktonic) taxa that are potentially useful in correlation (including **Coscinodiscus** spp.). A total of 206 taxa were used.

Figure 3.2 summarizes the zonation for the Labrador Shelf and northern Grand Banks, and is a comparison of probabilistic and conventional zonations for the region. Chronostratigraphic nomenclature is at the series level and is followed in Figure 3.3.

Plate 3.1



Depositional environment interpretations as used in Figure 3.3 are grouped into three basic categories, according to water depth and distance from shore. They are:

1. Shallow neritic; which comprises marginal marine to inner shelf sediments laid down in water less than approximately 100 m deep.
2. Deep neritic; which comprises sediments laid down in water depth between approximately 100 and 200 m.
3. Bathyal (middle to upper slope); which comprises sediments laid down between 200 and 1000 m water depth.

The micropaleontological criteria (including foraminifera and palynomorphs) for these interpretations have been discussed by Jenkins et al. (1974), Gradstein and Williams (1976) and Gradstein and Srivastava (1980).

Taxonomic Information

Four species of diatoms can be readily distinguished in the well assemblages studied. Unfortunately, the high degree of pyritization of these forms precludes the possibility of exact identification; for the purposes of this study the generic name **Coscinodiscus** has been adopted to apply to these forms. Two of them appear to be conspecific with two species originally described by Staesche and Hiltermann (1940) and assigned to this genus.

The species described in this study are simply designated **Coscinodiscus** spp. 1, 2, 3 and 4.

Coscinodiscus sp. 1

Plate 3.1, fig. 1-4

Valve discoid, averaging 0.2 mm in diameter, flat to slightly convex on both sides. Four raised knobs are present on each side, located near the perimeter of the valve, one in each quadrant and equidistant from each other. A slightly raised ridge connects each knob to the next one, forming a square pattern with a depression in the central part of the valve. In some specimens, however, the ridge connects opposite knobs, creating a cruciform pattern.

This species ranges all through the Tertiary, but is more common in sediments of Late Eocene to Pliocene age. **Coscinodiscus** sp. 1 is a major constituent of diatom abundance peaks in the Miocene in some wells (e.g. Indian Harbour M-52).

Coscinodiscus sp. 2

Plate 3.1, fig. 5, 6

Valve discoid, rectangular in girdle view, and averaging 0.2 mm in diameter. A well defined, broad, raised rim is present along the perimeter of each valve and extends inward approximately half the length of the radius, creating a depressed area in the centre of the valve.

This is the least common of the four species encountered in this study, and occurs in very small numbers or as scattered individuals in most wells, in sediments of Early Eocene to Miocene age.

Coscinodiscus sp. 3

Plate 3.1, fig. 7-12

Valve discoid, slightly to strongly convex. In well preserved specimens the girdle is flat and well defined, but in more poorly preserved ones it is less distinct and somewhat rounded. In general this species corresponds very well with the descriptions and figures given by Staesche and Hiltermann, 1940 (who term it **? Coscinodiscus**, 1940, p. 14-15, pl. 6), Bettenstaedt et al. (1962, p. 357-358, pl. 52, fig. 18-19) and Jacqué and Thouvenin (1975, p. 461, pl. II fig. A-E) for the form they designate **Coscinodiscus** sp. 1.

This is the most common of the diatom species encountered. It occurs in relatively large numbers throughout the Tertiary interval in most wells, and is often the principal component species of the Early Eocene diatom abundance peak (e.g. Karlsefni H-13).

Coscinodiscus sp. 4

Plate 3.1, fig. 13-16

Valve discoid, flat to slightly concave on both sides. It averages 0.2 mm in diameter and often exhibits a thin raised rim around the perimeter. As in **C.** sp. 3, the girdle is flat and well defined in well preserved specimens, less so in others. This species appears to be very similar or identical to the form designated **? Coscinodiscus** by Staesche and Hiltermann (1940, p. 14-15, pl. 6) and that termed **Coscinodiscus** sp. 2 by Bettenstaedt et al. (1962, p. 358, pl. 52, fig. 20 a-b) and Jacqué and Thouvenin (1975, p. 461, pl. II fig. F).

After **C.** sp. 3 this is the second most common form, ranging throughout the Tertiary, though it is most common in the Early Eocene.

