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CHANGES IN THE DISTRIBUTION OF $\delta^{13}C$ OF DEEP WATER ΣCO_2 BETWEEN THE LAST GLACIATION AND THE HOLOCENE

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Abstract. Carbon isotopic measurements on the benthic foraminiferal genus *Cibicidoides* document that mean deep ocean $\delta^{13}C$ values were 0.46 ‰ lower during the last glacial maximum than during the Late Holocene. The geographic distribution of $\delta^{13}C$ was altered by changes in the production rate of nutrient-depleted deep water in the North Atlantic. During the Late Holocene, North Atlantic Deep Water, with high $\delta^{13}C$ values and low nutrient values, can be found throughout the Atlantic Ocean, and its effects can be traced into the southern ocean where it mixes with recirculated Pacific deep water. During the glaciation, decreased production of North Atlantic Deep Water allowed southern ocean deep water to penetrate farther into the North Atlantic and across low-latitude fracture zones into the eastern Atlantic. Mean southern ocean $\delta^{13}C$ values during the glaciation are lower than both North Atlantic and Pacific $\delta^{13}C$ values, suggesting that production of nutrient-depleted water occurred in both oceans during the glaciation. Enriched ^{13}C values in shallow cores within the Atlantic Ocean indicate the existence of a nutrient-depleted water mass above 2000 m in this ocean.

INTRODUCTION

The biological and chemical processes that fractionate carbon isotopes in the ocean provide one of the most useful tracers for reconstructing past distributions of water masses and their properties. The present distribution of $\delta^{13}C$ of ΣCO_2 reproduces the general distribution of water masses in the oceans, and the gradients in $\delta^{13}C$ between locations record the net flow direction between ocean basins. Certain species of benthic foraminifera (*C. wuellerstorfi*, in particular) faithfully record these gradients of $\delta^{13}C$, providing the tool necessary to reconstruct the past distribution of $\delta^{13}C$. In this paper, we present the $\delta^{13}C$ distribution for the ocean during the last 30,000 years, and from these data determine the consequences of glacial-interglacial climate change on thermohaline circulation.

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$\delta^{13}C$ *Distribution in the Ocean*

The distribution of $\delta^{13}C$ in the ocean is controlled principally by photosynthesis and remineralization of organic carbon, and by mixing between water masses of different isotopic composition. Photosynthesis in surface water preferentially extracts ^{12}C from seawater, causing the enrichment of the surface water ΣCO_2 in ^{13}C. The value of $\delta^{13}C$ in seawater, after primary producers have removed all nutrients, is controlled by the mean $\delta^{13}C$ and the mean nutrient concentration of the ocean [Broecker, 1982; Broecker and Peng, 1982]. Today when all of the nutrients are stripped from the surface water, the ΣCO_2 of the surface reservoir has lost approximately 10% of its total dissolved inorganic carbon. Since the carbon that has been removed by phytoplankton has a $\delta^{13}C$ equal to approximately -20 ‰, the surface reservoir is enriched by 2.0 ‰ over the mean $\delta^{13}C$ of the deep water (Figure 1). The mean ocean $\delta^{13}C$ value equals 0.0 ‰ (PDB), so the surface value today equals approximately 2.0 ‰ (PDB). Complete nutrient utilization by phytoplankton generally occurs in the warm, well stratified regions of the oceans between 30°N and 30°S.

Deep water masses today form at high latitudes after physical processes have increased the surface water density and caused it to sink into the deep ocean. The initial carbon isotopic composition of the water mass, its preformed value, is determined by the extent of photosynthesis that has occurred in the seawater during its residence within the euphotic zone. Before sinking into the deep ocean, phytoplankton strip ^{12}C and

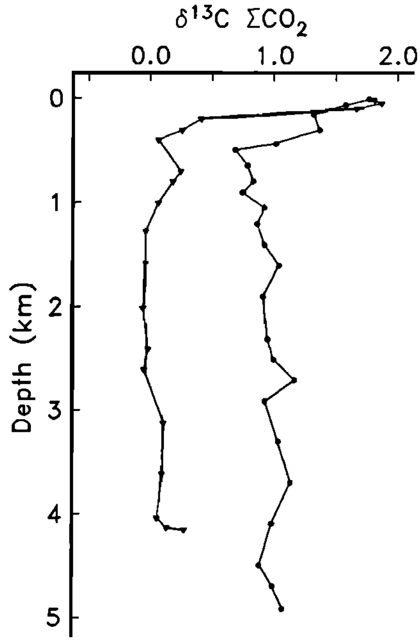

Fig. 1. The depth distribution of $\delta^{13}C$ in the Pacific (triangles) and Atlantic (circles) oceans. The warm surface layers of the oceans, where stratification is strong, are generally nutrient depleted, and all surface water $\delta^{13}C$ values in these regions approach 2.0 ‰ (PDB). The $\delta^{13}C$ differences between the deep waters reflects the presence of nutrient-depleted, high $\delta^{13}C$ deep water in the North Atlantic. Data from Kroopnick [1974, 1980].

nutrients (PO_4, NO_3) from the surface water, enriching it in ^{13}C. If the nutrient concentration is depleted to zero in the present ocean, then the preformed $\delta^{13}C$ value will be near to 2.0 ‰.

At their sites of formation the principal deep water masses (North Atlantic Deep Water (NADW), Antarctic Bottom Water(AABW)) are depleted in nutrients and enriched in ^{13}C relative to mean ocean water, but their nutrient concentrations are greater than zero, and their $\delta^{13}C$ values fall short of the values predicted for water stripped completely of its nutrients (Table 1). North Atlantic Deep Water is the most nutrient-depleted deep water mass forming in the oceans today. This water mass forms by the sinking of surface water in the Norwegian-Greenland Sea, mixing with Mediterranean Sea outflow and Labrador Sea water. Phosphate concentrations of these components are generally low (<1.0 $\mu M/kg$), and initial $\delta^{13}C$ values of NADW are enriched to 1.0 to 1.4 ‰ (PDB). Antarctic Bottom Water has more PO_4 at its source region than NADW, so it is generally lower in $\delta^{13}C$ (0.3 ‰ PDB).

After leaving the surface layers of the ocean, $\delta^{13}C$ of deep water masses changes only through two processes: remineralization of organic carbon and mixing between water masses with different isotopic compositions. Consequently, the $\delta^{13}C$ composition of seawater is not a conservative tracer of deep water masses. Within the

TABLE 1. The End-Member Values of $\delta^{13}C$ and [PO_4] for North Atlantic Deep Water (NADW), Antarctic Bottom Water (AABW), and Nutrient-Depleted Surface Water (SW)

Water Mass	[PO_4] μmole/kg	$\delta^{13}C$ ‰(PDB)
NADW	1.0	1.1
AABW	2.3	0.3
SW	0.0	2.0

Atlantic Ocean, however, the $\delta^{13}C$ distribution today is acting much like a conservative tracer because the rates of production and degradation of organic carbon are very low in this ocean. This generalization is especially true for the western basins of the Atlantic, where the effects of mixing between NADW and AABW occur as bathymetric gradients in $\delta^{13}C$ at sharp water mass boundaries and as less distinct latitudinal gradients that occur in the South Atlantic as these two water masses mix and flow to the east to join and form the Circumpolar Deep Water. The mixing of these water masses is demonstrated by the straight lines on property-property diagrams of $\delta^{13}C$ of ΣCO_2 and conservative tracers such as salinity or $\delta^{18}O$ of the seawater (Figure 2).

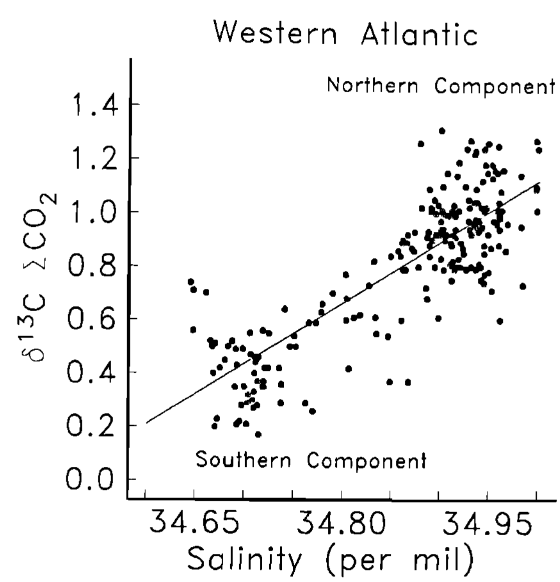

Fig. 2. The relationship between salinity and $\delta^{13}C$ in the western Atlantic demonstrating the mixing of North Atlantic Deep Water (northern component) and Antarctic Bottom Water (southern component) from GEOSECS stations ($\delta^{13}C$ data from Kroopnick, [1985]). The end-member compositions of salinity and $\delta^{13}C$, respectively, are 35.0 ‰ and 1.2 ‰ for NADW and 34.66 ‰ and 0.5 ‰ for AABW.

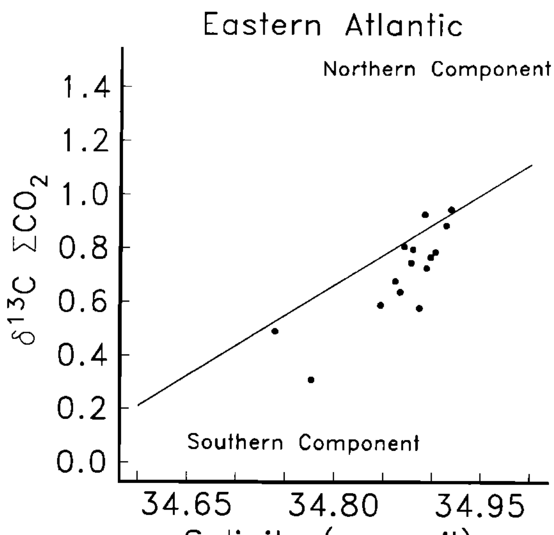

Fig. 3. The relationship between salinity and $\delta^{13}C$ for eastern Atlantic locations from GEOSECS data ($\delta^{13}C$ data from Kroopnick, [1985]). For comparable mixtures of northern and southern component deep water the eastern basins are depleted in $\delta^{13}C$ relative to the western basins. This difference in $\delta^{13}C$ results from the isolation of the eastern Atlantic and the greater input of remineralized organic carbon. The depletion in ^{13}C is proportional to the enrichment in other nonconservative properties ([Si]), showing that both degradation of organic matter and mixing affect the $\delta^{13}C$ distribution in the Atlantic.

The $\delta^{13}C$ composition of deep waters is not conservative on a global scale, nor is it conservative on a ocean basin scale in regions of high productivity or within basins with long residence times. One example of the nonconservative nature of $\delta^{13}C$ occurs in the eastern basins of the Atlantic Ocean, where deep water originally from the western basin is isolated and exposed to large amounts of settling particulate organic carbon (Figure 3). The $\delta^{13}C$ values (and [O_2]) of comparable water types are generally lower in the eastern Atlantic than in the western Atlantic (compare Figure 3 with Figure 2); enrichment of bioreactive constituents (SiO_2) in eastern Atlantic deep water [Broecker, 1981] are consistent with the observed decrease in $\delta^{13}C$. These geochemical changes occur because of the circulation patterns in the region and the isolation of the eastern basins from the mainstream of thermohaline flow. Long deep water residence times within the eastern Atlantic result in greater remineralization of organic carbon and lower $\delta^{13}C$ values compared to western Atlantic deep water. Similarly, Pacific deep water shows characteristics which result from mixing of two water masses and excess organic carbon remineralization (Figure 4). The salinity of this deep water shows that it is a mixture of northern and southern component deep water in a ratio of 1 to 3 or 4, and its $\delta^{13}C$ composition is about 0.4 ‰ lower than expected if $\delta^{13}C$ were completely conservative.

The present geographic gradients of $\delta^{13}C$ in the oceans follow the general distribution of water masses and record the net flow of deep water from the Atlantic to the Pacific. Each of the principal water masses (NADW and AABW) forms in the Atlantic and begins with $\delta^{13}C$ values that are different from each other, and enriched with respect to the mean ocean $\delta^{13}C$. During their transit to the Pacific, the isotopic composition of the deep water is altered by the oxidation of organic carbon and mixing, and the net result is a 1.2 ‰ difference in $\delta^{13}C$ between the deep water present in the northern North Atlantic and the deep water present in the Pacific. Of this observed difference, 0.4 ‰ results from "aging" effects, while 0.8 ‰ results from mixing with southern component deep water. When viewed in transects from the North Atlantic to Antarctic and through to the North Pacific, the principal water masses and the net direction of flow are recorded [Kroopnick, 1985].

In addition to effects of deep water circulation, temporal changes in benthic foraminiferal $\delta^{13}C$ occur because of global changes in the distribution of carbon between the ocean and various transient reservoirs (e.g., land vegetation, organic carbon in shelf sediments) [Shackleton, 1977b; Broecker, 1982]. Any individual record of benthic foraminiferal $\delta^{13}C$ can be a complicated combination of global effects, such as changes in the extent of land vegetation or burial of shelf organic carbon, and circulation effects, such as changes in deep water preformed $\delta^{13}C$ values, residence time within

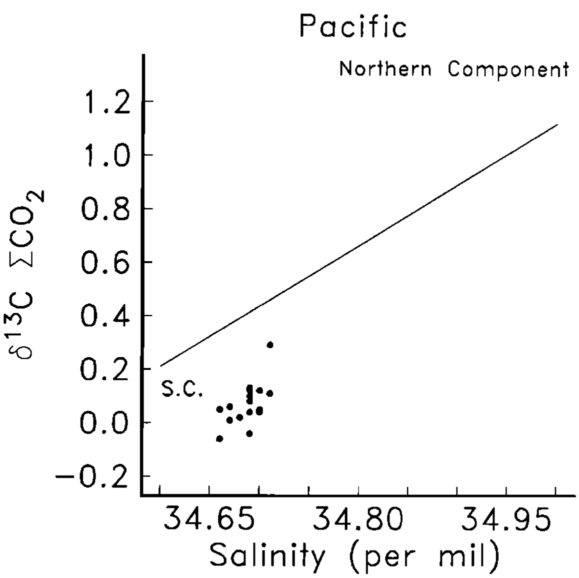

Fig. 4. The relationship between salinity and $\delta^{13}C$ for the Pacific Ocean from GEOSECS stations ($\delta^{13}C$ data from Kroopnick, [1974]; salinity data from Chung and Craig, [1973]). Note that this deep water mass is a mixture of NADW and AABW, but its $\delta^{13}C$ composition falls off the mixing line between northern and southern component deep water. The effect of long residence time within the Pacific Ocean allows more degradation of organic carbon within the water mass lowering both its $\delta^{13}C$ and [O_2].

particular basins, or changes in mixing ratios between the principal deep water sources.

But because the ocean mixes thoroughly on time scales of 1000 years or less, all cores in all ocean basins will be affected equally by transfer of carbon between the land and the sea. Consequently, the global effects alter only the mean $\delta^{13}C$ value for the entire ocean. Synoptic regional gradients in benthic foraminiferal $\delta^{13}C$ record the important features deep ocean circulation pattern, independent of changes in mean ocean $\delta^{13}C$. Thus they provide us with the means to reconstruct past patterns or direction of deep water flow and to estimate past changes in deep water residence time or changes in preformed $\delta^{13}C$ composition. In this paper we will determine the distribution of benthic foraminiferal $\delta^{13}C$ during the last glacial maximum, evaluate the distribution in terms of changing water mass chemistry, geometry and circulation, and compare the results to modern thermohaline flow.

