

Paleoecology of Late Eocene-Oligocene foraminiferal assemblages in a two-well transect across the North-East Newfoundland shelf

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ABSTRACT Core samples from the Paleogene of the Bonavista C-99 well on the northeast Newfoundland shelf and cuttings from downdip Blue H-28 contain foraminiferal assemblages which enable reconstruction of paleoenvironments along a downslope transect in Eocene through Late Oligocene-Miocene time. Comparison with coeval assemblages in North Sea wells with respect to structure and grain size of agglutinated taxa between the two areas reveal inter-basin differences.

Reconstruction of the paleobathymetry derived from foraminiferal analysis, confirms seismic evidence for shallowing at the Bonavista site beginning in the Early Oligocene. The relationship of the Bonavista assemblages to contour currents is explored with reference to modern regional analogues. Species such as *Reticulophragmium amplexens*, *Haplophragmoides walteri*, *Eponides umbonatus* and *Uvigerina* ex. gr. *miozea-nuttalli* persist stratigraphically higher in the deeper Blue site.

The paleoslope of this two-well transect is determined as approximately 0.48° during the Middle to Late Eocene and 0.68° during the Late Oligocene-Early Miocene. The bottom water hydrography of the transect can be evaluated by reference to these assemblages and a comparison to flysch-type agglutinated assemblages from a transect in the North Sea. The presence of an Upper Eocene-Middle Miocene hiatus at the Blue site contrasting with apparently continuous Tertiary deposition at Bonavista places a theoretical upper limit of 500-1000 m on the depth of the early Cenozoic western boundary undercurrent.

INTRODUCTION

The purpose of this study is to examine Paleogene benthic foraminiferal assemblages from a two-well transect on the Canadian Atlantic Margin in order to compare up- and downslope coeval faunas, and in turn to compare these to Paleogene assemblages from a well transect in the North Sea.

BP Columbia Bonavista C-99 is a new-field wildcat well situated approximately 175 km NNE of St. John's, Newfoundland, on Canada's east coast.

Originally drilled in 1974, it was re-entered in 1975 and drilled to a total depth of 3778.9 m. Texaco Shell et al. Blue H-28, also a new-field wildcat, was drilled in 1979 at a site approximately 125 km NE and depositionally downdip from Bonavista C-99. Both wells lie along multichannel seismic line 84-3 Lithoprobe East (Fig.1). Technical data on both wells are listed in Table 1.

Foraminiferal faunas from ditch cuttings in these wells have been the subject of several investigations (Gradstein, 1975; Gradstein & Agterberg, 1982, among others); but Bonavista C-99 is unusual among Canadian offshore wells in that 3 conventional cores were drilled in Paleogene levels, at 1776.0 to 1782.8, 2592.0 to 2600.9 and 3257.2 to 3266.2 m. Since all regional Tertiary micropaleontological zonations for the Newfoundland Shelf have so far been based largely on ditch cuttings, the Bonavista cores provide a unique and important opportunity to examine *in situ* foraminiferal assemblages. Furthermore, their relatively undisturbed nature allows more detailed comparisons with synchronous material from other localities, such as the Blue H-28 well and localities in the North Sea (Jones, 1988). Also, foraminiferal faunas in core material may be examined in relation

Location	Bonavista C-99	Blue H-28
	49 08' 05.98"N 51 14' 24.47"W	49 37' 26.53"N 49 18'00.36"W
Rotary Table	13.0m	15.0m
Water Depth	329.2m	1486.0m
Total Depth	3778.9m	6103.0m
Casing Points	762mm @ 408.7m 508mm @ 691.3m 340mm @ 1217.1 244mm @ 2488.4m 178mm @ 3656.1	762mm @ 1605.4m 508mm @ 2055.9m 340mm @ 2975.0m 244.5mm @ 4420.2m
Sampling interval (cuttings)	9.1m samples 18.3m intervals	10m samples 20m intervals
Conventional core #1	1776.0m-1782.8m (Rec. 6.7m)	none
Conventional Core #2	2 2592.0m-2600.9m (Rec. 8.2m)	
Conventional Core #3	3 3257.2m-3266.2m (Rec. 8.9m)	
Conventional Core #4	4 3769.2m-3778.9m (Rec. 0.8m)	

Table 1. Technical data on PB Columbia Bonavista C-99 and Texaco Shell et al. Blue H-28.

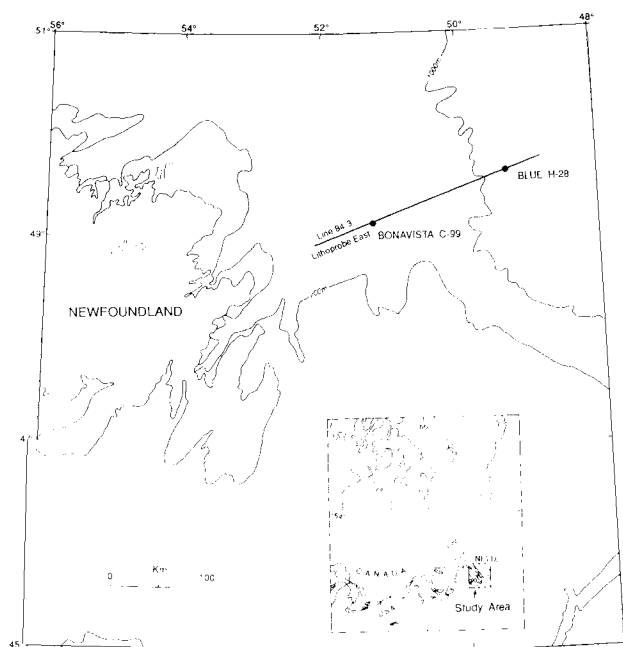


Fig 1 Location map of Bonavista C-99 and Blue H-28.

to more detailed lithology analysis than is possible with ditch cuttings.

The Paleogene foraminiferal suites observed in the Bonavista cores exhibit relatively little intra-sample variation in the fossil suites seen in each core, but marked differences in the foraminiferal content between cores.

These differences include calcareous vs. agglutinated ratios, absolute abundances and numbers of planktonic taxa present.

Deep-water agglutinated assemblages have been intensively studied in recent years (e.g. Miller *et al.*, 1982; Schroder, 1986; Jones, 1988,) and demonstrated to be useful for paleoecology and biostratigraphy. In particular, agglutinated assemblages similar to those found in Bonavista C-99 have been termed "flysch-type" by Gradstein & Berggren (1981) owing to their resemblance to classical agglutinated faunas first described from the Carpathian Flysch (Grzybowski, 1898).

This study examines the Bonavista C-99 assemblages recovered from the core material with reference to the recent literature in an attempt to place them in a paleoecological framework. Also, a comparison of the Bonavista foraminiferal samples is made with coeval downslope assemblages recovered from cuttings from the Blue H-28 well, yielding clues to paleoenvironmental relationships of coeval downslope faunas.

METHODS

The three cored intervals from the Bonavista C-99 well were lithologically described in detail and 12 samples measuring roughly 100 g each were taken, usually from less silty beds at irregular intervals. Samples were disaggregated and washed through a 63- μ m sieve using the "Industrial Soap" method

described by Thomas & Murney (1985). This process yielded residues ranging from 10-75 g. Samples were then oven dried and examined and splits were made to facilitate the counting procedure. Each split was then sieved using a 125-micron screen to remove most of the silt, and counts of foraminifera were made on the >125-micron fraction.