Diatom Stratigraphy

Labrador Sea

In Karlsefni H-13, (Fig. 3.3) the most northerly of the wells studied, **Coscinodiscus** sp. 3 appears first in Paleocene sediments, and only in small numbers. At the Paleocene Eocene boundary a diatom abundance peak is encountered with many **C.** sp. 3 and smaller numbers of **C.** sp. 4 and **C.** sp. 1 and very few **C.** sp. 2. The peak extends up into the Middle Eocene where the number of **C.** sp. 4 diminishes to zero. From late Eocene through Plio-Pleistocene only small numbers of diatoms are found, the majority of which are **C.** sp. 1 with very few **C.** sp. 3 and **C.** sp. 4 types present.

The Paleocene strata of Gudrid H-55 contain small numbers of all species of diatoms with **C.** sp. 3 predominat-

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Plate 3.1

Figures 1-16.

1. **Coscinodiscus** sp. 1 x 170 (from Dominion O-23, 1362-1399 m)
2. **Coscinodiscus** sp. 1 x 163 (from Dominion O-23, 1362-1399 m)

3,4. **Coscinodiscus** sp. 1 x 180 (from Bonavista C-99, 3356-3487 m, 2 views of the same specimen)

5,6. **Coscinodiscus** sp. 2 x 180 (from Dominion O-23, 1362-1399 m, 2 views of the same specimen)

7,8. **Coscinodiscus** sp. 3 x 140 (from Bonavista C-99, 3356-3487 m, 2 views of the same specimen showing characteristic biconvex form)

9,10. **Coscinodiscus** sp. 3 x 143 (from Dominion O-23, 1362-1399 m, 2 views of the same specimen, as in 7, 8)

11. **Coscinodiscus** sp. 3 x 184 (from Dominion O-23, 1362-1399 m)

12. **Coscinodiscus** sp. 3 x 644 (same specimen as no. 11, with higher magnification illustrating the pyritized nature of the test)

13,14. **Coscinodiscus** sp. 4 x 179 (from Dominion O-23, 1362-1399 m, 2 views of the same specimen revealing characteristic biconcave form)

15,16. **Coscinodiscus** sp. 4 x 123 (from Dominion O-23, 1362-1399 m, 2 views of the same specimen)

