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Article abstract

Cuttings from the Cenozoic section of LASMO/NSRL Cohasset Producer CPI P-51, a production well on the Scotian Shelf, offshore Atlantic Canada, contain relatively large numbers of small molluscs and other microinvertebrates. The stratigraphic distributions of these taxa have been compared with the previously established foraminiferal zonation for this site.

Over 50 species of these fossils are recognized, and many represent extant forms now found in much warmer conditions than presently exist on the Scotian Shelf. Occurrences of most of these warm-water forms are concentrated in the upper portion of the Lower Eocene and lower Middle Eocene, in the lower part of the Oligocene section and, to a lesser extent, in the Lower Miocene, supporting claims for climatic warming trends during these intervals in the foraminiferal literature.

There is some suggestion that at least part of the molluscan assemblage is allochthonous, having been transported into deeper waters from its nearshore origin. If true, this does not affect paleoclimatic interpretations. If the molluscs are in place, fluctuating numbers of these taxa with respect to foraminiferal numbers may suggest differences in the parameters affecting the productivity of the two groups.

The restricted stratigraphic ranges of some of these forms may prove useful in correlations with other Atlantic Canada sites where foraminiferal assemblages are impoverished. In one of the Cohasset species, the serpulid worm *Paliurus*, the known stratigraphic range appears to be extended from the Eocene up to the Oligocene. A second species, "*Coleolus*", present in Paleocene to Oligocene horizons, appears to be a homeomorph of a little-known Palaeozoic form.

The absent or very condensed Upper Eocene section of CPI P-51 may be related to increased deep-ocean circulation in the Early Oligocene, as suggested in some foraminiferal literature.

Tertiary molluscs of the Scotian Shelf, Atlantic Canada

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Cuttings from the Cenozoic section of LASMO/NSRL Cohasset Producer CP1 P-51, a production well on the Scotian Shelf, offshore Atlantic Canada, contain relatively large numbers of small molluscs and other microinvertebrates. The stratigraphic distributions of these taxa have been compared with the previously established foraminiferal zonation for this site.

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The absent or very condensed Upper Eocene section of CP1 P-51 may be related to increased deep-ocean circulation in the Early Oligocene, as suggested in some foraminiferal literature.

Des détritiques de la coupe cénozoïque de LASMO/NSRL Cohasset Producer CP1 P-51, un puits productif sur la Plate-forme Scotian, au large des provinces de l'Atlantique, renferment des quantités relativement importantes de petits mollusques et d'autres microinvertébrés. On a comparé les répartitions stratigraphiques de ces taxons avec la zonation des foraminifères de cet endroit réalisée antérieurement.

On reconnaît plus de 50 espèces des fossiles en question; beaucoup représentent des formes encore existantes qu'on trouve aujourd'hui dans des conditions beaucoup plus chaudes que celles actuellement présentes sur la Plate-forme Scotian. La majorité de ces formes d'eaux chaudes sont concentrées dans la partie supérieure de l'Éocène inférieur et la partie inférieure de l'Éocène moyen, dans la partie inférieure de la section de l'Oligocène, ainsi que, dans une moindre mesure, dans le Miocène inférieur, ce qui appuie les allégations de débuts de réchauffement climatique au cours de ces intervalles dans la littérature relative aux foraminifères.

Certains avancent qu'au moins une partie de l'association de mollusques est allochtone et que des mollusques auraient été transportés dans des eaux plus profondes depuis leur littoral d'origine. Le cas échéant, cela n'affecterait pas les interprétations paléoclimatiques. Si des mollusques sont présents, les fluctuations de ces taxons, du point de vue des quantités de foraminifères, pourraient laisser supposer des différences dans les paramètres affectant la productivité des deux groupes.

Les répartitions stratigraphiques limitées de certaines de ces formes pourraient s'avérer utiles dans les corrélations avec les autres endroits des provinces de l'Atlantique où les associations de foraminifères sont limitées. La répartition stratigraphique de l'une des espèces de Cohasset, le serpule *Paliurus*, semble s'étendre de l'Éocène à l'Oligocène. Une deuxième espèce, le *Coleolus*, qui est présente dans les horizons du Paléocène à l'Oligocène, semble être homéomorphe à une forme paléozoïque peu connue.

La section absente ou très concentrée de l'Éocène supérieur du puits CP1 P-51 pourrait être reliée à une circulation profonde accrue au cours de l'Oligocène inférieur, comme le supposent certains auteurs dans la littérature relative aux foraminifères.

[Traduit par la rédaction]

INTRODUCTION

LASMO/NSRL Cohasset Producer CP1 P-51 (hereinafter referred to as CP1 P-51) was one of the first production

oil wells to be developed on the Scotian Shelf, offshore Atlantic Canada. It is located in the Cohasset field some 40 km west of Sable Island, southeast of Nova Scotia (Fig. 1).

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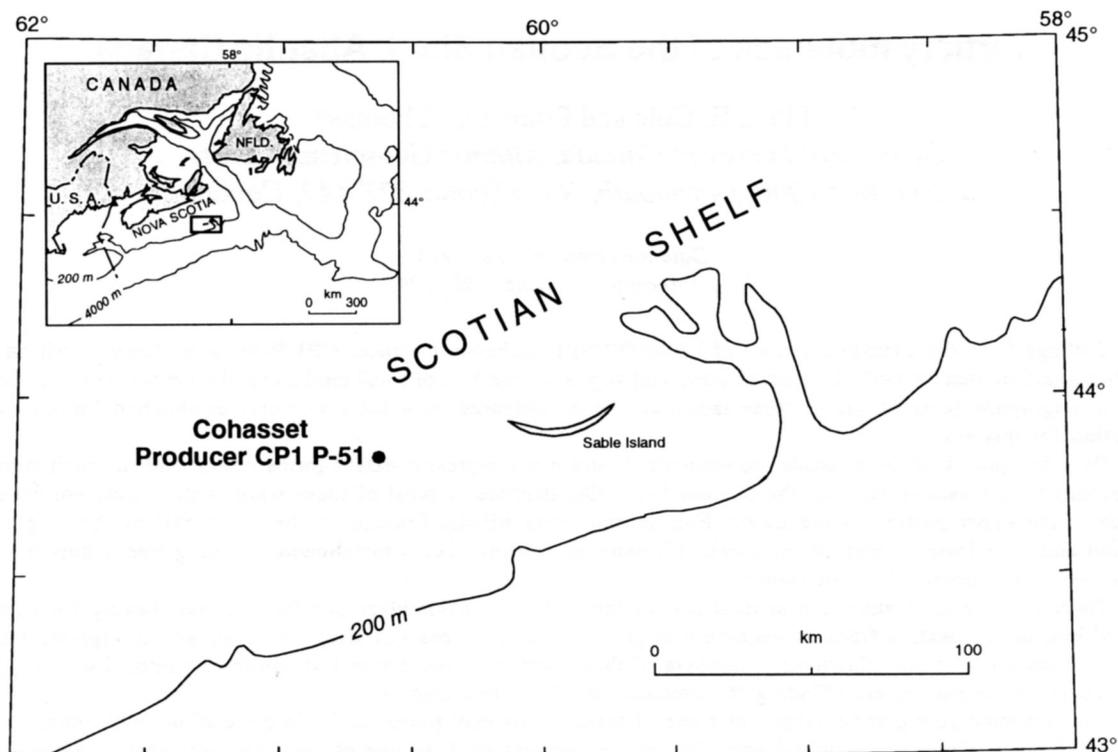


Fig. 1. Location map showing position of Cohasset Producer CP1 P-51.

The Scotian Shelf area has been the scene of intensive hydrocarbon exploration drilling since 1967, with some 140 wells completed by July, 1994. Since biostratigraphic studies of these wells began in the late 1960s, a large body of literature has been produced, concentrating on foraminiferal and ostracode faunas (e.g., Ascoli, 1976; Gradstein and Agterberg, 1982) and palynology (e.g., Barss *et al.*, 1979; Williams *et al.*, 1990).

CP1 P-51 was unusual in the close spacing of the cuttings samples (every 5 m) throughout the Tertiary section, collected by the well operator (LASMO Nova Scotia Limited) specifically for detailed biostratigraphic studies. This was done to facilitate a biostratigraphic study of the site on as fine a scale as possible. Technical data and location coordinates for CP1 P-51 are from LASMO Nova Scotia Limited (1993) and are given in Table 1. The samples were originally processed and analysed for foraminifera by the second author. During this study, the relatively diverse and well-preserved non-foraminiferal taxa were set aside for further study.

Originally, this paper was meant only to catalogue the species of smaller invertebrates and their stratigraphic ranges in CP1 P-51. However, when these data were plotted, patterns emerged which suggested that a number of distinct climatic events had influenced local molluscan faunas during the Cenozoic. Therefore, we have tried to rationalize the molluscan story of this site with the regional biostratigraphic and climatic record, as determined from the foraminifera.

We have chosen the term "smaller invertebrates" to include those fossils, primarily molluscs, which were not foraminifera, ostracodes, or any other of the traditional taxonomic groups used in petroleum biostratigraphy, but were

small enough to remain reasonably intact in the CP1 P-51 cuttings samples. The drilling process used in the petroleum industry simply does not permit the recovery of entire fossils larger than a centimetre or so in greatest dimension. Our smaller invertebrates are generally in the size range of one to ten millimetres.

PREVIOUS WORK

A large amount of work has been done in the last 160 years on the Tertiary molluscan faunas of the western Atlantic region, starting with early works such as Conrad (1835). Most has focussed on macroscopic material from outcrops exposed in various localities on the Atlantic and Gulf Coastal Plains of the eastern United States. An overview of this work prior to 1957 can be found in Gardner and Ladd (1957). Abbott (1974) provides a comprehensive examination of all Recent molluscan species to be found in American waters.

The lack of molluscan studies of material from the Cenozoic wedge of sediments on the eastern continental shelf is due to the relatively large size of these organisms. Even molluscan assemblages in core samples have rarely been systematically examined. Mixon *et al.* (1989) is one exception; these authors examined material from stratigraphic test holes in Virginia. Richards (1946) also published a brief note on similar materials. Dredge samples from off the eastern American coast have also been examined (Gibson, 1965).

In the Canadian offshore region, a few early studies of rock samples dredged from the Scotian Shelf included descriptions of relatively small molluscan species of Cretaceous and Tertiary ages (Dall, 1925; Stephenson, 1936). Other work has been carried out on Recent and Pleistocene mate-

Table 1. Technical data on LASMO/NSRL Cohasset Producer CP1 P-51 (from Thomas, 1994).

Location:	43°50'57.180"N, 60°37'39.972"W
Water Depth:	43.0 m
Total Depth Drilled:	2472 m
Rotary Table Height Above Sea Level:	41.0 m
Rotary Table Height Above Sea Floor:	84.0 m
Interval Studied:	170 - 1010 m
Data Release Date:	August 5, 1993

rial obtained from outcrops in several localities (e.g., Wagner, 1977), and a catalogue of the Atlantic Geoscience Centre's (Dartmouth, Nova Scotia) collection of molluscan species from various Canadian offshore areas has been prepared (Wagner, 1984). In a few cases, such as described in Schafer and Wagner (1978), living molluscan assemblages have been compared with the foraminiferal biota for certain marine localities.

As far as the present authors have been able to determine, however, this is the first work devoted to the molluscan assemblages from an extensive offshore Canadian Tertiary section and their stratigraphic relationships with the known foraminiferal zonation of the site.

METHODS

Each sample was oven-dried and subsequently weighed. These weights ranged from 100 to over 600 g, but most were between 200 to 400 g. The samples, unconsolidated sands and sandy or silty muds, required no disaggregation; these were simply washed through a stack of sieves, with a 1.700 mm opening sieve on top, a 0.250 mm one in the middle and a 0.063 mm on the bottom. Sample depths (170 to 1010 m) and percentages of dry weight >63 microns for the 163 samples are listed in Thomas (1994, table 2). The washed residues were then dry-sieved and a small portion of the >0.150 mm cut was examined and hand-picked for microfossil content.

The foraminiferal analysis of this Cenozoic section has been previously published (Thomas, 1994), and the resulting ages of strata are the standard used here (Fig. 2).

