24. THE FORAMINIFERAL ISOTOPIC RECORD ACROSS THE EOCENE/OLIGOCENE BOUNDARY AT DEEP SEA DRILLING PROJECT SITE 540[1]

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ABSTRACT

We analyzed the oxygen and carbon isotopic composition of planktonic and benthic foraminifers picked from 13 late Eocene to late Oligocene samples from DSDP Site 540 (23°49.73′N, 84°22.25′W, 2926 m water depth) from the Gulf of Mexico. An enrichment occurs in ^{18}O of about 0.5 to 0.8‰ in both benthic foraminifers and surface-dwelling planktonic foraminifers between the latest Eocene and early Oligocene. This early Oligocene maximum is followed by lower ^{18}O values.

A 1.2‰ $\delta^{13}C$ decrease in both benthic and planktonic foraminiferal data occurs from the late Eocene to the late Oligocene. There is a correspondence of the ^{13}C signal to deep-sea records; however, the amplitude of this change is greater than previously seen in deep-sea cores, possibly as a result of proximity to terrestrial sources of carbon.

The covarying isotopic changes in both benthic and planktonic foraminifers suggest global causes, such as ice volume increases and increased terrestrial carbon input to the ocean. However, during the latter part of the record (early–late Oligocene), the increases in the benthic ^{18}O without accompanying increases observed with planktonic foraminifers suggest that changes in only one part of the system occurred; one potential explanation being a decrease in bottom-water temperatures without concomitant changes in the surface waters. The ^{18}O differences between species of planktonic foraminifers and the difference between planktonic and benthic ^{18}O data indicate that diagenesis problems are minimal. These preliminary results are encouraging given that these cores are partially lithified.

INTRODUCTION

A general enrichment in ^{18}O occurs throughout the Tertiary until very high amplitude variations and positive ^{18}O values are seen in the Pleistocene (Shackleton and Opdyke, 1973; Shackleton and Kennett, 1975; Savin et al., 1975; Savin, 1977). The Eocene–Oligocene ^{18}O enrichment has been variously interpreted to be the result of cooling and/or ice volume fluctuations (Shackleton and Kennett, 1975; Savin et al., 1975; Douglas and Savin, 1978; Matthews and Poore, 1980). Most isotopic studies on benthic and planktonic foraminifers show an increase of 0.5 to 1.0‰ in $\delta^{18}O$ around the middle to late Eocene boundary, followed by a similar enrichment near the Eocene/Oligocene boundary (Shackleton and Kennett, 1975; Savin et al., 1975). More detailed studies have shown that the enrichment near the Eocene/Oligocene boundary actually occurs in the earliest Oligocene (Kennett and Shackleton, 1976; Keigwin, 1980). The enrichment has been shown to occur in both benthic and planktonic foraminifers in higher latitude sites, whereas a lower latitude site has shown less isotopic change in planktonic foraminifers (Keigwin, 1980).

Difficulties in interpreting the data are a result of (a) diagenesis (Garrison, 1981); (b) uncertainties in the habitat of various species of planktonic foraminifers, especially when trying to compare taxa from the same level in the water column through time; (c) the generally short-lived range of planktonic foraminifers and the changing interaction of one taxon with other competitive and fast evolving planktonic foraminifers; and (d) the uncertainties that exist as to why foraminifers that live in the same environment secrete a test of a different isotopic composition (the so-called "vital effect" phenomenon). In general, isotopic measurements made on monospecific long-ranging taxa yield the best results.

We analyzed the oxygen and carbon isotopic composition of planktonic and benthic foraminifers picked from 13 samples spanning the late Eocene into the late Oligocene interval of Site 540 (23°49.73′N, 84°22.25′W, 2926 m water depth). This site was chosen for isotopic study because it was continuously cored and is buried to a depth of less than 300 m. The site is believed to have been continuously deposited above the calcium carbonate compensation depth (CCD). The location of this site is near the southeast United States; the data from this site can be compared and linked to a data set from the southeast United States continental margin (Belanger, unpublished data).

Biostratigraphic age control for Site 540 is taken from Site 540 report (this volume) and determinations made by M.-P, Aubry (personal communication, 1982). M.-P, Aubry examined Samples 540-25-1, 50–52 cm and 540-25-1, 79–82 cm, and determined them to belong to calcareous nannoplankton Zone NP23 (= CP17; early/late Oligocene); in Samples 540-25-2, 120–123 cm and 540-25-3, 46–51 cm, she determined them to belong to Zone NP22 (= CP16; earliest Oligocene). Samples below these were determined to be Eocene in age.

