47. DETAILED STABLE ISOTOPE AND CARBONATE RECORDS FROM THE UPPER MAESTRICHTIAN–LOWER PALEOCENE SECTION OF HOLE 516F (LEG 72) INCLUDING THE CRETACEOUS/TERTIARY BOUNDARY[1]

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ABSTRACT

A detailed oxygen and carbon isotope study of the upper Maestrichtian–lower Paleocene section of Hole 516F from the Rio Grande Rise reveals that large isotopic anomalies are clearly associated with the Cretaceous/Tertiary boundary. Across the Cretaceous/Tertiary boundary, the total carbonate content reaches a maximum exceeding 80% before rapidly decreasing in covariance with the carbon isotope record. This strong covariance between $\delta^{13}C$ and percent $CaCO_3$ suggests either a significant reduction in primary productivity or a rapid shoaling of the calcium carbonate compensation depth. Importantly, the $\delta^{13}C$ record 2 Ma after the Cretaceous/Tertiary boundary remained depleted in ^{13}C by at least 0.5‰ compared to the late Maestrichtian.

INTRODUCTION

One of the major objectives of the Leg 72 drilling effort was the recovery of older sedimentary sections with which to reconstruct the paleoenvironmental history of the southwestern Atlantic. Initial shipboard analysis, later confirmed by shore-based biostratigraphic surveys (Pujol, this volume; site chapter, Site 516, this volume), indicated that a continuous depositional record had been recovered across the Cretaceous/Tertiary boundary within Core 516F-89. The boundary interval contains the *Micula mura* (upper Maestrichtian) and *Markalius inversus* (NP1) calcareous nannofossil zones and the lowermost Danian *Globigerina eugubina* and uppermost Maestrichtian *Globotruncana contusa* planktonic foraminiferal zones. Placement of the exact boundary in Section 516F-89-5 using the two microfossil groups agrees within 5–6 cm (516F-89-5, 33.5 cm based on the nannofossils; 516F-89-5, 26–28 cm based on the planktonic foraminifers). Preliminary biostratigraphic survey of the immediate boundary interval indicates moderate to severe dissolution of the foraminifers. We therefore undertook an initial stable isotope (oxygen and carbon) study of the bulk carbonate fraction of Cores 88, 89, and 90 of Hole 516F before the analyses of individual foraminiferal species from the upper Maestrichtian and lower Paleocene sections.

Site 516 is located in 1313 m of water on the northeastern flank of the Rio Grande Rise (Fig. 1). Hole 516F was washed to a sub-bottom depth of 169 m and then rotary-cored continuously to a depth of 1270.6 m. All core numbers in this paper refer to cores from Hole 516F. Core 89, which contains the Cretaceous/Tertiary boundary, was cored at a sub-bottom depth of 959 m. According to X-ray diffraction of the bulk sample powders, the carbonate mineralogy is almost entirely low-magnesium calcite in Cores 88 to 90.

MATERIALS AND METHODS

Cores (88, 89, 90) containing lower Paleocene and upper Maestrichtian sediments were sampled at roughly 20-cm intervals. Before samples were processed for micropaleontologic studies, approximately 0.5 g of unprocessed sediment was removed from each 5-cm^3 sample for stable isotopic and total calcium carbonate determinations. The sediment was dried and ground to a powder. Aliquots of the powder were precisely weighed and analyzed for total calcium carbonate content by a modified Hulseman technique. Duplicate analyses yielded a precision of better than ±2% (Table 1).

Stable oxygen and carbon isotopic analyses were performed on additional aliquots (0.5–1.0 mg) of the same powders (Williams et al., 1977). Briefly, the powder is roasted at 380°C in vacuo for 1 hour before acidification in purified phosphoric acid held at a constant 50°C in vacuo. The isotopic composition of the evolved CO_2 gas is compared with a reference CO_2 whose composition is known relative to the CO_2 gas from the PDB standard (Epstein et al., 1953). The data (Table 1) are presented in the standarized delta (δ) notation as per mil (‰) enrichments or depletions in ^{18}O or ^{13}C respectively. Replicate analyses of the powders yielded a precision (1 σ about the mean) of better than ±0.1 for both $\delta^{18}O$ and $\delta^{13}C$ values.

RESULTS

The $\delta^{18}O$, $\delta^{13}C$, and $CaCO_3$ records for Cores 88 to 90 are plotted relative to sub-bottom depth of Hole 516F in Figure 2. The $\delta^{18}O$ values for the bulk $CaCO_3$ range from −1.5 to −3.2‰ and exhibit several long-term and numerous short-term changes. In the upper Maestrichtian from Section 516F-90-6 to the lower part of Section 516F-90-1, $\delta^{18}O$ values decrease steadily by approximately 1‰; at least five rapid 0.5‰ decreases occur along this trend. From Section 516F-90-1 to a level near the Cretaceous/Tertiary boundary in Section 516F-89-5, $\delta^{18}O$ values increase by ~1‰ with four rapid 0.5‰ increases. In the lower Paleocene, represented by planktonic foraminiferal Zone Pl, the long term $\delta^{18}O$ trend is again toward lighter values with five to six rapid fluctu-