Microphotography for the plates was undertaken using Kodak Tech-Pan 35 mm film in a Leitz Aristophot, a device incorporating a camera body, an extendible bellows and interchangeable lenses.

Figured specimens are stored in the Mollusc Collection at the Geological Survey of Canada (Atlantic), Dartmouth, Nova Scotia.

In determining the stratigraphic boundaries of CP1 P-51 or any well entirely from cuttings, only the uppermost occurrence (the LAD (Last Appearance Datum) or stratigraphic exit) of a given marker species can have significant stratigraphic value; its earliest or lowest occurrence (FAD (First Appearance Datum) or stratigraphic entrance) may

be artificially low because of downhole caving. The sandy and unconsolidated nature of many of the sediments resulted in severe caving, with the result that microfossil assemblages in many levels contain numerous demonstrably younger taxa as contaminants.

The zonation used for the foraminiferal study was that proposed by Gradstein and Agterberg (1982), a quantitative scheme based on optimum sequences of common Tertiary microfaunal elements of the Canadian Atlantic Margin including benthic and planktic foraminifera, and a few other taxa such as diatoms and pteropods.

GEOLOGICAL SETTING

The Scotian Shelf (Fig. 1) has an average width of 200 km and a present average depth of some 125 m. It is underlain by sedimentary formations spanning most of the Mesozoic and Cenozoic. From the Middle Jurassic on, these units are largely marine in origin and in places total several kilometres in thickness.

By the beginning of the Tertiary, fine grained clastic sediments were being deposited in water depths of 200 to 600 m on the central part of the Scotian Shelf, in the vicinity of the Cohasset field. Ongoing subsidence of the region permitted the accumulation of Cenozoic marine sediments up to 1500 m thick in some places (Wade and MacLean, 1990).

The depositional unit encompassing all of the Tertiary on the Scotian Shelf is the Banquereau Formation (Williams *et al.*, 1985), which also includes Santonian to Maastrichtian sediments (Wade and MacLean, 1990). In general in this area, the Banquereau appears to represent nearly continuous, southeasterly prograding mudstones, grading upwards into more or less unconsolidated sands and conglomerates. Hardy (1975) proposed a subdivision of this formation into four component units, but this scheme has not been widely followed. At CP1 P-51 the top of the Banquereau lies somewhere above the top of sampling at 170 m, and the base lies unconformably on the Late Cretaceous Wyandot Formation (Thomas, 1994). Quaternary material was not sampled. Several unconformities, apparently subaqueous, have been delineated within the Cenozoic sections of many parts of the Scotian Shelf, and have been documented biostratigraphically (Ascoli, 1976; Barss *et al.*, 1979).

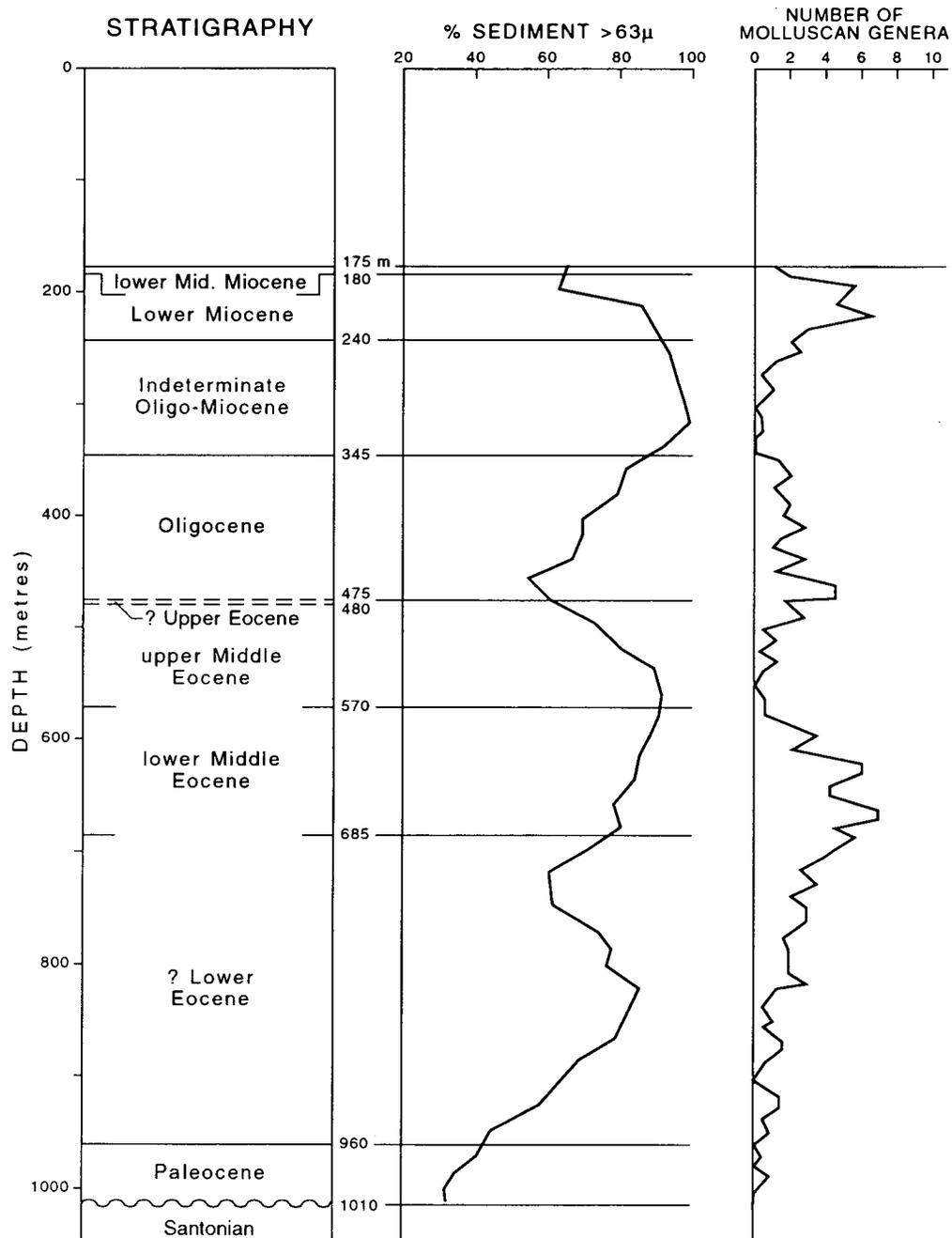


Fig. 2. Biostratigraphy of Cohasset Producer CP1 P-51 showing ages derived from Foraminifera (from Thomas, 1994), % sediment $>63 \mu$, and numbers of molluscan genera.

At the CP1 P-51 site, foraminiferal assemblages through the Cenozoic section indicate the following history (Thomas, 1994): Lower Paleocene sediments are missing, but more or less continuous deposition in a middle to upper bathyal (i.e., water depths of 200 to 1000 m) setting occurred from the early Late Paleocene to at least late Middle Eocene time. These sediments rest unconformably at this site on the Wyandot Formation, a chalky unit containing foraminifera of Santonian age (Piero Ascoli, personal communication, 1994). The benthic foraminiferal faunas of the Paleocene to upper Middle Eocene were mostly calcareous in nature, and relatively few planktics were found. Common Late Cretaceous foraminifera in these

levels indicate sourcing from an unknown eroding Mesozoic outcrop.

During the Late Eocene, deposition at the site was reduced and may even have ceased for a time. Abundant glauconite at this level suggests an extended interval of nondeposition at no greater than upper bathyal depth (~ 200 m) (Thomas, 1994).

Oligocene and Miocene assemblages attest to the continued shallowing at CP1 P-51 as sediments accumulated, and coarser clastic materials in these levels suggest increasing sedimentological dynamism.

RESULTS

The smaller invertebrates found in the Cenozoic of this site include at least 24 gastropod species (at least 22 genera), 15 bivalve species (13 genera), six scaphopod taxa (3 genera), two genera of solitary corals, and a serpulid worm. These taxa may comprise up to 70% of the total microfossils in a sieved fraction of a few samples, but generally average about 5%, including unidentifiable bivalve and gastropod fragments.

The stratigraphic distribution of these taxa is given in Figures 3, 4 and 5. Occurrences of species in samples are indicated by a presence/absence designation. Numbers of specimens of each taxon in a sample were not considered because of the somewhat unquantitative nature of the picking. However, the approximate percentage of the total fossil assemblage in each sample comprised of molluscs or mollusc fragments was noted and is given in Figure 6, along with estimates of numbers of foraminifera per sample, and occurrences of the most common invertebrate taxa.

The data can be summarized as follows: The only identifiable smaller invertebrates in the Paleocene (960-1010 m) were a few fragments that represent a form very like the scaphopod *Coleolus* originally described by Hall (1879).

In the Lower Eocene section (685-960 m), "*Coleolus*" sp. is common, and other scaphopods include *Dentalium* cf. *D. callithrax* Dall and *Dentalium occidentale* Stimpson. Rare bivalves include *Astarte* cf. *A. undata* Gould, *Crassostrea* cf. *C. virginica* (Gmelin), *Dacrydium vitreum* (Hollböll), and slightly larger numbers of *Glycymeris* cf. *G. americana* (De France). The ten gastropod taxa are *Buccinum* cf. *B. plectrum* Stimpson, *Diastoma* cf. *D. alternatum* (Say), *Helicacis* spp., *Turbonilla* cf. *T. emertoni* Verrill, *Odostomia* sp., *Retusa* sp., *Solariella* cf. *S. lamellosa* Verrill and Smith and *Turritellopsis* cf. *T. acicula* (Stimpson) and two indeterminate species. Of these, only *Helicacis* spp., *Retusa* sp. and *Solariella* cf. *S. lamellosa* Verrill and Smith are restricted to the Lower Eocene; the other taxa are present in the overlying Middle Eocene section. Coelenterates are represented by a single specimen of *Caryophyllia* sp.

The Middle Eocene can be divided by the foraminiferal assemblages into a lower (570-685 m) and an upper (485-570 m) half (Fig. 2), based on the uppermost occurrence of *Acarinina densa* (Cushman) as outlined by Gradstein and Agterberg (1982). This division is also reflected in the molluscan assemblages. The lower half contains at least twelve species of gastropods. The more common forms include *Alvania* cf. *A. acuticostata* (Dall), *Buccinum* cf. *B. plectrum* Stimpson, *Turbonilla* cf. *T. emertoni* Verrill, and *Turritellopsis* cf. *T. acicula* (Stimpson). The most common bivalve is *Glycymeris* cf. *G. americana* (De France). *Bathyarca centenaria* (Say), *Crassostrea* cf. *C. virginica* (Gmelin) and *Glycymeris* cf. *G. subtilis* (Nicol) also occur repeatedly, whereas three species are represented by individual specimens. Scaphopods are present in larger numbers than other molluscs, especially *Dentalium* cf. *D. callithrax* Dall, *D. occidentale* Stimpson and "*Coleolus*" sp. If our identification is accurate, this latter taxon was previously known only from Palaeozoic mate-