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METHODS

Raw sediment samples were dried, soaked in a calgon solution, disaggregated, and washed on a 63-μm sieve. Samples picked from a size fraction were roasted in a vacuum at 370°C for one hour. The samples were dissolved in phosphoric acid (50°C), and the resultant CO_2 and H_2O separated in a series of three distillations. This purified CO_2 was analyzed in a VG Micromass 602D mass spectrometer at the Benedum Stable Isotope Laboratory, Brown University. Results are reported in reference to PDB in standard δ notation (Craig, 1957), achieved through an intercalibration of three intermediate calcium carbonate powdered standards. Agreement between standards is $\pm 0.2‰$. Precision of carbonate standards run at the beginning and the end of each analytical session is ± 0.07 ($1\ \sigma$). One day's analyses were lost due to mechanical failure; this prevents reporting the lab's standard 10% duplicate results at this time.

Benthic foraminiferal isotopic analyses were performed on various species of the genus *Cibicidoides*, which were generally monospecific in each sample. In Holocene core top studies, this taxon has been shown to be a good interregional sensor for both the interregional $\delta^{18}O$ variations of seawater, and the $\delta^{13}C$ of ΣCO_2 of the modern ocean (Belanger et al., 1981; Graham et al., 1981). Three analyses on *Oridorsalis* spp. and two on *Hanzawaia cushmani* were also made.

Long-ranging planktonic foraminifers were chosen and size sorted (see Table 1) to be as consistent as possible with previous studies in the region (Belanger, unpublished data), and to be comparable to other Eocene and Oligocene studies (Keigwin, 1980; Poore and Matthews, 1984). Another important criterion in the selection of planktonic taxa to be analyzed was to utilize those taxa of proven utility in estimating surface-water conditions (Poore and Matthews, 1984). It is desirable to analyze taxa whose ranges overlap when attempting to determine whether the temporally changing taxa analyzed reflect consistent surface-dwelling conditions.

RESULTS

The results of this study are listed in Table 1, and shown in Figure 1. Table 2 lists the isotopic differences between selected taxa and *Globigerina ampliapertura* or *Globigerinatheka* spp. from three different studies. On the basis of this limited data, we accept *Pseudohastigerina* as a comparable surface-dwelling taxon to *Chiloguembelina*.

Both the surface planktonic *Chiloguembelina* and *Pseudohastigerina* data and the benthic *Cibicidoides* data show low $\delta^{18}O$ values in Core 26, and more positive values in Cores 24 and 25. There is a return to low $\delta^{18}O$ values in Cores 23 through 21 for planktonic surface dwellers, whereas the benthic data becomes correspondingly lighter in the upper part of Cores 24 and 23 before a subsequent enrichment in the upper part of Core 23 to Core 20. Both the planktonic and benthic trends covary during the late Eocene to early Oligocene and have their maximum ^{18}O values in the early Oligocene.

Table 1. Oxygen and carbon isotopic data for Hole 540.