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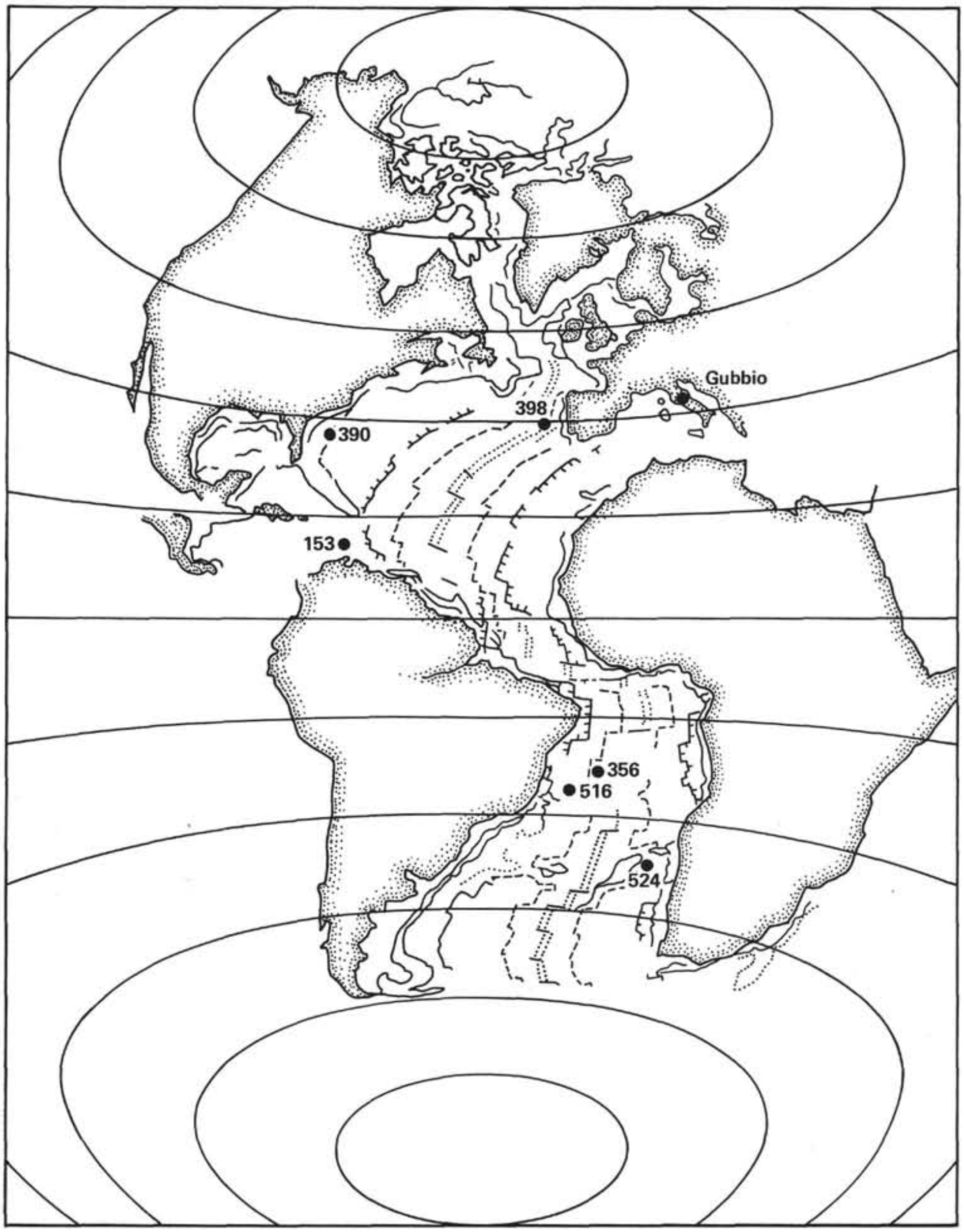

Figure 1. Reconstruction of the Atlantic Ocean at 65 Ma, showing the location of Site 516 and other DSDP sites or land-based sections (Gubbio) for which stable isotope data are available across the Cretaceous/Tertiary boundary. Site 153, Anderson and Schneidermann, 1973; Site 390, Létolle et al., 1978; Site 356, Thierstein and Berger, 1978; Site 398, Létolle, 1979, and Arthur and others, 1979; Site 524, Hsü et al., 1982; Gubbio section, Scholle and Arthur, 1980.

ations of magnitudes ranging from 0.5 to 1.5‰ (Fig. 2). In planktonic foraminiferal Zone P2 of Core 88, $\delta^{18}O$ values become steadily more positive again and exhibit very little short-term change.

The character of the carbon isotope record is quite different from the trends exhibited in the $\delta^{18}O$ record (Fig. 2). The total range in $\delta^{13}C$ values (2.3‰, from 0.5 to 2.8‰) is slightly greater than that of the $\delta^{18}O$ record (1.7‰), and the largest change is clearly associated with the Cretaceous/Tertiary boundary. In the upper Maestrichtian section from Sections 516F-90-6 to 516F-89-5, the $\delta^{13}C$ values are remarkably constant, varying less than 0.5‰ about a mean value of 2.4‰. A dramatic 1.8‰ depletion in ^{13}C occurs across the Cretaceous/Tertiary boundary from Section 516F-89-5 into 516F-89-4. The $\delta^{13}C$ values then increase steadily in the upper Paleocene, but the values in foraminiferal Zone P2 of Core 88 remain depleted in ^{13}C by at least 0.5‰ relative to the mean $\delta^{13}C$ value for the upper Maestrichtian (Fig. 2).

The character of the total calcium carbonate record is distinctly different from that of the two isotope records (Fig. 2). During the late Maestrichtian, the sediment of Hole 516F had a mean total $CaCO_3$ content of 70% and

Table 1. Oxygen and carbon isotopic results and percent calcium carbonte of bulk carbonate from Hole 516F.