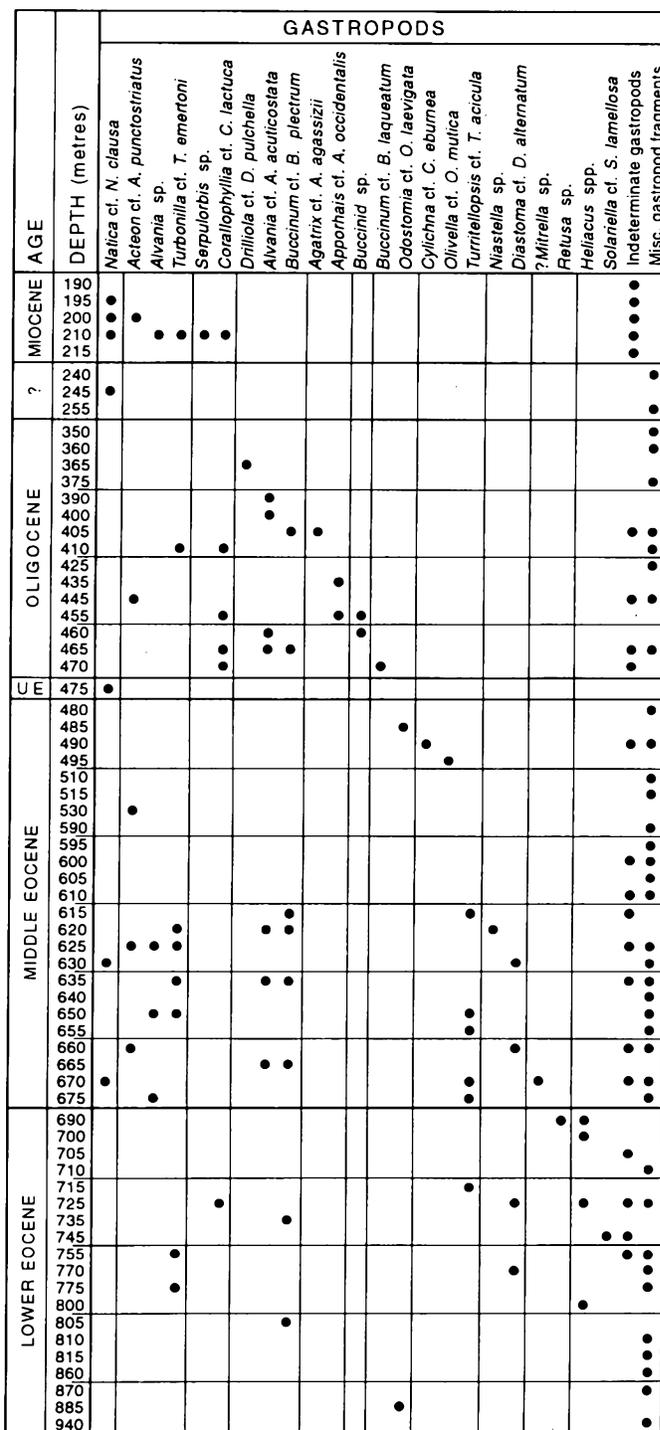


Fig. 3. Stratigraphic distribution of gastropod taxa in Cohasset Producer CP1 P-51.

rial (Hall, 1879). The serpulid worm *Paliurus* spp. also occurs in small numbers.

In contrast, the upper Middle Eocene assemblages are sparser, with five gastropod species (represented by one or two individuals), four bivalves, and substantially fewer scaphopods than in the underlying material. Again, some of these individuals may be caved from overlying sections, while a few, the gastropods *Odostomia* sp., *Cylichna* cf. *C. eburnea* Verrill and *Olivella* cf. *O. mutica* (Say) and the bivalve *Dacrydium*

AGE	DEPTH (metres)	BIVALVES																
		<i>Mercenaria</i> cf. <i>M. mercenaria</i>	<i>Clinocardium</i> cf. <i>C. ciliatum</i>	Taxodont fragments	<i>Tellina</i> cf. <i>T. agilis</i>	<i>Lucina</i> cf. <i>L. radians</i>	<i>Yoldia myalis</i>	Indeterminate sp.	<i>Portlandia</i> cf. <i>P. fraterna</i>	<i>Mulinia</i> cf. <i>M. lateralis</i>	<i>Liocyra</i> cf. <i>L. fluctuosa</i>	<i>Astarte</i> cf. <i>A. undata</i>	<i>Glycymeris</i> cf. <i>G. subtilis</i>	<i>Glycymeris</i> cf. <i>G. americana</i>	<i>Crassostrea</i> cf. <i>C. virginica</i>	<i>Dacrydium vitreum</i>	<i>Bathyrca centenaria</i>	
LOWER MIOCENE	180	•																
	190	•																
	195	•																
	200	•																
	205	•																
	210	•																
	215	•																
	220	•																
	225	•																
	230	•																
?	235	•																
	240	•																
	245	•																
	255	•																
	265	•																
	275	•																
	285	•																
	305	•																
	320	•																
	OLIGOCENE	355																
375																		
380																		
400																		
455																		
460																		
470		•																
MIDDLE EOCENE		480																
		485																
		555																
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	655																	
	660																	
665																		
670																		
675																		
LOWER EOCENE	685																	
	690																	
	695																	
	700																	
	710																	
	740																	
	815																	
	925																	

Fig. 4. Stratigraphic distribution of bivalve taxa in Cohasset Producer CP1 P-51.

vitreum (Hollböll), have their LAD in this level. A single sample at 475 m probably represents a very condensed Upper Eocene section, and contains a molluscan assemblage similar to that of the overlying Oligocene, although an unknown proportion of these taxa may represent caved material.

The Oligocene (345-475 m) contains some 12 gastropod taxa, including the LADs of *Alvania* cf. *A. acuticostata* (Dall) and *Buccinum* cf. *B. plectrum* Stimpson, among others. Bivalves are much less important, with only three recognizable species. The LADs of two of these, *Glycymeris* cf. *G. americana* (De France) and *Glycymeris* cf. *G. subtilis* (Nicol), are in this section. The other, a single specimen of *Mercenaria* cf. *M. mercenaria* (Linné), may be caved from above. The scaphopods include essentially the same forms as below. Several specimens of corals occur near the bottom of this section, the largest concentration of these fossils in the Cenozoic. The serpulid genus *Paliurus*, represented by at least two species, has its LAD here and is common.

The Oligocene or Lower Miocene indeterminate section above this, from 240 to 345 m, with the coarsest average clast size in the Cenozoic, contains a single identifiable gastropod (*Natica* cf. *N. clausa* Broderip and Sowerby), small numbers of four bivalve species, and a single scaphopod (*Dentalium* sp.).

The Lower Miocene section overlying this (180-240 m) is much richer, including eight species of gastropods and eight bivalve taxa, dominated by *Mercenaria* cf. *M. mercenaria* (Linné), *Lucina* cf. *L. radians* (Conrad), *Portlandia* cf. *P. fraterna* (Verrill and Bush) and *Yoldia* sp. The small scaphopod component is dominated by *Dentalium occidentale* Stimpson.

DISCUSSION

The Cenozoic stratigraphic record of the smaller invertebrate species at this site displays a number of features of interest to regional Cenozoic sedimentary and paleoceanographic history. In particular, it appears to contain evidence of several major faunal events, roughly correlative to oceanic circulation/climatic phenomena known from the foraminiferal record.

The exact provenance of the bivalves and gastropod species in the Paleocene, Eocene and Oligocene sections of the well, where the foraminiferal evidence suggests a middle to upper bathyal water depth, are unclear. It is entirely possible that some or all of these forms are allochthonous, having been transported downslope from shallower areas. Small numbers of Late Cretaceous planktic foraminifera in many of these samples indicate reworking of material from elsewhere, clearly demonstrating some hydrological dynamism in this environment (Thomas, 1994). In a nearby analogous setting, Elmore *et al.* (1979) reported long-distance downslope transport of small mollusc shells recovered from the Hatteras Abyssal Plain. Further evidence of possible transport of at least some of these forms lies in the abraded, worn appearance of many tests. Fragments of shells are also quite common, but it is unclear how much of this damage may have resulted from drilling.

Many of the mollusc specimens found appear similar or identical to modern species known from the southeastern coast of the United States (Abbott, 1974). Since the foraminifera indicate deeper water, these shells are most probably not *in situ*.

Whether the bivalves and gastropods are partially or

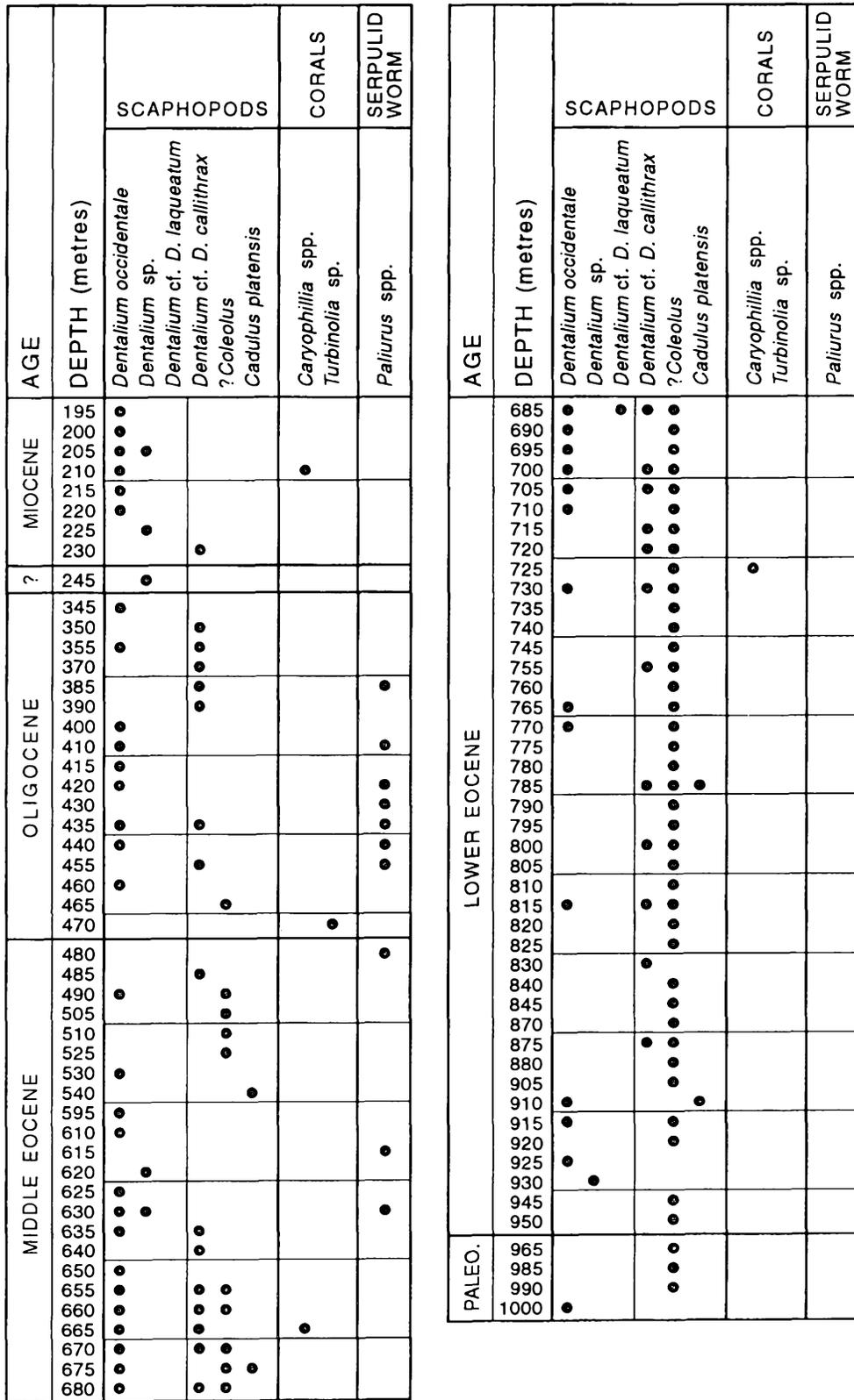


Fig. 5. Stratigraphic distribution of scaphopods, corals and *Paliurus* spp. in Cohasset Producer CP1 P-51.

all transported to the site from upslope or are *in situ*, does not invalidate climatic interpretations based on the assemblages, provided they are not reworked from significantly older strata. Indeed, regional warming and cooling trends would tend to have more effect in local neritic areas than in

bathyal depths as in the Paleogene at this site, where many benthic foraminiferal species tend to be more cosmopolitan in distribution (van Morkhoven *et al.*, 1986).