METHODS

The analysis of isotopic ratios for oxygen and carbon in foraminiferal tests follows the methods outlined initially by Shackleton and Opdyke [1973]. Foraminiferal tests are cleaned and reacted with 100% phosphoric acid in a vacuum. The reaction takes place in a constant temperature bath that is usually 50°C, although the temperature of the reaction is not critical. It is most important that both standards and unknowns are reacted at the same temperature, and this procedure is followed by all of the laboratories reporting data in this paper. The products of the reaction between phosphoric acid and $CaCO_3$ are CO_2 and H_2O, and these molecules are separated by fractional distillation using liquid nitrogen and a frozen solvent (e.g., isopropyl alcohol, methanol). The CO_2 is then analyzed on a isotopic ratio mass spectrometer. The results are expressed as per mil deviations from PDB, usually through the intermediate calibration standard NBS-20. Analytical precision of standards is reported by most laboratories to be 0.1 ‰ or less. In general, analytical precision is always less than the natural variability observed in replicate analyses of unknown benthic foraminiferal samples.

We present here only isotopic data produced from the analysis of *Cibicidoides* species and most of the analyses have been produced using *C. wuellerstorfi*. Previous studies [Belanger et al., 1981; Graham et al., 1981; Curry and Lohmann, 1982; Duplessy et al. 1984] have documented the utility and reliability of this species for $\delta^{13}C$ measurements (Figure 5). Within a given sample, *C. wuellerstorfi* always has the most enriched $\delta^{13}C$ composition of the calcitic benthic foraminifera [Woodruff et al., 1980] and is closest to equilibrium with respect to ambient $\delta^{13}C$ of ΣCO_2 of the overlying deep water. The $\delta^{13}C$ composition of *C. wuellerstorfi* is lower than the expected isotopic equilibrium values for $\delta^{13}C$ by about 0.9 ‰ [Rubinson and Clayton, 1969]. Thus it is probably only a coincidence that its observed $\delta^{13}C$ values are close to ambient $\delta^{13}C$ of deep water ΣCO_2. Coexisting *C. wuellerstorfi* and other species of *Cibicidoides* (e.g., *C. kullenbergi*, *C. bradyii*) exhibit no significant differences in $\delta^{13}C$ [Duplessy et al., 1980; Woodruff et al., 1981; Keigwin, 1982].

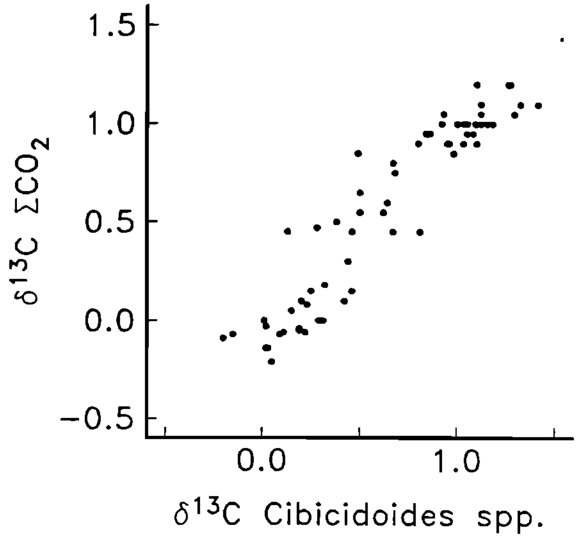

Fig. 5. Measured $\delta^{13}C$ for ambient sea water ΣCO_2 and core top *Cibicidoides* species [after Duplessy et al. 1984]. The isotopic compositions of this benthic taxon reliably reproduce the gradients observed in $\delta^{13}C$ in the modern ocean. Although the observed $\delta^{13}C$ values for *Cibicidoides* species coincidentally equal ambient $\delta^{13}C$ of ΣCO_2, the observed values are lower than expected equilibrium values for calcite by about 0.9 ‰ [Rubinson and Clayton, 1969].

We have chosen to analyze *Cibicidoides* species for three reasons: (1) their $\delta^{13}C$ variations most reliably reflect the gradients in the modern ocean [Belanger et al., 1981; Graham et al., 1981; Curry and Lohmann, 1982; Duplessy et al., 1984]; (2) the $\delta^{13}C$ values are closest to carbon isotopic equilibrium; and (3) the limited observations of living, stained individuals demonstrates that *Cibicidoides* have an epifaunal habitat [Corliss, 1985]. Studies of isotopic variability in core tops show that some species are not reliable recorders of modern ocean gradients in $\delta^{13}C$ and Apparent Oxygen Utilization (AOU) [Belanger et al., 1981]. We have chosen not to analyze *Uvigerina* because it does not always produce results which covary with $\delta^{13}C$ data of *Cibicidoides* species (compare Graham et al. [1981] with Zahn et al. [1986]). An infaunal habitat has been suggested for *Uvigerina* [Zahn et al., 1986] and other species [Corliss, 1985], a hypothesis which is consistent with their observed lower $\delta^{13}C$ compositions, and their temporal variations which parallel changes in sedimentary organic carbon preservation [Zahn et al., 1986]. Although reliable records of $\delta^{13}C$ change may be produced from other species, in regions where past changes in organic carbon input are suspected the most reliable results will come from analyses of *Cibicidoides* species.

Restricting analyses to a single species of benthic foraminifera may introduce systematic offsets into our results because glacial-interglacial changes in species abundance may create time series that are biased toward one extreme climatic regime. If a species is more abundant in interglacial sediments, then a time series containing only that species may be biased toward interglacial isotopic values because bioturbation will mix more interglacial individuals into glacial samples [Mix and Fairbanks, 1985]. Consequently, no true measurements of glacial maximum conditions will be seen in the time series, underestimating the amplitude of glacial-interglacial $\delta^{13}C$ changes. This problem can be avoided by carefully recording species abundance (generally expressed as concentration in number/gram sediment) throughout the time series and analyzing only species which have similar concentrations in both glacial and interglacial sediments. Unfortunately, this procedure is not always practical, nor is it always practiced. In general, we try to analyze data from cores with sufficiently high sedimentation rates so that bioturbation problems are minimized. Or we pay careful attention to the oxygen isotopic variations observed in the benthic foraminifera. If the glacial-interglacial amplitude of $\delta^{18}O$ is reduced by bioturbation [Shackleton, 1977a; Peng et al., 1977], then the carbon isotopic variations may be also affected.

The relationship between sedimentation rate, sampling frequency, and isotopic signal amplitude for our data is

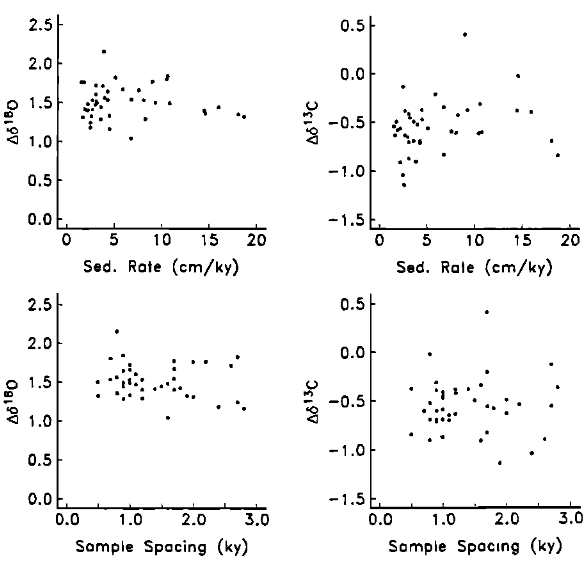

Fig. 6. Glacial-interglacial changes in $\delta^{18}O$ and $\delta^{13}C$ as a function of core sedimentation rate and sample spacing. Cores in this data set vary in average sedimentation rate from 1.5 cm/kyr to greater than 18 cm/kyr. Average sample spacing (Δt) varies from 0.5 to 2.8 kyr and averages about 1.5 kyr. No systematic differences in $\Delta\delta^{18}O$ can be observed as a function of either sedimentation rate or sample spacing. Thus we believe the data presented here are not biased significantly by bioturbation of low-sedimentation-rate cores or by insufficient sampling frequency.

presented in Figure 6. In general, there is no reduction in amplitude in the lower sedimentation rate cores in this data set. At low sedimentation rate (~2 cm/kyr) we observe a wide range of glacial-interglacial $\delta^{18}O$ amplitudes (1.2–1.8 ‰), but the observed $\Delta\delta^{18}O$ at low sedimentation rates are similar to those observed at sedimentation rates greater than 5 cm/kyr. Thus we believe that there is no reason to delete any cores from this data set based on sedimentation rate alone. Our conclusions support the observations of Pisias [1983], who noted that there was no significant difference between variance spectra of $\delta^{18}O$ records from cores with sedimentation rates of 2 cm/kyr or greater. Within this data set, cores vary in sedimentation from 1.5 to greater than 18 cm/kyr. Sample spacing (Δt) averages approximately 1.5 kyr, and we see no effect of sample density on the glacial-interglacial amplitude of $\delta^{18}O$ (Figure 6). Thus we are confident that the $\delta^{13}C$ signals that we are reporting are reliable and not significantly affected by bioturbation.

RESULTS

The isotopic data are tabulated in Appendix 1. We have determined a chronology for each record based on its correlation to Pacific Ocean core V19-30 [Shackleton et al., 1983a, 1983b]. Our correlation of the V19-30 $\delta^{18}O$ record with the chronology of Imbrie et al. [1984] is presented in Table 2. In the following sections we describe the observed changes in $\delta^{13}C$ for each ocean basin. A summary of the mean glacial (middle of stage 2, ~17–22 kyr) and interglacial values (Late Holocene, ~0–5 kyr) of $\delta^{13}C$ and $\delta^{18}O$ for each core in this data set are presented Table 3. We summarize the data for each major ocean basin in Table 4.

Pacific Ocean

Typical Pacific records for $\delta^{13}C$ and $\delta^{18}O$ are presented in Figure 7. A total of five records are

TABLE 2. Stratigraphic Control Points and Their Estimated Ages in Core V19-30

Depth, m	Age, kyr
0.00	0.0
0.93	12.0
1.16	15.0
2.60	24.0
4.70	59.0

The ages of the control points are from Imbrie et al. [1984], except for the control point at 1.16 m, which is from Shackleton and Pisias [1985].

tabulated in Appendix 1, and their mean glacial-interglacial difference equals 1.49 ‰ for $\delta^{18}O$ and -0.41 ‰ for $\delta^{13}C$ (Table 4). The variability in isotopic composition appears to increase during the glacial maximum, as noted by the larger standard deviations for mean glacial $\delta^{18}O$ and $\delta^{13}C$ values. Unfortunately, because of the small number of cores from the Pacific Ocean the difference is not highly significant. Today the Pacific is remarkably homogenous in its $\delta^{13}C$ composition [Kroopnick, 1974, 1985], and this homogeneity is reflected by the low variability in $\delta^{13}C$ observed in the average Late Holocene $\delta^{13}C$ values (Table 4). Similarly, temperature and salinity ($\delta^{18}O_w$) variations in the deep Pacific are small, so the variability observed in $\delta^{18}O$ of *Cibicidoides* in the Late Holocene Pacific samples is also low. The increased variability observed in the glacial Pacific data may suggest that the Pacific was more heterogenous in its $\delta^{13}C$ distribution.

Southern Ocean

Figure 8 presents two isotopic records from representative cores of the southern ocean. RC13-229 [Oppo and Fairbanks, 1987] and MD84-527 [Labeyrie et al., 1986] demonstrate that the glacial-interglacial change

TABLE 3. Mean Values of $\delta^{13}C$ for Late Holocene (0–5 kyr) and Glacial (17–22 kyr) for Each Core Listed in Appendix 1