Core-Section (interval in cm)	Depth (m)	Taxon	Size (μm)	$\delta^{18}O$ (‰ PDB)	$\delta^{13}C$ (‰ PDB)
20-2, 86–89	177.86	*Cibicidoides* spp.		1.52	0.24
21-2, 67–70	187.17	*Cibicidoides* spp.		1.46	0.57
		Oridorsalis spp.		1.60	−0.58
		Chiloguembelina cubensis	125–150	−0.74	0.46
22-1, 37–41	194.87	*Cibicidoides* spp.		1.57	0.94
		C. cubensis	125–150	−0.37	0.89
23-1, 49–52	204.49	*Cibicidoides* spp.		1.69	0.83
		Oridorsalis spp.		1.26	−0.92
		Hanzawaia cushmani		1.51	0.94
		C. cubensis	125–150	−0.77	0.68
23-3, 59–62	207.59	*Cibicidoides* spp.		1.23	0.94
		Oridorsalis spp.		1.51	−0.10
		C. cubensis	125–150	−0.87	1.09
24-1, 50–53	214.00	*Cibicidoides* spp.		1.05	0.50
		C. cubensis	125–150	−0.26	1.03
24-3, 48–51	216.98	*Cibicidoides* spp.		1.29	0.78
		C. cubensis	125–150	−0.43	0.88
24-5, 45–48	219.95	*Cibicidoides* spp.		1.33	0.95
		C. cubensis	125–150	−0.43	1.16
		Globigerina ampliapertura	250–300	−0.05	1.19
25-1, 50–52	223.50	*Cibicidoides* spp.		1.33	0.97
		C. cubensis	125–150	0.04	1.22
25-3, 46–51	226.46	*Cibicidoides* spp.		1.40	1.45
		H. cushmani		1.22	1.65
		C. cubensis	125–150	−0.38	1.20
26-1, 51–54	233.01	*Cibicidoides* spp.		0.73	1.06
		Globigerinatheka spp.	250–300	−0.07	0.82
		Globigerinatheka spp.	250–300	0.02	1.06
		Hantkenina sp.	250–300	0.22	1.40
26-1, 137–140	233.87	*Cibicidoides* spp.		1.07	1.46
		G. ampliapertura	250–300	−0.07	1.56
		Globigerinatheka spp.	250–300	0.15	1.07
		Pseudohastigerina sp.	125–150	−0.80	0.71
26-3, 64–67	236.14	*Cibicidoides* spp.		1.03	1.51
		G. ampliapertura	250–300	−0.61	1.39
		Globigerinatheka spp.	250–300	−0.04	1.25

Note: Size analyzed is indicated for planktonic taxa; the greater-than-150-μm size fraction was analyzed for benthic foraminifers.

DISCUSSION

Cibicidoides is the best sensor of bottom water conditions, with respect to both $\delta^{18}O$ and $\delta^{13}C$ (Belanger et al., 1981; Graham et al., 1981). The two preliminary data points on *Hanzawaia cushmani* are in close agreement with *Cibicidoides* data, suggesting that *Hanzawaia* may be another good sensor of bottom water conditions.

The *Cibicidoides* data show that an enrichment in ^{18}O of about 0.5‰ occurs somewhere within the latest Eocene and early Oligocene interval. In previous studies, this enrichment has been shown to occur in the earliest Oligocene (Kennett and Shackleton, 1976; Keigwin, 1980). This interval is not sampled and/or not recovered at this site. A second enrichment in *Cibicidoides* ^{18}O at Site 540 occurs in the late early Oligocene.

The benthic carbon isotopic signal has a relatively large range of 1.2‰. The highest values are in the late Eocene and early Oligocene, continually decreasing to a minimum in the latest sample studied (Zone P21a; Zone CP18). This trend is in general agreement, although with a 1.0‰ more positive offset, with the isotopic data recorded in continental margin Site ASP-5B off the North Carolina coast (Belanger, unpublished data). The carbon isotopic range of both the ASP-5B study (1.7‰; Belanger, unpublished data) and this study (1.2‰) is comparable, although amplified, relative to other deep-sea records (Keigwin, 1980; Miller and Curry, 1982; Poore and Matthews, in press). This may be a reflection of the sites being nearer to terrestrial sources of carbon, especially at ASP-5B.

The planktonic foraminifer taxa with the lowest $\delta^{18}O$ are assumed to be surface dwellers, such as *Chiloguembelina* and *Pseudohastigerina*. The $\delta^{18}O$ data on other planktonic foraminifers measured in this study suggest they live in a somewhat deeper habitat. The limited data on *Chiloguembelina* and *Pseudohastigerina* show an enrichment in ^{18}O in surface waters of approximately 0.5 to 0.8‰ from the late Eocene to early Oligocene. This is in contrast to an overall enrichment of only 0.3‰ for surface waters as determined by Keigwin (1980) at Site 292 in the tropical Philippine Sea.

The data in Figure 1 show good separation of planktonic ^{18}O among various taxa. Further, the covariance of planktonic and benthic ^{18}O and the continued isotopic separation of the two groups suggest that diagenetic alter-