20 ditch cuttings samples were examined from the interval 3830-4440 m of Blue H-28. The samples were prepared in much the same manner as the Bonavista core material. The cuttings samples, however, are composite, representing 10 m intervals separated by 20 m gaps.

Exact counts of species abundances were not made on the Blue material because of the unquantitative nature of cuttings. Despite this, generalized relative abundances of species and planktonic:benthic ratios should be accurate for gross comparisons with the Bonavista core material. All Bonavista and Blue samples used in this survey are listed in Table 2.

Biostratigraphic ages were determined by comparison, where possible, of the planktonic foraminiferal content with regional standard planktonic zonations such as that proposed by Gradstein and Srivastava (1980). Also employed was the quantitatively-derived (probabilistic) benthonic interval zonation erected by Gradstein and Kaminski (in prep.); benthic species were identified by comparison with the reference collections of these authors.

Picked slides containing the agglutinated components of five of the six samples used in Jones's (1988) North Sea transect study were also examined, along with count sheets for all six slides. For further information on this material, the reader is referred to Jones (1988).

The paleoslopes reconstructed and discussed below were derived by the use of a scale drawing. Chronostratigraphic columns representing the two wells were drawn, with key horizons such as the tops of series and unconformities shown. The two columns were drawn exactly 12.5 cm apart. Since the two wells are actually 125 km apart, the horizontal scale is 1:1,000,000. The vertical scale used (1 cm = 200 m) was 1:20,000, resulting in a vertical exaggeration of 50 x. Lines were drawn between the two wells connecting corresponding points such as present water depth or the tops of the Middle Eocene, and the dips of these lines were measured with a protractor. These apparent angles were then divided by a factor of 50 to represent the vertical exaggeration. The resulting values then represent an approximation of the paleoslopes, uncorrected for compaction. Since burial depth below the seafloor for both wells is comparable, as are gross lithologies, correction for compaction is not necessary.

RESULTS

Core descriptions - Bonavista C-99

Core 1 - 1776.0-1782.8 m. The topmost two metres is composed of hard brown finely laminated silty limestone containing a few concretions of hard gray limestone with fine calcitic veins, and a few small vugs. The rest of the core consists of soft, friable brown silty calcareous mudstone, with occasional small lumps of gray limestone.

Core 2 - 2592.0-2600.9 m. This core is composed almost entirely of finely interbedded light brown fine sandy siltstone and dark gray muddy siltstone. A few individual layers are up to a few centimetres thick, but most are much thinner.

	Bonavista C-99 (conventional core) m	Blue H-28 (cuttings) m
Core 1	1779.7	3830-3840
	1780.6	3860-3870
		3890-3900
Core 2	2592.2	3920-3930
	2594.8	3950-3960
	2595.4	3980-3990
	2597.5	4010-4020
	2599.2	4040-4050
	2600.0	4070-4080
Core 3		4100-4110
	3257.7	4130-4140
	3259.8	4160-4170
	3260.8	4190-4200
	3265.2	4220-4230
		4250-4260
		4280-4290
		4310-4320
		4340-4350
		4370-4380
	4400-4410	

Table 2. List of samples from Bonavista C-99 and Blue H-28

Core 3 - 3257.2-3266.2 m. This core consists entirely of uniformly dark gray indurated silty shale with fine laminations. According to the well history report (BP Exploration Canada, 1975) there is some dispersed dolomite present.

Cuttings descriptions - Blue H-28

The lithology of samples from the Paleogene of Blue H-28 were uniformly silty claystone, grading to silty shale in lower levels (Texaco Canada Resources Ltd., 1980).

Foraminiferal assemblages - Bonavista C-99

A total of 59 benthic and planktonic taxa including biogenic artifacts such as pyritized tubes and spheres were observed in the three cores.

Core 1 - The foraminiferal assemblage in the two samples from this core consists largely of agglutinated taxa, dominated by the tubular form *Rhabdammina discreta*. Other agglutinants include *Ammodiscus latus*, *Haplophragmoides kirki* and *Cyclammina* spp. Most of the agglutinated forms seen in this core are of medium to large size, often fairly coarse grained, and are white in colour. Calcareous forms such as *Quinqueloculina robusta*, *Cibicidoides* cf. *C. eocaenus*, *Buliminella elegantissima*, *Lenticulina* spp. and *Nodosaria* spp. are present in small numbers. Pyritized tubes, presumably representing small, infilled burrows, were roughly as common as *R. discreta*. There are no identifiable planktonic foraminifera. The samples are assigned to the *Uvigerina* ex gr. *miozea-nuttali* Zone (LateOligocene-Early Miocene) on the basis of comparison to cuttings samples from the same interval previously studied by Gradstein, (1975) and Gradstein & Agterberg (1982).

Core 2 - The six samples from this core contain a mixed assemblage of numerous calcareous and agglutinated benthics and some planktonics. Common agglutinated species are *Rhizammina* sp., *Rhabdammina discreta* gr. and *Ammosphaeroidina* sp. Present in smaller numbers are *Ammodiscus latus*, *Reophax* sp., *Haplophragmoides excavatum*, *Recurvoides* sp. and *Cyclammina cancellata*, among others. Most specimens of these taxa are medium to coarse-grained, small and medium in size, and brown in colour. A diverse calcareous benthic component includes several *Nodosaria* and *Dentalina* forms such as *Nodosaria* cf. *N. elegantissima* and *Dentalina* cf. *D. jacksonensis*. Also present in small numbers are *Turrilina robertsi*, *Bulimina midwayensis*, *Brizalina* sp., *Globocassidulina globosa*, *Nonion affine*, *Pullenia eocaenica* and *Gyroidina octocamerata*, and very small numbers of several other species.

Planktonic foraminifera are fairly common, and include *Turborotalia pomeroli*, *Globigerina* aff. *G. tripartita*, *G.* aff. *G. eocaenica* and *G. venezuelana*, a suite indicating a position in the *Turborotalia pomeroli* interval Zone (Late Eocene; Gradstein & Kaminski, in prep.).

Pyritized tubes or pyrite in any form, is not seen in these samples. Most samples, however, contain common small spherical to ovoid calcareous balls of light orange colour (as are most calcareous foraminifera). Their exact origin is undetermined, but they appear to be of biogenic provenance (possibly calcispherules).

Core 3 - The four samples from this core yield a predominantly agglutinated assemblage, dominated by *Rhizammina* spp., *Haplophragmoides* sp. and *Saccamina* sp. These species are fine to medium in texture, mostly small with some medium in size, and brown in colour. Present in smaller numbers are *Glomospira charoides* gr., *Ammobaculites* sp., *Karrerella* aff. *K. pokorny*, *Budashevella trinitensis* and *Reticulophragmium amplexens*. Calcareous taxa are limited to a few *Nodosariids* and *Lagenids*, and no planktonics were identified. Pyritized tubes (as in Core 1) are the most abundant "taxon" in the core. Two samples also contain small pyritized spherical objects of unknown derivation. The presence of *R. amplexens* places this core in Gradstein & Kaminski (in prep.) interval zones of *Plectofrondicularia* aff. *paucicostata* - *Reticulophragmium amplexens*.

Foraminiferal assemblages - Blue H-28

These samples all contain a predominantly agglutinated foraminiferal assemblage which changes in appearance from 3830 m down to 4440 m. At 3830 m they tend to be relatively large, fairly coarse-grained in texture and nearly white in colour. Below this they change to darker, brownish colours, and generally become smaller, with much finer grain sizes, although some larger specimens persist in some intervals. Although this change is generally somewhat gradual, at about 4100 m there appears to be a slightly greater degree of change than in other levels.