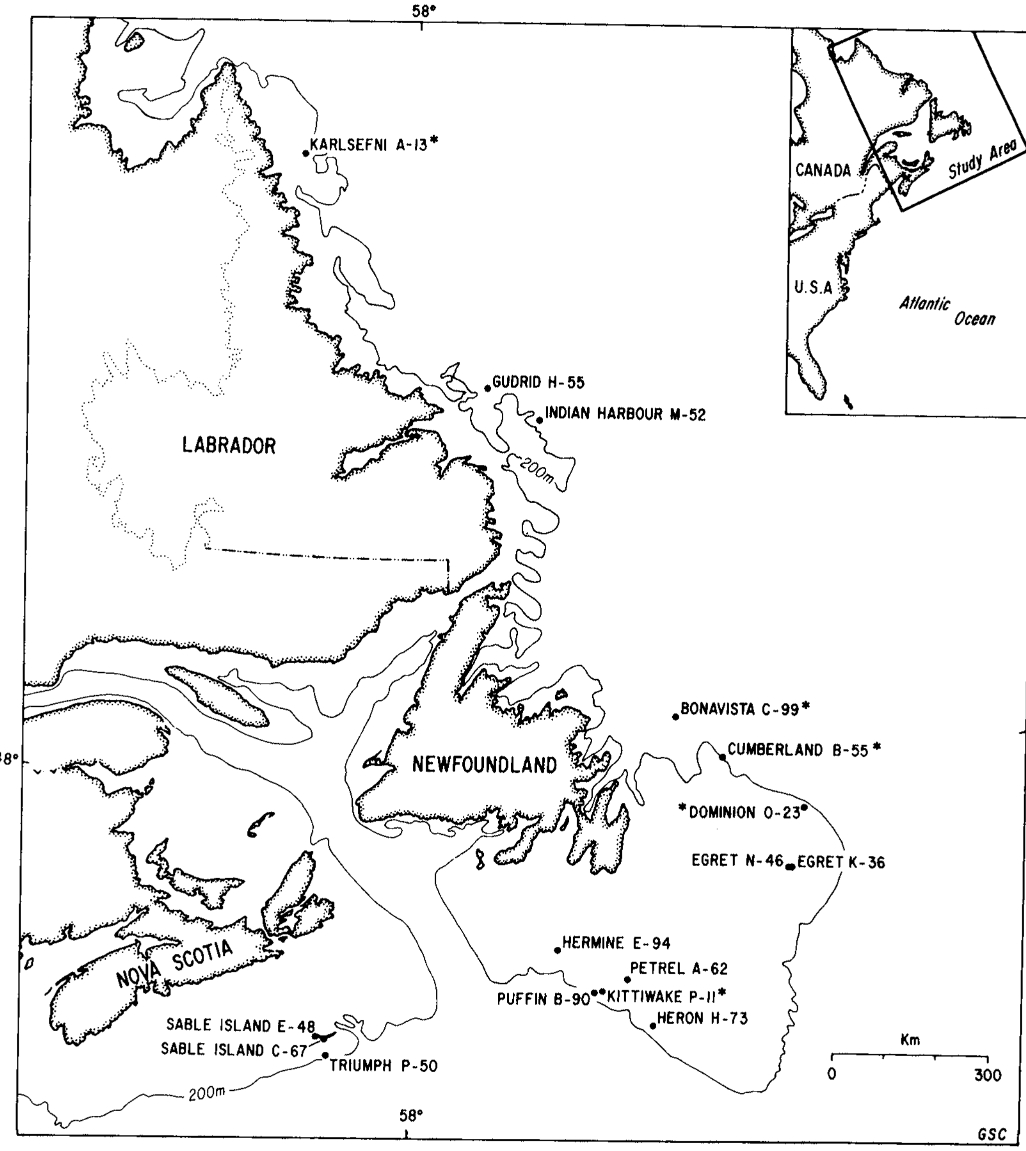


__Figure 3.1.__ Location map showing positions of wells studied. Wells marked with an asterisk (*) are illustrated in Figure 3.3.

ing. In the Early Eocene a peak occurs in which **C.** sp. 3 predominates. From Middle Eocene up to strata of uncertain age above the Miocene the number of diatoms present fluctuates; no peaks occur. From Early Oligocene onward **C.** sp. 1 predominates instead of **C.** sp. 3.

In Indian Harbour M-52 the sparse Paleocene diatom flora is again dominated by **C.** sp. 3 up to the Paleocene-Eocene boundary where a marked diatom abundance peak occurs. Here **C.** sp. 3 is supplemented by large numbers of **C.** sp. 2 and smaller numbers of **C.** sp. 1 and **C.** sp. 4. Diatoms (predominately **C.** sp. 1) are relatively common in the sediments of this well from the Middle Eocene through Middle Pliocene with a second peak occurring from the Upper Oligocene to the Middle Miocene. This peak, in contrast to the Late Paleocene-Early Eocene one, is composed almost exclusively of **C.** sp. 1. Above this peak, small numbers of **C.** sp. 4 dominate the diatom assemblages.