Core	Sedimentation Rate	Sample spacing	Holocene $\delta^{18}O$	Holocene $\delta^{13}C$		Glacial $\delta^{18}O$	Glacial $\delta^{13}C$		$\Delta^{18}O$	$\Delta^{13}C$
				North Atlantic Ocean						
V28-14	9 0	1 7	2.55±0 14	0 80±0 16	n= 2	4 32±0.14	1 21±0.16	n= 6	1.77	0.41
CH73-139	10.6	9	2.70±0.04	0.93±0 04	n= 7	4 54±0.17	0 62±0.20	n= 4	1 84	-0.31
CHN82-24	3.6	1.5	2.65±0 04	1.02±0.14	n= 5	4.09±0 01	0.53±0.08	n= 2	1.44	-0.49
V26-176	18 1	.8	2.70±0 19	0 87±0.22	n= 8	4.05±0 00	0.18±0 00	n= 1	1.35	-0.69
CH72-02	2.5	2.7	2.96±0.06	0.90±0 00	n= 2	4.20±0 06	0 77±0.10	n= 2	1.24	-0 13
CH75-04	6.8	1.7	3 01±0.27	0.67±0.27	n= 2	4.55±0 05	-0 16±0.18	n= 4	1.54	-0 83
CH75-03	5.1	2 7	2.83±0.08	0.87±0 04	n= 2	4.65±0.00	0 31±0.00	n= 1	1 82	-0.56
CH74-227	4.5	2 8	3.27±0.00	0.46±0 00	n= 1	4.43±0.02	0 09±0.13	n= 2	1 16	-0.37
V30-49	4 3	9	2.30±0 09	0 91±0.08	n= 5	3 94±0.16	0 20±0.09	n= 8	1 64	-0.71
M12392	10.5	7	2.51±0 22	0.97±0.10	n= 7	4.31±0 14	0 36±0 11	n=10	1 80	-0.61
KNR110-82	3.9	.8	1.92±0.08	1 11±0.12	n= 3	4.07±0.14	0.21±0 21	n=10	2.15	-0.90
KNR110-75	3.6	.9	2.46±0.12	0 97±0.25	n= 3	3.74±0 11	0 28±0 14	n= 9	1.28	-0.69
KNR110-71	3.1	1.1	2 26±0.08	1.10±0.16	n= 2	3.86±0 26	0.40±0.14	n= 7	1.60	-0 70
KNR110-66	4 0	8	2 16±0 14	0 71±0 21	n= 4	3 72±0.32	0.19±0 18	n= 7	1.56	-0 52
KNR110-91	2 7	1 2	2 28±0 06	0.71±0 26	n= 3	3 81±0 16	0 08±0.15	n= 6	1 53	-0 63
KNR110-50	3.2	1.0	2 53±0 19	0.65±0 37	n= 3	4.02±0 16	0 20±0 07	n= 9	1 49	-0 45
KNR110-58	3 0	1 1	2 62±0 16	0 62±0 21	n= 6	4 09±0.16	-0 03±0 13	n= 7	1 47	-0 65
KNR110-55	3 1	1 0	2 45±0.24	0.40±0.18	n= 5	3.97±0.30	-0.01±0.17	n= 6	1.52	-0 41
V25-59	3.1	1 0	2.56±0.10	0 89±0.06	n= 5	4 28±0.07	0 02±0 11	n= 4	1 72	-0.87
V22-197	7 6	1.0	2.71±0.16	0.77±0.20	n= 8	4 37±0.05	0 18±0 09	n= 4	1 66	-0.59
EN066-38	1.7	2 0	2.66±0.04	1 14±0.13	n= 2	3.97±0.04	0 51±0.09	n= 3	1.31	-0.63
EN066-16	2 7	1 4	2.78±0.50	0 83±0 23	n= 3	4 19±0.13	0.45±0.07	n= 6	1.41	-0 38
EN066-44	1.5	2 2	2.59±0.00	1 04±0.00	n= 1	4.35±0.08	0.50±0 05	n= 3	1.76	-0.54
EN066-10	1 8	2 0	2.25±0.00	0 82±0.00	n= 1	4 01±0 14	0 33±0.20	n= 2	1 76	-0.49
EN066-21	2 2	1 7	2.52±0 03	0.80±0 04	n= 2	3.92±0.14	0 24±0.18	n= 4	1 40	-0 56
EN066-36	1 9	1.8	2.81±0.08	0.69±0 08	n= 2	4.23±0 07	0 11±0.07	n= 4	1.42	-0 58
EN066-26	2 2	1 6	2.64±0.00	0.84±0 00	n= 1	4.12±0 11	-0.07±0.15	n= 5	1.48	-0 91
EN066-32	2.6	1.9	2 77±0 10	0.89±0 03	n= 3	4.09±0 05	-0.25±0.07	n= 2	1.32	-1.14
EN066-29	2 5	2 4	2 57±0.00	0.85±0 00	n= 1	3.75±0.35	-0.19±0 05	n= 2	1.18	-1 04
				South Atlantic Ocean						
BT4	6.8	1.6	2.52±0.07	0.38±0 07	n= 2	3.56±0.10	0 04±0 05	n= 2	1 04	-0 34
RC13-228	8 1	7	2 66±0.24	0.49±0.19	n= 7	4.19±0.14	-0.11±0.16	n= 8	1.53	-0 60
				Southern Ocean						
RC13-229	4.3	1.0	2.65±0 17	0 33±0.07	n= 3	4 18±0.07	-0.36±0 16	n= 6	1.53	-0.69
MD84-527	18 7	.5	2.95±0.19	0.29±0.14	n=11	4 27±0.05	-0.55±0.24	n= 8	1.32	-0.84
RC11-120	3 8	2.6	2.74±0 26	0.42±0 04	n= 2	4.45±0.00	-0 48±0.00	n= 1	1 71	-0.90
				Indian Ocean						
MD76-135	14.6	.8	2 49±0 16	-0.14±0 04	n= 5	3.85±0.35	-0.16±0.06	n= 3	1 36	-0 02
MD79-254	14 5	1.2	2 63±0.14	0.65±0.04	n= 4	3 95±0 00	0.27±0.00	n= 1	1.40	-0 38
MD76-125	8.3	1 2	2 66±0.14	0.23±0 05	n= 4	3 95±0 08	-0.19±0 05	n= 2	1.29	-0 42
				Pacific Ocean						
TR163	9 3	5	2 76±0.21	-0.03±0.31	n= 3	4.26±0.08	-0.40±0 08	n= 6	1 50	-0.37
V28-304	5.9	1 7	2.68±0.01	0.28±0.14	n= 3	4.35±0.02	0 07±0 12	n= 2	1 67	-0.21
KNR73-4	4.5	1 0	2.47±0.12	0.25±0.06	n= 4	3 80±0.18	-0.22±0 11	n= 4	1 33	-0 47
V19-30	10 8	9	2.82±0 15	-0.01±0.07	n= 3	4.31±0.07	-0.61±0 13	n= 2	1 49	-0.60
V35-05	16.0	9	2 42±0 18	0.01±0 03	n= 4	3.86±0.06	-0.38±0 11	n= 2	1 44	-0 39

The mean isotopic values were determined as averages of all data which fell within the prescribed stratigraphic intervals. The data are presented with respect to PDB, with no corrections for disequilibrium fractionation. All data are from *Cibicidoides* species. Δ equals the isotopic difference between glacial (17-22 kyr) and interglacial (0-5 kyr) means for each core expressed as (glacial - interglacial).

TABLE 4. Mean Values of $\delta^{18}O$ and $\delta^{13}C$ for Late Holocene (0–5 kyr) and Glacial (17–22 kyr) Summarized for Each Ocean Basin

	Late Holocene		Glacial	
Ocean	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$
North Atlantic, n=29	2.59 ±0.27	0.84 ±0.18	4.13 ±0.25	0.25 ±0.31
South Atlantic, n=2	2.59 ±0.10	0.44 ±0.08	3.88 ±0.45	-0.04 ±0.11
Indian, n=3	2.59 ±0.09	0.25 ±0.40	3.92 ±0.06	-0.03 ±0.26
Southern, n=3	2.78 ±0.15	0.35 ±0.07	4.30 ±0.14	-0.46 ±0.10
Pacific, n=5	2.63 ±0.18	0.10 ±0.15	4.12 ±0.26	-0.31 ±0.25

in $\delta^{13}C$ of the southern ocean is the largest observed in any ocean. Mean glacial-interglacial differences in $\delta^{13}C$ are -0.81 ‰, while the $\delta^{18}O$ difference equals 1.52 ‰. Most significantly, the southern ocean cores have the lowest $\delta^{13}C$ values observed in the glacial ocean (Table 4). The average values for all other ocean basins are at least 0.15 ‰ enriched in ^{13}C with respect to the southern ocean values. Geographic variability in $\delta^{13}C$ and $\delta^{18}O$ is low during both the interglacial and glacial, as shown by standard deviations of about 0.1 ‰ or less for both $\delta^{13}C$ and $\delta^{18}O$ (Table 4).

Indian Ocean

The isotopic records from three cores in the Indian ocean are presented in Figure 9. MD76-125 and MD79-254 each exhibit glacial-interglacial changes in $\delta^{13}C$ which are near to mean ocean changes (-0.4 ‰). The third core (MD76-135) shows no change in its $\delta^{13}C$. MD76-135 and MD76-125 were recovered from the same water depth (~1800 m), so the differences in $\delta^{13}C$ are not simply related to depth differences in the water column. These Indian Ocean cores average 1.33 ‰

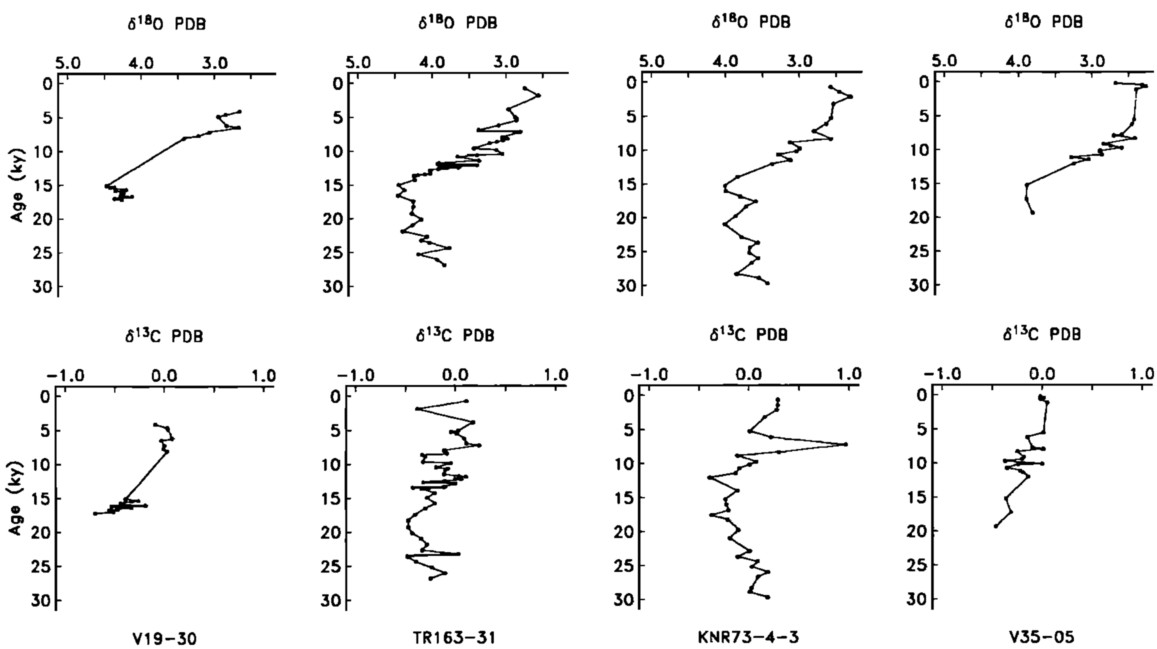

Fig. 7. Isotopic records for Pacific Ocean cores demonstrate the changes in $\delta^{13}C$ which are typical of this basin. Interglacial-glacial changes in $\delta^{18}O$ and $\delta^{13}C$ for the Pacific Ocean as a whole equal 1.49 ‰ and -0.41 ‰ respectively (Table 4).

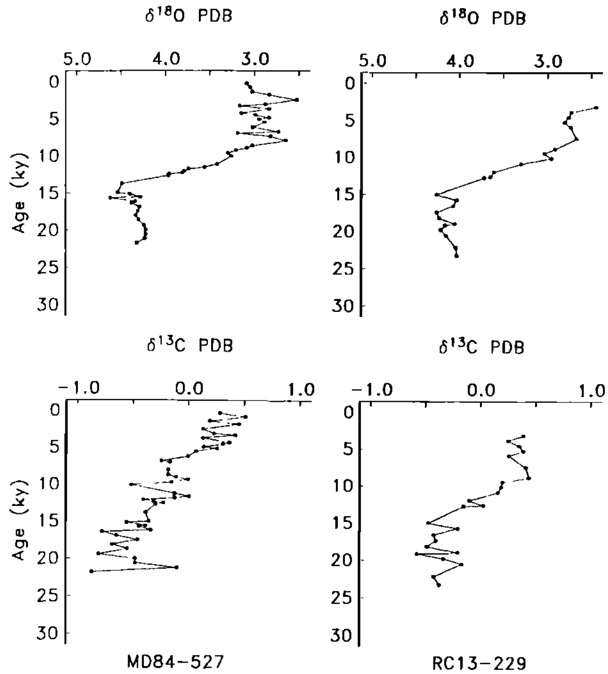

Fig. 8. Isotopic records for two southern ocean cores showing the changes in $\delta^{13}C$ which are typical of this basin. Interglacial-glacial changes in $\delta^{18}O$ and $\delta^{13}C$ for this ocean equal 1.52 ‰ and -0.81 ‰, respectively (Table 4).

enriched in $\delta^{18}O$ during the glacial maximum and 0.28 ‰ depleted in ^{13}C (Table 4). All of the cores are located near to margins of the Indian Ocean and may not be representative of the isotopic changes observed in pelagic regions of this ocean basin.

Atlantic Ocean

The Atlantic Ocean has been the focus of extensive research on deep water circulation studies because of its abundant carbonate sediments, simple stratigraphic tools, and large number of high-quality cores. Consequently, we have compiled a collection of 31 isotopic records for this ocean basin for the last glacial-interglacial transition. Of these cores, two are located in the South Atlantic, and they averaged 1.29 ‰ greater in $\delta^{18}O$ and 0.48 ‰ less in $\delta^{13}C$ during the glacial maximum (Table 4). Twenty-nine North Atlantic cores averaged 1.54 ‰ greater in $\delta^{18}O$ and 0.59 ‰ less in $\delta^{13}C$ during the glacial maximum. Like the Pacific Ocean, the glacial maximum $\delta^{13}C$ samples in the North Atlantic have nearly twice the standard deviation of the Late Holocene samples, suggesting that greater heterogeneity occurred in the geographic distribution of $\delta^{13}C$ during the glaciation than today. This difference in standard deviation is significant with a high degree of confidence ($p<0.1$).

The glacial-interglacial amplitude of $\delta^{13}C$ varies regionally and with depth in the Atlantic Ocean (Figure 10). Cores from shallow depths (<2000 m) in the Atlantic appear to be enriched in ^{13}C during the glacial maximum [Boyle and Keigwin, 1986; Zahn and Sarnthein, 1986; Cofer-Shabica and Peterson, 1986; Oppo and Fairbanks, 1987]. V28-14, in the Norwegian-Greenland Sea at 1855 m, shows a $\delta^{13}C$ enrichment of 0.4 ‰ during the glacial maximum (Table 3). At depths below 2000 m in the Atlantic, $\delta^{13}C$ is always lower during the glacial maximum than during the Late Holocene. In the northern North Atlantic the amplitude is about 0.3–0.5 ‰. The amplitude increases toward the south (Figure 10), and near the present mixing zone between northern and southern water masses at the equator, cores which are presently located in NADW display glacial-interglacial amplitudes of 0.5–0.9 ‰ in $\delta^{13}C$. The largest variations in $\delta^{13}C$ occur in the deep eastern Atlantic (below 4700 m), where glacial-interglacial differences in $\delta^{13}C$ exceed 1.0 ‰ (Table 3).

DISCUSSION

Global Deep Water $\delta^{13}C$ Change

Based on the information in Table 4, we have determined the mean change in $\delta^{13}C$ and $\delta^{18}O$ of the deep ocean. We averaged all of the cores analyzed within each ocean basin (Pacific, Indian, and Atlantic) and determined a mean change in benthic foraminiferal isotopic composition for the whole ocean weighted by the volumetric fraction of each ocean. The results are presented in Table 5. On average, the $\delta^{13}C$ composition of the deep water was 0.46 ‰ lower during the last glacial maximum than during the Late Holocene. This mean value equals the value presented by Boyle and

TABLE 5. Mean Glacial-Interglacial Changes in $\delta^{18}O$ and $\delta^{13}C$ and Volumetric Fraction of Each Ocean Used to Calculate the Mean Change in Deep Water Isotopic Composition

Ocean	Volume x 10^6 km^3	$\delta^{18}O$	$\delta^{13}C$
Pacific	656	1.49	-0.41
Atlantic	295	1.52	-0.58
Indian	246	1.33	-0.28
Southern	123	1.52	-0.81
Mean Ocean	1320	1.47	-0.46

The isotopic data are from Table 4, and the ocean volumes are from Worthington [1981]. The southern ocean volume includes Pacific, Indian and Atlantic Ocean sectors.