Well-preserved planktonics represent usually less than 10% of the total specimens. Large *Bathysiphon* sp. and *Cyclammina* spp. are the most common agglutinated forms, together accounting for more than 30% of most samples. Various calcareous taxa are present in small numbers, with *nodosariids* easily dominant, especially *Dentalina* cf. *D. jacksonensis*. Pyritized tubes are virtually absent, although occasional fragments of pyritized microfossils such as small gastropods are present.

As stated earlier, no exact counts of species abundances were made on the Blue cuttings material, but generalized relative abundances of species and planktonic:benthonic ratios should be accurate enough for gross comparisons with the Bonavista core material. The presence of *Globoquadrina venezuelana*, *Globigerina linaperta*, *G. aff. eocaena*, *G. aff. angustum bilicata* and *Catapsydrax cf. dissimilis* place the Blue samples in the Late Eocene *Turborotalia pomeroli* Zone (3830-4340 m) and the Middle Eocene *Plectofrondicularia aff. paucicostata* - *Reticulophragmium ampletens* Zones (4340-4440 m).

PALEOENVIRONMENTAL INTERPRETATION

1. Paleobathymetry

The vertical succession of foraminiferal assemblages seen in the Bonavista cores and Blue cuttings reflect changing environmental conditions at the well sites through the Paleogene.

Bonavista C-99 Cores 3 and 2, representing earlier and later periods within the Late Eocene, are generally consistent in overall benthic content with faunas from a middle to upper bathyal environment, i.e. 200-1000 m water depth. Shallow water forms such as miliolids and lenticulinids are relatively rare, yet the large concentrations of planktonic forms characteristic of deep bathyal and abyssal conditions (Grunig & Herb, 1980) are missing. Interestingly, one of the numerically more common calcareous benthics in Core 2 is *Brizalina* sp. In a study of the Paleogene of the Mackenzie Delta and Beaufort Sea, McNeil (1983) describes the presence of this or a similar *Brizalina* in an intermediate biofacies between "nearshore" and "deeper-water" environments, all of which were otherwise devoid of calcareous foraminifera. The lack of planktonic species and paucity of calcareous benthonics in Core 3 may well be a result of either disaerobic bottom conditions or diagenesis, in view of the abundance of pyritized tubes and "balls" in the samples.

2. Bottom water hydrography

The primarily agglutinated foraminiferal facies seen in Cores 1 and 3 of Bonavista and throughout the Upper Eocene section of Blue can be viewed as "flysch-type" sensu Gradstein & Berggren (1981). More particularly, these would correspond to their "A" type fauna for Paleogene faunas containing fairly large, coarse-textured forms often dominated by tubular species or fragments. According to the model developed by these authors and supported by Miller *et al.* (1982), Toxwinius (1983) and Jones (1988) among others, flysch-type faunas developed in areas of deep water where organic-rich clastic sedimentation rates are high and bottom-water circulation is poor. These conditions can lead to a lowering of pH and eH values at the sediment-water interface, along with low oxygen and high carbon dioxide concentrations, thus reducing carbonate availability. A prevalence of flysch-type faunas in the Paleocene has been documented for the Labrador Sea, just north of the Bonavista-Blue transect (Miller *et al.*, 1982), and a major faunal turnover from primarily agglutinated to largely calcareous has been described for deep areas of the southern Labrador Sea (Kaminski *et al.*). While much of the Paleogene stratigraphic record has been lost in Blue due to the unconformity, the faunal changes in the Bonavista site during the Paleogene generally follow this pattern.

Bonavista's foraminiferal fauna goes from a primarily agglutinated assemblage with a few *Nodosariids* and no

planktonics in the Middle Eocene (Core 3) to a mixed, much richer calcareous and agglutinated fauna with a large planktonic component at a higher stage in the Upper Eocene (Core 2). In the Late Oligocene-Early Miocene interval represented by Core 1, the fauna is again mixed, although somewhat less rich than in Core 2, and contains some taxa indicative of shallower conditions.

In a study of Paleocene flysch-type assemblages from a transect in the North Sea, Jones (1988) noted differences in agglutinated foraminiferal grain size, preservation, and composition which were apparently related to paleodepth at the various sites. He found that assemblages from upper slope locales (200-500 m) were fine to medium-grained, white in colour and more or less medium-sized. Middle slope (500-1000 m) faunas tended to be coarse-grained, coloured brownish-green to gray and relatively large in size. Basin-floor (1000-1500 m) agglutinants were small-sized, fine-grained and a wide range of colours.

Disregarding the colour comparisons as probably dependent on variables of sediment source, composition and related diagenetic processes, data concerning test and grain size of agglutinated specimens in the Bonavista and Blue material can be directly correlated to Jones's (1988) study. Examination of several slides prepared from Jones's study material supported this comparison.

In the Middle Eocene of the Bonavista-Blue transect area, both sites contained faunas characterized by agglutinated species of small to medium test size and fine to medium texture, as are seen in Bonavista's Core 3 and cuttings from the 4100-4680 m interval in Blue (Table 3). These features would tend to argue a basin floor or at least lower slope environment for the transect.

In the Late Eocene (represented by Core 2 in Bonavista and the interval 3830-4100 m in Blue), the agglutinated components exhibit some dramatic differences. The fauna in Bonavista remains small to medium in size but becomes coarser in grain size, approaching Jones's criteria for middle slope assemblages, but in Blue the agglutinated component becomes quite large and decidedly coarse in texture, becoming more like Jones's middle slope faunas than the upslope Bonavista assemblage, which still retains some specimens of the relatively small size of a lower slope or "basin floor" association. It is not clear why this ambiguity should exist on this transect. Gross lithological examination indicates a range of grain sizes is available for test construction at both sites, so some other parameter(s) may be of importance here. The implication here is that local conditions may complicate interbasin comparison of gross appearances of agglutinated assemblages.

In Oligocene-Miocene time (missing in Blue), Core 1 contains a typical middle slope assemblage according to Jones's (1988) standards, with numbers of large, relatively coarse-grained agglutinates. Also, the relatively few calcareous benthonic species present appear to suggest more nearshore conditions. This agrees with the seismic evidence of shallowing at the Bonavista site in late Paleogene time due to prograding deltaic sedimentation (see below).

3. Taxonomic comparison of North Sea and Northeast Newfoundland Shelf agglutinants

In a further comparison of Jones's (1988) data with that of the present study, the superfamilial distribution of the agglutinated

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STAGE	ZONE	BONAVISTA C-99	BLUE H-28
E. Miocene	<i>Uvigerina</i> ex. gr. <i>miozea-nuttalli</i>	Core 1 white preservation aggluts. large, coarse-grained calcareous benthics rare pyritized tubes common no planktonics	
Oligocene	<i>Turrilina</i> <i>alsatica</i>		missing
L. Eocene	<i>Turborotalia</i> <i>pomeroyi</i>	Core 2 preservation browner aggluts. small-medium, medium-coarse grained calcareous benthics common no pyritized tubes planktonics common	3830-4100m white preservation aggluts. medium-large, coarse grained calcareous benthics rare no pyritized tubes planktonics common
M. Eocene	<i>Plectrofrondicularia</i> aff. <i>paucicostata</i> / <i>Reticulophragmium</i> <i>amplectens</i>	Core 3 brown preservation aggluts. small-medium, medium-fine grained calcareous benthics rare pyritized tubes common no planktonics	4100-4680m preservation browner aggluts. small-medium, medium-fine grained calcareous benthics common planktonics rare

Table 3 Comparison of gross characteristics of foraminiferal assemblages in Bonavista C-99 cores and Blue H-28 cuttings.