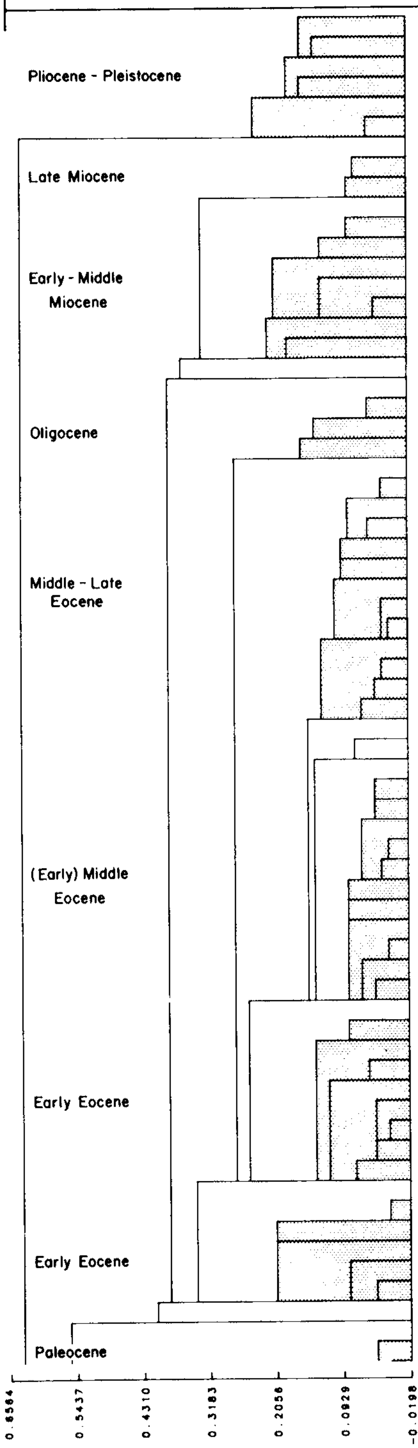
Northern Grand Banks

Only the upper portion of the Paleocene is present in Bonavista C-99 (Fig. 3.3) but this, and the Early Eocene section shows a very large diatom peak composed mostly of **C.** spp. 3 and 4. From a point just above this peak up to the Plio-Pleistocene diatoms are relatively scarce and no peaks are apparent.

In Cumberland B-55 a peak occurs at the Paleocene-Eocene boundary as in the Labrador Sea wells (Fig. 3.3). Similarly, this peak is also composed predominately of **C.** sp. 3, with the other types present in low numbers. **C.** spp. 1 and 3 occur commonly in the Middle Eocene up to the Late Oligocene where **C.** sp. 4 reappears and contributes to a minor peak in the Middle to Late Miocene section, which rapidly diminishes in Plio-Pleistocene sediments.

The lower boundary of the Tertiary in Dominion O-23 is at an unconformity which separates Lower Cretaceous from Lower Eocene strata (Fig. 3.3). Just above this unconformity, and possibly truncated by it, is a large abundance peak of almost exclusively **C.** sp. 3. The peak diminishes rapidly stratigraphically upward, leaving a small, mixed diatom fauna which continues up to the Late Eocene where a second large peak composed of **C.** spp. 3, 4 and 1 begins. This second peak extends up through the condensed Oligocene section and ends abruptly in Late Oligocene time. Diatoms occur commonly through the Miocene footage with **C.** sp. 3 remaining predominant.

OPTIMUM CLUSTERING OF CENOZOIC FORAMINIFERAL EXITS
(16 Wells; $k_c \geq 3 / m_c \geq 3$)