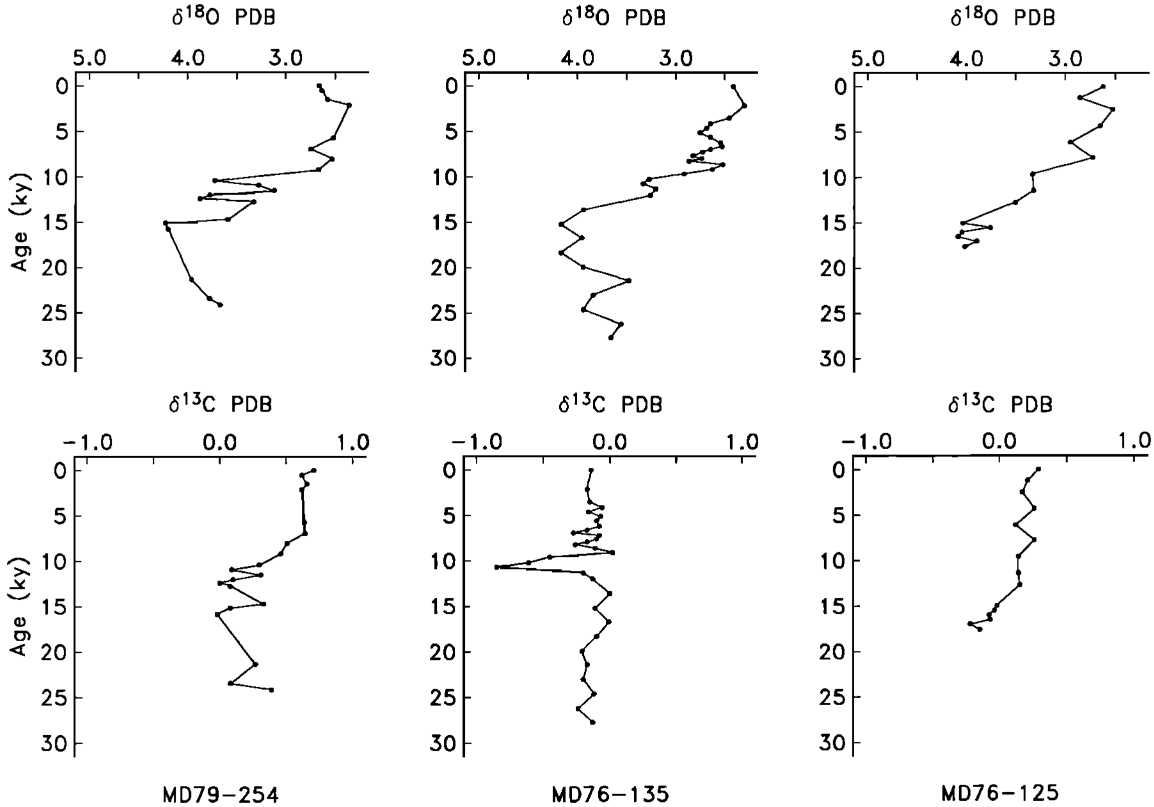

Fig. 9. Isotopic records for three cores from the Indian Ocean. Interglacial-glacial differences in $\delta^{18}O$ and $\delta^{13}C$ average 1.33 ‰ and -0.28 ‰, respectively, in the Indian Ocean. These cores are from marginal locations in the Indian Ocean; consequently, the average isotopic changes may not be representative of pelagic regions of the Indian Ocean.

Keigwin [1985/86], which they calculated using one core each from the Atlantic and Pacific oceans. The data presented in this paper show that their cores were representative of the mean changes of the deep water in those ocean basins as a whole. The data from the southern and Indian oceans, added to the global data set in this paper, have a mean glacial-interglacial difference which is near to the value presented by Boyle and Keigwin [1985/86]. This mean value (0.46 ‰) probably will not change significantly from the addition of new deep water $\delta^{13}C$ records because it is now based on a large data set from the Atlantic Ocean and an adequate data set from the Pacific Ocean. Only the addition of more cores from the Indian Ocean is likely to affect our estimate of the mean glacial-interglacial $\delta^{13}C$ change for deep water. Because the cores in our data set are dominantly from below 2000 m water depth, our average reflects only the mean changes in deep water $\delta^{13}C$. Our estimate is larger than the 0.32 ‰ decrease calculated by Duplessy et al. [this issue], because these authors attempted to quantify the $\delta^{13}C$ changes in intermediate water masses during the last glaciation. To the extent that shallow cores appear to have increased in $\delta^{13}C$ during the last glacial maximum, our value is a maximum estimate of the global $\delta^{13}C$ change.

Atlantic Ocean Glacial Circulation

The principal changes in circulation of the Atlantic Ocean include: (1) decreased production of nutrient-depleted deep water (>2000 m) in the North Atlantic, (2) greater northward penetration of low-^{13}C deep water from southern ocean source regions, and (3) the presence of a nutrient-depleted intermediate water mass shallower than 2000 m. These results are based on the observed changes in the geographic distribution of $\delta^{13}C$ during the glaciation. During the last glacial maximum, southern ocean deep water became reduced in $\delta^{13}C$ by more than 0.8 ‰ (Table 4). Cores presently within NADW decreased in $\delta^{13}C$ by about 0.5 ‰ during the glaciation in the North Atlantic, but toward the equatorial region, the amplitude of $\delta^{13}C$ increased (Figure 10). At this time, the isotopic composition of western equatorial cores fell between northern North Atlantic and southern ocean values (Figure 11). Because mixing between water masses of different composition is the principal method for altering the distribution of $\delta^{13}C$ in the western basins of the Atlantic (see Figure 2), these results suggest that the mixing zone between northern and southern component deep water migrated to the north during the glacial maximum. Our observations

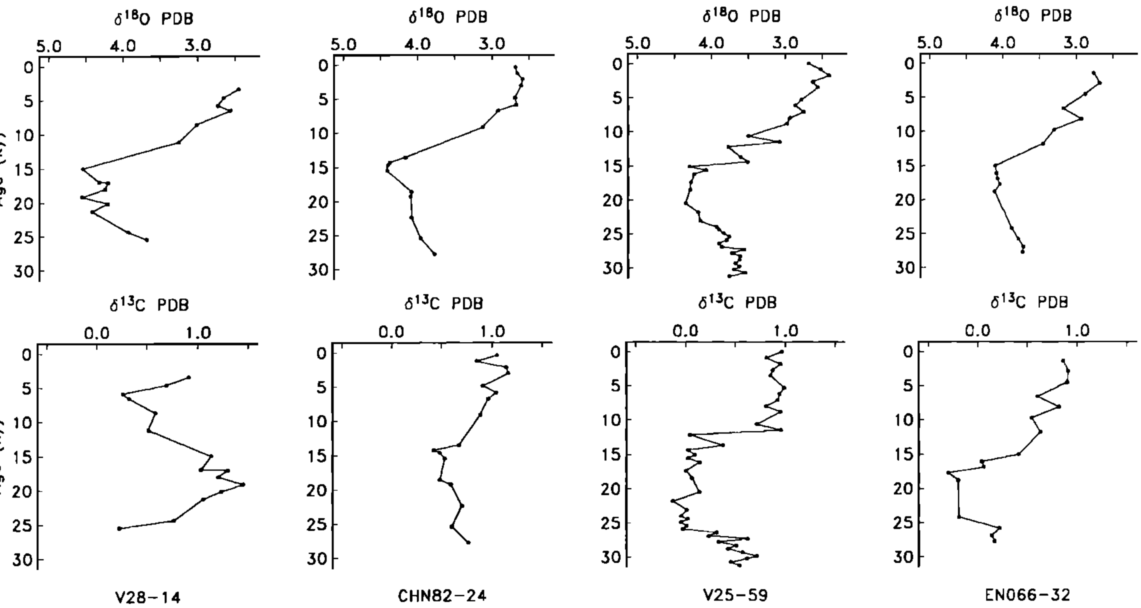

Fig. 10. Isotopic records for Atlantic Ocean cores. V28-14 is from the Norwegian-Greenland Sea at about 1800 m water depth. It is the only core in this data set which increases in $\delta^{13}C$ during the glacial maximum. All cores from below 2000 m decrease in $\delta^{13}C$ during the glaciation, and their amplitude increases toward the equator (V25-59). Highest amplitude $\delta^{13}C$ records and lowest glacial values are observed in the deep eastern Atlantic below 4700 m.

support the observations and conclusions of Oppo and Fairbanks [1987].

The lowest $\delta^{13}C$ values observed in the glacial Atlantic Ocean are found in eastern Atlantic locations below 4700 m. Curry and Lohmann [1983, 1985] suggested that these values resulted from the increased residence time of the deep water, resulting from decreased glacial production of NADW. They assumed that the input composition of the deep water entering the eastern Atlantic through low-latitude fracture zones had a $\delta^{13}C$ value equal to the $\delta^{13}C$ values of cores in the eastern equatorial Atlantic from above the sill depth of the fracture zones. Thus they assumed that the bathymetric gradient in $\delta^{13}C$ of 0.7 ‰ approximated the geographic difference in $\delta^{13}C$ between the western and eastern basins of the equatorial Atlantic. It is clear from the above discussion that a greater proportion of southern component deep water was flowing into the western Atlantic during the glaciation [Oppo and Fairbanks, 1987] and that this affected the input composition of the deep water flowing into the eastern Atlantic Ocean. The $\delta^{13}C$ value of this ventilating deep water (at the sill depth of the Romanche Fracture Zone, ~4000 m) is best recorded by the western Atlantic $\delta^{13}C$ records of KNR110-50 and KNR110-58, which have average glacial $\delta^{13}C$ values of 0.20 and -0.03 ‰, respectively (Table 3). The lowest $\delta^{13}C$ values observed in the deepest eastern equatorial Atlantic are -0.19 and -0.25 ‰, respectively, for EN066-29 and and EN066-32. Since lower values are observed in the eastern Atlantic than are observed at any depth in the western Atlantic, some alteration of the isotopic value of the deep water must have occurred after it enter the eastern basin (see Figure 3). However, this effect of the longer residence time on the glacial isotopic records of the deep eastern Atlantic cores is limited to a maximum of 0.1–0.3 ‰ $\delta^{13}C$ out of the total bathymetric decrease of 0.7 ‰ observed in the eastern basin. This 0.1–0.3 ‰ difference in $\delta^{13}C$ because of increased carbon remineralization is similar to the magnitude of this effect today (compare Figure 2 with Figure 3).

The presence of a ^{13}C enriched water mass shallower than 2000 m is observed in the limited data presented in this paper. Convincing evidence for the geographic extent of this intermediate water mass has been presented by Zahn and Sarnthein [1986], who mapped the bathymetric distribution of enriched ^{13}C values in glacial benthic foraminifera sampled on the west African continental margin, and by Cofer-Shabica and Peterson [1986], Boyle and Keigwin [1986], and Oppo and Fairbanks [1987], who determined that glacial Caribbean benthic foraminifera were enriched in ^{13}C and depleted in Cd. Because the Caribbean is ventilated through straits with a sill depth of about 1800 m, the dominant signal measured in this marginal sea reflects changes in $\delta^{13}C$ at 1800 meters in the North Atlantic. The source of this intermediate water is not yet confirmed, but Zahn and Sarnthein [1986] and Oppo and Fairbanks [1987] suggest that the Mediterranean Sea is the likely source. Oppo and Fairbanks [1987] demonstrate that glacial Mediterranean outflow was probably higher in $\delta^{13}C$ than Holocene outflow.

Glacial Pacific Deep Water

Two aspects of the $\delta^{13}C$ data for the Pacific suggest that there may have been source of nutrient-depleted

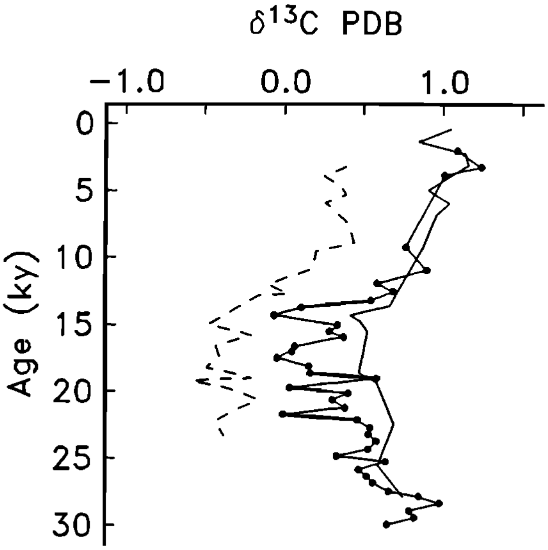

Fig. 11. Carbon isotopic variations in KNR110-82 from the western equatorial Atlantic Ocean. Lines indicate the $\delta^{13}C$ changes in one core from the North Atlantic (Solid line: CHN82-24) and one core from the southern ocean (Dashed line: RC13-229). Note that the equatorial Atlantic core and the North Atlantic core have equal $\delta^{13}C$ values during the Late Holocene. During the glaciation, the equatorial Atlantic core has values which are between southern ocean and North Atlantic values. Since mixing is the dominant process affecting the $\delta^{13}C$ distribution within the western basins of the Atlantic today, these results demonstrate that the mixing zone between northern and southern component deep water migrated to the north during the glacial maximum.

water produced in this ocean. The mean value of benthic foraminiferal $\delta^{13}C$ in the Pacific Ocean is greater than the mean value of $\delta^{13}C$ for the southern ocean during the glacial maximum (Table 4). Today, the $\delta^{13}C$ composition of southern ocean deep water falls between the values of NADW and mean Pacific Ocean deep water because it is a mixture of these two components. Thus Late Holocene benthic foraminifera from the southern ocean are higher in $\delta^{13}C$ than Pacific benthic foraminifera (Table 4). During the last glacial maximum, the mean isotopic composition of southern ocean benthic foraminifera was 0.15 ‰ lower than Pacific Ocean benthic foraminifera. Although the small number of records in each ocean basin limits our confidence in this difference, it has important implications about Pacific Ocean deep circulation. Since both NADW and Pacific deep water were enriched in ^{13}C compared to southern ocean deep water, southern ocean deep water could not have been a simple mixture of NADW and recirculated Pacific deep water as it is today. Oppo and Fairbanks [1987] first noted that Pacific and Southern Ocean benthic foraminifera were similar in $\delta^{13}C$ during the glaciation and concluded that glacial northern Atlantic water was not mixed into this region. Our results extend this observation to suggest that a separate source of nutrient-depleted water may have mixed with southern ocean water to produce the Pacific $\delta^{13}C$ values.

Close examination of the Pacific data shows that some individual cores have glacial $\delta^{13}C$ values as low as southern ocean cores, while others are greatly enriched in ^{13}C (Table 3). Heterogeneity like this normally would support an hypothesis of mixing between two water masses in the glacial Pacific Ocean. In the modern Pacific Ocean the geographic variability of $\delta^{13}C$ is small and results in the low standard deviation for the mean value presented in Table 4. In contrast, the mean value for the glacial samples shows a larger standard deviation suggesting that there was greater geographic variability in $\delta^{13}C$ at that time. Greater variability within the Pacific basin may have resulted from production of deep water within the Pacific and mixing between this water mass and southern ocean deep water. This mixing would produce a standard deviation of the $\delta^{13}C$ values which approaches the standard deviation observed in the present-day and glacial Atlantic Oceans, where mixing between two water masses is clearly an active process. But two ambiguities limit our conclusions about mixing between Pacific water masses: (1) Because of the small number of samples in our Pacific data set the difference in variance is not significant with a high degree of statistical confidence. Only a more extensive suite of Pacific $\delta^{13}C$ records will confirm our observations. (2) The two Pacific cores with the most enriched glacial $\delta^{13}C$ values (V28-304 and KNR73-3) are not located near to each other, so we cannot develop a simple geometry for mixing between water masses of different composition.