Figure 6 shows the downhole distributions of the ten stratigraphically most long-ranging mollusc species (i.e.,

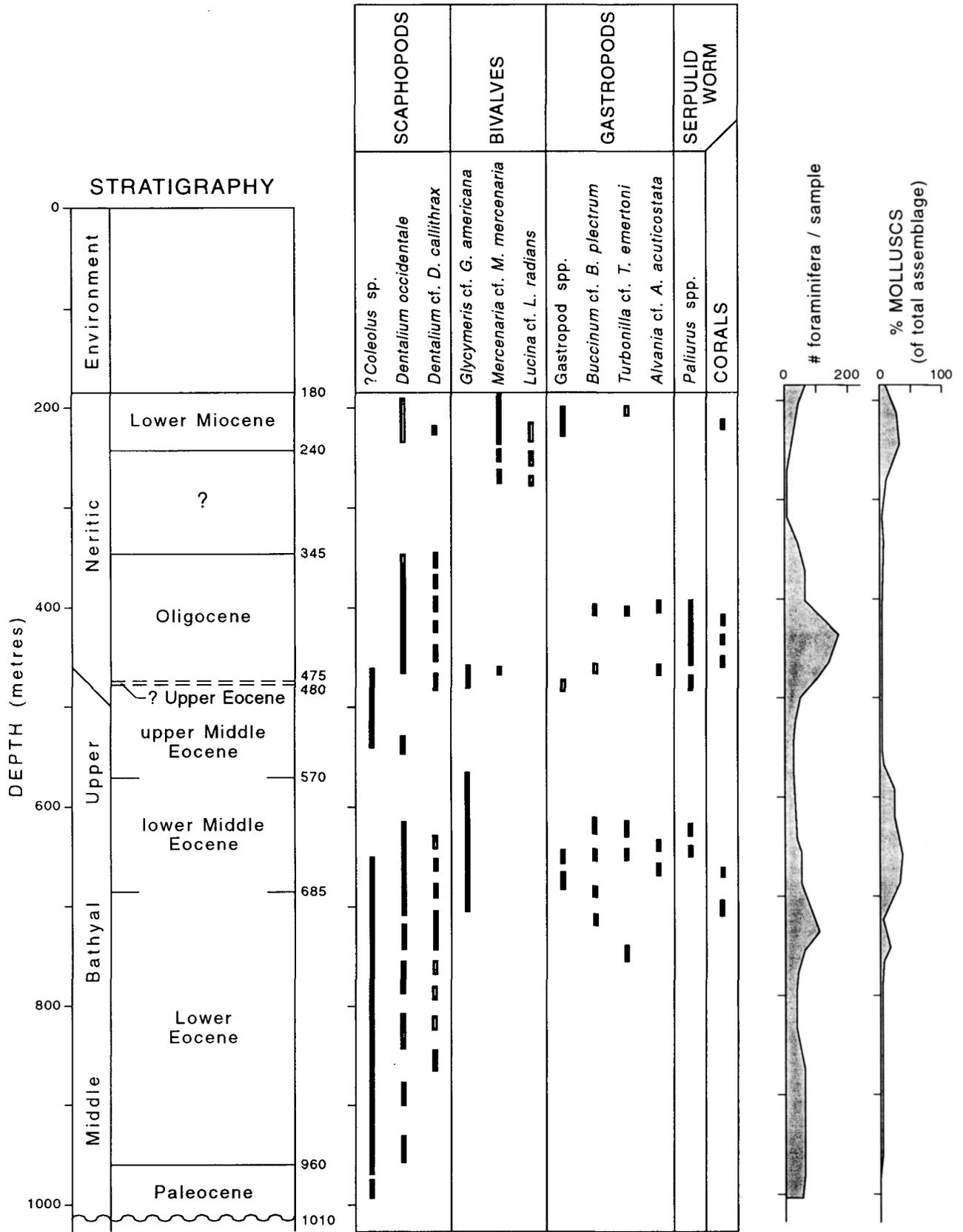


Fig. 6. Occurrences of most common smaller invertebrate taxa in Cohasset Producer CP1 P-51, along with estimates of total foraminifera per sample and molluscs or mollusc fragments as a percentage of the total microfossil assemblage.

those occurring in eight or more samples), the common serpulids *Paliurus* spp. and the rare corals. Also shown are the percentages of microfossil preparations comprised of molluscs

or mollusc fragments, and the numbers of foraminiferal tests in the samples. These last two figures as shown are averaged over approximately 35 m intervals.

The preponderance of scaphopods in the Paleocene and most of the Early Eocene is probably related to the middle bathyal water depth in this interval. The scaphopod genus *Cadulus* and species *Dentalium callithrax* appear to prefer open shelf to upper slope environments (Abbott, 1974).

Near the top of the Lower Eocene section, and continuing into the lowermost Middle Eocene, small numbers of several gastropod species and one bivalve appear. The bivalve, *Glycymeris* cf. *G. americana* (De France), and two of the gastropods, *Alvania* cf. *A. acuticostata* (Dall) and *Heliacus* cf. *H. sigsbeeii* (Dall), are considered to be warmer-water forms (see Appendix). The first appearance of the serpulid *Paliurus* and a few corals also occur in this interval. It is not clear from this record whether warming in upslope, shallower areas had occurred at this time, or if the site had simply shoaled enough to reach the lower depth limits of organisms already established in the warmer, shallower water. One of the scaphopods, *Dentalium* cf. *D. callithrax* Dall, possibly also indicative of relatively warm conditions, is present at the site from near the beginning of the Eocene, which tends to suggest the second scenario.

Around the mid-point of the Middle Eocene all of these warmer indicators disappear temporarily. Although the cuttings-based chronostratigraphic control is imprecise (Thomas, 1994), this disappearance may reflect the climatic cooling documented by Miller (1992) from oxygen isotope studies of foraminiferal tests from about this time throughout the North Atlantic regionally, and other locations.

The upper half of the Middle Eocene section probably contains only scaphopods; the very few bivalves, gastropods and *Paliurus* specimens at the top of this interval are all seen in overlying material and may well represent cavings. The later half of the Middle Eocene, according to Keller *et al.* (1992) was a time of widespread surface water cooling in low latitudes, possibly linked to pulses in Antarctic glaciation. They found that this climatic shift had a greater impact on surface-dwelling planktic foraminifera than on intermediate or deep-dwelling taxa. Because taxa living in shallow conditions would also tend to be affected more by this cooling trend, the disappearance of much of the smaller invertebrate fauna in the Cohasset site appears to be reasonably correlated to this cooling event even if the fauna is derived from an upslope source. Miller (1992) summarizes current information on the widespread occurrence of erosional events about the base of the Oligocene. The evidence suggests that deep-water circulation was much more vigorous during the Early Oligocene than previously, and is thought to have been related to the formation of bipolar ice sheets. The hiatus or very condensed section at the Cohasset site in the Upper Eocene occurs to varying degrees at a few other Scotian Shelf sites (Ascoli, 1976; F.C. Thomas, unpublished data), and may be an expression of this climatic change, possibly as a result of enhanced or invigorated circulation at depth.

The Oligocene section of Cohasset contains the same gastropods as occur in the Eocene, though in slightly smaller numbers. The worm *Paliurus*, previously only known from Eocene and older sediments (Gabb, 1876), is well repre-

sented, and the corals also re-appear, along with small numbers of the bivalve *Glycymeris* cf. *G. americana* (De France). A single specimen of another bivalve, *Mercenaria* cf. *M. mercenaria* (Linné), may well be caved. Two scaphopods, including the presumably warm-water *Dentalium* cf. *D. callithrax* Dall, re-appear. With the exception of the scaphopods, however, the molluscs and corals all disappear again well before the top of the Oligocene section.

Possibly this brief "warm" interval may relate in some way to the temporary disappearance of the Oligocene ice sheets postulated by Miller *et al.* (1987). Furthermore, Keller *et al.* (1992) describe evidence for a second Antarctic glaciation pulse or sudden cooling event at mid-Oligocene time, which may have been responsible for the second extirpation before the end of the Oligocene. Hansen (1992) has demonstrated the sensitivity of Paleogene molluscan shelf faunas to changes in temperature in the Gulf Coast area, showing that molluscan diversity drops significantly in response to lowered temperatures.

If many of the molluscs at CPI P-51 are reworked from a contemporaneous upslope source, the apparent increase in numbers in the lower Oligocene may simply be a result of an increase in shoreline erosion due to the Oligocene glacioeustatic sea level drop documented by Miller *et al.* (1987), among others. Its composition as stated above, however, still suggests a relatively warm neritic environment, at least during the initial phase of this regression.

The smaller invertebrate fauna of the Lower Miocene is somewhat less clear in its climatic associations. The scaphopods are less common, possibly a result of the significantly shallower conditions, as evidenced by the foraminifera (Thomas, 1994). The most common bivalve is *Mercenaria* cf. *M. mercenaria*, but the warm water indicator *Lucina* cf. *L. radians* is also present. A few specimens of unidentified gastropods are present, some of which seem to correlate positively with the two previous "warm" intervals. A single coral also occurs.

Miller *et al.* (1987) mentioned evidence of a possible second temporary absence or reduction of glaciation in the Early Miocene. Perhaps a somewhat tenuous correlation with this event could be argued for this fauna, although its character is admittedly ambiguous.

The ocean circulation history and neritic climatic evidence suggested by the molluscs and other smaller invertebrates for the site cannot be substantiated by the foraminiferal record (Thomas, 1994). The foraminifera, being predominantly benthic and overwhelmingly *in situ* (except for downhole caving contamination), are principally upper to mid-bathyal (i.e., 200 to 1000 m water depth) in habitat (except for the outer neritic Lower Miocene section) and thus show no major climatic variations. Many are well-known species described as cosmopolitan in the literature (e.g., Tjalsma and Lohmann, 1983; van Morkhoven *et al.*, 1986).

There appears to be no clear correlation between absolute numbers of foraminifera and proportion of molluscs (Fig. 6). In Oligocene levels, for instance, where the foraminifera are most abundant and diverse, numbers of molluscs are low. In the upper Lower Eocene, lower Middle Eocene

and Lower Miocene, where foraminiferal assemblages are less rich, the molluscs are more abundant. These data would tend to suggest either that foraminiferal productivity and molluscan productivity are regulated by different mechanisms, or, perhaps more likely, that the molluscan component is at least partly allochthonous, and its relative numbers within the stratigraphic column have more to do with pulses of downslope transport than the *in situ* benthic environment.

Alternatively, when the numbers of molluscan genera, arguably a better measure of faunal richness, are compared to the % sediment >63 μ , an inverse relationship is seen, at least above the mid-Lower Eocene, where gastropods and bivalves become more common (Fig. 2). Higher numbers of genera appear to correlate positively with sections of lower sand and silt components. Assuming that much of the sedimentary input from upslope is coarser material, this tends to suggest that at least some bivalves and gastropods are in fact, endemic at depth.

Finally, this study also extends the known ranges of two invertebrate taxa. The serpulid worm genus *Paliurus* Gabb, previously known only from Eocene levels, occurs at the Cohasset site through the Oligocene. Much more dramatically, the known range of the enigmatic "*Coleolus*", which we believe to be a scaphopod, is now extended from the Paleozoic up into the Oligocene. This huge apparent increase in stratigraphic range strongly indicates that our species is an unrelated homeomorph of Hall's (1879) species. For now, we choose to retain the name because of its close resemblance to Hall's original description.

CONCLUSIONS

The smaller invertebrates of the microfossil assemblages in the Cenozoic section of Cohasset Producer CP1 P-51 appear to provide some background climatic information to the paleoenvironments of their source areas. Conclusions to be drawn from this study are:

- (1) It is unclear whether the majority of bivalves and gastropods found in the well are *in situ* or were transported downslope from a shallower source area.
- (2) If most of the molluscan fauna is *in situ*, the fluctuating numbers relative to foraminifera suggest productivity of the two groups is dependent on different factors.
- (3) The relatively large numbers of warm water forms among the smaller invertebrates suggest somewhat warmer conditions than at present for the source environments of these taxa. The sporadic occurrences of these warm indicators may reflect climatic warmings in the lower Middle Eocene, Oligocene and possibly Early Miocene.
- (4) Certain common species such as the bivalve *Glycymeris* cf. *G. americanus* and the gastropods *Buccinum* cf. *B. plectrum* and *Alvania* cf. *A. acuticostata* show restricted stratigraphic ranges which may prove to be useful in local Cenozoic biostratigraphy, often appearing in samples fairly poor in foraminifera.
- (5) The serpulid worm *Paliurus*, previously known only from the Eocene, ranges up into the Oligocene at this site.