			GRADSTEIN (Unpublished; 9 Wells)								GRADSTEIN & WILLIAMS (1976; 4 Wells)							
			NEOGENE			PALEOGENE					NEOGENE				PALEOGENE			
			T1	T2	T3	T4	T5	T6	T7a	T7b	C. TERETIS	A. GURICHI	C. CONTRARIA	S. CARINATA	T. ALSATICA	PTEROPOD SP1	S. SPECTABILIS	G. CORONA
9	0.1645	FURSENKOINA GRACILIS																
11	0.1388	NONIONELLA PIZARRENSE																
77	0.1958	ELPHIDIUM SP •	●								X							
10	0.1627	UVIGERINA CANARIENSIS		X														
65	0.2507	COSCINODISCUS SP1		X									X					
228	0.0461	CASSIDULINA TERETIS •	●								X							
17	0.6924	ASTERIGERINA GURICHI		●								X						
22	0.0603	COSCINODISCUS SPP		X									X					
16	0.0813	CERATOBULIMINA CONTRARIA											X					
67	0.3474	SCAPHOPOD SP1		●														
18	0.0820	SPIROPLECTAMMINA CARINATA •		?	●									X				
14	0.1331	TEXTULARIA AGGLUTINANS																
71	0.2209	EPISTOMINA ELEGANS			X									X				
181	0.1242	CYCLOGYRA INVOLVENS		X									?					
21	0.0329	GUTTULINA PROBLEMA		?	●									X				
20	0.2321	GYROIDINA GIRARDANA •			●									X				
15	0.1968	GLOBIGERINA PRAEBULLOIDES •			●									X				
26	0.3877	UVIGERINA DUMBLEI				X												
70	0.4157	ALABAMINA WOLTERSTORFFI			X		?							X				
24	0.0375	TURRILINA ALSATICA •				●									X			
25	0.1457	COARSE ARENACEOUS SPP.				X												
27	0.1675	EPONIDES UMBONATUS			?													
69	0.2848	NODOSARIA SP8			X									X				
81	0.0157	GLOBIGERINA VENEZUELANA				X									?	X		
33	0.0835	TURBOROTALIA POMEROLI •					●									X		
82	0.0425	SUBBOTINA LINAPERTA •					●									X		
31	0.0957	PTEROPOD SP1 •					●		?							X		
29	0.0908	CYCLAMMINA AMPLECTENS •					●									X		
84	0.0988	SUBBOTINA YEGUAENSIS					●											
173	0.0159	ANOMALINA SP1																
85	0.0010	PSEUDOHASTIGERINA MICRA					●											
34	0.1274	MARGINULINA DECORATA				?	●									X		
40	0.0129	BULIMINA ALAZANENSIS					X											
118	0.0261	EPISTOMINA SP5						X									X	
75	0.0528	LENTICULINA ULATISENSIS															X	
41	0.1572	PLECTOFRONDICULARIA SP1					●	X										
74	0.0622	EPONIDES SP5					X										X	
42	0.1450	CIBICIDOIDES ALLENI					X										X	
30	0.0301	CIBICIDOIDES BLANPIEDI						X									X	
35	0.0234	SPIROPLECTAMMINA DENTATA					X											
32	0.0524	QUADRIMORPHINELLA INCAUTA																
36	0.0007	PSEUDOHASTIGERINA WILCOXENSIS						●										
86	0.0184	TURRILINA BREVISPIRA					X	X										
57	0.0735	SPIROPLECTAMMINA SPECTABILIS •						●									X	
90	0.0757	ACARININA DENSA •						●										
88	0.0735	SIPHOGENEROIDES ELEGANTA						X										
49	0.0100	OSANGULARIA EXPANSA																
190	0.0580	ANOMALINOIDES ACUTA					X									X		
53	0.0232	UVIGERINA BATJESI						X										
44	0.2613	CIBICIDOIDES AFF WESTI																
45	0.0791	BULIMINA TRIGONALIS					X											
63	0.1353	NODOSARIA SP11						X										
43	0.0438	BULIMINA MIDWAYENSIS							X									
50	0.1167	SUBBOTINA PATAGONICA •							●									
46	0.0333	MEGASPORE SP1 •							●									X
96	0.0031	ACARININA INTERMEDIA WILCOXENSIS							●									
93	0.0291	ACARININA AFF. BROEDERMANNI						X	●									
230	0.0666	BULIMINA OVATA							X									
176	0.3711	ALLOMORPHINA SP1						X										
54	0.0049	TEXTULARIA PLUMMERAE								X								X
52	0.2143	ACARININA SOLDADOENSIS																
164	0.2189	NUTTALIDES TRUMPYI																
62	0.0820	GAVELINELLA DANICA																
47	0.0333	PLANOROTALITES PLANOCONICUS •							●									
159	0.4381	MOROZOVELLA ARAGONENSIS							●									
56	0.5972	GLOMOSPIRA CORONA							X	X								X
59	0.0342	RZEHAKINA EPIGONA								X								
55		GAVELINELLA BECCARIIFORMIS •																

COMPARISON OF CONVENTIONAL AND PROBABILISTIC ZONATIONS

Figure 3.2. *Summary of zonation for Labrador Shelf to Grand Banks based on a comparison of probabilistic and conventional zonations for the region, based on optimum clustering of microfossil exits (from Gradstein and Agterberg, in press).*