CONCLUSIONS

1. The geographic distribution of $\delta^{13}C$ is controlled by photosynthetic removal of carbon from the surface ocean and oxidative degradation in the deep ocean. Water masses are formed at the surface by cooling and mixing of water types with different preformed $\delta^{13}C$ values. After removal from the surface ocean, $\delta^{13}C$ of a water mass changes only as a result of mixing between two water masses, or from the oxidation of the organic particles settling through the water column. The relative intensities of these two effects vary regionally because of the dynamics of deep water circulation and differences in surface water productivity within and between oceans. Today, the $\delta^{13}C$ distribution in the western Atlantic is dominated by mixing between NADW and southern-source deep water because of the presence of these two water masses flowing in opposite directions within that basin and because surface water productivity is very low in the Atlantic Ocean. In contrast, the $\delta^{13}C$ values of the eastern Atlantic and the Pacific oceans are each lower than would be expected if mixing alone controlled their distribution. Degradation of organic carbon because of longer residence times within these basins (the "aging" effect) has lowered the $\delta^{13}C$ values by 0.2 ‰ in the eastern Atlantic and up to 0.4 ‰ in the Pacific.

2. $\delta^{13}C$ values of the genus *Cibicidoides* faithfully record the gradients in isotopic composition of the overlying bottom water. Thus the chemistry of their

shells provides us with a unique record of the past distribution of $\delta^{13}C$ in the oceans. Since the geographic distribution of $\delta^{13}C$ is controlled to a great extent by circulation patterns, we can evaluate the changes in $\delta^{13}C$ in terms of changes in bottom and deep water circulation and chemistry.

3. Largest glacial-interglacial changes in $\delta^{13}C$ occur in southern ocean cores (0.8 ‰), followed by Atlantic (0.5 ‰) and Pacific (0.3 ‰) cores. In the modern ocean, lowest observed $\delta^{13}C$ values occur in the Pacific Ocean, where the effects of long residence time have lowered the $\delta^{13}C$ value by 0.4 ‰ from its conservative-mixing value. Late Holocene $\delta^{13}C$ values for southern ocean fall between the values of NADW and recirculated Pacific deep water, showing the effects of mixing ^{13}C-enriched NADW into the southern ocean. During the glaciation, southern ocean cores have lowest observed $\delta^{13}C$ values, demonstrating that reduced glacial production of NADW decreased its effect on southern ocean chemistry. Since Pacific Ocean cores also have greater $\delta^{13}C$ values than southern ocean cores during the last glacial maximum, some alternate source of nutrient-depleted water must have been produced in the Pacific Ocean.

4. High-amplitude changes in $\delta^{13}C$ in equatorial Atlantic cores probably resulted from increased northward penetration of a low-$\delta^{13}C$ southern-source deep water into the North Atlantic during the glaciation. The lowest $\delta^{13}C$ values in the equatorial region occur in the deep eastern Atlantic, and these values are near in composition to southern ocean $\delta^{13}C$ values. Western equatorial Atlantic locations also have low values during the glaciation, but the values are about 0.2 ‰ higher than in the deep eastern Atlantic. This difference places a maximum constraint on the effects of increased residence time on eastern Atlantic $\delta^{13}C$ values, and it is similar in magnitude to the effect of residence time observed in the modern eastern Atlantic.

APPENDIX 1. ISOTOPIC DATA FOR *Cibicidoides* spp. FROM CORES DISTRIBUTED THROUGHOUT THE WORLD'S OCEAN

Core: V28-14
65°N 30°W
1855 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.500	3.5	2.45	0.91
0.700	4.7	2.65	0.69
0.900	5.9	2.64	0.28
0.900	5.9	2.82	0.25
1.000	6.6	2.56	0.32
1.100	8.7	3.02	0.58
1.200	11.2	3.25	0.51
1.300	15.0	4.54	1.13
1.490	17.0	4.32	1.03
1.500	17.1	4.20	1.30
1.600	18.1	4.42	1.07
1.600	18.1	4.06	1.32
1.700	19.2	4.55	1.45
1.800	20.2	4.40	1.47
1.800	20.2	4.00	0.98
1.900	21.3	4.42	1.05
2.200	24.4	3.93	0.76
2.300	25.5	3.68	0.22

Source: Shackleton [unpublished data]
Species. *C. wuellerstorfi*

Core: CH73-139C
55°N 16°W
2209 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.000	0.0	2.67	0.96
0.150	1.2	2.66	0.95
0.200	1.6	2.65	0.93
0.300	2.4	2.68	0.89
0.400	3.2	2.72	0.96
0.500	4.0	2.75	0.88
0.600	4.8	2.74	0.97
0.700	5.6	2.83	0.76
0.850	6.8	2.90	0.69
0.900	7.2	2.91	0.76
1.000	8.0	2.97	0.67
1.100	8.8	3.01	0.73
1.200	9.6	3.48	0.89
1.300	10.4	3.49	0.79
1.350	10.8	3.54	0.81
1.450	11.6	3.50	0.76
1.500	12.3	4.14	0.41
1.550	13.0	3.96	0.59
1.600	13.7	4.42	0.59
1.700	15.1	4.81	0.61
1.750	15.6	4.59	0.71
1.850	16.7	4.54	0.72
1.900	17.3	4.61	0.74
2.000	18.3	4.56	0.80
2.100	19.4	4.30	0.56
2.250	21.0	4.70	0.36
2.350	22.1	4.69	0.36
2.450	23.2	4.58	0.61
2.550	24.2	4.22	0.43
2.650	25.3	4.18	0.51
2.750	26.4	4.30	0.65
2.850	27.5	4.57	0.54
3.000	29.1	4.76	0.26
3.100	30.1	4.47	0.25
3.200	31.2	4.49	0.06
3.300	32.3	4.33	0.25

Source: Duplessy [1982]
Species. *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: CHN82-24 43°N 30°W 3070 m			
0.040	0.4	2.69	1.11
0.040	0.4	2.68	0.99
0.070	1.3	2.66	0.85
0.100	2.2	2.61	1.27
0.100	2.2	2.58	1.01
0.130	3.1	2.59	1.29
0.130	3.1	2.63	1.03
0.190	4.9	2.69	0.91
0.220	5.9	2.67	1.04
0.250	6.8	2.84	1.05
0.250	6.8	3.00	0.87
0.330	9.2	3.13	0.88
0.545	13.6	4.16	0.67
0.590	14.3	4.37	0.42
0.620	14.7	4.40	0.48
0.650	15.5	4.41	0.53
0.730	18.6	4.08	0.48
0.750	19.3	4.09	0.59
0.830	22.4	4.08	0.70
0.910	25.5	3.96	0.60
0.970	27.8	3.77	0.76
1.100	32.9	3.93	1.00
1.165	35.4	3.81	0.63
1.190	36.3	4.02	1.23
1.260	39.1	3.78	0.95
1.300	40.6	3.69	0.93
1.330	41.8	3.93	0.86
1.385	43.9	3.42	0.89

Source Boyle and Keigwin [1985/86]
Species· *C. wuellerstorfi*, *C. kullenbergi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
1.450	8.7	2.46	1.01
1.500	9.0	2.61	1.08
1.600	9.6	2.57	1.11
1.690	10.2	2.95	1.33
1.800	10.9	2.74	0.95
2.010	11.8	3.31	0.74
2.110	12.0	3.33	0.84
2.200	12.2	3.45	0.40
2.300	12.4	3.50	0.66
2.390	12.6	3.20	0.60
2.620	13.0	3.53	0.08
3.200	14.1	3.51	0.60
3.470	14.6	4.01	0.03
3.710	15.4	4.17	0.52
3.810	16.8	3.56	0.90
3.920	18.4	4.05	0.18
4.280	23.4	3.76	0.55
4.690	29.2	3.45	0.35
4.790	30.6	3.70	0.17
4.980	33.2	2.61	1.15
5.080	34.6	3.69	0.24
5.180	36.0	3.77	0.31
5.320	38.0	4.07	0.63
5.430	39.6	3.99	-0.51

Source: Keigwin [unpublished data]
Species. *C. wuellerstorfi*, *C. kullenbergi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: CH75-04 10°N 56°W 3820 m			
0.000	0.0	2.82	0.86
0.125	4.0	3.20	0.48
0.425	7.5	3.07	0.56
0.525	8.6	3.31	0.52
0.613	9.6	3.75	0.62
0.637	9.9	3.84	0.49
0.687	10.4	3.14	0.51
0.962	15.1	4.60	0.08
1.087	16.6	4.48	-0.03
1.175	17.8	4.48	-0.02
1.288	19.2	4.58	-0.05
1.375	20.3	4.60	-0.41
1.475	21.6	4.56	-0.17

Source: Duplessy [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: CH75-03 10°N 57°W 3410 m			
0.013	0.4	2.88	0.89
0.075	2.3	2.77	0.84
0.150	6.8	2.99	0.78
0.225	8.5	3.33	0.55
0.512	11.4	3.58	0.76
0.837	15.1	4.68	0.04
0.937	17.5	4.65	0.31
1.237	24.6	4.25	0.48
1.268	25.3	4.28	0.39
1.450	29.6	4.69	0.04
1.487	30.5	4.64	0.15

Source: Duplessy [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: V26-176 36°N 72°W 3942 m			
0.000	0.0	2.54	1.15
0.100	0.6	2.53	1.04
0.200	1.2	3.05	1.14
0.300	1.8	2.72	0.84
0.390	2.3	2.69	0.62
0.500	3.0	2.48	0.63
0.600	3.6	2.73	0.90
0.770	4.6	2.88	0.66
1.000	6.0	2.80	1.45
1.100	6.6	2.96	1.16
1.290	7.8	2.63	0.79
1.400	8.4	1.68	2.81
1.400	8.4	2.81	1.23

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: CH72-02 40°N 22°W 3485 m			
0.000	0.0	2.92	0.90
0.040	2.2	3.00	0.90
0.100	5.4	2.76	0.92
0.250	13.1	3.78	0.75
0.300	15.1	4.27	0.80
0.350	16.5	4.29	0.82
0.400	18.0	4.24	0.70
0.520	21.4	4.16	0.84
0.600	23.7	4.00	0.92

Source: Duplessy [unpublished data]
Species. *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: CH74-227 35°N 29°W 3225 m			
0.300	5.0	3.27	0.46
0.400	6.7	3.27	0.86

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.500	8.4	3.24	0.68
0.600	10.1	3.76	0.23
0.700	11.9	3.84	0.22
0.800	15.2	4.41	0.16
0.900	18.5	4.44	0.18
1.000	21.7	4.41	-0.01
1.100	25.0	4.03	0.03
1.200	28.3	3.87	0.08
1.300	31.5	3.98	0.29
1.400	34.8	3.75	0.11

Source: Duplessy [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: V30-49 18°N 21°W 3093 m			
0.010	0.4	2.23	0.86
0.040	1.6	2.28	0.80
0.080	3.3	2.22	0.91
0.100	4.1	2.18	1.06
0.100	4.1	2.45	0.94
0.120	4.7	2.44	0.97
0.160	5.6	2.17	0.71
0.240	7.3	2.22	0.48
0.300	8.6	2.69	0.71
0.320	8.9	2.71	0.47
0.400	10.2	2.92	0.53
0.440	10.9	3.20	0.49
0.480	11.6	3.09	0.43
0.500	12.1	3.36	0.20
0.500	12.1	3.49	0.51
0.520	12.7	3.36	0.56
0.560	13.9	3.45	0.46
0.600	15.1	4.10	0.25
0.640	15.9	4.08	0.11
0.700	17.1	3.99	0.16
0.720	17.6	4.20	0.32
0.760	18.4	4.06	0.23
0.800	19.2	3.84	0.22
0.840	20.0	4.04	0.14
0.880	20.8	3.74	0.02
0.900	21.2	3.88	0.27
0.920	21.7	3.77	0.23
1.000	23.3	3.98	0.54
1.040	24.1	3.26	0.02
1.080	24.9	3.25	-0.01
1.100	25.3	3.54	0.37
1.120	25.7	3.46	0.38

Source: Mix and Fairbanks [1985]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: M12392 25°N 17°W 2573 m			
0.005	0.1	2.66	0.96
0.032	0.7	2.69	1.01
0.032	0.7	2.55	1.11
0.032	0.7	2.49	1.12
0.075	1.5	2.80	0.80
0.087	1.8	2.41	1.02
0.087	1.8	2.15	0.85
0.125	2.7	2.16	0.92
0.138	3.0	2.53	1.15
0.138	3.0	2.58	1.02
0.187	4.2	2.51	0.99
0.237	5.4	2.61	1.04
0.237	5.4	2.56	0.99
0.312	7.3	2.73	0.96
0.412	9.1	3.09	0.65
0.512	10.1	3.54	0.70
0.562	10.6	3.31	0.51
0.613	11.1	3.33	0.57
0.613	11.1	3.32	0.22
0.712	12.1	3.67	0.51
0.762	12.6	3.75	0.35
0.812	13.0	3.62	0.23
0.913	14.0	3.82	0.25
1.013	15.0	4.47	0.41
1.013	15.0	4.57	0.37
1.112	15.6	4.50	0.46
1.212	16.2	4.45	0.26
1.212	16.2	4.56	0.23
1.312	16.8	4.36	0.31
1.413	17.4	4.51	0.25
1.480	17.8	4.48	0.48
1.513	18.0	4.09	0.51
1.612	18.6	4.36	0.45
1.712	19.2	4.39	0.29
1.712	19.2	4.37	0.56
1.812	19.7	4.36	0.36
1.913	20.3	4.22	0.32
2.013	20.9	4.13	0.21
2.015	20.9	4.37	0.53
2.112	21.5	4.13	0.21
2.193	22.0	4.31	0.21
2.312	22.7	4.25	0.27
2.412	23.3	4.18	0.30
2.513	24.0	3.98	0.45
2.612	25.0	4.06	0.38
2.713	26.1	4.01	0.34
2.810	27.1	4.23	0.32
2.812	27.1	4.23	0.25
2.912	28.1	4.03	0.60
3.013	29.1	4.00	0.41
3.112	30.2	3.84	0.45
3.213	31.2	3.79	0.10
3.220	31.3	4.11	0.08
3.312	32.2	3.85	0.37
3.412	33.2	4.04	0.41
3.513	34.2	3.99	0.24
3.592	35.1	3.73	0.25

Source: Shackleton [1977b], Zahn et al. [1986]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-82 4°N 43°W 2816 m			
0.010	2.0	1.94	1.09
0.070	3.2	1.99	1.24
0.100	3.8	1.71	0.87
0.100	3.8	1.95	1.15
0.130	9.2	2.25	0.80
0.130	9.2	2.94	0.75
0.170	10.9	2.93	0.90
0.200	11.9	3.18	0.59
0.230	12.5	3.29	0.96
0.230	12.5	3.45	0.43
0.270	13.2	3.81	0.55
0.300	13.7	4.35	0.24
0.300	13.7	3.95	-0.08
0.300	13.7	4.31	0.24
0.300	13.7	4.25	0.03
0.330	14.3	4.06	-0.06
0.370	15.0	4.32	0.45
0.370	15.0	4.26	0.23
0.400	15.5	3.73	0.50
0.400	15.5	4.12	0.16
0.400	15.5	4.57	0.22
0.430	15.9	4.32	0.56
0.430	15.9	4.18	0.21
0.470	16.6	4.16	0.15
0.470	16.6	4.13	-0.01
0.500	17.0	4.20	0.05
0.530	17.5	4.04	-0.04
0.570	18.1	4.32	0.16
0.600	18.6	3.87	0.17
0.630	19.0	3.72	0.73
0.630	19.0	4.11	0.44
0.670	19.7	4.18	0.15
0.670	19.7	4.14	-0.08
0.700	20.1	4.04	0.41
0.730	20.6	4.15	0.31
0.770	21.2	4.06	0.39
0.800	21.7	4.06	0.10
0.800	21.7	3.46	-0.03
0.800	21.7	4.37	-0.08