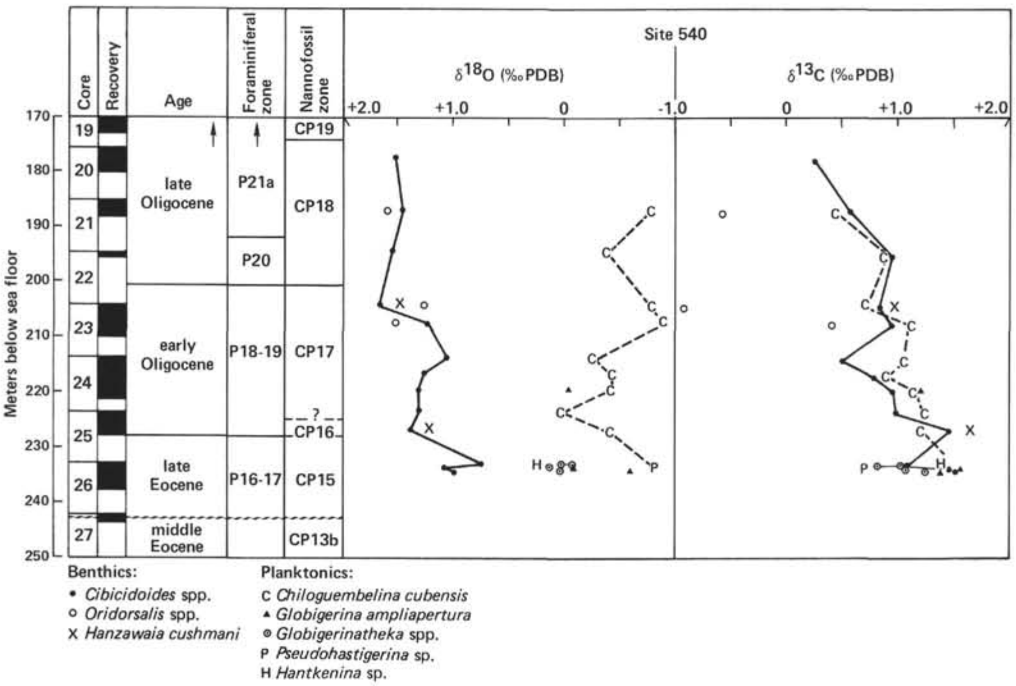

Figure 1. Stable isotopic record for the late Eocene to late Oligocene at Site 540, Gulf of Mexico. Note the maximum ^{18}O values in the Oligocene. The planktonic foraminiferal maximum in the late Oligocene is the result of measurements on deeper-dwelling taxa (see text).

Table 2. Isotopic comparison of some taxa to *Globigerina ampliapertura* and *Globigerinatheka* from three different studies

No. compared	Taxon	Taxon: *G. ampliapertura* $\delta^{18}O$	$\delta^{13}C$	Taxon: *Globigerinatheka* $\delta^{18}O$	$\delta^{13}C$
2	*Pseudohastigerina barb.*[a]	−0.12	−0.63		
5	*Chiloguembelina cubensis*[a]	−0.10 ± 0.2	−0.43 ± 0.2		
1	*C. cubensis*[b]	−0.21	−0.11		
3	*Pseudohastigerina* sp.[b]	−0.18	−0.89		
1	*Pseudohastigerina* sp.[b]			−0.46	−1.06
1	*C. cubensis*[c]	−0.38	−0.03		
1	*Pseudohastigerina*[c]	−1.15	−0.36		
2	*Globigerinatheka*[c]	+0.39	−0.32		

[a] Poore and Matthews (1984).
[b] Belanger (unpublished data).
[c] This study.

ation is minimal. Despite the observed induration of sediments seen at this site, this site shows promise for more detailed analyses.

CONCLUSIONS

With the limited data of this study, we show that an enrichment occurs in ^{18}O of about 0.5 to 0.8‰ in both benthic foraminifers and surface-dwelling planktonic foraminifers between the latest Eocene and early Oligocene. This early Oligocene maximum is followed by lower ^{18}O values in the late early Oligocene.

A 1.2‰ $\delta^{13}C$ decrease in both benthic and planktonic foraminiferal data occurs from the late Eocene to the late Oligocene. There is a correspondence of the ^{13}C signal to deep-sea records; however, the amplitude of this change is greater than previously seen in deep-sea cores.

The closeness of *Hanzawaia* to *Cibicidoides* $\delta^{13}C$ and $\delta^{18}O$ tentatively suggest that the genus *Hanzawaia* may be a genus of comparable utility as *Cibicidoides* for Paleogene analyses.

The ^{18}O differences between species of planktonic foraminifers and the difference between planktonic and benthic ^{18}O data indicate that diagenesis problems are minimal. These preliminary results are encouraging, because these cores are partially lithified.

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