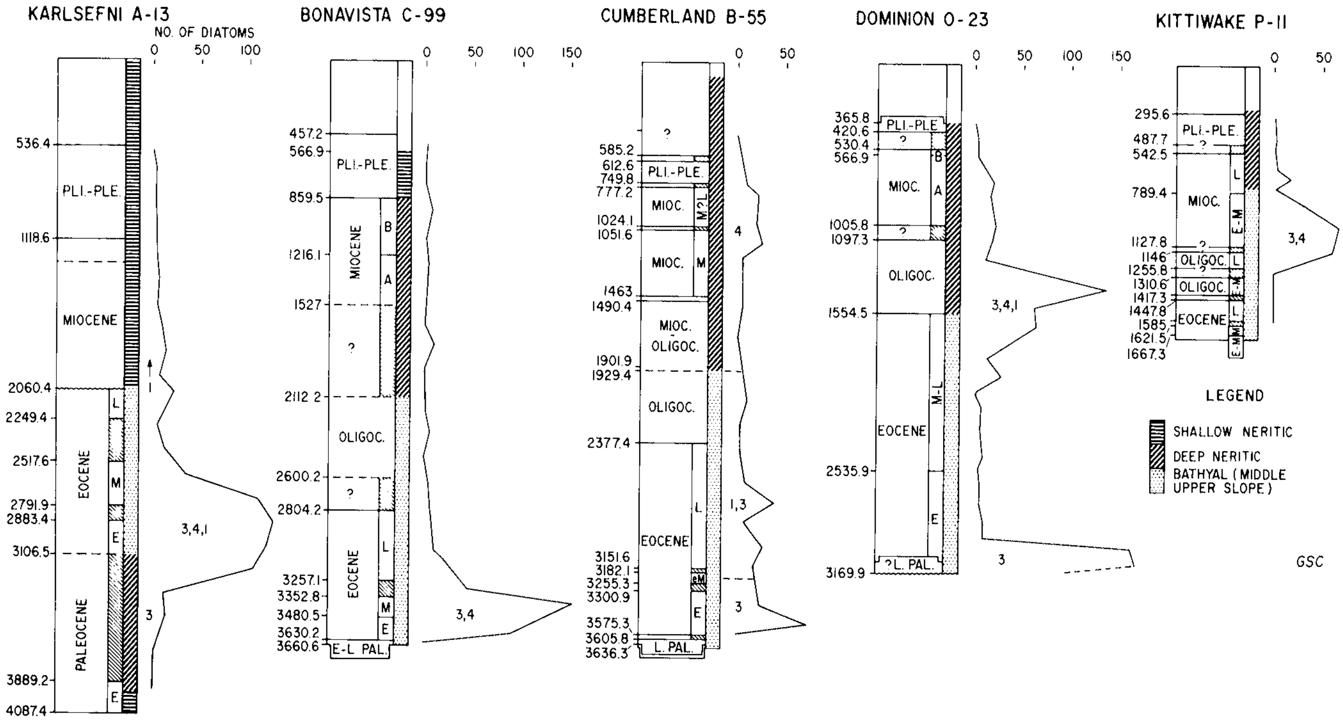


Figure 3.3. *Comparison of five wells from Labrador Shelf and Grand Banks showing stratigraphic locations of diatom abundance peaks. Paleoenvironmental information is also shown, Numbers (1, 2, 3 and 4) indicate dominant diatom species.*

In the very condensed Tertiary interval of Egret N-46 the number of diatoms present decreases sharply from a large peak in the Early Eocene down to a very low value in Early-Middle Miocene strata. Throughout this well **C.** sp. 3 out numbers **C.** sp. 1 by a factor of 3:1, with the other species all but absent.

Egret K-36, situated very close to N-46, exhibits a similarly condensed Tertiary interval. In this well however, diatoms are quite scarce throughout the sampled interval, indicating that the diatom-rich sediments were not penetrated, due to the presence of an unconformity separating Middle Eocene and Maastrichtian sediments.

Southern Grand Banks

In Heron H-73 a small number of diatoms of **C.** spp. 3 and 4 are present at the unconformity separating the Cretaceous from the Lower Eocene. Above this are only a few specimens of **C.** sp. 1, which continue up through the Tertiary.

The condensed Tertiary interval of Petrel A-62 contains only small numbers of pyritized diatoms, mostly **C.** sp. 1.

In Kittiwake P-11 (Fig. 3.3), few diatoms are present up to the Upper Oligocene level where a peak composed mostly of **C.** spp. 3 and 4 appears and continues up through strata of Early Miocene age. The peak disappears in the Middle Miocene where **C.** sp. 1 becomes more common. Above that, few diatoms exist in the well samples.