- (6) We have discovered a probable scaphopod species closely resembling Hall's (1879) Paleozoic "*Coleolus*" in sediments of Paleocene to Oligocene age in this site. We regard our form as an unrelated homeomorph, however, because of the great stratigraphic gap between the two species.
- (7) The very condensed or absent Upper Eocene section in this site may be an expression of enhanced deep circulation during the Early Oligocene, as postulated in some of the foraminiferal literature.

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APPENDIX

Systematic paleontology

Information on the individual taxa of smaller invertebrates of CP1 P-51 is provided in this section. Since this is not a formal systematic taxonomic treatment of these fossils, the classifications are simplified from standard, well-known texts; for the corals Wells (1956); for the worms Howell (1962); for the gastropods and bivalves (down to the family level) by Morton (1979); and for the scaphopods Ludbrook (1960).

A "Remarks" section for each taxon outlines the known stratigraphic range and present depth range. For the molluscs, the latter is, unless otherwise noted, taken from Abbott (1974). Formal descriptions, along with synonymy lists, are beyond the scope of this paper, particularly since most of the molluscan forms at least are well known; in some cases, however, circumstances warrant a few notes on the size, condition or appearance of the specimens.

The "Levels" section lists the samples in which each taxon was found and outlines the stratigraphic distribution of the form at CP1 P-51.

Phylum Coelenterata Frey and Leuckart, 1847
Class Anthozoa Ehrenberg, 1834
Order Scleractinia Bourne, 1900
Family Caryophylliidae Gray, 1847

Genus *Caryophyllia* Lamarck, 1801
Caryophyllia spp.
 Fig. 7.1 to 7.6

Remarks: Solitary corals of this genus range from Upper Jurassic to Recent and are cosmopolitan from 0 to 2700 m depth (Wells, 1956). Three of the four coral specimens found appear to belong to this genus; they are apparently of at least two species. All specimens are single and measure less than 10 mm in length.

Levels: 725, 665, 455 m. Lower Eocene to Lower Miocene.

Genus *Turbinolia* Lamarck, 1816
Turbinolia sp.
 Fig. 7.7, 7.8

Remarks: This genus is restricted to Eocene-Oligocene in the Atlantic realm. Wells (1956) gives no depth range. Our specimen is conical, 5 mm in length, with markedly fewer septae than the *Caryophyllia* spp.

Levels: 470 m, base of Oligocene.

Phylum Annelida Lamarck, 1809
Class Polychaeta Grube, 1850
Order Sedentariida Lamarck, 1818
Family Serpulidae Burmeister, 1837

Genus *Paliurus* Gabb, 1876
Paliurus spp.
 Fig. 7.17 to 7.19

Remarks: First described by Gabb (1876), from the Eocene of North America. We have found no further references to it in the literature. Several specimens were found, belonging mostly to one species, with one or two specimens that appear to belong to a second species. All are fragments of slightly curved calcareous tubes which exhibit a more or less triangular cross section, with a round central cavity. Most are under 2 mm in length.

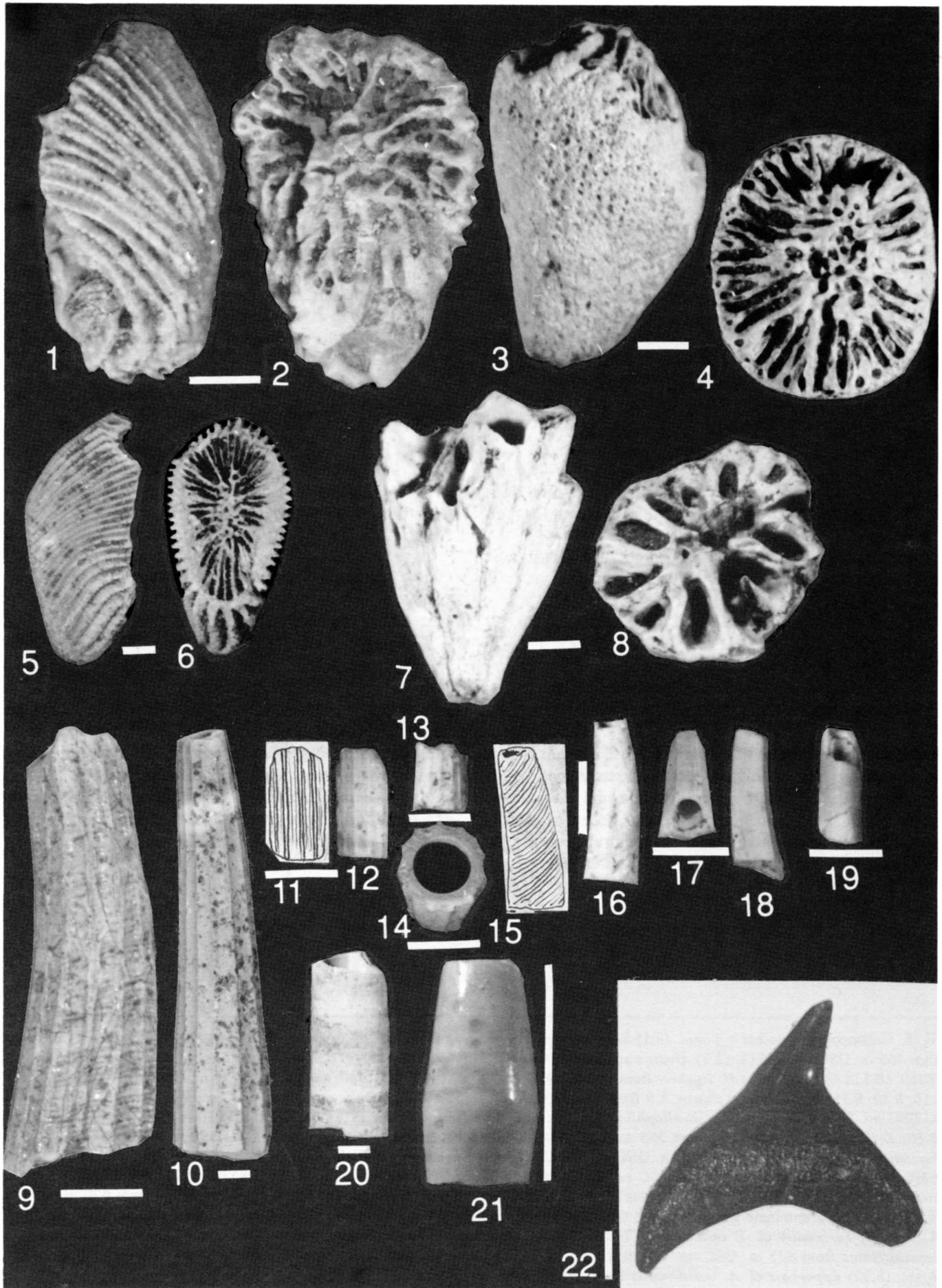
Levels: 630, 615, 480, 455, 440, 435, 430, 420, 410, 385 m. Occurrences of this genus in Oligocene sediments extend its known stratigraphic range from the Eocene.

Phylum Mollusca
Class Gastropoda
Order Archaeogastropoda Thiele, 1925
Family Trochidae Rafinesque, 1815

Genus *Solariella* Wood, 1842
Solariella cf. *S. lamellosa* Verrill and Smith, 1880
 Fig. 8.1

Remarks: In the modern Atlantic, *S. lamellosa* is found from Massachusetts to the West Indies; 30 to 300 m is its

Fig. 7. Corals and scaphopods. Scale bar = 1 mm. (7.1, 7.2) *Caryophyllia* sp. coral from 665 m. Side and top views of same specimen. GSC no. 78502. (7.3, 7.4) *Caryophyllia* sp. coral from 860 m. Side and top views of same specimen. GSC no. 78503. (7.5, 7.6) *Caryophyllia* sp. coral from 850 m. Side and top views of same specimen. GSC no. 78504. (7.7, 7.8) *Turbinolia* sp. coral from 470 m. Side and top views of same specimen. GSC no. 78505. (7.9, 7.10) *Dentalium* cf. *D. callithrix*. 7.9 from 355 m. GSC no. 78506. 7.10 from 755 m. GSC no. 78507. (7.11, 7.12) *Dentalium* cf. *D. laqueatum* from 685 m. GSC 78508. 7.11 is a drawing to illustrate the surface ornamentation. (7.13, 7.14) *Dentalium* sp. Both from 630 m. 7.14 is a cross sectional view showing round internal cavity and ribs. GSC no. 78509 (7.13) and GSC no. 78510 (7.14). (7.15, 7.1) "*Coleolus*" sp. from 630 m. GSC no. 78510. 7.15 is a drawing to show the oblique striae. (7.17, 7.18) *Paliurus* sp. (serpulid) from 425 m. GSC no. 78511. Note triangular cross section of shell. (7.19) *Paliurus* sp. from 385 m. GSC no. 78512. Note more rounded cross section. (7.20) *Dentalium occidentale* from 195 m. GSC no. 78513. (7.21) *Cadulus* cf. *C. platensis* from 540 m. GSC no. 78514. (7.22) Shark tooth from 195 m. GSC no. 78515. This is the largest intact fossil tooth taken so far from offshore Nova Scotia wells.



usual depth range, but has been recorded from 1400 m. From this information, the single, well-preserved, 3 mm specimens we found may well have been *in situ* rather than transported.

Levels: 745 m, just below the Oligocene-Eocene boundary.

Order Mesogastropoda
Family Rissoidae Gray, 1847

Genus *Alvania* Risso, 1826

Alvania cf. *A. acuticostata* (Dall, 1889)

Fig. 8.2

Remarks: At present, *A. acuticostata* ranges from North Carolina to Barbados and is found at depths from 60 to 1300 m.

Levels: 665, 635, 620, 465, 460, 400, 390 m. Several specimens in Oligocene and lower Middle Eocene strata.

Alvania sp.

Fig. 8.3

Remarks: This alvanid carries the characteristic spiral lines on the protoconch, but in this form they carry on through the entire shell.

Levels: 675, 650, 625, 210 m. One specimen at 210 m (Lower Miocene), a few more in lower Middle Eocene.

Family Turritellidae Clarke, 1851

Genus *Turritellopsis* G.O. Sars, 1878

Turritellopsis cf. *T. acicula* (Stimpson, 1851)

Fig. 9.6 to 9.9

Remarks: According to Richards (1962), *T. acicula* is now found in waters from Labrador to Massachusetts. Abbott (1974) concurs, giving 10 to 100 m depth as its usual bathymetric range. Its wide range in shallow areas of Recent seas indicates that it tolerates a variety of temperature conditions. Our specimens were mostly in the 1 to 2 mm size range.

Levels: 715, 675, 670, 655, 650, 615 m. Several specimens in lower Middle and Lower Eocene samples.

Family Architectonicidae Gray, 1850

Genus *Heliacus* d'Orbigny, 1842

Heliacus cf. *H. sigsbeeii* (Dall, 1889)

Fig. 8.5, 8.6

Remarks: At present, *H. sigsbeeii* is a subtropical form, found from Florida to Barbados, in water to 600 m depth. Given this present geographic range, the very similar form in CP1P-51 could perhaps also be considered a warm-water indicator. All specimens are in excellent condition, and approximately 1 mm in diameter.

Levels: 700, 800 m. Several specimens in Lower Eocene levels.

Heliacus sp.

Fig. 8.7, 8.8

Remarks: These low-spined, umbilicate forms appear to belong to *Heliacus*, but are too damaged or smooth to attribute confidently to *H. sigsbeeii*.

Levels: 725, 700, 690 m. A few specimens in Lower Eocene.