Core-section (interval in cm)	$\delta^{18}O$	$\delta^{13}C$	$CaCO_3$ (%)
88-1, 10–11	−2.11 ± 0.21 (2)	1.77 ± 0.03 (2)	74.6
29–31	−2.25	1.87	85.2[a]
49–51	−2.08	1.78	80.7
69–70	−2.22 ± 0.04 (2)	1.83 ± 0.01 (2)	87.1
89–91	−2.19	1.84	81.5
110–112	−2.14	1.90	79.5
130–132	−2.13	1.84	79.9
148–150	−2.29	1.89	81.6
88-2, 18–20	−2.33	1.80	81.7
38–40	−2.23 ± 0.17 (2)	1.85 ± 0.00 (2)	79.6
59–61	−2.33	1.78	84.5
78–79	−2.32	1.80	81.2
97–99	−2.45	1.69	87.6
120–122	−2.52	1.74	80.4
140–142	−2.47 ± 0.14 (2)	1.80 ± 0.04 (2)	79.4
88-3, 10–12	−2.45	1.54	59.6
28–30	−2.56	1.87	70.0
51–53	−2.48	1.76	77.2
89-1, 19–21	−2.82	1.30	52.8
39–41	−2.80	1.35	49.4
59–60	−3.06	1.41	67.8
79–81	−2.94 ± 0.06 (2)	1.43 ± 0.01 (2)	76.0
100–101	−2.92	1.43	76.1
119–121	−3.25 ± 0.01 (3)	1.46 ± 0.01 (3)	60.5
140–141	−2.84	1.43	51.1
89-2, 10–12	−2.69	1.59	67.1
29–31	−2.77	1.62	65.8
49–50	−3.00	1.40	47.6
69–71	−3.22 ± 0.05 (2)	1.43 ± 0.01 (2)	67.7
89–91	−3.18	1.40	55.0
110–112	−3.00	1.45	65.8
126–127	−2.28 ± 0.38 (2)	1.65 ± 0.05 (2)	77.5
147–149	−2.84 ± 0.01 (3)	1.49 ± 0.04 (3)	85.2
89-3, 21–23	−2.27 ± 0.23 (2)	1.59 ± 0.01 (2)	86.4
40–43	−2.92	1.39	67.1
58–60	−2.49 ± 0.03 (2)	1.24 ± 0.00 (2)	28.8
78–80	−2.83 ± 0.06 (3)	1.35 ± 0.03 (3)	51.4
99–100	−2.44 ± 0.33 (3)	1.27 ± 0.08 (3)	35.7
118–122	−1.91 ± 0.04 (2)	0.97 ± 0.14 (2)	23.8
141–143	−3.02	0.99	31.7 ± 1.3 (2)
89-4, 9–11	−2.95	1.04	38.5
30–32	−3.15	1.21	75.9
50–52	−2.66	0.91	40.7
67–69	−2.64	0.98	31.2
90–92	−1.92 ± 0.16 (2)	0.73 ± 0.16 (2)	11.9
110–112	−2.11 ± 0.00 (2)	1.26 ± 0.04 (2)	29.1
130–132	−3.00	1.57	85.2
149–150	−2.79	1.74	88.9
89-5, 18–19	−2.55	1.76	83.2
44–46	−2.18 ± 0.07 (2)	2.44 ± 0.04 (2)	74.5 ± 8.2 (2)
63–64	−1.89 ± 0.23 (3)	2.30 ± 0.07 (3)	74.5
82–84	−1.98	2.34	60.5
100–103	−1.98	2.34	64.8
122–124	−2.35 ± 0.00 (2)	2.26 ± 0.01 (2)	63.4
140–143	−2.07	2.24	56.2
89-6, 8–10	−2.21	2.46	47.3
27–30	−1.96	2.47	52.0 ± 3.6 (2)
50–52	−2.31	2.31	70.8
69–70	−2.51	2.48	86.7
90–92	−2.42	2.36	40.8
109–110	−2.31	2.28	78.4
130–132	−2.36	2.28	50.3
146–147	−2.54	2.39	71.3
90-1, 10–12	−2.80	2.11	77.1
30–32	−2.73	2.10	80.5
49–51	−2.44	2.09	54.3
70–72	−2.96	2.30	74.8
90–92	−2.96 ±0.18 (2)	2.18 ± 0.02 (2)	74.4
109–111	−2.75	2.30	70.8
130–132	−2.95	2.23	75.0
90-2, 8–11	−2.37	2.30	51.4
30–32	−2.76	2.26	72.9
50–52	−2.50	2.28	56.7
70–73	−2.58	2.26	78.1

Table 1. (Continued).

Core-section (interval in cm)	$\delta^{18}O$	$\delta^{13}C$	$CaCO_3$ (%)
90-2, 90–92	−2.49	2.39	75.7
110–112	−2.60 ± 0.01 (2)	2.37 ± 0.05 (2)	73.5
130–133	−2.72	2.30	71.4
148–149	−2.44	2.41	73.1
90-3, 20–22	−2.16	2.52	77.5
37–39	−2.31	2.33	73.4
60–62	−2.51	2.56	76.2
82–84	−2.56	2.32	79.0
99–102	−0.238	2.74	66.6
120–122	−2.14 ± 0.08 (2)	2.43 ± 0.01 (2)	77.4
139–141	−2.01	2.51	46.7
90-4, 9–11	−2.17	2.40	78.1
30–32	−2.06	2.41	64.2
50–52	−2.15 ± 0.20 (2)	2.43 ± 0.08 (2)	82.2 ± 1.0 (2)
70–72	−2.28	2.29	79.3
90–91	−2.53 ± 0.01 (2)	2.23 ± 0.02 (2)	68.2
110–112			32.6
130–132	−2.41	2.57	77.8
147–149	−2.24	2.34	82.8
90-5, 20–22	−1.74	2.39	67.6
38–40	−2.08	2.29	83.6
60–62	−1.65 ± 0.15 (3)	2.33 ± 0.01 (3)	56.2 ± 3.0 (2)
80–82	−2.04 ± 0.17 (2)	2.34 ± 0.08 (2)	26.5
100–102	−2.08 ± 0.06 (2)	2.31 ± 0.08 (2)	78.2
120–122	−1.55	2.40	71.0
141–143	−1.64 ± 0.16 (2)	2.39 ± 0.01 (2)	55.4
90-6, 11–13	−1.76	2.12	84.5
30–32	−1.69	2.27	76.2 ± 3.2 (2)
50–52	−2.42	2.33	77.0
70–72	−2.00	2.35	54.1

Note: Numbers in parentheses indicate number of determinations. Oxygen and carbon isotope values in ‰ to the PDB standard. All $\delta^{13}C$ values are positive numbers.

[a] Sample 516F-88-1, 24 cm.

underwent at least two rapid $CaCO_3$ decreases exceeding 40% (indicated by two lower arrows). However, no long-term trends are discernible. In Section 516F-89-6 across the Cretaceous/Tertiary boundary into the lowest Paleocene of Section 516F-89-5, the total $CaCO_3$ undergoes a steady increase to a maximum of 82%. At this point, two prominent $CaCO_3$ minima occur, representing decreases of 80 and 70% respectively (two upper arrows, Fig. 2). After recovering at the boundary of Sections 2 and 3 of Core 89, the remainder of the lower Paleocene record is characterized by 10–20% fluctuations about mean $CaCO_3$ contents of 70–80%.

A detailed plot of the three geochemical indexes through the upper Maestrichtian and lower Paleocene sections of Core 89 illustrates the relationships between the records across the Cretaceous/Tertiary boundary (Fig. 3).