Region	North Sea (Jones, 1988)						NE Newfoundland Shelf				
	Upper Slope		Middle Slope		Lower Slope		Upper Slope	Middle/Lower Slope			
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Bonavista C-99			Blue H-28	
							Core 1	Core 2	Core 3	3830-4070	4070-4100
Ammodiscacea(%)	77	24	61	85	59	54	90	55	35	60	45
Lituolacea(%)	23	76	39	15	41	46	10	45	65	40	55

Table 4 Superfamily composition of agglutinated foraminiferal species in samples from North Sea well transect (Jones, 1988) vs. present study.

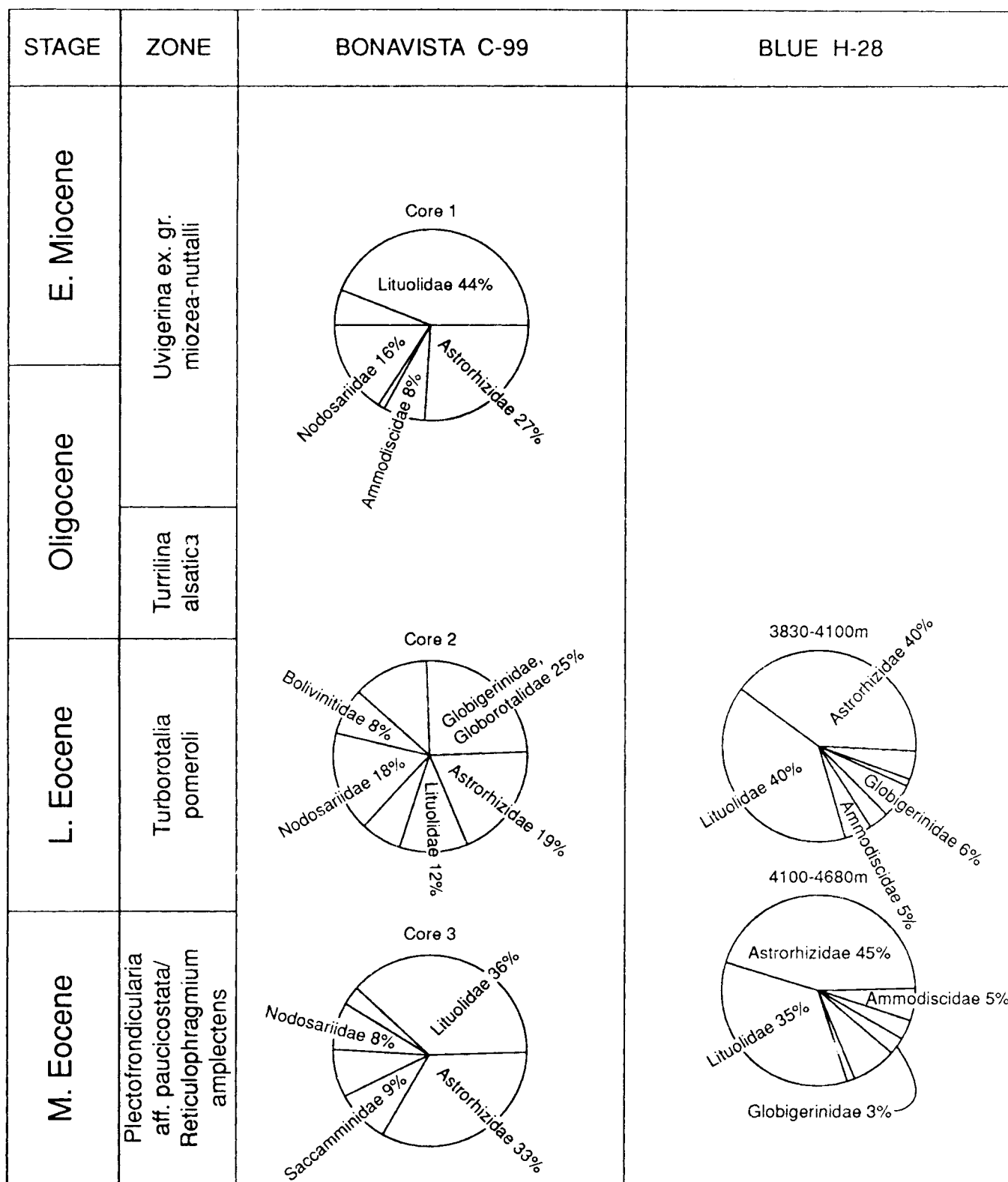


Fig 2 Pie diagrams of Bonavista C-99 and Blue H-28 assemblages showing proportions of major families.

taxa in both data sets were examined. Table 4 presents the breakdown of numbers of specimens of each of the two principal superfamilies Ammodiscacea and Lituolacea in the six North Sea site/samples, averaged values for the agglutinated components of the samples from the three Bonavista C-99 cores, and averaged values for the same fraction of the upper and lower half of the Blue H-28 section.

The relative abundances of the two superfamilies in samples of suggested similar depth ranges show some similarities but are not closely compatible. In Jones's two upper slope sites the relative percentages of the two groups differ widely, with Ammodiscaceans comprising 77% at most in the shallower site. In Bonavista's Core 1, also presumably an upper slope environment, Ammodiscaceans account for approximately 90% of the agglutinated component. In Jones's other sites, the percentage of Ammodiscaceans generally declines with increasing depth, with a concomitant increase in the Lituolacean fraction. The same trend is apparent in the two lower Bonavista cores, implying deeper conditions in Core 3, although the absolute numbers are somewhat different. Similarly, the upper half of the Blue section (3830-4070 m) shows a higher average value for percent Ammodiscaceans than does the lower half (4070-4440 m).

The differences in actual percentages between the North Sea and Northeast Newfoundland Shelf assemblages can easily be attributed to variances in bottom hydrological conditions as suggested by the substantially more common calcareous components in the latter region, compared to the nearly wholly agglutinated North Sea foraminifera.

If the entire foraminiferal assemblages are illustrated as pie diagrams (Fig.2), the changing nature of the assemblages through time is readily apparent.

Overall, the superfamily distributions seen in the Northeast Newfoundland Shelf assemblages tend to support a lower or middle slope environment for Bonavista Cores 2 and 3 and the Upper to Middle Eocene Blue section, and a possible upper slope regime for the Late Oligocene-Early Miocene Core 1 at the Bonavista site.

4. Relationship to contour currents

While direct comparisons of fossil assemblages to modern ones are not always simple, such studies often yield insights into paleoenvironments. In an examination of this problem, Scott *et al.* (1983), offer encouraging results, suggesting that there is good communality at the generic level, at least, between fossil Paleogene and modern slope agglutinated faunas. At the species level, however, this similarity tends to wane, in part because of differential preservation and other factors.