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.830	22.1	4.12	0.47
0.870	22.7	3.99	0.55
0.900	23.2	4.00	0.54
0.930	23.7	3.80	0.59
0.970	24.3	3.75	0.64
0.970	24.3	3.15	0.44
1.000	24.8	3.24	0.62
1.000	24.8	3.62	0.07
1.030	25.2	3.77	0.65
1.030	25.2	3.26	0.66
1.070	25.8	3.58	0.48
1.100	26.3	3.65	0.58
1.100	26.3	3.80	0.48
1.130	26.8	3.18	0.31
1.130	26.8	3.90	0.71
1.130	26.8	4.04	0.70
1.170	27.4	3.35	0.67
1.200	27.8	3.53	0.86
1.230	28.3	3.62	1.12
1.230	28.3	3.78	0.85
1.270	28.9	3.40	0.80
1.300	29.4	3.75	0.71
1.300	29.4	3.87	0.95
1.330	29.9	3.33	0.65
1.330	29.9	3.69	0.67

Source: Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-75			
4°N 43°W			
3063 m			
0.010	0.2	2.52	0.41
0.010	0.2	2.43	1.20
0.070	1.7	2.35	1.02
0.070	1.7	2.78	1.49
0.100	2.5	2.33	0.84
0.130	5.1	2.03	0.54
0.130	5.1	2.68	1.36
0.170	9.5	3.02	0.32
0.200	11.3	2.92	0.50
0.230	13.4	4.01	0.65
0.230	13.4	3.96	0.36
0.270	14.0	3.67	0.28
0.270	14.0	3.90	0.07
0.300	14.5	3.11	-0.43
0.300	14.5	3.36	-0.03
0.300	14.5	4.02	0.14
0.330	15.0	4.01	0.47
0.330	15.0	4.00	-0.24
0.370	15.7	3.96	0.34
0.400	16.2	3.90	0.47
0.430	16.7	4.10	0.30
0.430	16.7	3.87	0.85
0.430	16.7	4.23	0.19
0.470	17.4	3.26	-0.04
0.470	17.4	3.79	0.01
0.470	17.4	4.16	0.16
0.500	17.9	3.85	0.41
0.530	18.4	3.76	0.30
0.570	19.1	3.95	0.38
0.600	19.6	3.78	0.48
0.630	20.1	3.65	0.19
0.630	20.1	3.26	-0.29
0.630	20.1	3.95	0.39
0.670	20.7	3.60	0.22
0.670	20.7	3.60	0.19
0.700	21.3	3.65	0.30
0.730	21.8	3.69	0.34
0.770	22.4	3.91	0.42
0.800	23.0	3.98	0.72
0.830	23.5	2.84	0.13
0.870	24.1	3.65	0.60
0.870	24.1	3.70	0.75
0.900	24.6	3.75	0.60
0.930	25.2	3.65	0.72
0.970	25.8	3.70	0.64
1.000	26.3	3.80	0.77
1.000	26.3	3.59	0.60
1.030	26.9	3.37	0.56
1.070	27.5	2.89	0.44
1.070	27.5	3.60	0.63
1.070	27.5	3.99	0.65
1.070	27.5	3.68	0.67
1.100	28.0	3.67	0.42
1.130	28.6	3.22	0.81
1.130	28.6	4.11	0.35
1.170	29.2	4.04	0.59
1.200	29.7	3.86	1.18
1.200	29.7	3.68	1.04
1.200	29.7	3.97	0.84
1.230	30.2	3.36	0.58
1.270	30.9	3.44	0.84
1.300	31.4	3.46	0.70
1.330	31.9	3.67	0.92
1.330	31.9	3.86	0.70

Source: Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-71			
4°N 44°W			
3164 m			
0.010	1.1	2.44	1.20
0.010	1.1	2.16	1.22
0.010	1.1	2.35	1.20
0.070	3.5	2.22	0.99
0.070	3.5	2.19	0.98
0.100	7.0	2.68	1.36
0.100	7.0	2.20	0.66
0.100	7.0	2.56	1.39
0.130	9.2	2.57	1.37
0.130	9.2	3.18	0.76
0.130	9.2	3.11	1.07
0.170	10.4	3.13	0.91
0.170	10.4	2.89	0.36
0.200	11.3	2.96	0.75
0.230	12.2	3.62	0.28
0.230	12.2	3.39	0.28
0.270	13.3	3.53	0.73
0.300	14.2	4.41	0.64
0.300	14.2	3.74	0.34
0.330	15.0	4.33	0.48
0.370	15.9	4.19	0.51
0.370	15.9	4.20	0.43
0.400	16.6	4.07	0.28
0.430	17.2	3.84	0.34
0.470	18.1	3.12	-0.01
0.470	18.1	3.86	0.47
0.500	18.8	3.66	0.28
0.530	19.4	4.24	0.56
0.570	20.3	3.95	0.37
0.570	20.3	3.54	0.85
0.600	21.0	4.11	0.44
0.630	21.7	4.06	0.34
0.630	21.7	3.84	0.37
0.670	22.5	3.60	0.17
0.700	23.2	3.69	0.76
0.700	23.2	3.61	0.53
0.730	23.9	3.80	0.49
0.770	24.9	3.46	0.33
0.800	25.6	3.70	0.50
0.830	26.4	3.61	0.77
0.830	26.4	4.26	0.60
0.870	27.4	3.75	0.52
0.900	28.1	3.62	0.67
0.900	28.1	4.12	0.71
0.930	28.8	3.55	0.67
0.970	29.8	3.49	0.69
1.000	30.6	4.00	0.73
1.000	30.6	3.38	0.49
1.000	30.6	4.13	0.87
1.030	31.3	3.96	0.84
1.070	32.3	3.46	0.54
1.100	33.1	3.91	0.56
1.130	33.8	3.56	0.81

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
1.170	34.8	3.48	0.77
1.200	35.6	3.59	0.94
1.230	36.3	3.42	1.04
1.270	37.3	3.58	0.47
1.300	38.0	3.82	0.78
1.330	38.8	3.10	0.49
1.370	39.8	3.82	0.75
1.400	40.5	3.91	1.27
1.430	41.3	3.83	0.96
1.470	42.3	4.01	0.89

Source: Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Core: KNR110-66
5°N 43°W
3547 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.000	0.0	1.99	0.90
0.000	0.0	2.33	0.64
0.000	0.0	2.44	0.88
0.000	0.0	2.42	0.90
0.070	1.4	1.80	0.96
0.070	1.4	2.46	0.88
0.070	1.4	2.42	0.90
0.100	2.0	1.63	0.04
0.100	2.0	2.25	1.03
0.100	2.0	2.51	0.98
0.130	2.6	1.98	0.43
0.170	5.9	1.89	0.56
0.170	5.9	2.29	1.18
0.200	7.3	2.97	0.40
0.200	7.3	2.68	1.01
0.230	8.1	2.46	0.79
0.230	8.1	2.34	0.33
0.270	9.1	2.72	0.59
0.300	10.1	3.54	0.04
0.300	10.1	3.29	0.35
0.330	11.1	2.76	-0.25
0.330	11.1	3.28	0.75
0.370	11.9	3.15	-0.12
0.400	12.5	3.65	-0.01
0.430	13.1	3.66	0.03
0.470	13.9	3.54	-0.15
0.500	14.5	3.96	0.22
0.530	15.1	4.44	0.48
0.530	15.1	4.20	0.43
0.530	15.1	4.10	0.27
0.570	15.9	3.63	0.35
0.570	15.9	3.94	0.42
0.600	16.6	4.21	0.27
0.600	16.6	4.00	0.48
0.630	17.2	3.58	0.21
0.670	18.0	3.27	-0.07
0.700	18.6	3.86	0.39
0.730	19 [illegible]	3.38	-0.05
0.770	20.1	4.06	0.21
0.800	20.7	4.06	0.33
0.830	21.3	3.82	0.32
0.870	22.2	3.77	0.56
0.900	22.8	4.01	0.36
0.930	23.4	3.65	0.28
0.930	23.4	3.32	-0.35
0.970	24.2	3.52	0.17
1.000	24.9	4.11	0.76
1.000	24.9	3.72	0.74
1.030	25.5	3.23	0.13
1.030	25.5	3.15	0.05
1.070	26.3	3.30	0.26
1.100	26.9	3.50	0.34
1.130	27.6	3.95	0.62
1.170	28.4	4.40	0.82
1.170	28.4	3.51	0.18
1.200	29.0	3.28	0.38
1.230	29.6	3.84	0.66
1.270	30.5	3.28	0.70
1.270	30.5	4.46	0.94
1.270	30.5	3.79	-0.01
1.300	31.1	3.85	0.23
1.300	31.1	4.19	0.62
1.300	31.1	3.95	0.89
1.330	31.7	3.38	0.56
1.330	31.7	4.00	0.85

Source. Curry and Lohmann [1983, 1985]
Species *C. wuellerstorfi*

Core: KNR110-91
5°N 43°W
3810 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.020	1.4	2.27	0.86
0.020	1.4	2.39	0.93
0.070	1.9	2.40	0.86
0.070	1.9	2.19	0.82
0.100	3.5	2.29	0.31
0.100	3.5	2.13	0.52
0.130	10.0	2.77	0.50
0.130	10.0	3.35	0.68
0.130	10.0	2.82	0.53
0.130	10.0	3.13	0.15
0.170	12.4	3.81	0.20
0.200	13.0	3.73	0.22
0.200	13.0	3.39	0.41
0.230	13.6	3.63	-0.21
0.270	14.4	3.58	-0.37
0.270	14.4	4.47	0.22
0.270	14.4	4.05	0.30
0.270	14.4	4.39	0.04
0.300	15.0	4.03	-0.10
0.300	15.0	4.37	0.08
0.300	15.0	4.48	0.06
0.330	15.8	4.14	-0.10
0.330	15.8	4.29	0.28
0.330	15.8	4.03	0.35
0.370	16.8	3.75	-0.13
0.370	16.8	4.43	0.30
0.400	17.6	3.30	0.07
0.400	17.6	4.75	0.67
0.400	17.6	4.17	0.29
0.400	17.6	4.13	0.04
0.430	18.3	3.71	0.07
0.470	19.4	3.72	0.02
0.470	19.4	3.97	0.40
0.500	20.1	3.68	-0.08
0.530	20.9	3.65	-0.12
0.570	21.9	3.73	-0.04
0.570	21.9	4.01	0.25
0.600	22.7	3.90	0.25
0.600	22.7	4.13	0.02
0.630	23.5	3.47	-0.03
0.630	23.5	3.96	0.32
0.670	24.6	3.76	0.24
0.700	25.5	3.95	0.28
0.730	26.3	3.97	0.28
0.770	27.5	3.79	0.51
0.770	27.5	3.53	0.23
0.800	28.3	3.57	0.11
0.830	29.2	3.46	-0.06
0.830	29.2	4.33	0.10
0.830	29.2	3.95	0.33
0.870	30.4	3.83	0.31
0.900	31.2	3.88	0.47
0.930	32.1	4.07	0.77
0.930	32.1	3.73	0.33
0.970	33.2	3.47	0.47
1.000	34.1	3.48	0.44
1.030	34.9	3.94	0.73
1.030	34.9	4.20	0.30
1.070	36.1	3.68	0.43
1.100	36.9	3.49	0.63
1.130	37.8	3.50	0.56
1.130	37.8	3.68	0.27
1.170	39.0	3.77	0.34
1.200	39.8	3.79	0.53
1.270	41.8	3.61	0.49
1.300	42.7	3.62	0.57
1.300	42.7	3.59	0.26
1.330	43.5	3.58	0.47

Source· Curry and Lohmann [in manuscript]
Species· *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-50			
5°N 43°W			
3995 m			
0.010	0.1	2.46	0.58
0.010	0.1	2.45	0.94
0.070	1.8	2.48	0.68
0.070	1.8	3.00	1.21
0.100	4.5	2.26	0.23
0.100	4.5	1.82	0.47
0.100	4.5	3.09	0.03
0.130	10.3	3.13	0.31
0.130	10.3	3.71	0.23
0.170	11.5	3.23	-0.05
0.170	11.5	3.41	-0.25
0.200	13.4	3.78	-0.25
0.230	15.1	4.26	0.10
0.230	15.1	4.32	0.09
0.270	15.7	3.95	-0.01
0.300	16.2	3.95	-0.01
0.300	16.2	4.22	0.34
0.300	16.2	4.08	0.18
0.330	16.7	3.80	-0.12
0.330	16.7	4.18	0.32
0.370	17.4	4.03	0.14
0.400	17.9	4.13	0.22
0.430	18.4	4.16	0.17
0.470	19.1	4.07	0.28
0.470	19.1	3.81	0.06
0.500	19.6	4.01	0.23
0.530	20.1	4.14	0.16
0.570	20.7	4.14	0.12
0.570	20.7	3.91	0.20
0.600	21.2	3.49	0.08
0.600	21.2	3.79	0.26
0.640	21.9	4.10	0.38
0.670	22.4	3.82	0.17
0.670	22.4	4.02	0.31
0.700	22.9	3.48	0.07
0.700	22.9	3.99	0.15
0.700	22.9	3.99	0.33
0.730	23.4	3.67	0.59
0.730	23.4	3.96	-0.15
0.730	23.4	4.10	0.45
0.770	24.0	3.11	0.16
0.770	24.0	3.96	0.13
0.800	24.5	3.97	0.08
0.800	24.5	3.91	0.39
0.830	25.0	3.38	0.41
0.870	25.7	3.66	0.20
0.900	26.2	3.48	0.29
0.930	26.7	3.30	0.17
0.970	27.3	3.73	0.49
1.000	27.8	3.17	0.17
1.000	27.8	3.79	0.11
1.030	28.3	3.86	0.26
1.070	29.0	3.71	0.76
1.100	29.5	3.59	0.68
1.130	30.0	4.29	0.76
1.130	30.0	3.78	0.43
1.170	30.7	3.71	0.55
1.200	31.2	3.80	0.33
1.230	31.7	3.23	0.37
1.230	31.7	4.26	0.49
1.230	31.7	4.05	0.34
1.270	32.3	3.65	0.60
1.300	32.8	3.74	0.60
1.330	33.3	3.89	0.75
1.330	33.3	4.07	0.65