First, however, a brief lithologic examination of Core 89 is warranted, because lithification, recrystallization, drilling disturbance, and other sedimentologic properties may be important in the interpretation of the isotopic and carbonate records. As is shown in Figure 3, Core 89 is primarily a calcareous nannofossil chalk with only six marly intervals and minimal signs of bioturbation. Biostratigraphic identification of the Cretaceous/Tertiary boundary in the upper part of Section 516F-89-5 is well below the first of three closely spaced marly intervals in which $CaCO_3$ contents decrease to 10, 23,

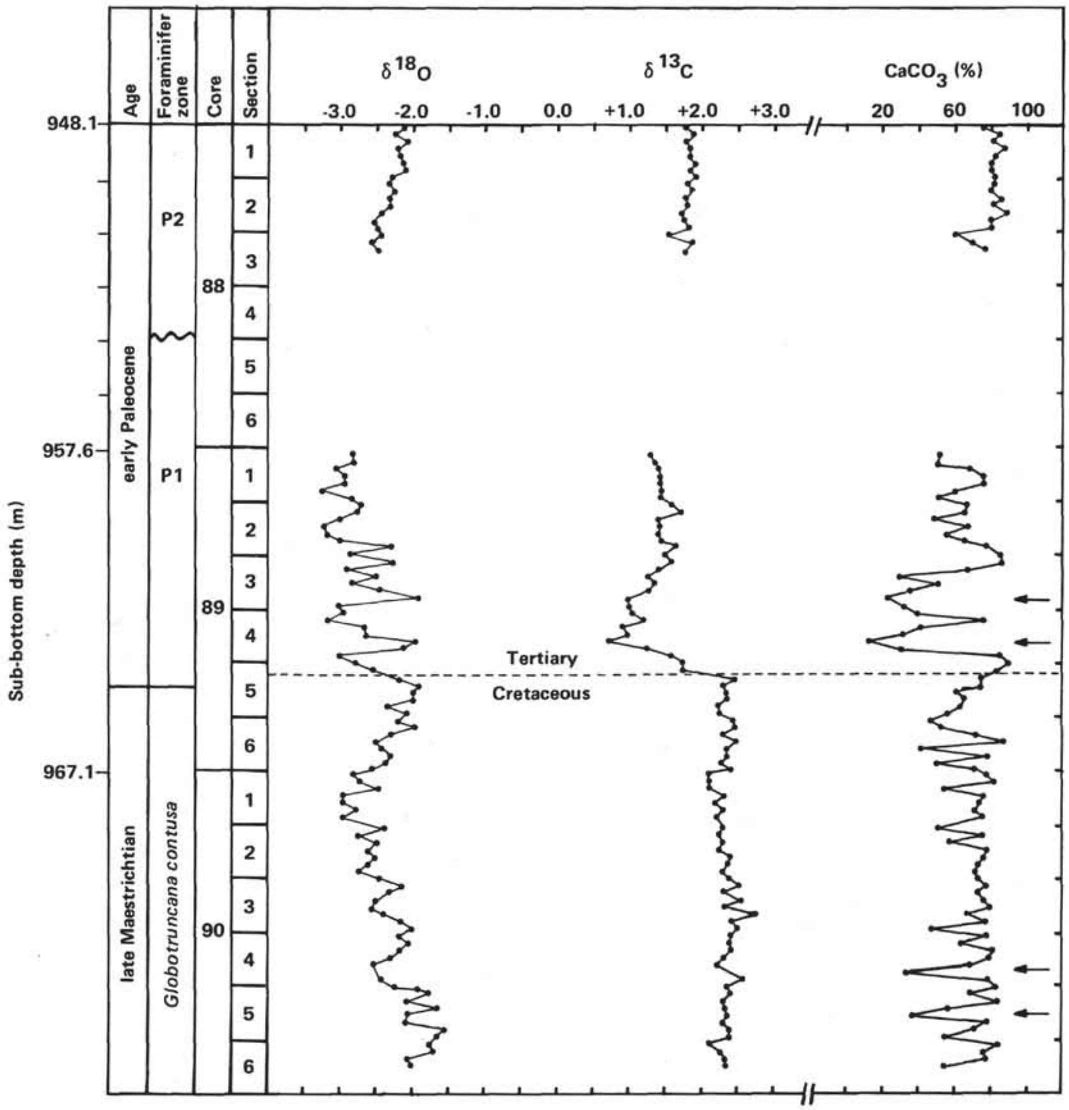

Figure 2. Oxygen isotope, carbon isotope, and total calcium carbonate records for the upper Maestrichtian–lower Paleocene section of Hole 516F (Cores 89, 89, 90). All analyses are based on bulk sediment; $\delta^{18}O$ and $\delta^{13}C$ values in ‰, to the PDB standard. The position of the Cretaceous/Tertiary boundary is placed at 516F-89-5, 30 cm, between the Cretaceous/Tertiary boundaries as defined by the calcareous nannofossils and planktonic foraminifers. Arrows indicate rapid $CaCO_3$ changes.

and 30%, respectively. The potential influence of diagenesis on the $\delta^{18}O$ signal cannot be unequivocally ruled out at this time, however.

A lead-lag relationship appears to exist among the records (Fig. 3). Approximately 40 cm below the Cretaceous/Tertiary boundary, as determined from the calcareous nannofossils, the $\delta^{18}O$ record begins a prominent decrease of >1.2‰ across the boundary. The start of this ^{18}O depletion precedes the beginning of the 1.8‰ ^{13}C depletion across the Cretaceous/Tertiary boundary by 20 cm. Both of these isotopic depletions occur within the broad $CaCO_3$ maximum (>70%) spanning the Cretaceous/Tertiary boundary and precede the major $CaCO_3$ drop of 80% in the lower Paleocene by a significant interval of 60–80 cm (Fig. 3). The carbonate minimum of 10% in Section 516F-89-4 coincides precisely with the most depleted $\delta^{13}C$ value, and both these minima occur at a time when the $\delta^{18}O$ values have become 1‰ more positive. Although the $CaCO_3$ record shows little correlation with the carbon isotope record below the Cretaceous/Tertiary boundary, they exhibit a high degree of covariance (low $CaCO_3$, less positive $\delta^{13}C$ values) throughout the Paleocene section of Core 89. Intervals where the correspondence is particularly strong can be seen in Figure 3. The significance of this relationship is illustrated by a $CaCO_3/\delta^{13}C$ plot for Core 89 (Fig. 4), which clearly shows that below the Cretaceous/Tertiary boundary, $\delta^{13}C$ values are systematically positive regardless of carbonate content and that, above the boundary, a strong linear correlation ($r = 0.84$; $r^2 = 0.71$) exists between low $CaCO_3$ and less positive $\delta^{13}C$ values. A $CaCO_3/\delta^{18}O$ plot for Core 89 (Fig. 5) shows that no such relationship exists between the $\delta^{18}O$ and $CaCO_3$ values with regard to stratigraphic position above and be-