Family Vermetidae Rafinesque, 1815

Genus *Serpulorbis* Sassi, 1827

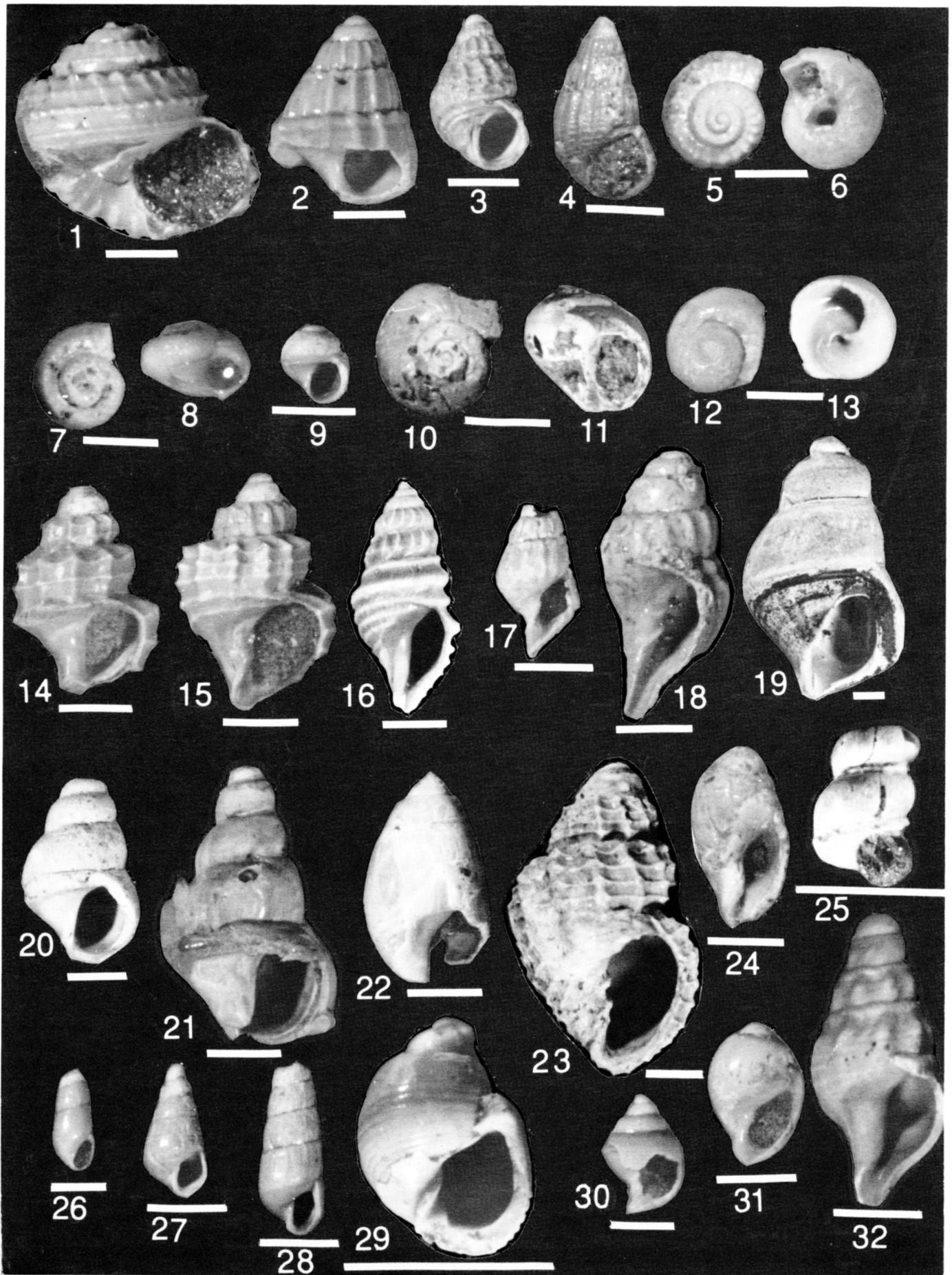
Serpulorbis sp.

Fig. 9.11, 9.12

Remarks: Serpulorbids are found today in tropical, shallow water. At lengths of about 2.5 mm, our two trochospiral, irregularly coiled specimens are probably juveniles, lacking the longitudinal cording diagnostic of adults. They may belong to *S. decussatus* (Gmelin, 1791), but identification of a juvenile is uncertain at best.

Levels: 210 m (Lower Miocene).

Fig. 8. Gastropods. Scale bar = 1 mm. (8.1) *Solariella* cf. *S. lamellosa* from 745 m. GSC no. 78516. (8.2) *Alvania* cf. *A. acuticostata* from 465 m. GSC no. 78517. (8.3) *Alvania* sp. from 210 m. GSC no. 78518. (8.4) *Diastoma* cf. *D. alternatum* from 650 m. GSC no. 78519. (8.5, 8.6) *Heliceus* cf. *H. sigsbeeii* from 700 m. GSC no. 78520. (8.7, 8.8) *Heliceus* sp. from 725 m. GSC no. 78521. (8.9, 8.10, 8.11, 8.12, 8.13) *Natica* cf. *N. clausa*. 8.9 from 210 m. GSC no. 78522. 8.10, 8.11 from 630 m. GSC no. 78523. 8.12, 8.13 from 475 m. GSC no. 78524. (8.14, 8.15) *Corallophila* cf. *C. lactuca*. 8.14 from 470 m. GSC no. 78525. 8.15 from 1045 m. GSC no. 78526. (8.16) *Drilliola* cf. *D. pulchella* from 365 m. GSC no. 78527. (8.17) Indeterminate gastropod from 455 m. GSC no. 78528. (8.18) *Buccinum* cf. *B. plectrum* from 775 m. GSC no. 78529. (8.19) *Buccinum* cf. *B. laqueatum* from 470 m. GSC no. 78230. (8.20) Indeterminate gastropod from 195 m. GSC no. 78531. (8.21) *Buccinid?* from 460 m. GSC no. 78532. (8.22) *Olivella* cf. *O. mutica* from 495 m. GSC no. 78533. (8.23) *Agatrix* cf. *A. agassizii* from 405 m. GSC no. 78534. (8.24) *Mitrella* sp. from 670 m. GSC no. 78535. (8.25) Indeterminate gastropod from 620 m. GSC no. 78536. (8.26) *Odostomia* cf. *O. laevigata* from 485 m. GSC no. 78537. (8.27, 8.28) *Turbonilla* cf. *T. emertoni*. 8.27 from 210 m. GSC no. 78538. 8.28 from 410 m. GSC no. 78539. (8.29) *Acteon* cf. *A. punctostriatus* from 445 m. GSC no. 78540. (8.30, 8.31) Indeterminate gastropods from 470 m. GSC no. 78541 (8.30) and 78542 (8.31). (8.32) *Apporhais* cf. *A. occidentalis* from 435 m. GSC no. 78543.



Family Cerithiidae Fleming, 1822

Genus *Diastoma* Deshayes, 1850*Diastoma* cf. *D. alternatum* (Say, 1822)

Fig. 8.4

Remarks: Currently ranging from the Gulf of St. Lawrence to coastal Virginia, *D. alternatum* is usually found in waters shallower than 40 m (Abbott, 1974). The specimens are very similar to this species. Given its present broad geographic range it appears to be another fairly tolerant taxon. Its present shallow depth range suggests that this form may be part of a transported, allochthonous element in CP1 P-51.

Levels: 770, 725, 660, 630 m. Lower and lower Middle Eocene.

Family Apporhaidae Morch, 1852

Genus *Apporhais* da Costa, 1778*Apporhais* cf. *A. occidentalis* Beck, 1836

Fig. 8.32

Remarks: Richards (1962) describes the range of the apparently tolerant form *A. occidentalis* as from the Gulf of St. Lawrence to North Carolina. Abbott (1974) agrees, giving its bathymetric distribution as subtidal to 700 m. Our very similar specimens range up to 4 mm in length.

Levels: 455, 435 m. Small numbers in two lower Oligocene samples.

Family Naticidae Gray, 1840

Genus *Natica* Scopoli, 1777*Natica* cf. *N. clausa* Broderip and Sowerby, 1829

Fig. 8.9 to 8.13

Remarks: Richards (1962) describes *N. clausa* as found from Arctic Canada to North Carolina, as does Abbott (1974), in depths to 2400 m. Feyling-Hansen (1955) records *N. clausa* as widespread in the northern regions of the Atlantic, preferring shallower water in the north, deeper water towards the south. Our specimens are probably *N. clausa*, but are too damaged for positive identification. Given its present depth range, this form may well have been endemic at the Cohasset site.

Levels: 670, 630, 475, 245, 210, 200, 195 m. Scattered samples from lower Middle Eocene to Lower Miocene.

Family Coralliophilidae Chenu, 1859

Genus *Coralliophila* Chenu, 1859*Coralliophila* cf. *C. lactuca* Dall, 1889

Fig. 8.14, 8.15

Remarks: The present geographic range of *C. lactuca* is Florida and the Gulf of Mexico, at 300 to 550 m water depth. Our closely related forms may also represent warm conditions, possibly in shallower areas upslope.

Levels: 725, 470, 465, 455, 410, 210 m. Several specimens in the lower Middle Eocene, one in Oligocene and small numbers in Lower Miocene.

Order Neogastropoda

Family Columbellidae Swainson, 1840

Genus *Mitrella* Risso, 1826? *Mitrella* sp.

Fig. 8.24

Remarks: This specimen appears to be a *Mitrella*, but is too badly worn for certain identification.

Levels: 670 m (lower Middle Eocene).

Family Buccinidae Rafinesque, 1815

Genus *Buccinum* Linné, 1758*Buccinum* cf. *B. plectrum* Stimpson, 1865

Fig. 8.18

Remarks: Richards (1962) indicates the present distribution of *B. plectrum* as from the Arctic to the Gulf of St. Lawrence, as does Abbott (1974). In all our specimens only the initial part of the shell is intact.

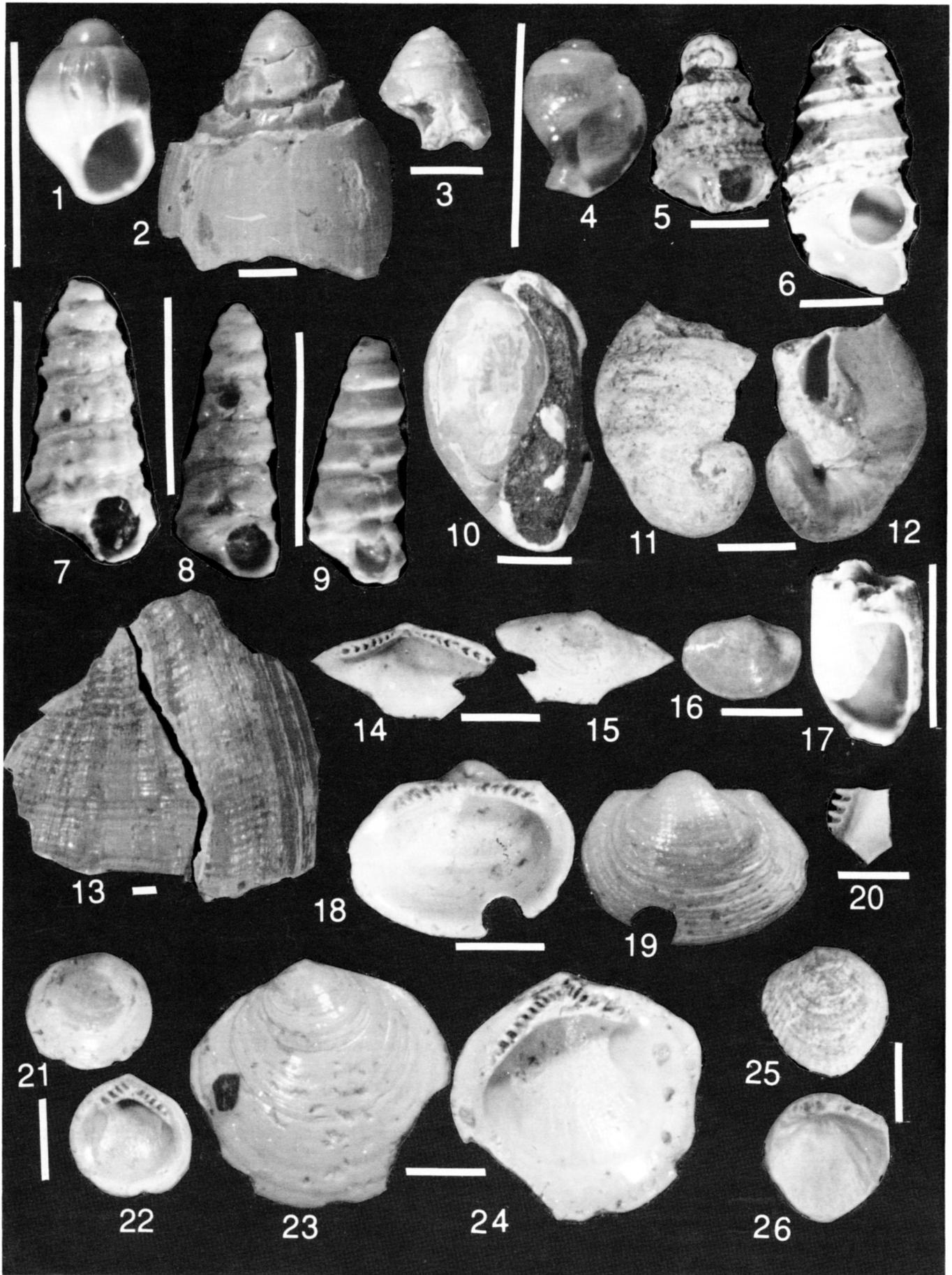
Levels: 805, 735, 665, 635, 620, 615, 465, 405 m. Several specimens occur in Lower and lower Middle Eocene and Oligocene samples.