Source Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-58			
5°N 43°W			
4341 m			
0.010	0.2	2.17	0.73
0.010	0.2	2.17	0.20
0.010	0.2	2.89	0.64
0.030	0.6	2.61	0.35
0.070	1.4	2.50	1.05
0.070	1.4	2.96	0.89
0.100	2.0	2.47	0.79
0.100	2.0	2.79	0.61
0.130	2.6	2.76	0.85
0.130	2.6	2.91	0.37
0.170	3.6	2.44	0.40
0.170	3.6	2.54	0.80
0.200	9.3	3.31	0.48
0.200	9.3	3.17	0.28
0.230	11.6	3.29	0.24
0.230	11.6	3.32	0.27
0.270	13.0	3.96	0.22
0.270	13.0	4.02	-0.36
0.300	14.1	3.36	0.24
0.300	14.1	4.29	0.21
0.330	15.1	4.79	0.51
0.330	15.1	4.01	-0.01
0.330	15.1	4.29	0.10
0.370	16.0	4.19	-0.05
0.370	16.0	4.12	0.31
0.370	16.0	4.01	0.17
0.400	16.7	4.19	0.08
0.400	16.7	4.18	0.09
0.400	16.7	4.38	0.00
0.430	17.4	4.02	-0.23
0.430	17.4	4.36	-0.11
0.470	18.3	4.10	-0.14
0.500	19.0	4.19	0.00
0.530	19.7	3.74	-0.15
0.570	20.7	4.11	0.00
0.600	21.3	4.14	0.07
0.630	22.0	4.15	0.19
0.670	23.0	3.99	-0.03
0.730	24.6	3.84	0.20
0.770	25.9	3.77	0.14
0.770	25.9	3.89	-0.06
0.800	26.8	4.03	0.16
0.830	27.8	4.08	0.21
0.870	29.0	3.35	0.12
0.870	29.0	3.87	0.27
0.870	29.0	3.43	0.46
0.870	29.0	3.67	0.08
0.900	30.0	3.90	0.35
0.930	30.9	3.76	0.26
1.000	33.1	3.75	0.24
1.030	34.1	3.81	0.31
1.030	34.1	3.87	0.43
1.070	35.4	3.42	0.09
1.070	35.4	3.77	-0.10
1.100	36.3	3.73	0.60
1.100	36.3	3.66	0.13
1.130	37.2	3.48	0.18
1.130	37.2	3.64	0.50
1.170	38.5	3.37	0.22
1.170	38.5	3.79	0.27
1.200	39.5	3.31	0.56
1.230	40.4	3.63	0.30
1.230	40.4	4.20	0.10
1.270	41.7	3.80	0.53
1.300	42.6	3.51	0.20
1.300	42.6	3.57	0.32

Source: Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: KNR110-55			
5°N 43°W			
4556 m			
0.010	0.3	2.56	0.61
0.010	0.3	2.65	0.21
0.010	0.3	2.57	0.85
0.030	1.0	2.10	-0.08
0.030	1.0	3.27	0.54
0.030	1.0	2.70	0.70
0.070	2.4	2.16	0.43
0.070	2.4	2.10	-0.51

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.070	2.4	2.09	0.46
0.070	2.4	2.26	0.02
0.100	3.6	2.30	0.54
0.100	3.6	1.74	0.34
0.100	3.6	2.72	0.69
0.130	4.9	2.59	0.44
0.170	6.7	3.48	0.32
0.170	6.7	2.55	-0.50
0.170	6.7	2.56	0.95
0.200	7.9	2.67	0.07
0.230	9.2	2.89	0.66
0.230	9.2	2.78	0.69
0.270	10.5	3.64	-0.04
0.300	11.1	3.28	0.50
0.300	11.1	3.68	-0.36
0.330	11.7	3.70	0.29
0.330	11.7	3.62	0.24
0.370	15.1	4.51	-0.05
0.400	15.8	4.18	0.13
0.400	15.8	3.91	-0.34
0.400	15.8	3.94	0.24
0.430	16.5	3.85	0.15
0.470	17.4	3.97	-0.17
0.470	17.4	4.29	0.12
0.500	18.1	4.22	0.22
0.500	18.1	4.45	0.16
0.530	18.8	3.38	-0.25
0.530	18.8	3.98	-0.17
0.570	19.8	3.09	-0.30
0.570	19.8	3.97	-0.05
0.600	20.5	4.07	-0.03
0.630	21.2	4.08	0.17
0.670	22.1	3.80	0.06
0.700	22.8	4.04	0.01
0.730	23.5	3.74	0.03
0.730	23.5	4.00	0.10
0.770	24.5	3.21	-0.27
0.770	24.5	3.75	-0.28
0.800	25.2	4.37	0.41
0.800	25.2	4.04	-0.31
0.800	25.2	4.05	0.19
0.830	25.9	3.46	0.13
0.830	25.9	3.67	-0.15
0.870	26.8	3.41	0.18
0.900	27.5	3.41	0.02
0.930	28.2	3.96	0.02
0.930	28.2	4.21	0.21
0.970	29.2	3.33	0.21
0.970	29.2	3.38	-0.08
1.000	29.9	3.69	-0.15
1.030	30.6	3.50	-0.11
1.030	30.6	3.67	0.12
1.070	31.5	3.62	-0.01
1.100	32.3	3.61	0.18
1.130	33.0	3.61	0.20
1.170	33.9	3.56	0.27
1.200	34.6	3.62	0.08
1.230	35.3	3.76	0.05
1.230	35.3	3.89	0.39
1.230	35.3	3.83	0.56
1.270	36.3	3.94	0.60
1.270	36.3	4.02	0.06
1.300	37.0	3.62	0.15
1.300	37.0	4.12	0.55
1.300	37.0	3.93	0.48

Source: Curry and Lohmann [in manuscript]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: V25-59 1°N 33°W 3824 m			
0.000	0.0	2.68	0.96
0.025	0.9	2.52	0.81
0.050	1.8	2.41	0.95
0.075	2.7	2.63	0.87
0.100	3.5	2.56	0.85
0.150	5.3	2.78	0.99
0.175	6.2	2.87	0.94
0.200	7.1	2.75	0.92
0.225	8.0	2.94	0.80
0.250	8.8	2.98	0.95
0.300	10.6	3.50	0.71
0.325	11.5	3.08	0.95
0.350	12.2	3.77	0.04
0.400	13.7	3.60	0.37
0.425	14.4	3.51	0.02
0.450	15.1	4.30	0.09
0.475	15.6	4.07	0.02
0.500	16.2	4.23	0.14
0.550	17.4	4.28	0.00
0.600	18.5	4.29	0.06
0.675	20.5	4.35	0.14
0.700	21.8	4.18	-0.13
0.725	23.1	4.15	0.01
0.750	24.0	3.93	-0.05
0.775	24.4	3.90	0.02
0.800	24.9	3.84	-0.05
0.825	25.4	3.76	0.01
0.850	25.9	3.80	-0.03
0.875	26.4	3.90	0.31
0.900	26.9	3.86	0.23
0.925	27.3	3.56	0.62
0.950	27.8	3.72	0.33
0.975	28.3	3.61	0.51
1.000	28.8	3.62	0.42
1.025	29.3	3.68	0.57
1.050	29.8	3.62	0.71
1.075	30.2	3.70	0.61
1.100	30.7	3.54	0.45
1.125	31.2	3.76	0.54
1.150	31.7	3.58	0.70
1.175	32.2	3.54	0.56
1.200	32.7	3.63	0.37
1.225	33.1	3.69	0.51

Source: Mix and Fairbanks [1985]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: V22-197 14°N 10°W 3167 m			
0.080	0.7	2.55	0.69
0.080	0.7	2.51	0.46
0.100	0.8	2.67	0.67
0.150	1.2	2.70	0.79
0.150	1.2	2.80	1.01
0.200	1.6	2.88	1.08
0.250	2.0	2.75	0.97
0.250	2.0	2.60	0.75
0.300	2.5	2.50	0.62
0.350	3.6	2.71	0.90
0.400	4.6	2.99	0.53
0.450	5.6	3.12	0.69
0.500	6.6	2.77	0.77
0.550	7.1	3.64	0.37
0.600	7.5	3.15	0.61
0.650	8.0	2.70	1.17
0.780	9.4	3.40	0.02
0.960	11.4	3.39	0.36
1.050	13.1	4.31	0.19
1.150	15.1	4.56	0.14
1.150	15.1	4.26	0.08
1.240	16.3	4.42	0.25
1.350	17.8	4.31	0.21
1.450	19.1	4.41	0.27
1.550	20.5	4.41	0.05
1.650	21.8	4.35	0.18
1.750	23.2	4.39	0.08
1.850	24.5	3.97	0.03
1.950	25.8	4.04	0.18

Source: Shackleton [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-38 5°N 20°W 2931 m			
0.030	2.2	2.52	0.98
0.030	2.2	2.75	1.11
0.060	4.2	2.69	1.24
0.090	6.3	3.17	0.93
0.090	6.3	2.82	0.85
0.120	8.3	2.96	1.09
0.160	11.0	3.17	0.69
0.190	12.4	3.99	0.41
0.220	13.6	4.05	0.50
0.260	15.1	4.23	0.69
0.290	17.1	3.98	0.59
0.320	19.2	3.93	0.41
0.350	21.2	4.00	0.52
0.390	24.0	3.94	0.55
0.390	24.0	3.90	0.60
0.420	26.0	3.85	0.62
0.460	28.8	3.89	0.70
0.490	30.8	3.92	0.53

Source: Curry and Lohmann [1983, 1985]
Species· *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-16 5°N 21°W 3152 m			
0.040	1.1	2.54	0.94
0.070	2.3	2.44	0.99
0.100	4.9	3.35	0.57
0.140	8.4	2.81	0.95
0.170	11.0	3.09	0.77
0.200	12.9	4.14	0.47
0.240	15.0	4.38	0.44
0.270	15.7	4.19	0.31
0.300	16.3	4.35	0.43
0.340	17.2	4.38	0.43
0.370	17.8	4.30	0.40
0.400	18.5	4.08	0.46
0.440	19.3	4.13	0.51
0.440	19.3	4.15	0.50
0.470	20.0	4.20	0.54
0.500	20.6	4.14	0.44
0.500	20.6	3.96	0.28
0.600	22.8	4.02	0.71
0.700	24.9	3.55	0.84
0.700	24.9	3.97	0.81

Source. Curry and Lohmann [1983, 1985]
Species *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-44 5°N 22°W 3428 m			
0.040	2.4	2.62	1.15
0.040	2.4	2.55	0.94
0.070	7.8	2.95	0.95
0.070	7.8	2.90	1.15
0.100	9.7	3.69	0.61
0.140	11.6	3.59	0.59
0.170	15.0	4.40	0.60
0.200	16.4	4.31	0.54
0.200	16.4	3.87	0.40
0.240	18.3	4.36	0.45
0.270	19.8	4.60	0.62
0.270	19.8	3.94	0.48
0.300	21.2	4.71	0.48
0.300	21.2	4.16	0.50
0.340	23.1	4.65	0.75
0.340	23.1	4.02	0.55
0.370	24.5	4.14	0.61
0.370	24.5	4.01	0.57
0.370	24.5	3.81	0.53
0.400	25.9	4.04	0.69
0.440	27.8	4.17	0.62
0.470	29.3	3.94	0.71
0.470	29.3	3.97	0.84
0.470	29.3	3.82	0.67
0.470	29.3	4.01	0.49

Source: Curry and Lohmann [1983, 1985]
Species. *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-10 7°N 22°W 3527 m			
0.040	2.8	2.25	0.82
0.070	5.2	2.49	0.80
0.100	7.7	2.69	0.85
0.140	9.6	3.21	0.48
0.170	10.9	2.92	0.55
0.240	13.9	3.96	0.53
0.270	15.2	4.02	0.40
0.300	16.9	3.87	0.36
0.340	19.1	4.11	0.19
0.370	20.7	3.91	0.47
0.400	22.4	3.81	0.54
0.440	24.6	3.79	0.44

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.470	26.3	3.79	0.54
0.470	26.3	3.89	0.48
0.500	27.9	3.79	0.65

Source: Curry and Lohmann [1983,1985]
Species· *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-21 4°N 21°W 3995 m			
0.030	2.5	2.50	0.78
0.060	4.0	2.54	0.83
0.110	6.5	2.55	0.90
0.160	9.7	3.06	0.69
0.200	12.1	3.42	0.54
0.230	13.0	3.53	0.34
0.260	13.9	3.88	0.17
0.300	15.0	4.09	0.12
0.330	16.2	4.07	0.19
0.360	17.4	3.72	-0.02
0.400	19.0	4.03	0.27
0.430	20.2	3.98	0.28
0.460	21.4	3.97	0.42
0.500	23.1	3.84	0.39
0.560	25.5	3.42	0.09
0.660	29.5	3.64	0.55
0.660	29.5	3.82	0.43

Source· Curry and Lohmann [1983, 1985]
Species· *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-36 4°N 20°W 4270 m			
0.040	2.6	2.59	0.99
0.040	2.6	2.91	0.51
0.070	4.8	2.87	0.63
0.100	7.1	2.99	0.60
0.140	9.3	3.56	0.58
0.170	10.7	3.12	0.75
0.200	12.2	3.75	0.33
0.240	14.9	4.28	0.38
0.270	16.3	4.24	0.19

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.300	17.6	4.18	0.06
0.340	19.4	4.29	0.23
0.340	19.4	4.33	0.16
0.370	20.7	4.27	0.03
0.400	22.0	4.16	0.14
0.440	23.7	3.95	0.22
0.470	25.1	3.95	0.14
0.600	30.8	3.70	0.17

Source. Curry and Lohmann [1983, 1985]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-26			
3°N 20°W			
4745 m			
0.040	2.5	2.64	0.84
0.100	6.3	2.67	0.52
0.140	8.8	3.04	0.24
0.170	10.7	3.28	0.51
0.200	12.6	3.62	0.20
0.240	15.0	4.19	0.19
0.270	15.9	4.11	0.10
0.300	16.9	4.16	-0.16
0.340	18.1	4.23	-0.18
0.370	19.0	4.03	-0.25
0.400	19.9	4.10	-0.06
0.440	21.1	4.23	0.10
0.470	22.0	4.01	0.05
0.500	22.9	3.97	0.13
0.600	26.0	3.59	0.07

Source: Curry and Lohmann [1983, 1985]
Species· *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-32			
2°N 20°W			
5003 m			
0.040	1.4	2.76	0.86
0.070	2.9	2.68	0.91
0.100	4.5	2.88	0.90
0.140	6.6	3.18	0.60
0.170	8.1	2.93	0.82

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.200	9.7	3.31	0.54
0.240	11.8	3.46	0.63
0.300	15.0	4.11	0.41
0.340	16.1	4.09	0.04
0.370	16.9	4.08	0.06
0.400	17.7	4.05	-0.30
0.440	18.8	4.12	-0.20
0.640	24.2	3.89	-0.19
0.700	25.8	3.80	0.22
0.740	26.9	3.73	0.14
0.770	27.7	3.74	0.17

Source: Curry and Lohmann [1983, 1985]
Species: *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: EN066-29			
2°N 20°W			
5104 m			
0.040	2.9	2.41	0.85
0.040	2.9	2.72	0.84
0.100	6.1	2.86	0.48
0.140	8.3	3.01	0.77
0.200	11.5	3.14	0.21
0.200	11.5	3.19	0.18
0.240	15.0	4.03	-0.04
0.300	16.5	3.87	-0.29
0.300	16.5	4.24	-0.34
0.400	19.0	3.50	-0.16
0.500	21.5	4.00	-0.23
0.540	22.5	3.99	0.01
0.600	24.0	3.62	0.27
0.640	25.0	3.44	0.01
0.700	26.5	3.75	0.06

Source· Curry and Lohmann [1983, 1985]
Species *C. wuellerstorfi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: BT4			
4°S 10°E			
1000 m			
0.050	0.5	2.57	0.33
0.190	3.2	2.47	0.43

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.290	8.6	3.00	0.15
0.390	9.9	3.08	0.09
0.500	10.9	2.87	0.20
0.590	11.4	2.93	0.03
0.690	12.2	3.36	0.10
0.790	13.2	3.46	-0.06
0.900	14.3	3.70	0.24
0.990	15.2	3.83	0.19
1.090	16.6	3.77	0.16
1.190	18.0	3.49	0.00
1.290	19.4	3.63	0.07
1.490	22.2	3.59	0.02
1.590	23.6	3.47	0.02
1.690	25.0	3.30	0.19
1.790	26.4	3.52	0.19
1.890	27.7	3.48	0.01