The primarily agglutinated assemblage seen in Core 3 may have modern analogues at the present sediment surface near the Bonavista site and on the modern lower Scotian Slope. In an ecological study of the northeast Newfoundland slope area, Schafer *et al.* (1983) described an association of agglutinated genera containing common *Ammobaculites*, *Glomospira*, *Karreriella*, *Reophax*, *Haplophragmoides* and *Saccamina*. Using numerical methods, they were able to correlate this assemblage with the coarser sediments, reduced temperature and slightly elevated oxygen concentrations of the Western Boundary Undercurrent (WBU) which impinges on the lower slope at a depth of approximately 2500 m or more. In a study of modern

benthic foraminiferal faunas on the lower Scotian Slope, Schroder (1986) found several agglutinated species which seemed to favour areas overlain by the WBU. Table 5 provides a comparison of the common agglutinated taxa from the three sample suites. While the content of these modern agglutinated assemblages are not identical to that seen in Core 3, there appears to be enough similarity to suggest some communality in bottom hydrologic conditions.

Although the WBU is a relatively recent phenomenon (Schnitker, 1979), contour currents in general are not, and many workers suggest major increases in bottom water circulation, with concomitant initiations of deep boundary currents in the Late Eocene to early Oligocene (Miller *et al.*, 1984). The presence of seismic reflector R4 at DSDP Site 112 (54 01'N, 46 36'W; southern Labrador Sea) may indicate the presence of an unconformity which could be the result of contour-current erosion at about this time just north of the Bonavista-Blue transect (Miller *et al.*, 1982). Also, the Late Eocene-Middle Miocene unconformity (discussed further below) in Blue may partly be a result of this increased circulation. Furthermore, since there appears to be no corresponding hiatus in upslope Bonavista, the inference is that the upper limit of this late Paleogene western boundary undercurrent lay between the coeval paleodepths of these two sites.

Core 1 is also nearly devoid of planktonic foraminifera, and contains abundant pyritized tubes. Several of its few calcareous species, however, indicate slightly shallower conditions, and the agglutinated forms include a relatively higher percentage of Lituolids, again implying reduced water depth. Seismic line 84-3 Lithoprobe East, passing through the Bonavista site reveals the progressive thickening of the sedimentary wedge during the Late

Genus	Schroder, 1986	W	Schafer et al., 1983	C
Bonavista C-99 Core 3				
<i>Ammobaculites</i>	11%	PP4	yes	H yes
<i>Bathysiphon</i>	11%	PP4		H yes
<i>Budashevella</i>	11%	PP4		H yes
<i>Cyclammina</i>	11%	PP4		H yes
<i>Glomospira</i>	11%	PP4	yes	H yes
<i>Haplophragmoides</i>	11%	PP4	yes	H yes
<i>Hormosina</i>	11%	PP4		H yes
<i>Hyperammina</i>	11%	yes PP4		H yes
<i>Karreriella</i>	11%	PP4	yes	H yes
<i>Recurvoides</i>	11%	PP4	yes	H yes
<i>Reophax</i>	11%	PP4	yes	
<i>Rhabdammina</i>	11%	yes		
<i>Rhizammina</i>	11%	PP4	yes	H yes
<i>Saccamina</i>	11%	PP4	yes	H yes
<i>Spiroplectammina</i>	11%	PP4	yes	
<i>Textularia</i>	11%	PP4		H yes
<i>Trochamminoides</i>	11%	PP4		H yes

Note: Schroder's samples also listed *Cribrostomoides*, and those from Schafer *et al.* also contained *Sigmoilopsis*, but those taxa only appeared in the Holocene and Miocene respectively (Loeblich and Tappan, 1988).

Table 5. Common agglutinated genera in modern Western Boundary Undercurrent environments on the Scotian Slope (Schroder, 1986), East Newfoundland Slope (Schafer *et al.*, 1983) and Bonavista C-99 Core 3

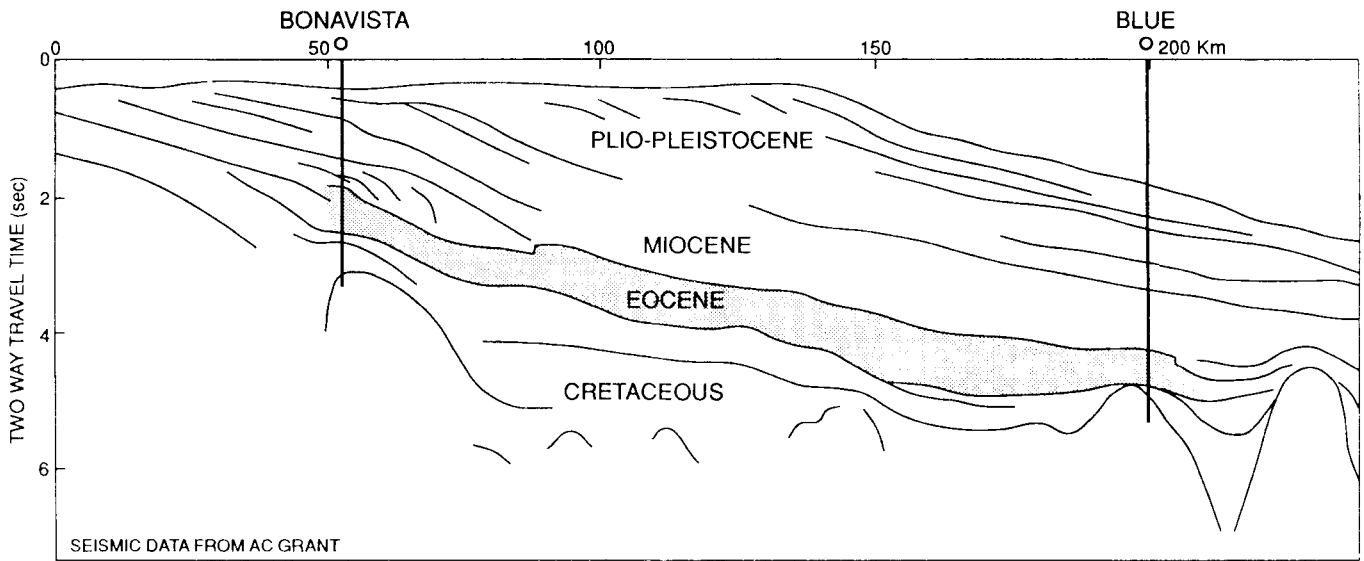


Fig 3 Seismic section of line 84-3 Lithoprobe East, 1984, AGC.