Buccinum cf. *B. laqueatum* Conrad, 1841

Figs. 8.19, 9.13

Remarks: Conrad (1841) originally described *B. laqueatum* from the Upper Tertiary (Miocene) of the eastern seaboard of the United States. The specimen figured in Plate 2 (fig. 19) is a juvenile, that in Plate 3 (fig. 13) is a large (10 x 10 mm) fragment of an adult.

Fig. 9. Gastropods and bivalves. Scale bar = 1 mm. (9.1, 9.2, 9.3, 9.4, 9.5) Indeterminate Gastropods. 9.1 from 445 m. GSC no. 78544. 9.2 from 405 m. GSC no. 78545. 9.3 from 4 m. GSC no. 78546. 9.4 from 465 m. GSC no. 78547. 9.5 from 635 m. GSC no. 78548. (9.6, 9.7, 9.8, 9.9) *Turritellopsis* cf. *T. acicula*. 9.6 from 670 m. GSC no. 78549. 9.7, 9.8 from 675 m. GSC no. 78550 (9.7) and GSC no. 78551 (9.8). 9.9 from 650 m. GSC no. 78552. (9.10) *Cylichna* cf. *C. eburnea* from 490 m. GSC no. 78553. (9.11, 9.12) *Serpulorbis* sp. from 210 m. GSC no. 78554. (9.13) *Buccinum* cf. *B. laqueatum* from 1035 m. A relatively large fragment of a later whorl. GSC no. 78555. (9.14, 9.15) *Yoldia myalis* from 235 m. GSC no. 78556. (9.16) *Portlandia* cf. *P. fraterna* from 215 m. GSC no. 78557. (9.17) *Retusa* sp. from 690 m. GSC no. 78558. (9.18, 9.19) *Bathyarca centenaria* 670 m. GSC no. 78560. (9.20) Taxodont hinge fragment from 200 m. GSC no. 78559. (9.21, 9.22, 9.23, 9.24) *Glycymeris* cf. *G. americana*. 9.21, 9.22 from 665 m. GSC no. 78561. 9.23, 9.24 from 650 m. GSC no. 78562. (9.25, 9.26) *Glycymeris* cf. *G. subtilis* from 655 m. GSC no. 78563.



Levels: The former is from 470 m (Oligocene), the second was caved to 1035 m, in Upper Cretaceous material.

Buccinid sp.
Fig. 8.21

Remarks: This indeterminate taxon ranges in size from 2 to 5 mm in length.

Levels: 460, 455 m. Small numbers appear in the lower section of the Oligocene.

Family Olividae Latreille, 1825

Genus *Olivella* Swainson, 1831
Olivella cf. *O. mutica* (Say, 1822)
Fig. 8.22

Remarks: The present range of *O. mutica* is from North Carolina to Texas and the West Indies according to Richards (1962) suggesting an affinity for warm, probably shallow waters. Our single specimen is 3 mm in length.

Levels: 495 m (upper Middle Eocene).

Family Cancellariidae Forbes and Hanley, 1853

Genus *Agatrix* R. Petit, 1967
Agatrix cf. *A. agassizii* (Dall, 1889)
Fig. 8.23

Remarks: The present range of *A. agassizii* is from North Carolina to the Caribbean, at depths of 35 to 100 m. This is probably an adult example of a closely-related form 5 mm in length.

Levels: 405 m (Oligocene).

Family Turridae Swainson, 1840

Genus *Drilliola* Cossman, 1903
Drilliola cf. *D. pulchella* (Verrill, 1880)
Fig. 8.16

Remarks: Verrill (1882) reported *D. pulchella* (= *Taranis pulchella*) from 1000 m depth off Massachusetts. Our well-preserved specimen is virtually identical to the one illustrated in Abbott, (1974). Its known depth habitat and good condition strongly suggest that it was living at the site.

Levels: 365 m (Oligocene).

Order Cephalaspidea
Family Pyramidellidae Gray, 1840

Genus *Odostomia* Fleming, 1813
Odostomia cf. *O. laevigata* d'Orbigny, 1842
Fig. 8.26

Remarks: The present geographic range of *O. laevigata* is from North Carolina to the West Indies. Abbott (1974) fur-

ther indicates that this species is ectoparasitic on other marine molluscs and worms.

Levels: Two widely separated samples, at 485 m (Oligocene) and 885 m (Lower Eocene). It seems possible that the lower occurrence is caved.

Genus *Turbonilla* Risso, 1826
Turbonilla cf. *T. emertoni* Verrill, 1882
Fig. 8.27, 8.28

Remarks: Verrill (1882) originally described *T. emertoni* from 500 m water depth off Massachusetts, suggesting an affinity for cool, deep water. Our very similar specimens are generally less than 2 mm in length.

Levels: 775, 755, 650, 635, 625, 620, 410, 210 m. Occurs in levels from Lower Eocene to Lower Miocene. The former finds may represent cavings from the lower Middle Eocene, where it is most plentiful.

Family Acteonidae d'Orbigny, 1842

Genus *Acteon* de Montfort, 1810
Acteon cf. *A. punctostriatus* (C.B. Adams, 1840)
Fig. 8.29

Remarks: *A. punctostriatus* is presently found from Massachusetts to Argentina, from the low tide line to 120 m. Most of our specimens are 1 to 2 mm in length. The shallow habitat of the modern form suggests that our variety may be present as a transported element in CP1 P-51's Tertiary section.

Levels: 660, 625, 530, 445, 200 m. Occurs sporadically from lower Middle Eocene up to Lower Miocene.

Family Cylichnidae A. Adams, 1850

Genus *Cylichna* Loven, 1846
Cylichna cf. *C. eburnea* Verrill, 1885
Fig. 9.10

Remarks: The modern geographic range of *C. eburnea* is along the eastern seaboard of the United States, to depth of about 150 m. Our very similar specimen is about 3.5 mm in length.

Levels: 495 m (upper Middle Eocene).

Family Retusidae Thiele, 1925

Genus *Retusa* Brown, 1827
Retusa sp.
Fig. 9.17

Remarks: This lone, badly damaged specimen is just over 1 mm in length.

Levels: 690 m (Lower Eocene).

Miscellaneous gastropods

Figs. 8.20, 8.25, 8.30, 8.31, 9.1 to 9.5

Remarks: These are damaged or juvenile specimens that have not been identified as to genus.

Levels: Found in most samples throughout the studied interval.

Class Scaphopoda Bronn, 1862**Family Dentaliidae Gray, 1834****Genus *Dentalium* Linné, 1758***Dentalium* cf. *D. callithrax* Dall, 1889

Fig. 7.9, 7.10

Remarks: *D. callithrax* is presently found from North Carolina to the West Indies, at depths of 400 to 3200 m. Our specimens are broken fragments, some as much as 13 mm in length.

Levels: 875, 830, 815, 800, 785, 755, 730, 720, 715, 705, 700, 685, 680, 670, 665, 660, 655, 640, 635, 485, 455, 435, 390, 385, 370, 355, 350, 230 m. Fairly common in the Oligocene and most of the Eocene.

Dentalium cf. *D. laqueatum* Verrill, 1885

Fig. 7.11, 7.12

Remarks: The modern distribution of *D. laqueatum* is the same as for *D. callithrax*, but in shallower water, from 8 to 400 m depth. Our single specimen is a 1 mm broken segment.

Levels: 685 m (topmost Lower Eocene).

Dentalium occidentale Stimpson, 1851

Fig. 7.20

Remarks: At present, *D. occidentale* is found from Newfoundland to North Carolina, at depths from 40 to 2000 m. It is one of the single most common molluscan taxa in the Cenozoic section of CP1 P-51, usually appearing as a smooth-walled, calcareous tube, round in cross-section, representing a fragment of a whole shell.

Levels: *D. occidentale* is found in most levels of the well, less commonly in the Lower Eocene and Paleocene.

Dentalium sp.

Fig. 7.13, 7.14

Remarks: Only fragments of this taxon occur, and it could be one of several species. It is round in cross-section, with 10 to 12 weak ribs, with concave spaces between them. Most fragments are only 1 to 2 mm in length.

Levels: 930, 630, 620, 245, 225, 205 m. A few specimens appear in levels from Eocene to Lower Miocene.

Family Siphonodentaliidae Simroth, 1894**Genus *Cadulus* Philippi, 1844***Cadulus* cf. *C. platensis* Henderson, 1920

Fig. 7.21

Remarks: Members of this genus exhibit bulbous swellings in the centre of the shell, and are all inhabitants of deep water in relatively low latitudes. *C. platensis* is now present from Georgia to Florida in depths to 1300 m. As with the other scaphopods, our specimens tend to be fragments of shells, in this species usually about 1 mm in length.

Levels: 910, 785, 675, 540 m. A few specimens, in Middle and Lower Eocene strata.

Class Uncertain**? Family Coleolidae Fisher, 1962****? Genus *Coleolus* Hall, 1879***Coleolus* sp.

Fig. 7.15, 7.16

Remarks: This form occurs as a tapering calcareous tube, with very fine, oblique striations. Our specimens are generally 1 to 2 mm in length. The known stratigraphic range of Hall's original enigmatic fossil is Silurian to Carboniferous and it is believed to represent a pelagic organism (Fisher, 1962). Syssoiev (1957) placed *Coleolus* in the Mollusca, on the basis of its apparent close resemblance to scaphopod shells, a similarity shared by our taxon.

There is a strong resemblance to Hall's (1879) *Coleolus*, with its oblique striations. In view of the known Paleozoic range of this genus, however, such an identification would have to be considered extremely tentative; therefore we consider our form to be an unrelated homeomorph.

Levels: Present in most samples from 990 to 665 m. Also 525, 510, 505, 490 and 465 m. Present in most Paleocene and Lower Eocene samples, less common in Middle Eocene and Oligocene sections.

Class Bivalvia**Order Nuculacea****Family Nuculidae Gray, 1824****Genus *Yoldia* (Moller, 1842)***Yoldia myalis* (Couthouy, 1838)

Fig. 9.14, 9.15

Remarks: Richards (1962) gives the present Atlantic range of *Y. myalis* as Labrador to Cape Cod. Abbott (1974) gives Hudson Strait to Massachusetts, 20 to 150 m. This is apparently a cool-water species.

Levels: 285, 235, 220, 215 m. A few specimens occur in or just below Lower Miocene sediments.

Genus *Portlandia* Morch, 1857*Portlandia* cf. *P. fraterna* (Verrill and Bush, 1898)

Fig. 9.16

Remarks: At present *P. fraterna* is found from the Gulf of St. Lawrence to Georgia, at depths of 200 to 3200 m. Our specimens are between 1 to 2 mm in length.

Levels: 235, 230, 220 m. Lower Miocene.

Taxodont hinge fragment

Fig. 9.20

Remarks: Numerous fragments of this type are found in several sections of the core.

Levels: 815, 710, 695, 615, 610, 595, 585, 485, 455, 400, 320, 305, 275, 255, 245, 240, 235, 225, 220, 210, 205, 200, 190 m. Eocene, Oligocene, and most commonly in Lower Miocene.