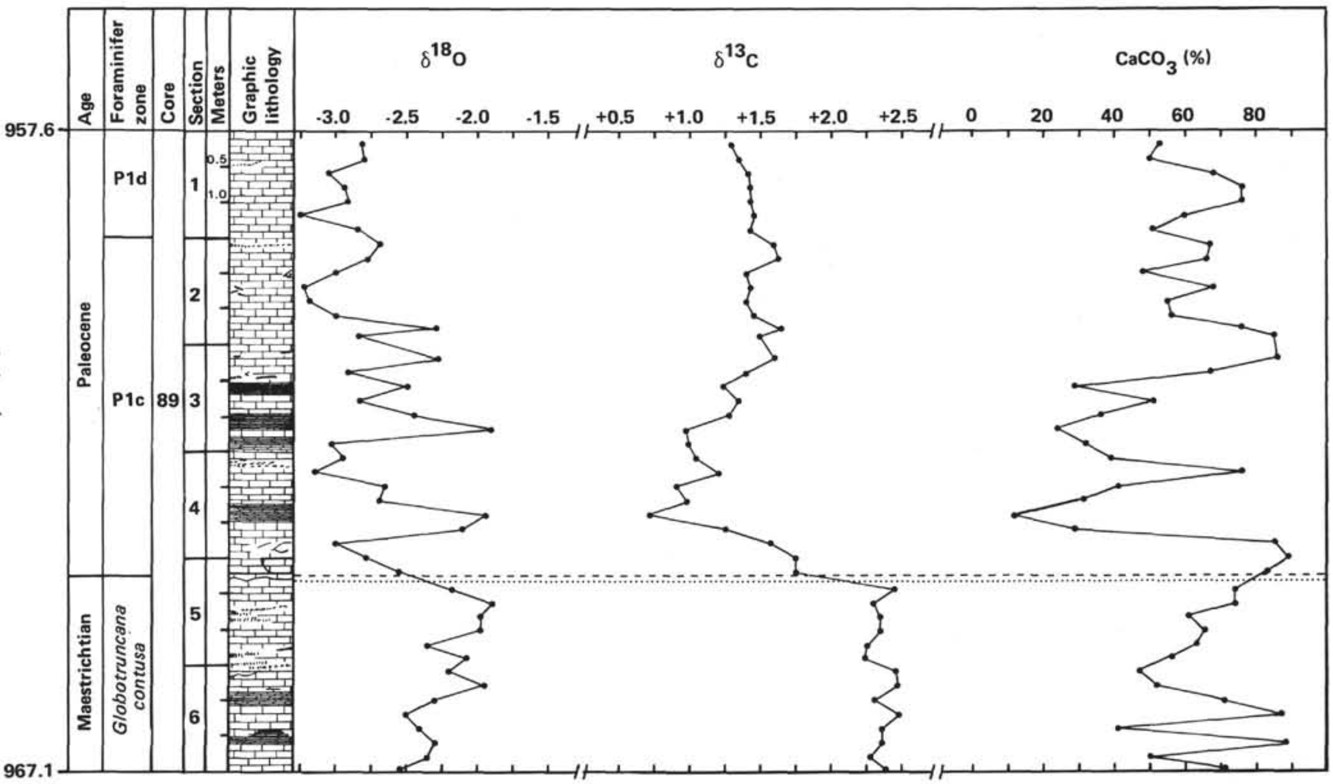

Figure 3. Detailed $\delta^{18}O$, $\delta^{13}C$, and $CaCO_3$ plots for Core 516F-89, across the Cretaceous/Tertiary boundary showing both the graphic lithology and the placement of this boundary according to the calcareous nannofossils (dotted line) and planktonic foraminifers (dashed line). Oxygen and carbon isotope values in ‰, to the PDB standard. Key for graphic lithology given in Explanatory Notes chapter (Coulbourn, this volume).

low the Cretaceous/Tertiary boundary. More importantly, perhaps, more negative $\delta^{18}O$ values above the Cretaceous/Tertiary boundary are associated with high carbonate values and not vice versa (except in the case of a few samples, which are identified by asterisks in Fig. 5). Early or late cementation of the chalk, however, may still have had an effect on the $\delta^{18}O$ values during the high carbonate intervals (Arthur, pers. comm., 1982).

Figure 3, shows that, above a 60-cm interval across the Cretaceous/Tertiary boundary in Sections 516F-89-5 and 516F-89-4 where the $\delta^{18}O$ and $\delta^{13}C$ records are both becoming negative, the $\delta^{18}O$ record undergoes a significant 1‰ ^{18}O enrichment as the $\delta^{13}C$ record continues to decrease. The $\delta^{18}O$ record continues to exhibit rapid 0.5–1.3‰ positive and negative events, whereas the $\delta^{13}C$ record begins a gradual increase but does not achieve values as positive as those characteristic of preboundary samples (Fig. 3). Additionally, little direct correlation is evident between individual fluctuations in the $\delta^{18}O$ and $CaCO_3$ records, although somewhat of a general trend exists toward more negative $\delta^{18}O$ and higher $CaCO_3$ values in Sections 1 to 3 of Core 89.

DISCUSSION: IMPLICATIONS OF THE DATA

The stable isotope and carbonate records from the late Maestrichtian–early Paleocene section of Hole 516F clearly imply that significant changes in productivity occurred in the South Atlantic during this critical time in earth history. An age model was constructed using the known ages of the biostratigraphic boundaries to approximate rates and duration of these changes (Fig. 6). Sedimentation rates for the early Paleocene section were estimated using principally the planktonic foraminiferal zonations from the shipboard analysis of Pujol (this volume; see also site chapter, Site 516, this volume). Absolute ages for the top of Zones P3, P2, and P1 were taken from Hardenbol and Berggren (1978) as 58, 60, and 62 Ma, respectively. The Cretaceous/Tertiary boundary was assumed to be at 65 Ma and located at 516F-89-5, 30 cm, midway between the planktonic foraminiferal and calcerous nannofossil datum levels. In the Late Cretaceous section of Hole 516F, the late Maestrichtian/early Maestrichtian boundary between Cores 92 and 93 was assumed to be 67.5 Ma, as used by other authors (Arthur et al., 1979). This age model is preliminary and subject to revision as detailed biostratigraphic and paleomagnetic data become available and accumulation rate estimates can be made using the bulk density determinations.

