Barker, P. F., Kennett, J. P., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 113

56. CARBON ISOTOPE STRATIGRAPHY OF BULK SEDIMENTS, ODP SITES 689 AND 690, MAUD RISE, ANTARCTICA[1]

N. J. Shackleton[2] and M. A. Hall[2]

ABSTRACT

Carbon isotope measurements were made on bulk sediments from the well preserved calcareous sequences recovered at ODP Sites 689 and 690 on the Maud Rise, Weddell Sea, Antarctica. The very positive $\delta^{13}C$ values that characterize the late Paleocene and the rapid trend toward lighter values in the early Eocene established in other sites are clearly recorded here and may be of value for long-distance stratigraphic correlation. However, values in the late Eocene are significantly more positive than have been reported from other areas. The general pattern of the records from Sites 689 and 690 is sufficiently unlike those previously reported from lower latitudes that we suggest that carbon isotope data should be used only with considerable caution for correlating sequences from such high latitudes with lower latitude records.

INTRODUCTION

ODP Sites 689 (64°31′S, 03°6′E; 2080 m) and 690 (65°10′S, 1°12′E; 2914 m) provided a unique opportunity to investigate carbonate ooze sequences under present day polar waters. Well preserved carbonates were recovered spanning most of the Paleogene.

It is generally agreed that for most purposes stable isotope analyses of bulk sediment are of little value, and that in order to obtain useful paleoenvironmental information it is necessary to analyze controlled sizes of selected foraminiferal species, for example (Berger et al., 1978). However, it is necessary to analyze bulk sediment to obtain appropriate data for contributing to our understanding of the history of the ocean carbon budget. This contribution provides a high latitude data set that supplements the information obtained from Cenozoic sequences from midlatitudes (Shackleton and Hall, 1984; Renard et al., 1983) and low latitudes (Shackleton, Hall, and Bleil, 1985).

Although there are significant spatial variations in $\delta^{13}C$ in ocean surface waters today (Kroopnick et al., 1977) spatial variability in the $\delta^{13}C$ content of surface sediments is quite small compared with the range observed through the Cenozoic (Shackleton, 1987) which leads to the possibility that the bulk sediment record of $\delta^{13}C$ may provide additional data for stratigraphic purposes. The second objective of this contribution is to provide the data for testing this concept.

ANALYTICAL METHODS AND DATA

Samples from Holes 689B, 690B, and 690C averaging a few mg in weight were dried and then vacuum roasted to remove organic contaminants. The sediment was reacted with 100% orthophosphoric acid at 90°C in a common acid bath and the evolved carbon dioxide analyzed in a VG SIRA 9 mass spectrometer. Analytical accuracy is better than $\pm 0.1‰$ although overall reproducibility as judged by repeat analyses is sometimes not as good due to the heterogeneity of the sediment.

Measurements are listed in Tables 1, 2, and 3. As an aid to preliminary evaluation of the data, each sample is assigned an age based on magnetobiostratigraphy as used in Stott et al. (this volume).

DISCUSSION

Figure 1 shows the $\delta^{13}C$ record for both sites plotted on the same time scale as was used for the discussion of planktonic foraminiferal paleotemperature data by Stott et al. (this volume).

Our first observation is that at the level of resolution shown here there are no apparent differences between the two sites. This suggests that it might be fruitful to investigate the possibility of using high resolution $\delta^{13}C$ stratigraphy to correlate the two sites with higher precision than can be achieved using conventional biostratigraphical methods. Although more accurate correlation could certainly also be achieved by quantitative biostratigraphical methods, $\delta^{13}C$ analysis of bulk sediment is more rapid and requires little expertise.

Comparison with other records is revealing. The late Paleocene $\delta^{13}C$ peak at around 60 Ma and the very rapid decline at the Paleocene-Eocene boundary is very characteristic of the record as previously observed in other areas, and it seems likely that $\delta^{13}C$ events in this time interval will be valuable for long distance correlation. However, the pattern of variation in the later Eocene and the Oligocene is somewhat different in character from the lower latitude sequences as previously summarized (Shackleton, 1986, fig. 3), although it does quite closely resemble that obtained from planktonic foraminifers in DSDP Leg 29 sediments (Shackleton and Kennett, 1975, fig. 4). Neither the well-marked peak in $\delta^{13}C$ values at about 35 Ma, nor the minimum at around 30 Ma, are recorded in the record shown by Shackleton (1986, fig. 3). It may be that $\delta^{13}C$ stratigraphy will be of particular value within the Antarctic-Subantarctic water masses but that caution should be used in applying the approach globally.