Order Arcacea**Family Arcidae Lamarck, 1809****Genus *Bathyarca* Kobelt, 1891***Bathyarca centenaria* (Say, 1824)

Fig. 9.18, 9.19

Remarks: Conrad (in Harris, 1893) reported *B. centenaria* from the Upper Tertiary (Miocene) of eastern North America. It is very similar to, and may be synonymous with *B. pectunculoides* (Scacchi), a species now found from the Gulf of St. Lawrence to Massachusetts, at depths of 50 to 1000 m. The few specimens in this site may be *in situ*, given the present depth range of the extant form.

Levels: 670, 650 m. A few specimens appear in two lower Middle Eocene samples.

Family Glycymerididae Newton, 1922**Genus *Glycymeris* da Costa, 1778***Glycymeris* cf. *G. americana* (DeFrance, 1826)

Fig. 9.21 to 9.24

Remarks: Richards (1962) gives the present distribution of *G. americana* as from North Carolina to the West Indies and Texas. Abbott (1974) gives the range as North Carolina to Brazil, 3 to 40 m water depth. Some of our specimens are up to 3 mm in diameter. This could well be a part of a transported fauna from warmer, neritic sources.

Levels: 740, 700, 690, 685, 675, 665, 660, 655, 650, 640, 630, 625, 620, 615, 610, 600, 595, 590, 575, 480, 460 m. Common in the lower Middle Eocene.

***Glycymeris* cf. *G. subtilis* (Nicol, 1956)**

Fig. 9.25, 9.26

Remarks: Abbott (1974) reports *G. subtilis* as from Bermudan waters, at 100 to 200 m depth. Our specimens average only 1 to 2 mm in size.

Levels: 655, 585, 380, 375, 355 m. Scattered specimens in Middle Eocene and Oligocene.

Indeterminate Glycymerid hinge fragment

Fig. 10.1, 10.2

Remarks: This 4-mm long hinge-line fragment appears to belong to the Glycymerid family.

Levels: 595 m (Middle Eocene).

Order Mytiloida**Family Mytilidae Rafinesque, 1815****Genus *Dacrydium* Torell, 1859***Dacrydium vitrium* (Holböll, in Möller, 1842)

Fig. 10.3, 10.4

Remarks: This wide-ranging species currently occurs from Greenland south to the Gulf of Mexico, in water from 12 to 3200 m depth. The excellent, "fresh" condition of the two specimens of this small, delicate species suggest that they may have been caved to their present positions from much younger, possibly Recent levels.

Levels: 925, 565 m (Eocene).

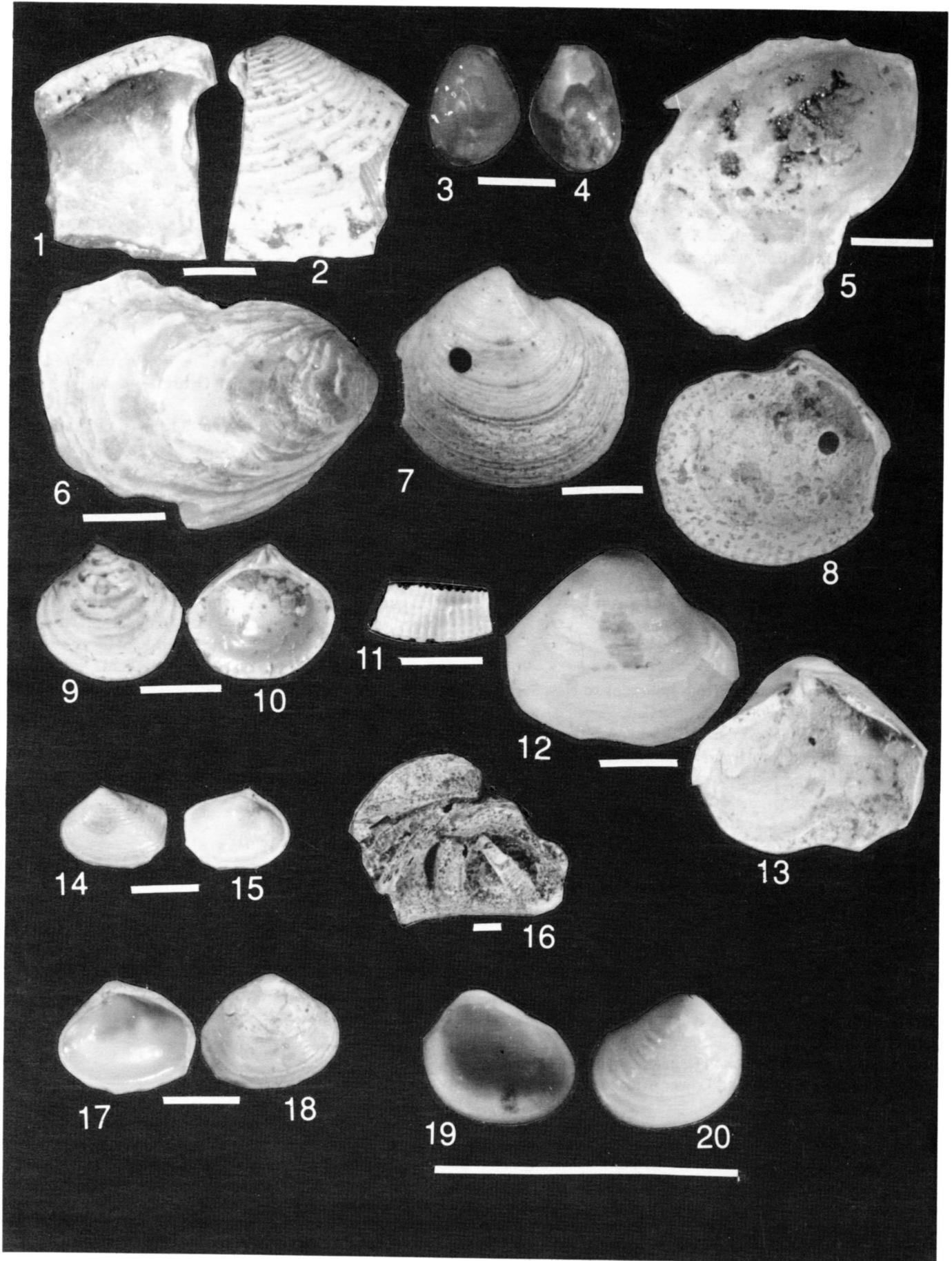
Order Pteroida**Family Ostreidae Rafinesque, 1815****Genus *Crassostrea* Sacco, 1897***Crassostrea* cf. *C. virginica* (Gmelin, 1791)

Fig. 10.5, 10.6

Remarks: The modern range of this well-known, edible species is from the Gulf of St. Lawrence to the West Indies, usually in less than 100 m of water. Our specimens appear identical to the modern form, but are obviously juvenile.

Levels: 710, 595, 590, 555 m. Few specimens, in Middle and Lower Eocene.

Fig. 10. Bivalves. Scale bar = 1 mm. (10.1, 10.2) Indeterminate Glycymerid hinge fragment from 595 m. GSC no. 78564. (10.3, 10.4) *Dacrydium vitreum* from 925 m. GSC no. 78565. 10.3 interior of valve, 10.4 exterior. (10.5, 10.6) *Crassostrea* cf. *C. virginica* from 595 m. GSC no. 78566. 10.5 interior of valve, 10.6 exterior. (10.7, 10.8) *Lucina* cf. *L. radians* from 210 m. GSC no. 78567. 10. exterior of valve, 10.8 interior. (10.9, 10.10) *Astarte* cf. *A. undata* 665 m. GSC no. 78568. 10.9 exterior of valve, 10.10 interior. (10.11) *Clinocardium* cf. *C. ciliatum* fragment from 595 m. GSC no. 78569. (10.12, 10.13) *Mulinia* cf. *M. lateralis* from 220 m. GSC no. 78570. 10.12 exterior of valve, 10.13 interior. (10.14, 10.15) *Tellina* cf. *T. agilis* from 195 m. GSC no. 78571. 10.14 exterior of valve, 10.15 interior. (10.16) *Mercenaria* cf. *M. mercenaria* hinge fragment 195 m. GSC 78572. Note pitted, corroded condition. (10.17, 10.18) *Liocyma* cf. *L. fluctuosa* from 220 m. GSC no. 78573. 10.17 interior of valve, 10.18 exterior. (10.19, 10.20) Indeterminate bivalve from 215 m. GSC no. 78574. 10.19 interior of valve, 10.20 exterior.



Order Heterodonta
Family Lucinidae Fleming, 1828

Genus *Lucina* Bruguiere, 1797
Lucina cf. *L. radians* Conrad, 1841
Fig. 10.7, 10.8

Remarks: Richards (1962) gives the current distribution of *L. radians* (= *Phacoides radians* (Conrad)) as North Carolina to the West Indies. Abbott (1974) agrees, giving a depth range of 10 to 170 m. This is another form normally associated with warm, shallow water, and so may be transported downslope in CP1 P-51.

Levels: 285, 245, 225, 220, 215, 210 m. Few specimens in Lower Miocene levels and just below.

Family Thyasiridae Dall, 1901

Indeterminate bivalve
Fig. 10.19, 10.20

Remarks: This 0.5 mm specimen is very similar to the genus *Thyasira*, but lacks the diagnostic folding.
Levels: 220 m (Lower Miocene).

Family Astartidae d'Orbigny, 1844

Genus *Astarte* J. Sowerby, 1816
Astarte cf. *A. undata* Gould, 1841
Fig. 10.9, 10.10

Remarks: *A. undata* ranges from Labrador to New Jersey, from 10 to 200 m water depth.

Levels: 700, 690, 665, 275, 245, 225 m. A few specimens of our closely related form occur at the Lower-Middle Eocene boundary and in and just below the Lower Miocene.

Family Carditidae Oken, 1818

Genus *Clinocardium* Keen, 1936
Clinocardium cf. *C. ciliatum* (Fabricius, 1780)
Fig. 10.11

Remarks: Feyling-Hansen (1955) gives the present geographic range of *C. ciliatum* as circum-Arctic, including Greenland to Massachusetts on the Atlantic coast, as does Richards (1962), and reports it to be more common in waters greater than 50 m depth.

Levels: 595, 190 m. A few small fragments appeared in widely scattered Middle Eocene and Lower Miocene levels.

Genus *Mulinia* Gray, 1837
Mulinia cf. *M. lateralis* (Say, 1822)
Fig. 10.12, 10.13

Remarks: Richards (1962), gives the present distribution of *M. lateralis* as New Brunswick to Texas and the West Indies. Abbott (1974) gives Maine to Florida, in shallow water. Our single, damaged specimen is about 3 mm in length.

Levels: 220 m (Lower Miocene).

Family Tellinidae de Blainville, 1814

Genus *Tellina* Linné, 1758
Tellina cf. *T. agilis* Stimpson, 1858
Fig. 10.14, 10.15

Remarks: The present range of *T. agilis* is from the Gulf of St. Lawrence south to coastal Georgia, in shallow water, subtidal to 100 m depth.

Levels: Few specimens at 195 and 215 m (Lower Miocene).

Family Veneridae Rafinesque, 1815

Genus *Mercenaria* Schumacher, 1817
Mercenaria cf. *M. mercenaria* (Linné, 1758)
Fig. 10.16

Remarks: *M. mercenaria*, commonly called the Northern Quahog, is a tolerant species today found from the Gulf of St. Lawrence to Florida, offshore, but usually in less than 100 m depth. Our specimens are all fragments, identifiable by their relative thickness and sometimes by the hinge structure, as in the figured specimen.

Levels: 470, 275, 265, 245, 240, 235, 230, 225, 220, 215, 205, 200, 195, 190, 180 m. One of the more common molluscs in Lower Miocene strata. Its few occurrences further down could be attributed to caving.

Genus *Liocyma* Dall, 1870
Liocyma cf. *L. fluctuosa* (Gould, 1841)
Fig. 10.17, 10.18

Remarks: In the modern Atlantic, the cool-water *L. fluctuosa* ranges from Greenland to Nova Scotia, in waters to 400 m depth and Feyling-Hansen (1955) reports it as circum-Arctic. Our single specimen is about 1.5 mm in length.

Levels: 220 m (Lower Miocene).