According to our age model, the upper 900,000 yr. of the late Maestrichtian is represented by our data, with a sample spacing of approximately 20,000 yr. (Fig. 6). Only the $\delta^{18}O$ record showed any trends through this interval with an apparent warming (depleted values) near 65.3 Ma and two relative cold periods at 65.8 Ma and just before the Cretaceous/Tertiary boundary. The $\delta^{18}O$ and $\delta^{13}C$ changes that are associated with the Cretaceous/Tertiary boundary actually preceded the boundary by ~60,000 and ~20,000 yr. respectively. The shift toward lighter $\delta^{13}C$ values continued for more than 100,000 yr. after the Cretaceous/Tertiary boundary, and then the

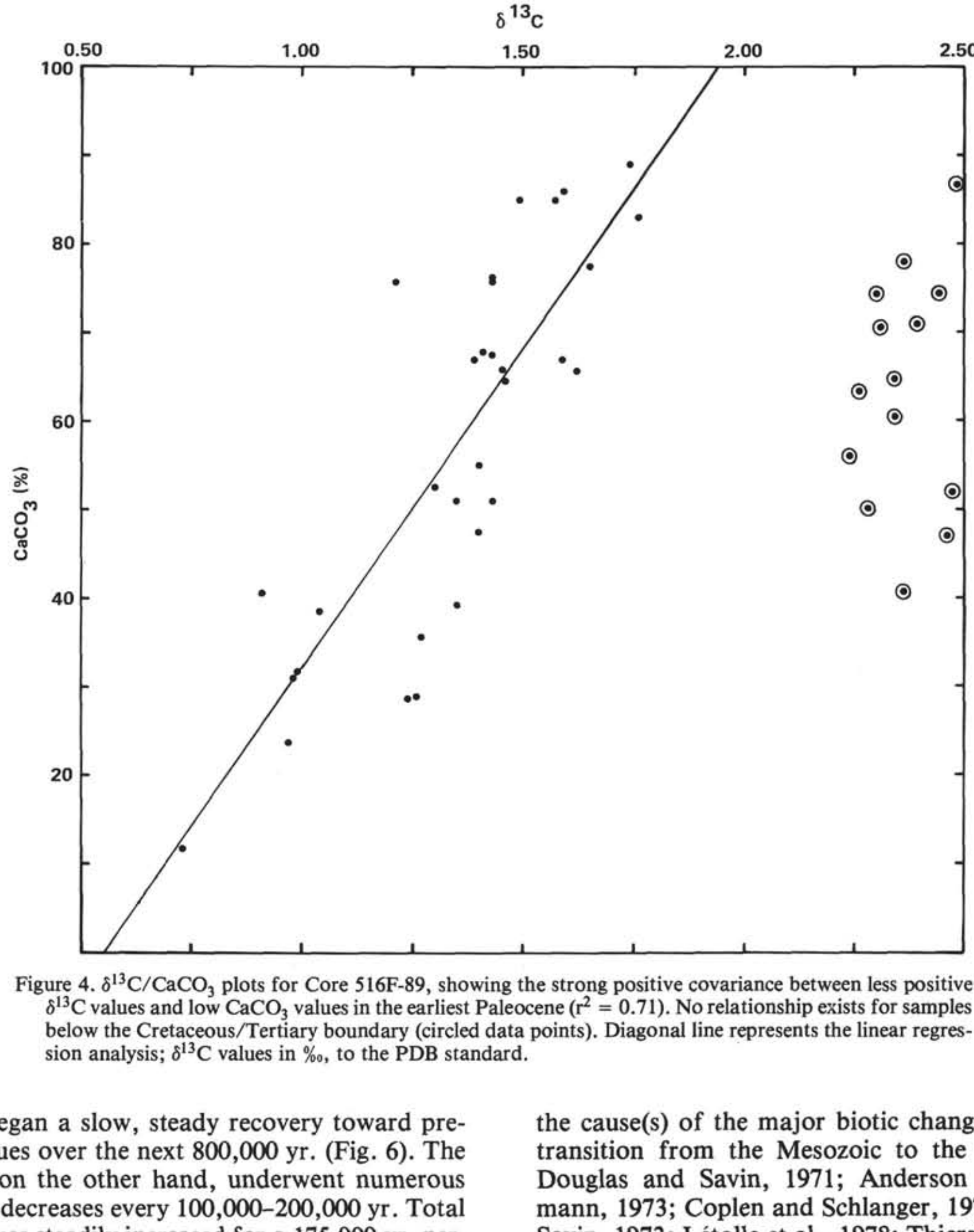

Figure 4. $\delta^{13}C/CaCO_3$ plots for Core 516F-89, showing the strong positive covariance between less positive $\delta^{13}C$ values and low $CaCO_3$ values in the earliest Paleocene (r^2 = 0.71). No relationship exists for samples below the Cretaceous/Tertiary boundary (circled data points). Diagonal line represents the linear regression analysis; $\delta^{13}C$ values in ‰, to the PDB standard.

$\delta^{13}C$ values began a slow, steady recovery toward preboundary values over the next 800,000 yr. (Fig. 6). The $\delta^{18}O$ record, on the other hand, underwent numerous increases and decreases every 100,000–200,000 yr. Total carbonate values steadily increased for a 175,000-yr. period across the Cretaceous/Tertiary boundary, reaching a $CaCO_3$ maximum 50,000–75,000 yr. after the Cretaceous/Tertiary boundary. The major $CaCO_3$ minimum did not occur until at least 100,000 yr. after the Cretaceous/Tertiary boundary (Fig. 6). Over the next 700,000-yr. period, percent $CaCO_3$ approached preboundary $CaCO_3$ values several times, at intervals of 100,000 and 200,000 yr., and attained another broad $CaCO_3$ maximum lasting 50,000–75,000 yr. at approximately 64.55 Ma (Fig. 6). A lack of core recovery in Core 88 produced an apparent break in the records from 64.1 to 63.2 Ma. During the interval from 63.2 to 62.7 Ma, all of these records showed very little change. Two million years after the Cretaceous/Tertiary boundary, however, the $\delta^{13}C$ record remained depleted by at least 0.5‰ compared to the preboundary section (Fig. 6).