ACKNOWLEDGMENTS

We are very grateful to the shipboard party of ODP Leg 113 for the time they devoted to sampling for this project. We thank Julie Cartledge for help in the laboratory. Jim Kennett made comments on a draft of this MS that were in every case helpful. This work was carried out with the support of NERC grant GR3/3606.

REFERENCES

Berger, W. H., Killingley, J. S., and Vincent, E., 1978. Stable isotopes in deep-sea carbonates: Box Core ERDC-92, West Equatorial Pacific. *Oceanologica Acta* 1:203–216.

Kroopnick, P. M., Margolis, S. V., and Wong, C. S., 1977. $\delta^{13}C$ variations in marine carbonate sediments as indicators of the CO_2 balance between the atmosphere and oceans. *In* Andersen, N. R., and

[1] Barker, P. F., Kennett, J. P., et al., 1990. *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program).

[2] University of Cambridge, Subdepartment of Quaternary Research, Godwin Laboratory, Free School Lane, Cambridge CB2 3RS, UK.

Malahoff, A. (Ed.), *The Fate of fossil Fuel CO_2 in the Oceans*, New York (Plenum), 295–321.

Renard, M., Richebois, G., and Letolle, R., 1983. Trace element and stable isotope geochemistry of Paleocene to Coniacian carbonate samples from Hole 516F, Comparison with North Atlantic and Tethys sites. *In* Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office), 399–420.

Shackleton, N. J., 1986. Paleogene stable isotope events. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 57:91–102.

Shackleton, N. J., 1987. The carbon isotope history of the Cenozoic. *In* Brooks, J., and Fleet, A. J. (Eds), *Petroleum Source Rocks* Oxford (Blackwell), 427–438.

Shackleton, N. J., and Hall, M. A., 1984. Carbon isotope data from Leg 74 sediments. *In* Moore, T. C., Rabinowitz, P. D., et al., *Init. Repts. DSDP*, 74: Washington (U.S. Govt. Printing Office), 613–619.

Shackleton, N. J., Hall, M. A., and Bleil, U., 1985. Carbon isotope stratigraphy, Site 577. *In* Heath, G. R., Burckle, L. D., et al., *Init. Repts. DSDP*, 86: Washington (U.S. Govt. Printing Office), 503–511.