Source· Shackleton [unpublished data]
Species. *Cibicidoides* spp

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: RC13-228			
22°S 11°E			
3204 m			
0.000	0.0	3.19	0.14
0.020	0.3	2.62	0.44
0.070	0.9	2.58	0.64
0.130	1.7	2.53	0.75
0.180	2.4	2.51	0.40
0.230	3.1	2.58	0.49
0.320	4.5	2.63	0.55
0.380	5.4	2.77	0.59
0.430	6.1	2.75	0.42
0.480	6.9	2.87	0.27
0.520	7.5	2.70	0.12
0.630	9.0	3.21	0.05
0.730	9.9	3.54	0.06
0.820	10.7	3.81	-0.15
0.880	11.2	3.82	-0.12
0.930	11.6	3.47	-0.25
0.980	12.7	4.22	0.03
1.070	15.0	4.51	0.09
1.130	15.6	4.33	-0.29
1.180	16.1	4.44	-0.06
1.200	16.3	4.34	-0.09
1.230	16.6	4.39	-0.02
1.270	17.0	4.50	0.03
1.320	17.6	4.23	-0.14
1.430	18.7	4.18	-0.15
1.480	19.2	4.21	0.00

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
1.500	19.4	4.12	-0.49
1.630	20.7	4.15	-0.03
1.680	21.2	4.12	-0.06
1.730	21.8	4.05	-0.08
1.820	22.7	4.16	0.33
1.880	23.3	4.21	0.20
1.930	23.8	3.94	0.09
1.980	24.3	3.81	0.21
2.020	24.7	3.80	0.27

Source: Shackleton [unpublished data]
Species. *Cibicidoides* spp

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: RC13-229			
26°S 11°E			
4194 m			
0.025	3.2	2.73	0.31
0.025	3.2	2.16	0.47
0.045	3.9	2.73	0.25
0.065	4.6	2.76	0.35
0.085	5.3	2.81	0.39
0.100	5.9	2.66	0.27
0.100	5.9	2.83	0.25
0.145	7.5	2.67	0.41
0.200	8.9	2.92	0.44
0.250	9.5	3.04	0.20
0.300	10.2	2.96	0.19
0.310	10.9	3.30	0.16
0.350	12.0	3.61	-0.10
0.400	12.7	3.65	0.03
0.410	12.8	3.72	-0.15
0.450	15.0	4.26	-0.47
0.500	15.8	4.03	-0.20
0.550	16.6	4.07	-0.42
0.600	17.4	4.20	-0.29
0.600	17.4	4.31	-0.52
0.650	18.2	4.23	-0.48
0.700	19.0	4.05	-0.20
0.710	19.2	4.16	-0.57
0.750	19.8	4.21	-0.33
0.800	20.6	4.15	-0.16
0.900	22.2	4.04	-0.42
1.000	23.3	4.03	-0.37

Source: Oppo and Fairbanks [1987]
Species: *C. wuellerstorfi*, *C. kullenbergi*

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: MD84-527			
44°S 51°E			
3269 m			
0.050	0.3	3.09	0.28
0.130	0.8	3.05	0.51
0.230	1.4	3.03	0.19
0.300	1.8	2.84	0.45
0.400	2.5	2.53	0.13
0.500	3.1	2.88	0.23
0.530	3.3	3.17	0.42
0.600	3.7	2.84	0.13
0.700	4.3	3.15	0.37
0.730	4.5	2.99	0.31
0.800	4.9	2.84	0.14
0.830	5.1	2.95	0.26
0.900	5.5	2.89	0.07
1.000	6.2	3.02	0.00
1.100	6.8	2.73	-0.24
1.130	7.0	3.19	-0.16
1.200	7.4	2.82	-1.25
1.300	8.0	2.65	-0.18
1.430	8.7	3.03	-0.18
1.500	9.0	3.09	-0.11
1.600	9.3	3.21	0.00
1.700	9.7	3.30	-0.15
1.800	10.1	3.26	-0.51
2.100	11.2	3.42	-0.12
2.200	11.6	3.56	0.01
2.300	11.8	3.74	-0.12
2.400	12.1	3.79	-0.40
2.500	12.3	3.81	-0.31
2.600	12.5	3.96	-0.22
2.700	12.7	3.97	-0.29
2.800	13.8	4.49	-0.38
2.900	15.0	4.54	-0.35
2.930	15.2	4.40	-0.55
3.000	15.6	4.28	-0.38
3.020	15.7	4.62	-0.44
3.100	16.2	4.34	-0.33
3.130	16.4	4.38	-0.77
3.200	16.9	4.29	-0.64
3.300	17.5	4.31	-0.45
3.400	18.1	4.33	-0.68
3.500	18.7	4.30	-0.54
3.600	19.4	4.24	-0.80
3.700	20.0	4.22	-0.47
3.800	20.6	4.22	-0.47
3.900	21.2	4.23	-0.09
4.000	21.8	4.32	-0.86

Source: Labeyrie et al. [1987]
Species. *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: RC11-120			
44°S 80°E			
3193 m			
0.050	0.9	2.92	0.39
0.150	3.9	2.37	0.29
0.150	3.9	2.74	0.61
0.300	8.5	2.84	0.45
0.400	10.7	3.88	0.15
0.450	11.4	3.45	0.12
0.600	14.9	4.52	-0.23
0.800	20.8	4.45	-0.48
0.850	22.2	4.55	-0.32
0.900	23.7	4.43	-0.46
0.950	25.1	4.36	-0.12

Source: Shackleton [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: MD76-135			
14°N 51°E			
1895 m			
0.000	0.0	2.41	-0.14
0.100	2.1	2.29	-0.17
0.200	3.5	2.45	-0.15
0.300	4.1	2.64	-0.06
0.400	4.6	2.68	-0.16
0.500	5.1	2.75	-0.07
0.600	5.6	2.64	-0.10
0.700	6.2	2.54	-0.08
0.800	6.6	2.52	-0.17
0.900	6.9	2.64	-0.27
1.000	7.2	2.72	-0.08
1.100	7.6	2.82	-0.10
1.200	7.9	2.73	-0.17
1.300	8.2	2.86	-0.26
1.400	8.6	2.51	-0.11
1.500	9.1	2.62	0.02
1.600	9.6	2.91	-0.45
1.700	10.2	3.27	-0.61
1.800	10.7	3.33	-0.85
1.900	11.3	3.20	-0.20
2.000	12.0	3.26	-0.13
2.100	13.6	3.93	0.00
2.200	15.2	4.16	-0.11
2.300	16.7	3.95	-0.01
2.400	18.3	4.16	-0.10
2.500	19.9	3.93	-0.21
2.600	21.4	3.47	-0.17
2.700	23.0	3.83	-0.20

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
2.800	24.6	3.93	-0.12
2.900	26.2	3.55	-0.24
3.000	27.7	3.65	-0.13

Source: Duplessy and Labeyrie [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: MD79-254			
18°S 39°E			
1934 m			
0.000	0.0	2.74	0.71
0.100	0.5	2.71	0.62
0.300	1.5	2.65	0.66
0.400	2.1	2.43	0.62
0.700	5.7	2.59	0.64
0.800	6.9	2.82	0.65
0.900	8.0	2.60	0.51
1.000	9.2	2.74	0.46
1.100	10.4	3.80	0.30
1.200	10.9	3.27	0.09
1.300	11.5	3.19	0.31
1.400	12.0	3.77	0.10
1.500	12.4	3.95	0.00
1.600	12.7	3.32	0.08
2.100	14.7	3.58	0.33
2.200	15.1	4.22	0.08
2.300	15.8	4.19	-0.02
3.100	21.3	3.95	0.27
3.400	23.4	3.77	0.08
3.500	24.1	3.66	0.39

Source: Duplessy and Labeyrie [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: MD76-125			
8°N 75°E			
1878 m			
0.000	0.0	2.62	0.29
0.100	1.2	2.85	0.21
0.200	2.5	2.52	0.17
0.300	4.3	2.65	0.26
0.400	6.1	2.95	0.12
0.500	7.8	2.72	0.26
0.600	9.6	3.33	0.14
0.700	11.4	3.32	0.14
0.800	12.7	3.50	0.15
1.000	15.0	4.03	-0.02
1.100	15.5	3.75	-0.04
1.200	16.0	4.04	-0.08
1.300	16.5	4.08	-0.07
1.400	17.0	3.89	-0.22
1.500	17.6	4.01	-0.15

Source: Duplessy and Labeyrie [unpublished data]
Species: *Cibicidoides* spp.

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: TR163-31			
4°S 84°W			
3210 m			
0.010	0.8	2.75	0.11
0.050	1.9	2.56	-0.38
0.070	3.9	2.97	0.18
0.110	5.1	2.88	0.03
0.120	5.3	2.86	-0.04
0.130	5.6	2.86	0.02
0.160	6.3	3.10	0.09
0.190	7.0	3.37	0.11
0.200	7.3	2.81	0.24
0.230	8.0	3.05	-0.11
0.240	8.3	2.98	-0.09
0.250	8.5	3.04	-0.08
0.260	8.7	2.69	-0.40
0.260	8.7	3.54	-0.26
0.270	8.9	3.22	-0.30
0.310	9.7	3.43	-0.32
0.320	9.9	3.13	-0.04
0.350	10.5	3.05	-0.19
0.360	10.7	3.39	-0.07
0.370	10.9	3.65	-0.10
0.400	11.5	3.36	-0.11
0.430	11.8	3.90	0.04
0.440	11.9	3.92	0.11
0.490	12.2	3.39	0.00
0.510	12.3	3.80	-0.02
0.520	12.3	3.98	0.14
0.550	12.5	3.48	-0.18
0.550	12.5	3.80	-0.01
0.590	12.7	4.03	-0.19
0.590	12.7	3.79	-0.45
0.610	12.9	4.02	0.00
0.710	13.4	4.02	-0.11
0.720	13.5	4.09	-0.42
0.730	13.6	4.19	-0.26
0.750	13.7	4.24	-0.33
0.850	14.3	4.23	-0.20
0.970	15.0	4.45	-0.28
1.090	15.8	4.37	-0.20
1.210	16.6	4.46	-0.30
1.330	17.5	4.25	-0.40
1.450	18.3	4.25	-0.47
1.590	19.3	4.27	-0.47
1.710	20.2	4.14	-0.43
1.830	21.0	4.26	-0.34
1.950	21.9	4.39	-0.28
2.070	22.7	4.06	-0.33
2.150	23.3	4.14	0.03
2.190	23.6	4.03	-0.48
2.310	24.4	3.76	-0.39
2.430	25.3	4.18	-0.23
2.550	26.1	3.93	-0.10
2.670	26.9	3.83	-0.25

Source: Shackleton [unpublished data]
Species: *Cibicidoides* spp

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
Core: V28-304			
29°N 134°E			
2942 m			
0.000	0.0	2.69	0.11
0.040	1.4	2.67	0.35
0.120	4.1	2.69	0.37
0.160	5.5	2.59	0.20
0.160	5.5	2.67	0.28
0.200	6.9	2.80	0.26
0.400	13.0	3.71	-0.12
0.440	13.7	4.22	-0.02
0.480	13.8	3.85	-0.16
0.760	14.6	4.15	-0.11
0.900	15.3	4.42	0.06
1.000	17.0	4.36	-0.01
1.100	18.7	4.33	0.16
1.300	22.2	4.12	0.05
1.600	27.3	3.77	-0.08
1.900	32.4	3.55	0.11

Source: Shackleton [unpublished data]
Species: *Cibicidoides* spp

Core: KNR73-4-3
0° 106°W
3606 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.100	0.7	2.58	0.29
0.135	1.5	2.46	0.29
0.170	2.2	2.31	0.28
0.200	3.2	2.54	0.16
0.270	5.3	2.57	0.01
0.300	6.2	2.64	0.22
0.335	7.3	2.81	0.97
0.370	8.4	2.57	0.30
0.400	8.9	3.13	-0.11
0.470	9.8	2.99	0.08
0.500	10.2	3.04	0.01
0.535	10.7	3.29	-0.09
0.600	11.5	3.12	-0.13
0.635	12.1	3.37	-0.39
0.670	14.0	3.84	-0.11
0.700	15.3	4.01	-0.23
0.735	16.1	4.00	-0.22
0.770	16.9	3.80	-0.20
0.800	17.6	3.59	-0.37
0.835	18.3	3.72	-0.21
0.900	19.8	3.86	-0.10
0.950	21.0	4.01	-0.19
1.035	22.9	3.78	0.01
1.070	23.7	3.56	-0.11
1.100	24.4	3.67	0.09
1.135	25.2	3.68	0.03
1.170	26.0	3.56	0.19
1.200	26.7	3.65	0.09
1.270	28.3	3.85	0.03
1.300	28.9	3.55	0.01
1.335	29.7	3.43	0.19

Source. Boyle and Keigwin [1985/86]
Species: *C. wuellerstorfi, C. kullenbergi*

Core: V19-30
3°S 83°W
3091 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.320	4.1	2.66	-0.09
0.360	4.6	2.85	0.03
0.380	4.9	2.95	0.04
0.480	6.2	2.84	0.08
0.500	6.5	2.67	-0.03
0.560	7.2	3.07	0.00
0.600	7.7	3.22	-0.01
0.630	8.1	3.41	0.03
1.180	15.1	4.47	-0.39
1.200	15.3	4.36	-0.26
1.230	15.4	4.42	-0.33
1.270	15.7	4.20	-0.44
1.300	15.9	4.35	-0.41
1.320	16.0	4.26	-0.19
1.350	16.2	4.24	-0.53
1.390	16.4	4.27	-0.33
1.410	16.6	4.28	-0.47
1.440	16.7	4.12	-0.56
1.480	17.0	4.36	-0.51
1.520	17.2	4.26	-0.70

Source. Shackelton [unpublished data]
Species: *Cibicidoides* spp.

Core: V35-05
7°N 112°E
1950 m

Depth, m	Age, kyr	$\delta^{18}O$	$\delta^{13}C$
0.020	0.2	2.68	-0.02
0.050	0.4	2.32	0.02
0.070	0.6	2.27	-0.02
0.125	1.1	2.46	0.11
0.125	1.1	2.41	0.02
0.125	1.1	2.34	0.01
0.650	5.5	2.43	0.01
0.725	6.2	2.46	-0.15
0.900	7.7	2.60	-0.10
0.925	7.9	2.71	0.01
0.975	8.3	2.42	-0.25
1.075	9.1	2.85	-0.18
1.125	9.4	2.75	-0.20
1.175	9.7	2.60	-0.37
1.230	10.1	2.89	0.00
1.250	10.2	2.90	-0.24
1.325	10.7	2.87	-0.35
1.375	11.1	3.29	-0.22
1.425	11.4	3.05	-0.19
1.550	12.0	3.25	-0.14
2.475	15.2	3.87	-0.33
2.475	15.2	3.92	-0.39
2.775	17.2	3.90	-0.31
3.090	19.3	3.81	-0.46

Source. Oppo and Fairbanks [1987]
Species: *C. wuellerstorfi, C. kullenbergi*

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