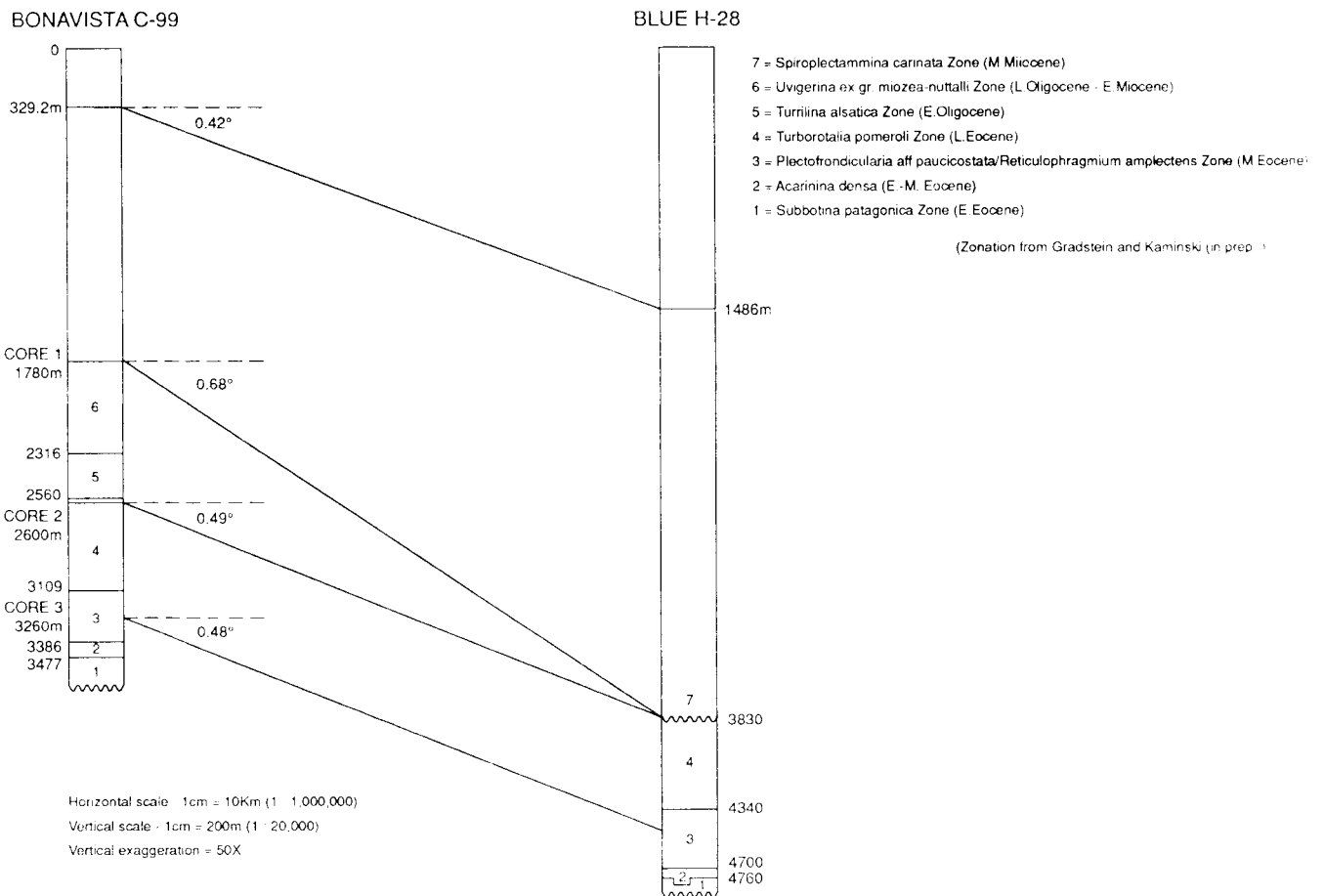


Fig 4 Paleoslopes of Bonavista - Blue transect.

Oligocene to Early Miocene time represented by Core 1, thereby reducing the water depth (Fig.3 and A.C. Grant "(ACG)", pers. comm., 1989).

The Late Eocene interval 3830-4340 m in the Blue well is fairly uniform in foraminiferal composition, although the upper 300 m or so are slightly richer in planktonics averaging about 6%, whereas below 4100 m the planktonic component drops to approximately 3%.

In general, the foraminiferal assemblage seen in Blue H-28 from 3830 m down to 4070 m closely resembles that of Bonavista's Core 1 in details of preservation. In both sites, agglutinated forms exhibit a white, sugary appearance and species common to both show very similar size ranges. Pressing the comparison, Bonavista's Core 1 assemblage closely matches that seen in this interval of Blue H-28, minus Blue's planktonics and most of its calcareous benthonics. One noticeable difference, however, is the nearly total absence in Blue of the pyritized tubes so common in Bonavista's Core 1, implying that whatever organism made the tubes at the Bonavista site was not present at the deeper Blue location.

5. Paleoslope reconstruction

Paleoslope reconstruction of the Bonavista Blue transect (Fig.4) shows a marked increase in slope from approximately 0.45° and 0.41° in the times represented by Cores 3 and 2 respectively to 0.64° at the time of deposition of the Core 1 sediments in the Late Oligocene-Early Miocene, based on the depth of the Miocene/Eocene hiatus in Blue.

This hiatus has effectively wiped out the foraminiferal record of paleoenvironments at the Blue site for this Late Eocene to Middle Miocene period (Fig.5), making direct comparison to the Bonavista site impossible. However, some hints remain of the differing depositional realms at the two localities. When the stratigraphic tops of the species common to both wells are

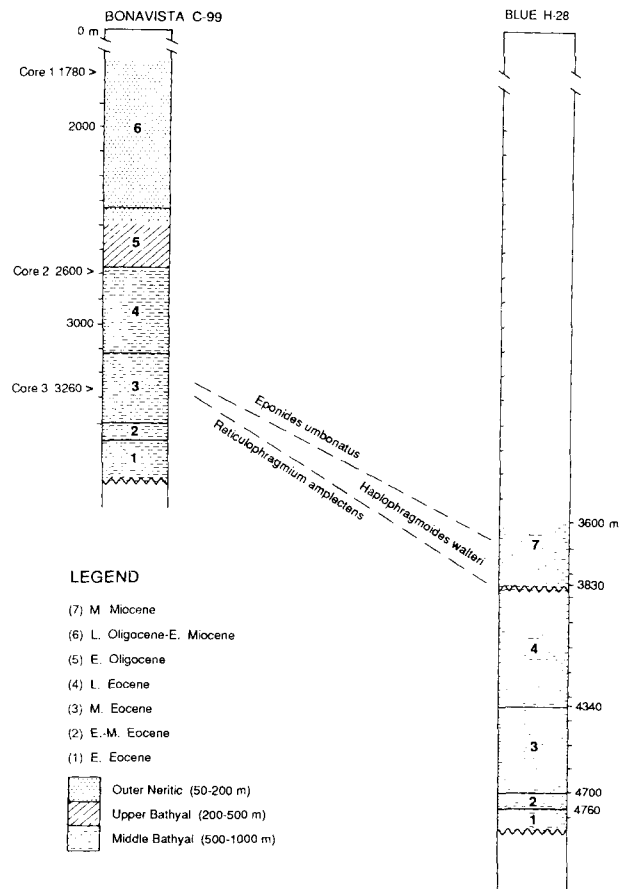


Fig 5 Correlation chart showing ages and environments of Bonavista and Blue

BONAVISTA C-99

1774		<i>Quttulina problema</i>
1776		Coarse agglutinated foram spp.
	L. Oligo-E. Miocene	<i>Cyroidina girardana</i>
2030		<i>Spiroplectamina carinata</i>
2249		<i>Dentoglobigerina tripartita</i>
		<i>Globigerina praebulloides</i>
2316		<i>Ammodiscus latus</i>
2377	E. Oligocene	<i>Turrilina alsatica</i>
		<i>Uvigerina ex.gr. miozea-nuttali</i>
2560		<i>Globobulimina venezuelana</i>
		<i>Turborotalia pomeroli</i>
2661		<i>Subbotina linaperta</i>
2865		<i>Planorotalites pseudoscutulus</i>
2987	L. Eocene	<i>Bulimina alazanensis</i>
3048		<i>Subbotina yeguensis</i>
		<i>Eponides umbonatus</i>
3078		<i>Reticulophragmium amplexens</i>
		<i>Haplophragmoides walteri</i>
3109		<i>Ammospheroidina pseudopauciloculata</i>
		<i>Ammarginulina aubertae</i>
3257		<i>Pseudohastigerina micra</i>
	M. Eocene	<i>Turrilina robertsi</i>
		<i>Bulimina aff. jacksonensis</i>
3325		<i>Karrerella conversa</i>
		<i>Plectofrondicularia aff. paucicostata</i>
3356		<i>Margulinina decorata</i>
3386		<i>Spiroplectamina spectabilis</i> 100
		<i>Cibicides alleni</i>
		<i>Acarinina densa</i>
3417		<i>Morozovella spinulosa</i>
3447	E.-M. Eocene	<i>Morozovella aragonensis</i>
		<i>Morozovella caucasica</i>
		<i>Acarinina aff. broedemanni</i>
		<i>Globigerapsis kugleri</i>
3478		<i>Glomospira corona</i>
		<i>Subbotina patagonica</i>
		<i>Cibicides bianpiedi</i>
3508	E. Eocene	<i>Planorotalites planoconicus</i>
		<i>Acarinina wilcoxensis</i>
		<i>Pseudohastigerina wilcoxensis</i>
3630		<i>Megaspora</i> sp. 1