Shackleton, N. J., and Kennett, J. P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP sites 277, 279, and 281. *In* Kennett, J. P., Houtz, R. E., et al., *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office), 743–755.

Date of initial receipt: 30 June 1989
Date of acceptance: 21 July 1989
Ms 113B-211

Table 1. Stable isotope analyses in ODP Hole 689B. Ages estimates as in Stott et al. (this volume).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/791	23.09	9.622	bulk	3.57	1.45
S 87/786	30.59	12.747	bulk	4.10	2.26
S 87/785	34.56	14.401	bulk	4.17	2.02
S 87/784	36.09	15.039	bulk	4.10	2.26
S 87/783	37.57	15.656	bulk	3.98	2.54
S 87/782	39.05	16.272	bulk	4.07	2.55
S 87/780	40.57	16.906	bulk	4.18	2.52
S 87/779	42.07	17.531	bulk	4.18	2.41
S 87/771	53.70	22.377	bulk	1.99	1.92
S 87/770	55.70	23.211	bulk	2.08	2.34
S 87/768	58.20	24.252	bulk	2.39	2.62
S 87/767	59.70	24.877	bulk	2.50	2.07
S 87/766	61.20	25.502	bulk	2.46	1.72
S 87/765	62.08	25.869	bulk	2.28	1.51
S 87/764	63.27	26.239	bulk	2.81	2.05
S 87/763	64.77	26.416	bulk	3.13	2.60
S 87/762	66.27	26.593	bulk	2.29	1.54
S 87/761	67.77	26.770	bulk	2.55	1.08
S 87/760	69.27	26.947	bulk	2.48	1.46
S 87/759	70.77	27.123	bulk	2.46	1.51
S 87/758	72.87	27.371	bulk	2.33	1.81
S 87/757	74.37	27.548	bulk	2.45	2.06
S 87/756	75.87	27.724	bulk	2.40	1.69
S 87/755	77.37	27.901	bulk	2.50	1.57
S 87/754	78.87	28.098	bulk	2.57	1.45
S 87/753	80.37	28.341	bulk	2.63	1.39
S 87/752	82.48	28.684	bulk	2.26	1.94
S 87/2453	82.48	28.684	bulk	1.94	1.73
S 87/751	83.98	28.927	bulk	2.43	1.47
S 87/2454	83.98	28.927	bulk	1.97	1.20
S 87/750	85.48	29.170	bulk	2.59	1.76
S 87/2455	85.48	29.170	bulk	2.20	1.61
S 87/749	86.98	29.414	bulk	2.70	1.36
S 87/2456	86.98	29.414	bulk	2.27	1.12
S 87/748	88.48	29.657	bulk	2.68	1.52
S 87/2457	88.48	29.657	bulk	2.40	1.43
S 87/747	89.98	29.900	bulk	2.45	1.33
S 87/2458	89.98	29.900	bulk	2.14	1.21
S 87/746	90.90	30.050	bulk	2.50	1.57
S 87/2459	90.90	30.050	bulk	2.11	1.06
S 87/745	92.10	30.244	bulk	2.54	1.63
S 87/2460	92.10	30.244	bulk	2.20	1.38