Numerous researchers have used the isotopic records from either DSDP or land-based sections to postulate the cause(s) of the major biotic changes heralding the transition from the Mesozoic to the Cenozoic (e.g., Douglas and Savin, 1971; Anderson and Schneidermann, 1973; Coplen and Schlanger, 1973; Douglas and Savin, 1973; Létolle et al., 1978; Thierstein and Berger, 1978; Arthur et al., 1979; Létolle, 1979; Scholle and Arthur, 1980; Hsü et al., 1982). Based on anomalously high amounts of iridium in these and other sedimentary sections containing the Cretaceous/Tertiary boundary, some type of extraterrestrial event, involving an asteroid or cometary impact, has gained widespread favor as the cause of the terminal Cretaceous extinctions (Alvarez et al., 1980; Ganapathy, 1980; Smit and Hertogen, 1980; Emiliani, 1980; Hsü, 1980, 1981; Hsü et al., 1982). A prominent iridium anomaly of 0.95 ± 0.18 ppb is associated with the Cretaceous/Tertiary boundary at Site 516 (Michel et al., this volume). Our interpretation is restricted, however, to what the isotope and $CaCO_3$ records of Site 516 suggest about the response of the South Atlantic to the events at the end of the Cretaceous.

For at least 800,000 yr. before the Cretaceous/Tertiary boundary, the South Atlantic was characterized by a relatively deep, stable calcium carbonate compensa-

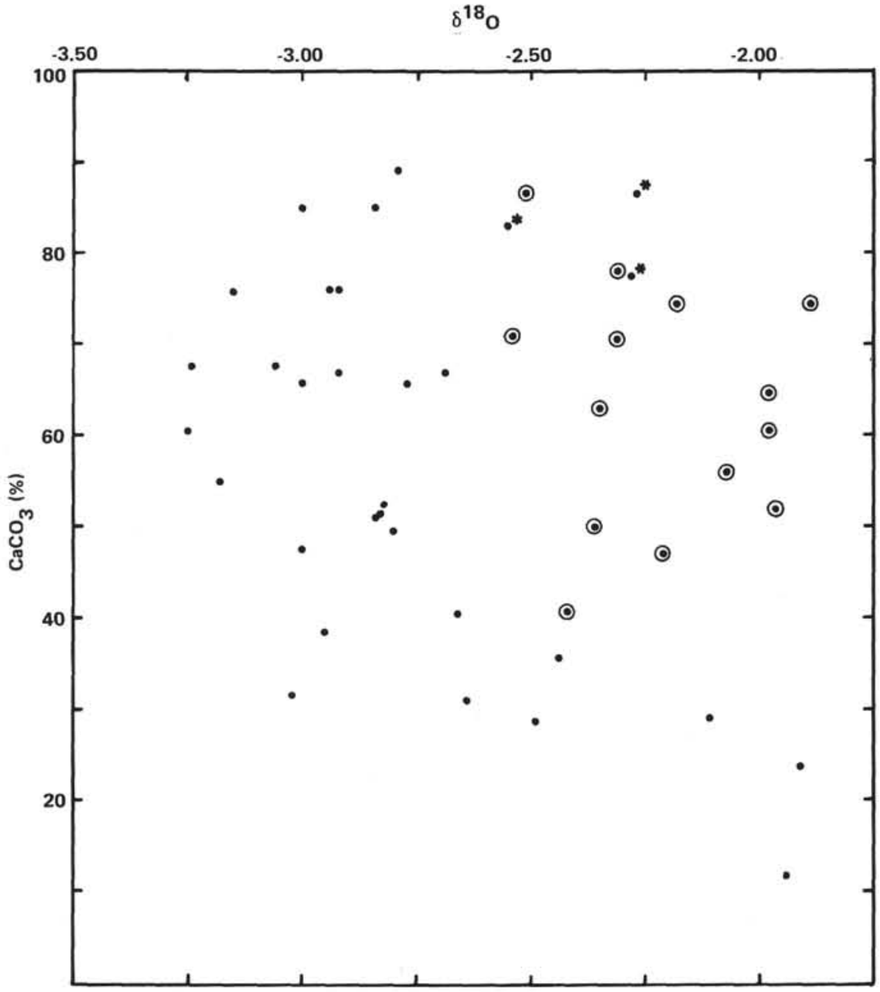

Figure 5. $\delta^{18}O/CaCO_3$ plot for Core 516F-89, showing the lack of correlation between these variables across the Cretaceous/Tertiary boundary. Asterisks denote the few samples that had more positive $\delta^{18}O$ values and high $CaCO_3$ values above the Cretaceous/Tertiary boundary. Circled data points represent samples below the Cretaceous/Tertiary boundary; $\delta^{18}O$ values in ‰, to the PDB standard.

tion depth (CCD) and a diverse calcareous nannoplankton flora; $\delta^{13}C$ values were typical of marine biogenic carbonate (Fig. 6). Preservation of the nannofossil assemblages is good, but preservation of the planktonic foraminifers is only moderately good (Pujol, this volume; site chapter, Site 516, this volume). A strict interpretation of the late Maestrichtian $\delta^{18}O$ data in terms of isotopic paleotemperatures (Epstein et al., 1953) suggests that the South Atlantic was warm with extremes ranging between 25 to 18°C (assuming the diagenetic effects were minimal and the isotopic composition of the South Atlantic, δw, was $-1.0‰$).