BLUE H-28

3310		<i>Uvigerina ex.gr. miozea-nuttali</i>
		<i>Epistamina elegans</i>
	M. Miocene	<i>Globorotalia aff. kugleri</i>
		<i>Globigerina apertura</i>
		<i>Catapsydrax aff. dissimilis</i>
3640		<i>Eponides umbonatus</i>
		<i>Reticulophragmium amplexens</i>
3830		<i>Haplophragmoides walteri</i>
		<i>Globobulimina venezuelana</i>
		<i>Globigerina gortanii</i>
		<i>Subbotina linaperta</i>
	L. Eocene	<i>Globigerina praebulloides</i>
		<i>Epistamina</i> sp. 5
		<i>Tenuitella angustiumbilitata</i>
		<i>Subbotina eocena</i>
		<i>Subbotina yeguensis</i>
4070		<i>Ammospheroidina pseudopauciloculata</i>
		<i>Dentoglobigerina tripartita</i>
4340		<i>Uvigerina batjesi</i>
		<i>Spiroplectamina spectabilis</i> 10
		<i>Nuttalides truempyi</i>
		<i>Anomalinoidea acuta</i>
4490	M. Eocene	<i>Cibicides alleni</i>
		<i>Turrilina robertsi</i>
		<i>Bulimina bradburyi</i>
4635		<i>Turborotalia pomeroli</i>
4670		<i>Globigerapsis kugleri</i>
	E.-M. Eocene	<i>Spiroplectamina spectabilis</i> 100
		<i>Acarinina partacamerata</i>
4700		<i>Acarinina densa</i>
		<i>Acarinina soldadoensis</i>
4730		
4760	E. Eocene	

Fig 6 Correlation chart of Tertiary microfossil tops.

correlated (Fig.6), the results show the generally orderly stratigraphic succession of species well-documented from this region (Gradstein & Agterberg, 1982), punctuated by a few interesting anomalies.

Most obviously, the tops of certain planktonic species appear to be somewhat higher in Bonavista. *Dentoglobigerina tripartita* and *Globigerina praebulloides*, for instance disappear in the Early Oligocene in Bonavista, yet apparently disappear well below the truncated top of the Upper Eocene section in Blue. This anomaly can probably be attributed to the hiatus in the Blue well. More dramatically, *Turborotalia pomeroli* occurs up to the top of the Late Eocene in Bonavista, but tops out at Middle Eocene levels in Blue, most probably a victim of inconsistencies inherent in sampling of rare discrete events.

Certain benthonic species also exhibit unusual occurrence patterns in the two wells. *Reticulophragmium amplexens* and *Haplophragmoides walteri* disappear in lower levels of the Upper Eocene in Bonavista, but persist to the top of the truncated Upper Eocene in Blue, evidence that an unknown but possibly quite thick section of the Upper Eocene is missing at the Blue site.

This idea is supported by the relative tops of some other benthonic taxa such as *Ammosphaeroidina pauciloculata*, *Spiroplectammina spectabilis* and *Cibicidoides alleni*, which have extinction levels at similar Middle Eocene ages in both wells, an indication that up to at least the Late Eocene, bottom environments at both sites remained somewhat similar.

Two calcareous benthonic species, *Eponides umbonatus* (topping in mid-Late Eocene in Bonavista) and *Uvigerina* ex gr. *miozea-nuttalli* (Early Oligocene in Bonavista) persist to the Middle Miocene at the Blue site. Although little environmental information is available on the recently-designated *U. ex. gr. miozea-nuttalli* (Thomas, 1988), *Eponides umbonatus* (= *Oridorsalis umbonatus*) is a well-known modern cosmopolitan inhabitant of cool, lower slope conditions and now occurs frequently at depths of 2750 m and lower on the Scotian Slope (Thomas, 1987), and everywhere below 500 m on the northeast Newfoundland margin (Cole, 1981). The *E. umbonatus* data, then, further supports a progressive shallowing of the Bonavista site in post-Late Eocene time, contrasting with the continued bathyal depth of the Blue location during that period.

INFERRED SEDIMENTATION AND HYDROLOGIC HISTORY OF THE BONAVISTA-BLUE TRANSECT

Synthesizing various aspects of the foraminiferal assemblages found in the two wells enables reconstruction of Late Eocene to Oligocene paleoenvironments of the sites:

1. In the Middle Eocene, both sites appear to have been subject to the kinds of conditions (rapid, organic-rich clastic sedimentation, poor circulation) which would support a flourishing "flysch-type" primarily agglutinated foraminiferal fauna and simultaneously suppress development of a rich calcareous association. The planktonic foraminifera present at the Blue site in this interval are in keeping with its more seaward position on the transect. The nature of the benthic assemblages at both sites suggest a depth range of at least 1000 m. For unknown reasons, however, the burrowing organism responsible for the pyritized tubes so common at the Bonavista site either did not colonize the more offshore Blue locality, or its tubes were not preserved there.
2. By Late Eocene time both sites appear to have shallowed

somewhat, with the foraminiferal assemblages at both localities taking on some of the characteristics of middle slope (500-100-m) faunas. At Bonavista, however, a large and diverse calcareous component is present, with most specimens generally representing common mid-slope taxa. The "pyritized tube" organism has either disappeared from the site, or, more likely, diagenetic conditions unfavorable for the formation of pyrite prevail there. At Blue, the agglutinants have become classic "mid-slope" in appearance, but calcareous benthic species are still uncommon, even though the preservation of planktonic forms appears reasonably good. Perhaps the quality of planktonic preservation is a function of the rapid sedimentation rate at the site, as evidenced by the comparatively thick, albeit truncated Late Eocene section. Relative proportions of agglutinated taxa belonging to the superfamilies Ammodiscacea and Lituolacea tend to support this hypothesis.

3. By Late Oligocene-Early Miocene time deltaic progradation of sediments has shoaled the Bonavista site somewhat, allowing the colonization of some shallower-dwelling calcareous forms, and initiating a normal mid-slope agglutinated fauna. For some reason the "pyrite tube" organism (or conditions right for the pyritization of its burrows) re-inhabits the site. Coeval events at the Blue site are unknown.

4. According to previous researchers, some time around the beginning of the Oligocene saw the initiation of more vigorous deep circulation in northern Atlantic areas, which in turn extirpated flysch-type agglutinated assemblages in much of the region. This increased circulation also triggered the development of contour currents, which, in turn, presumably created the late Paleogene erosional events seen in so many deep locations such as in the Blue well. Whether or not any of these events affected the Bonavista site is unclear; there do not, at least, appear to be any long gaps in the Oligocene record at Bonavista.