Table 1 continued).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/744	93.60	30.488	bulk	2.51	1.34
S 87/2461	93.60	30.488	bulk	2.32	1.42
S 87/743	95.10	30.731	bulk	2.59	1.22
S 87/2462	95.10	30.731	bulk	2.28	1.23
S 87/742	96.60	30.974	bulk	2.89	1.32
S 87/2463	96.60	30.974	bulk	2.67	1.31
S 87/741	98.10	31.218	bulk	2.59	1.49
S 87/2464	98.10	31.218	bulk	2.28	1.45
S 87/740	101.78	31.815	bulk	2.20	1.79
S 87/2249	101.78	31.815	bulk	2.01	1.89
S 87/2465	101.78	31.815	bulk	2.14	1.79
S 87/739	103.28	32.058	bulk	2.38	1.44
S 87/2250	103.28	32.058	bulk	2.26	1.30
S 87/2466	103.28	32.058	bulk	2.44	1.53
S 87/738	104.78	32.385	bulk	2.11	1.62
S 87/2467	104.78	32.385	bulk	1.99	1.62
S 87/737	106.28	32.735	bulk	2.06	2.07
S 87/2468	106.28	32.735	bulk	2.09	2.04
S 87/736	107.78	33.092	bulk	2.17	1.94
S 87/2469	107.78	33.092	bulk	2.06	1.88
S 87/735	109.28	33.450	bulk	2.17	1.72
S 87/2470	109.28	33.450	bulk	1.99	1.61
S 87/734	110.19	33.668	bulk	2.03	1.83
S 87/733	111.39	33.955	bulk	2.30	1.93
S 87/2243	111.39	33.955	bulk	2.01	1.90
S 87/732	112.89	34.313	bulk	2.08	2.04
S 87/2244	112.89	34.313	bulk	1.89	1.89
S 87/731	114.90	34.794	bulk	2.18	1.95
S 87/2245	114.90	34.794	bulk	1.99	1.95
S 87/730	116.40	35.152	bulk	2.37	2.19
S 87/729	117.90	35.510	bulk	2.34	2.61
S 87/2247	117.90	35.510	bulk	2.20	2.76
S 87/728	119.92	35.993	bulk	2.17	2.43
S 87/2248	119.92	35.993	bulk	2.19	2.63
S 87/727	120.98	36.247	bulk	1.50	2.47
S 87/2236	120.98	36.247	bulk	1.27	2.67
S 87/726	122.48	36.605	bulk	1.31	2.39
S 87/2237	122.48	36.605	bulk	1.09	2.48
S 87/725	123.98	36.964	bulk	1.48	2.54
S 87/2238	123.98	36.964	bulk	1.31	2.58
S 87/724	125.48	37.343	bulk	1.71	2.50
S 87/2239	125.48	37.343	bulk	1.23	2.52
S 87/723	126.98	37.706	bulk	1.31	2.84
S 87/2240	126.98	37.706	bulk	1.33	3.07
S 87/722	128.48	38.063	bulk	1.45	2.94
S 87/2241	128.48	38.063	bulk	1.15	2.92
S 87/721	129.38	38.277	bulk	1.05	2.60
S 87/2242	129.38	38.277	bulk	1.12	2.74
S 87/720	130.72	38.574	bulk	1.12	1.81**
S 87/2229	130.72	38.574	bulk	0.90	2.22
S 87/719	132.22	38.856	bulk	1.28	2.06**
S 87/2230	132.22	38.856	bulk	0.84	2.73
S 87/718	133.72	39.109	bulk	1.40	2.06**
S 87/2231	133.72	39.109	bulk	0.97	2.03
S 87/717	135.22	39.362	bulk	1.12	1.86**
S 87/2232	135.22	39.362	bulk	1.23	1.93
S 87/716	136.72	39.615	bulk	1.17	2.14**
S 87/2233	136.72	39.615	bulk	1.31	2.10
S 87/715	138.22	39.868	bulk	1.08	1.99**
S 87/2234	138.22	39.868	bulk	1.28	1.90
S 87/714	139.10	40.016	bulk	1.04	2.02**
S 87/2235	139.10	40.016	bulk	1.44	2.18
S 87/713	139.22	40.037	bulk	0.99	1.96**
S 87/2222	139.22	40.037	FINE	1.45	2.27
S 87/712	140.72	40.290	bulk	0.96	2.16**
S 87/2223	140.72	40.290	<64 μm	1.26	2.16
S 87/711	142.22	40.543	bulk	0.84	2.14**
S 87/2224	142.22	40.543	<64 μm	1.33	2.32
S 87/710	143.72	40.795	bulk	0.77	2.26**
S 87/2225	143.72	40.795	<64 μm	0.87	1.82
S 87/709	145.22	41.048	bulk	0.86	2.23**
S 87/2226	145.22	41.048	<64 μm	1.14	2.08
S 87/708	146.72	41.301	bulk	0.67	2.26**
S 87/2227	146.72	41.301	<64 μm	0.98	2.07
S 87/707	147.58	41.446	bulk	0.15	2.22**
S 87/809	147.58	41.446	bulk	1.15	1.89
S 87/2228	147.58	41.446	<64 μm	0.91	1.79
S 87/706	149.91	41.839	bulk	0.65	1.27**
S 87/808	149.91	41.839	bulk	1.18	2.07