Puffin B-90, situated within 20 km of Kittiwake P-11 contains a somewhat thicker Tertiary interval but all species of diatoms remain scarce throughout the well and no peaks appear.

In the very condensed Tertiary interval of Hermine E-94 (520 m) diatoms are practically absent except for a small number of **C.** sp. 1 in the few samples believed to be of Early Oligocene age.

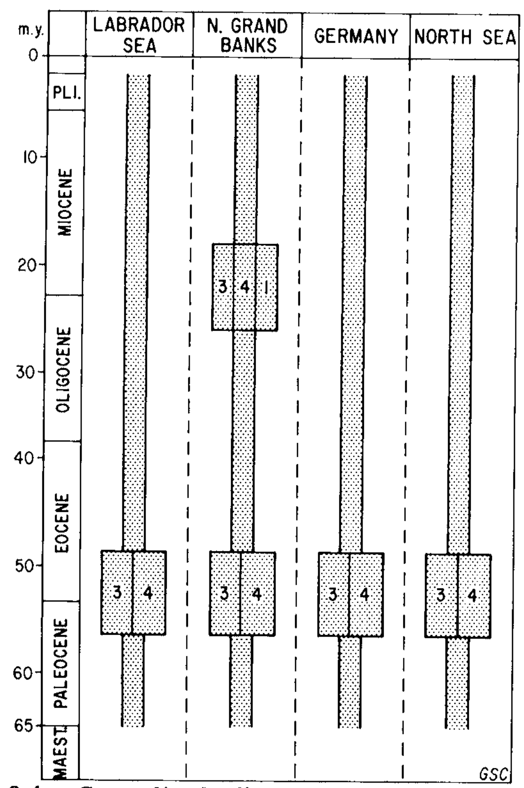


Figure 3.4. *Generalized diagram comparing the stratigraphic location and composition of diatom abundance peaks in offshore eastern Canada and European locations. The normal background count of diatoms is indicated by the narrow stippled bars. Peaks are shown as boxes containing numbers which indicate dominant diatom species present.*

The Late Paleocene-Early Eocene peak is present in regions, while the Late Oligocene-Early Miocene peak in Dominion O-23 (Northern Grand Banks) is restricted to that locality.

Scotian Shelf

The Tertiary intervals of the three Scotian Shelf wells studies are all condensed, ranging from 600 to 1500 m in thickness, and diatoms are rare in all three wells.

In Sable Island C-67 some specimens of **C.** sp. 1 are present in Lower Miocene strata and they constitute the entire diatom assemblage in the well.

Sable Island E-48 also contains very few diatoms, represented only by occasional specimens of **C.** spp. 1 and 3 in sediments of Paleocene to Oligocene age.

In Triumph P-50, the most southerly of the wells studied, a few specimens of **C.** sp. 3 occur in sediments of Early to Middle Eocene age. Above that, scattered individuals of **C.** sp. 1 are present up to the Middle Miocene, where all diatoms disappear.

Comparison With Diatom Distribution in Northwestern Germany and the North Sea

In a summary of occurrences of various microfossil groups in Germany, Bettenstaedt et al. (1962) citing Staesche and Hiltermann (1940) report our **Coscinodiscus** sp. 3 (which they designate **Coscinodiscus** sp. 1) as being frequently found in the lowermost Eocene of Germany, Denmark and Holland and occasionally found in Middle Eocene and Lower-Middle Miocene, though it is very rare in the Upper Eocene. This stratigraphic distribution is rather similar to that described in this report for the Labrador Sea wells (Fig. 3.4).

Coscinodiscus sp. 4, (which Bettenstaedt et al. designate as **C.** sp. 2) is found in northwestern Germany quite frequently in Middle and Lower Eocene but is rarer in lowermost Eocene, Paleocene and Middle Miocene. On the Canadian continental shelf this species is also most common in the Middle and Lower Eocene and occurs in small numbers throughout the Tertiary interval.

In a study of Lower Tertiary volcanic activity in the North Sea Jacqué et al. (1975) found **Coscinodiscus** spp. 3 and 4 to be abundant in tuffaceous sediments of Ypresian (Early Eocene) age. They attribute this frequency peak to the enrichment of seawater in silica and/or CaO caused by explosive volcanic eruptions. This interpretation does not, however, explain the presence of diatom peaks on the Canadian continental shelf where no evidence of volcanic activity is found in sediments of that age.