The cooling just prior to the Cretaceous/Tertiary boundary and the subsequent temperature increase across the boundary amounted to a rapid 5–6°C increase ($\sim -1.2‰$) lasting slightly more than 100,000 yr. (Fig. 6). Such large paleotemperature estimates, however, may be the result of the influence of cementation of the chalk. Although the total $CaCO_3$ content through this interval remains high, few foraminifers are present in the greater-than-150 micron fraction. Beginning with the iridium anomaly at the end of the Cretaceous and continuing for a little more than 100,000 yr., the sharp $\delta^{13}C$ decrease, the covariance between the $\delta^{13}C$ and $CaCO_3$ record after the Cretaceous/Tertiary boundary, and the elimination of the Maestrichtian nannofossil population suggest a near total collapse in the primary productivity of the South Atlantic in agreement with carbon isotope records from other South Atlantic sites, 356 and 524 (Thierstein and Berger, 1978; Hsü et al., 1982). At the time of lightest $\delta^{13}C$ values in the entire Hole 516F record (about 64.9 Ma), either a rapid shoaling of the CCD or greatly decreased productivity reduced the $CaCO_3$ content from a maximum of nearly 90% to a minimum of less than 12%. The positive covariance between low $CaCO_3$ and negative $\delta^{13}C$ values throughout the lower Paleocene (Fig. 4) illustrates how the two parameters are closely related. The $\delta^{18}O$ record indicates that a brief cooling was coincident with the early Paleocene $\delta^{13}C$ and $CaCO_3$ minima (Fig. 6). As the Paleocene calcareous nannoplankton flora became established, the $\delta^{13}C$ values and $CaCO_3$ contents increased and the South Atlantic remained warm (21–28°C). By 63 Ma, the isotope and $CaCO_3$ records had stabilized at

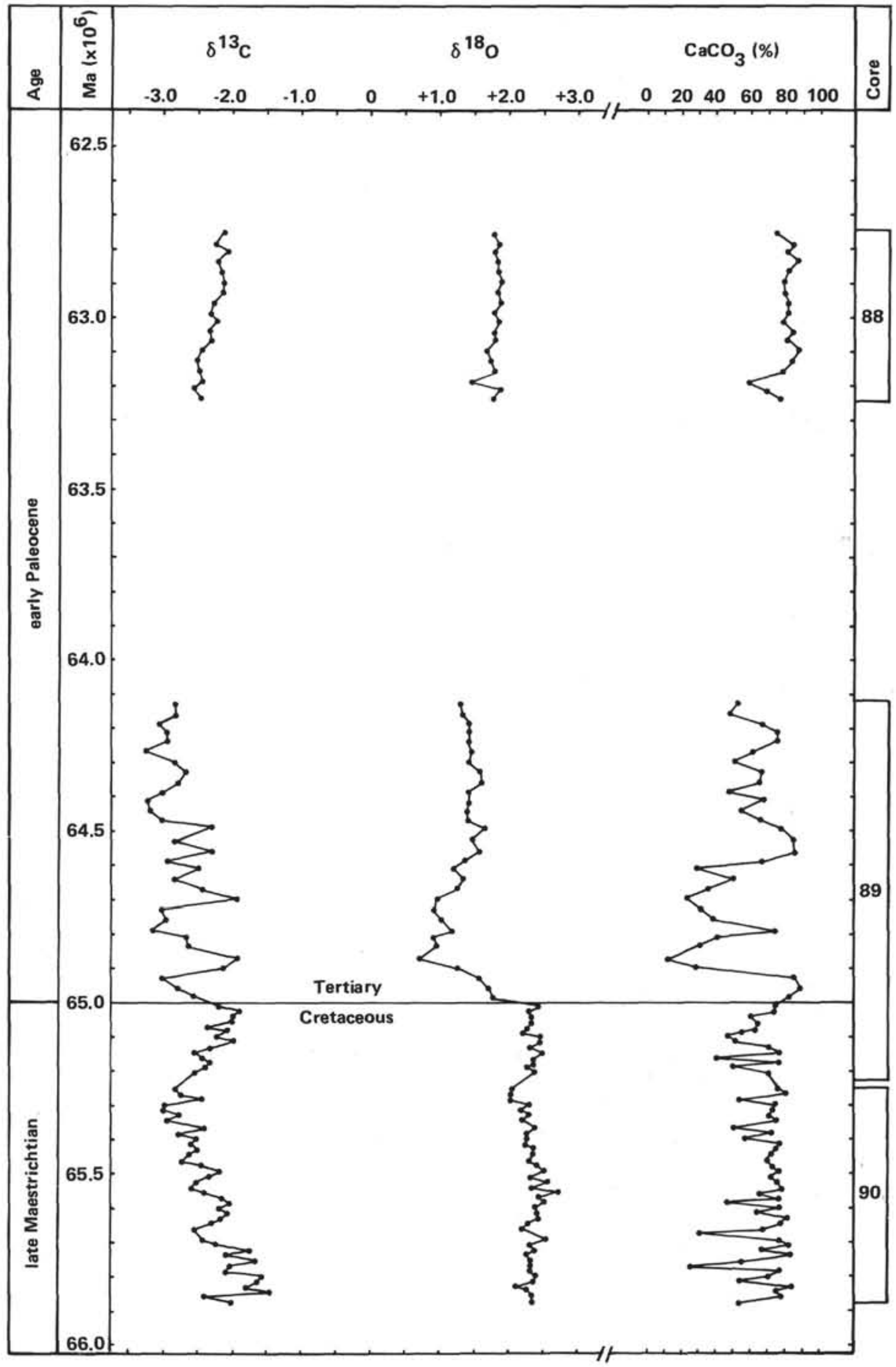

Figure 6. The age model for the stable isotope and carbonate records from the late Maestrichtian–early Paleocene section of Hole 516F. Sedimentation rates were estimated using the preliminary planktonic foraminiferal biostratigraphy (Pujol, this volume). Oxygen and carbon isotope values in ‰, to the PDB standard.

levels similar to those before the Cretaceous/Tertiary boundary. The events contained in the isotope and $CaCO_3$ records of Hole 516F are consistent with those from other South Atlantic DSDP sites, but a direct comparison with Site 524 is not possible because of the low $CaCO_3$ contents (< 20%) across the Cretaceous/Tertiary boundary and the presence of numerous turbidite events between the pelagic intervals of that site (Hsü et al., 1982).

SUMMARY

We believe that the stable isotope and calcium carbonate records across the Cretaceous/Tertiary boundary at Site 516 portray in detail the events that affected the South Atlantic during the transition from the Mesozoic to Cenozoic. The sedimentary record of Site 516 appears to be near-continuous and undisturbed from the Maestrichtian into the Danian interval of the Paleocene. Thus, we believe that the short-term events in the isotope and $CaCO_3$ records reveal the rate and duration of changes occurring in the South Atlantic. As further paleomagnetic, geochemical, and paleontologic data become available for Site 516, the age model presented here can be refined, and the response of the South Atlantic can be more accurately compared to the changes occurring in the North Atlantic, Pacific, and Tethyan regions.

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