Table 1 continued).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/2441	149.91	41.839	<64 μm	0.90	2.18
S 87/705	151.41	42.092	bulk	0.88	1.63**
S 87/2442	151.41	42.092	<64 μm	0.78	1.98
S 87/704	152.91	42.345	bulk	0.51	1.88**
S 87/806	152.91	42.345	bulk	1.10	2.07
S 87/2443	152.91	42.345	<64 μm	0.81	2.06
S 87/703	154.41	42.598	bulk	0.57	1.72**
S 87/805	154.41	42.598	bulk	1.10	1.97
S 87/2444	154.41	42.598	<64 μm	0.75	1.99
S 87/702	155.91	42.851	bulk	0.79	1.77**
S 87/804	155.91	42.851	bulk	1.03	2.20
S 87/2445	155.91	42.851	<64 μm	0.71	2.06
S 87/701	157.41	43.104	bulk	0.68	1.62**
S 87/803	157.41	43.104	bulk	0.94	2.16
S 87/2446	157.41	43.104	<64 μm	0.62	2.13
S 87/700	158.28	43.251	bulk	1.13	2.43**
S 87/802	158.28	43.251	bulk	0.82	2.27
S 87/2201	158.28	43.251	<64 μm	0.41	2.23
S 87/2447	158.28	43.251	<64 μm	0.54	2.30
S 87/699	159.62	43.477	bulk	1.05	2.81**
S 87/801	159.62	43.477	bulk	1.05	2.22
S 87/2202	159.62	43.477	<64 μm	0.88	2.22
S 87/2448	159.62	43.477	<64 μm	0.74	2.22
S 87/698	161.12	43.730	bulk	1.09	2.17**
S 87/2203	161.12	43.730	<64 μm	0.58	2.33
S 87/2449	161.12	43.730	<64 μm	0.41	2.34
S 87/697	162.62	43.983	bulk	1.43	2.02**
S 87/2204	162.62	43.983	<64 μm	−0.04	2.21
S 87/2221	162.62	43.983	<64 μm	0.05	2.26
S 87/2450	162.62	43.983	<64 μm	−0.07	2.20
S 87/695	164.12	44.404	bulk	1.33	1.89**
S 87/2205	164.12	44.404	<64 μm	0.56	1.71
S 87/2451	164.12	44.404	<64 μm	0.58	1.72
S 87/696	165.62	44.669	bulk	1.55	2.23**
S 87/2206	165.62	44.669	<64 μm	0.43	1.45
S 87/2452	165.62	44.669	<64 μm	0.40	1.37
S 87/694	169.32	45.136	bulk	1.65	2.21**
S 87/2207	169.32	45.136	<64 μm	0.30	1.82
S 87/693	170.78	45.311	bulk	1.76	2.30**
S 87/2208	170.78	45.311	<64 μm	0.39	1.61
S 87/692	172.32	45.495	bulk	1.64	2.20**
S 87/3609	172.32	45.495	<64 μm	0.56	1.63
S 87/691	173.82	45.675	bulk	1.65	2.32**
S 87/2210	173.82	45.675	<64 μm	0.53	1.63
S 87/690	175.32	45.855	bulk	0.65	1.57
S 87/2211	175.32	45.855	<64 μm	0.55	1.59
S 87/689	176.02	45.938	bulk	0.61	1.50
S 87/2212	176.82	46.034	<64 μm	0.52	1.54
S 87/688	178.92	46.286	bulk	0.55	1.32
S 87/2213	178.92	46.286	<64 μm	0.36	1.31
S 89/535	179.26	46.326	bulk	0.44	1.42
S 87/687	180.42	46.465	bulk	0.48	1.27
S 87/2214	180.42	46.465	<64 μm	0.30	1.37
S 87/686	181.92	46.645	bulk	0.41	1.28
S 87/685	183.42	46.824	bulk	0.44	1.42
S 87/2215	183.42	46.824	<64 μm	0.25	1.41
S 87/684	188.61	47.446	bulk	0.37	1.10
S 87/2216	188.61	47.446	<64 μm	0.26	1.22
S 89/536	190.46	47.667	bulk	0.17	1.09
S 87/683	191.61	47.805	bulk	0.43	1.33
S 87/2217	191.61	47.805	<64 μm	0.13	1.34
S 87/682	198.31	48.607	bulk	0.15	1.67
S 87/2218	198.31	48.607	<64 μm	−0.01	1.66
S 87/681	199.78	48.783	bulk	0.02	1.69
S 87/2219	199.78	48.783	<64 μm	−0.12	1.73
S 89/537	200.16	48.828	bulk	−0.07	1.65
S 87/680	201.28	48.963	bulk	0.06	1.58
S 87/679	202.78	49.142	bulk	0.22	1.70
S 87/678	204.28	49.322	bulk	0.23	1.68
S 87/677	205.10	50.753	bulk	0.11	1.65
S 87/676	208.02	57.708	bulk	−0.26	1.45
S 87/675	209.52	58.118	bulk	0.08	2.18
S 89/538	209.86	58.211	bulk	−0.05	1.97
S 87/674	211.02	58.528	bulk	0.22	2.61
S 87/673	212.54	58.950	bulk	0.32	2.90
S 87/672	237.09	67.275	bulk	0.64	2.23
S 87/539	237.27	67.313	bulk	0.43	1.95