Environmental Parameters

Paleoenvironmental evidence from the wells studied for this report (Fig. 3.3), indicate that while no diatom peaks appear in sediments originating in very shallow water, they are found in strata deposited under neritic and bathyal conditions.

If as we reasonably expect, the peaks reflect diatom blooms, higher nutrient levels in the upper water mass level may be responsible. The Early Eocene and Miocene peaks broadly correspond to periods of maximum northward excursion of lower latitude surface waters (Gradstein and Srivastava, 1980) which may have led to improved surface water mixing and (slope) upwelling due to convergence. The pyritized nature of the molds of the original silicious diatom frustules indicates a weakly reducing or reducing diagenetic regime.

Conclusions

1. On the Labrador Shelf **Coscinodiscus** spp. 3 and 4 occur abundantly in Upper Paleocene - Lower Eocene sediments. Above this, **Coscinodiscus** sp. 1 becomes the most common form but no distinct frequency peaks occur, with the exception of one in the Late Oligocene - M. Miocene time in Indian Harbour M-52.
2. In the northern Grand Banks area this Late Paleocene - Early Eocene frequency peak of **Coscinodiscus** spp. 3 and 4 is also present; a second peak occurs in Miocene - Oligocene sediments in Cumberland B-55 and Dominion O-23, two of the wells most distant from the present landmass.
3. In the southern Grand Banks and Scotian Shelf areas, diatoms are much less common in Tertiary strata and only one abundance peak occurs (in the Oligocene-Miocene of Kittiwake P-11).
4. Broadly defined, the temporal distributions of **Coscinodiscus** spp. 3 and 4 generally concur with those given by Staesche and Hiltermann (1940), Bettenstaedt et al. (1962) and Jacqué et al. (1975) for northwest Europe and the North Sea. In these areas the two species are abundant in Lower Eocene sediments and occur less frequently in some strata of both older and younger age.
5. Diatom peaks occur in sediments from both bathyal and neritic environments.

References

Bettenstaedt, F., Fahrion, H., Hiltermann, H., and Wick, W.
1962: Tertiar Norddeutschlands in Leitfossilien der Micropalaontologie, Gebrüder Borntraeger, Berlin, 2 vol., 431 p.

Jacqué, M. and Thouvenin, J.
1975: Lower Tertiary Tuffs and Volcanic Activity in the North Sea. In Petroleum and the Continental Shelf of North-west Europe, ed. A.W. Woodland; J. Wiley and Sons, New York, I, p. 455-465.

Jenkins, W.A.M., Ascoli, P., Gradstein, F.M., Jansa, L.F., and Williams, G.L.
1974: Stratigraphy of the Amoco IOE A-1 Puffin B-90 well, Grand Banks of Newfoundland; Geological Survey of Canada, Paper 74-61; p. 1-9.

Gradstein, F.M. and Agterberg, F.
Models of Cenozoic Foraminiferal Stratigraphy - Northwest Atlantic Margin. Proceedings of the 26th International Geological Congress Paris, July 7-17, 1980. (in press)

Gradstein, F.M. and Williams, G.L.
1976: Biostratigraphy of the Labrador Shelf, Part I. Geological Survey of Canada Open File Report 349, p. 1-39.

Gradstein, F.M. and Srivastava, S.P.
1980: Aspects of Cenozoic stratigraphy and paleoceanography of the Labrador Sea and Baffin Bay; Paleogeography, Paleoclimatology, Paleoecology, v. 30 (1980), p. 261-295.

Staesche, K. and Hiltermann, H.
1940: Mikrofaunen aus dem Tertiar Nordwestdeutschlands; Abhandlungen der Reichsstelle fur Bodenforschung Neue Folge, Heft 201; 26 p., 53 pl.

Stainforth, R.M., Lamb, J.L., Luterbacher, H., Beard, J.H., and Jeffords, R.H.
1975: Cenozoic planktonic foraminiferal zonation and characteristics of index forms; University of Kansas Paleontology Contributions Article 62, 425 p.