5. The apparent continuity of the stratigraphic record at the Bonavista site indicates that its mid-slope (500-1000 m) bathymetric position lay upslope of the upper limit of the Paleogene western boundary undercurrent, an important clue to reconstructing Paleogene circulation history and paleoenvironments on the northeast Newfoundland margin.

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REFERENCES

- BP Exploration Canada, 1975. *Well history - suspension report*. BP Columbia Bonavista C-99. BP Exploration Canada, Calgary.
- Cole, F.E., 1981. *Taxonomic notes on the bathyal zone benthonic foraminiferal species off Northeast Newfoundland*. Bedford Institute of Oceanography Report Series, No. BI-R-81-7, June, 1981, 121p., Dartmouth, Nova Scotia.
- Gradstein, F.M., 1975. *Biostratigraphy (Foraminifera) and depositional environment of BP Columbia Bonavista C-99, East Newfoundland Basin*. Report No. EPGs-PAL.33-75FMG, 7p. (Unpublished manuscript)
- Gradstein, F.M. and Agterberg, F.P., 1982. Models of Cenozoic foraminiferal stratigraphy - Northwest Atlantic Margin. In Cubitt, J.M. and Reymont, R.A.

- (Eds.), *Quantitative Stratigraphic Correlation*. John Wiley and Sons, Chichester, U.K., 119-174.
- Gradstein, F.M. and Berggren, W.A., 1981. Flysch-type agglutinated foraminifera and the Maestrichtian to Paleogene history of the Labrador and North Seas. *Mar. Micropal.*, **6**, 211-268.
- Gradstein, F.M. and Kaminski, M.A., in prep. Cenozoic biostratigraphy and paleoceanography, North Sea and Labrador Shelf.
- Gradstein, F.M. and Srivastava, S.P., 1980. Aspects of Cenozoic stratigraphy and paleogeography of the Labrador Sea and Baffin Bay. *Palaeogeog., Palaeoclim., Palaeoecol.*, **30**, 261-295.
- Gradstein, F.M. and Thomas, F.C., 1983. Stratigraphy and depositional environment of Texaco Blue H-28. Report No. EPGs-PAL.1-83FMG/FCT, 3p. (Unpublished manuscript)
- Grunig, A. and Herb, R., 1980. Paleoecology of Late Eocene benthonic foraminifera from Possagno (Treviso - Northern Italy). In: Ingle, J.C. Jr., Kennett, J.P., Kolpack, R. and Vincent, E. (Eds.), *Studies in Marine Micropaleontology and Paleoecology*. Cushman Foundation, Special Publication No.19, 68-85.
- Grzybowski, J., 1898. Mikroskopowe badania namntow wierthicznych z kopala naftowych. I. Pas potocki i okolice Krosna. II. Uwagi ogolne. *Kosmos*, **22**, 393-439.
- Jones, G.D., 1988. A paleoecological model of Late Paleocene "flysch-type" agglutinated foraminifera using the paleoslope transect approach, Viking Graben, North Sea. *Abhandlungen der Geologische Bundesanstalt, Vienna*, Band **41**, 143-153.
- Kaminski, M.A., Gradstein, F.M. and Berggren, W.A., 1989. Paleogene benthic foraminifer biostratigraphy and paleoecology at Site 647, southern Labrador Sea. In Srivastava, S.P., Arthur, M. et al. (Eds.), *Proceedings of the Ocean Drilling Project, Results*, v.105. Ocean Drilling Project, College Station, Texas, 705-730.
- Loeblich Jr., A.R. and Tappan, H., 1988. *Foraminiferal genera and their classification*. Van Nostrand Reinhold Co., New York, 2 vol., 970 p. +217 p.
- McNeil, D.H., 1983. Paleogene agglutinated foraminifera from the Mackenzie Delta and Beaufort Sea areas of Arctic Canada. In: Verdenius, J.G., van Hinte, J.E. and Fortuin, A.R. (Eds.), *Proceedings of the First Workshop on Arenaceous Foraminifera, 7-9 September, 1981*. Publication No.108, Institutt for Kontinentalsokkelundersokelser, Trondheim, Norway, 109.
- Miller, K.G., Curry, W.B. and Ostermann, D.R., 1984. Late Paleogene (Eocene to Oligocene) benthic foraminiferal oceanography of the Goban Spur region, Deep Sea Drilling Project Leg 80. In: Graciansky, P.C., Poag, C.W. et al. (Eds.), *Initial Reports of the Deep Sea Drilling Project*, **LXXX**, Washington, (U.S. Government Printing Office), 505-538.
- Miller, K.G., Gradstein, F.M. and Berggren, W.A., 1982. Late Cretaceous to Early Tertiary agglutinated benthic foraminifera in the Labrador Sea. *Micropaleont.*, New York, **28**, 1-30.
- Schafer, C., Cole, F. and Carter, L., 1983. Paraecology of bathyal zone foraminifera genera and species assemblages off Northeast Newfoundland. In: Verdenius, J.G., van Hinte, J.E. and Fortuin, A.R. (Eds.), *Proceedings of the First Workshop on Arenaceous Foraminifera, 7-9 September, 1981*. Publication No. 108, Institutt for Kontinentalsokkelundersokelser, Trondheim, Norway, 133-146.
- Schnitker, D., 1979. The deep waters of the western North Atlantic during the past 24,000 years, and the re-initiation of the Western Boundary Undercurrent. *Mar. Micropaleont.*, **4**, 265-280.
- Schroder, C.J., 1986. *Deep-water arenaceous foraminifera in the Northwest Atlantic Ocean*. Canadian Technical Report of Hydrography and Ocean Sciences, Dartmouth, Nova Scotia, No.71, 191p.
- Scott, D., Gradstein, F.M., Schafer, C., Miller, A. and Williamson, M., 1983. The Recent as a key to the past: does it apply to agglutinated foraminiferal assemblages? In: Verdenius, J.G., van Hinte, J.E. and Fortuin, A.R. (Eds.), *Proceedings of the First Workshop on Arenaceous Foraminifera, 7-9 September, 1981*. Publication No. 108, Institutt for Kontinentalsokkelundersokelser, Trondheim, Norway, 147-158.
- Texaco Canada Resources Ltd., 1980. Well Report - Texaco Shell et al. Blue H-28. Texaco Canada Resources, Ltd., Calgary, Alberta, 32p. (Unpublished manuscript)
- Thomas, F.C., 1987. *Lower Scotian Slope benthic foraminifera - their taxonomy and occurrences*. Canadian Technical Report of Hydrography and Ocean Sciences, Dartmouth, Nova Scotia, no.81, 68p.
- Thomas, F.C., 1988. Taxonomy and stratigraphy of selected Cenozoic benthic foraminifera, Canadian Atlantic Margin. *Micropaleont.*, New York, **34**, 67-82.
- Thomas, F.C. and Murney, M.G., 1985. *Techniques for extraction of foraminifers and ostracodes from sediment samples*. Canadian Technical Report of Hydrography and Ocean Sciences, Dartmouth, Nova Scotia, no.54, 24p.
- Toxwenius, B.W., 1983. Paleogene arenaceous foraminiferal assemblages from the West Greenland Basin and their paleoecological implication. In: Verdenius, J.G., van Hinte, J.E. and Fortuin, A.R. (Eds.), *Proceedings of the First Workshop on*
- Arenaceous Foraminifera, 7-9 September, 1981*. Publication No. 108, Institutt for Kontinentalsokkelundersokelser, Trondheim, Norway, 171.