**Denotes analyses thought to be analytically unreliable.

Table 2. Isotopic analyses for ODP Hole 690B. Ages estimates as in Stott et al. (this volume).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/668	41.58	25.129	bulk	1.49	1.84
S 87/666	44.58	25.590	bulk	2.31	2.23
S 87/665	46.08	25.821	bulk	2.66	2.04
S 87/664	47.58	26.052	bulk	2.76	2.17
S 87/663	49.08	26.283	bulk	2.75	2.17
S 87/662	49.98	26.421	bulk	1.77	1.82
S 87/661	51.18	26.606	bulk	2.26	1.62
S 87/660	52.68	26.837	bulk	2.29	1.64
S 87/659	54.13	27.060	bulk	2.33	1.83
S 87/658	55.68	27.299	bulk	1.91	2.09
S 87/657	57.18	27.530	bulk	2.25	1.95
S 87/656	58.68	27.761	bulk	2.28	2.19
S 87/655	59.58	27.899	bulk	2.18	1.89
S 87/654	60.85	28.095	bulk	2.63	1.46
S 87/653	62.35	28.325	bulk	2.68	1.74
S 87/652	63.85	28.556	bulk	2.68	1.29
S 87/651	65.35	28.787	bulk	2.34	2.08
S 87/650	66.85	29.018	bulk	2.41	1.36
S 87/649	68.35	29.249	bulk	2.15	1.47
S 87/648	69.27	29.391	bulk	2.41	1.63
S 87/647	70.58	29.592	bulk	2.59	0.97
S 87/646	72.08	29.823	bulk	2.42	1.32
S 87/645	73.58	30.054	bulk	2.59	1.35
S 87/644	75.08	30.285	bulk	2.51	1.47
S 87/643	76.58	30.516	bulk	2.47	1.14
S 87/642	78.08	30.747	bulk	2.69	1.24
S 87/641	78.98	30.885	bulk	2.51	1.55
S 87/640	80.18	31.070	bulk	2.59	1.32
S 87/639	81.07	31.207	bulk	2.44	1.66
S 87/638	81.68	31.301	bulk	2.23	1.10
S 87/637	82.57	31.646	bulk	2.37	1.18
S 87/636	83.18	31.916	bulk	2.27	1.77
S 87/635	84.17	32.320	bulk	2.01	1.80
S 87/634	84.68	32.528	bulk	1.86	2.19
S 87/633	85.57	32.891	bulk	2.30	1.58
S 87/632	86.18	33.140	bulk	2.37	1.70
S 87/631	87.07	33.504	bulk	2.14	1.85
S 87/630	87.68	33.753	bulk	2.30	1.86
S 87/629	88.57	34.116	bulk	2.12	2.00
S 87/628	89.88	34.651	bulk	2.43	2.05
S 87/627	91.38	35.263	bulk	2.20	2.81
S 89/540	91.76	35.418	bulk	2.19	2.47
S 87/626	92.88	37.191	bulk	2.12	2.36
S 87/625	94.38	38.614	bulk	1.64	2.06
S 87/624	95.88	39.013	bulk	1.58	1.72
S 87/623	97.38	39.412	bulk	1.53	1.95
S 87/622	98.28	39.651	bulk	1.43	1.82
S 87/621	99.58	39.997	bulk	1.39	1.92
S 87/620	101.08	40.396	bulk	1.36	2.10
S 89/541	101.47	40.500	bulk	1.44	2.01
S 87/619	102.58	40.795	bulk	1.28	2.12
S 87/618	104.08	41.194	bulk	1.09	2.18
S 87/617	105.58	41.593	bulk	0.99	2.24
S 87/616	107.08	44.445	bulk	0.95	1.56
S 87/615	107.98	44.767	bulk	0.99	1.61
S 87/614	109.28	44.930	bulk	0.97	1.44
S 89/542	111.13	45.160	bulk	0.55	1.14
S 87/613	112.28	45.304	bulk	0.92	1.64
S 87/612	113.78	45.491	bulk	0.74	1.74
S 87/611	115.28	45.678	bulk	0.71	1.64
S 87/610	116.78	45.865	bulk	0.61	1.70
S 87/609	117.67	45.976	bulk	0.53	1.59
S 87/608	119.28	49.214	bulk	0.46	1.47
S 87/607	120.78	49.586	bulk	0.32	1.49
S 89/543	121.16	49.681	bulk	0.32	1.41
S 87/606	122.28	49.959	bulk	0.37	1.57
S 87/605	123.78	50.331	bulk	0.34	1.68
S 87/604	125.28	50.703	bulk	0.38	1.59
S 87/603	126.78	51.075	bulk	0.27	1.68
S 87/602	127.67	51.296	bulk	0.11	1.63
S 87/600	128.79	51.574	bulk	0.19	1.76
S 87/601	128.89	51.599	bulk	0.21	1.75
S 87/599	130.39	51.971	bulk	0.02	1.51
S 89/544	130.76	52.063	bulk	−0.08	1.43
S 87/597	131.79	52.318	bulk	−0.07	0.66*
S 87/598	131.89	52.343	bulk	0.01	1.59
S 87/596	132.39	52.476	bulk	0.13	0.89*
S 87/595	133.79	52.885	bulk	0.21	1.52

Table 2 (continued).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/594	133.89	52.915	bulk	0.36	1.37
S 87/593	135.39	53.354	bulk	0.05	1.47
S 87/592	137.29	53.910	bulk	0.12	1.64
S 87/591	138.58	54.169	bulk	−0.05	1.40
S 87/590	140.08	54.451	bulk	−0.08	0.92
S 89/545	140.46	54.522	bulk	0.13	0.91
S 87/589	141.58	54.732	bulk	0.12	1.15
S 87/588	143.08	55.014	bulk	0.44	1.42
S 87/587	144.58	55.296	bulk	0.13	1.34
S 87/586	146.08	55.577	bulk	0.17	1.54
S 87/585	148.30	55.995	bulk	0.10	1.54
S 87/921	149.72	56.077	bulk	0.31	1.70
S 87/584	149.80	56.082	bulk	0.22	1.54
S 87/922	149.82	56.083	bulk	0.35	1.66
S 87/923	149.92	56.089	bulk	0.41	1.77
S 87/924	150.02	56.095	bulk	0.27	1.71
S 87/925	150.15	56.102	bulk	0.20	1.73
S 89/546	150.16	56.103	bulk	0.15	1.50
S 87/926	150.26	56.109	bulk	0.24	1.79
S 87/583	151.30	56.169	bulk	0.11	1.47
S 87/927	152.79	56.255	bulk	−0.01	1.50
S 87/582	152.80	56.255	bulk	−0.05	1.34
S 87/928	152.87	56.259	bulk	0.09	1.38
S 87/929	152.94	56.264	bulk	0.15	1.36
S 87/930	153.02	56.268	bulk	0.28	1.42
S 87/931	153.09	56.272	bulk	0.28	1.51
S 87/932	153.18	56.277	bulk	0.32	1.62
S 87/933	153.28	56.283	bulk	0.35	1.56
S 87/934	153.37	56.288	bulk	0.37	1.58
S 87/935	153.44	56.292	bulk	0.36	1.58
S 87/936	153.50	56.296	bulk	0.35	1.65
S 87/937	153.60	56.302	bulk	0.23	1.69
S 87/938	153.71	56.308	bulk	0.34	1.70
S 87/939	153.82	56.314	bulk	0.33	1.68
S 87/940	153.94	56.321	bulk	0.31	1.63
S 87/941	154.04	56.327	bulk	0.43	1.67
S 87/942	154.13	56.332	bulk	0.42	1.65
S 87/943	154.22	56.337	bulk	0.38	1.59
S 87/581	154.30	56.342	bulk	−0.05	1.30
S 87/944	154.34	56.344	bulk	0.36	1.59
S 87/945	154.44	56.350	bulk	0.42	1.63
S 87/946	154.55	56.357	bulk	0.43	1.64
S 87/947	154.66	56.363	bulk	0.36	1.65
S 87/948	154.76	56.369	bulk	0.39	1.66
S 87/991	154.76	56.369	bulk	0.04	1.66
S 87/949	154.84	56.373	bulk	0.44	1.65
S 87/992	154.84	56.373	bulk	0.06	1.62
S 87/950	154.95	56.380	bulk	0.37	1.64
S 87/993	154.95	56.380	bulk	0.13	1.51
S 87/951	155.01	56.383	bulk	0.30	1.65
S 87/994	155.01	56.383	bulk	0.02	1.57
S 87/952	155.12	56.389	bulk	0.26	1.66
S 87/995	155.12	56.389	bulk	0.05	1.62
S 87/953	155.22	56.395	bulk	0.37	1.72
S 87/996	155.22	56.395	bulk	0.15	1.67
S 87/954	155.33	56.402	bulk	0.32	1.65
S 87/997	155.33	56.402	bulk	0.07	1.63
S 87/955	155.42	56.407	bulk	0.19	1.56
S 87/998	155.42	56.407	bulk	0.13	1.64
S 87/956	155.52	56.413	bulk	0.00	1.42
S 87/999	155.52	56.413	bulk	0.04	1.53
S 87/957	155.62	56.418	bulk	0.21	1.59
S 87/1000	155.62	56.418	bulk	0.21	1.63
S 87/958	155.71	56.424	bulk	−0.15	1.10
S 87/1001	155.71	56.424	bulk	0.17	1.56
S 87/580	155.80	56.429	bulk	0.07	1.54
S 87/959	155.82	56.430	bulk	0.00	1.18
S 87/1002	155.82	56.430	bulk	0.11	1.58
S 87/960	155.92	56.436	bulk	0.07	1.28
S 87/1003	155.92	56.436	bulk	0.11	1.62
S 87/961	156.02	56.441	bulk	0.13	1.39
S 87/1004	156.02	56.441	bulk	0.15	1.59
S 87/962	156.09	56.446	bulk	0.05	1.56
S 87/1005	156.09	56.446	bulk	0.10	1.64
S 87/963	156.21	56.452	bulk	0.10	1.58
S 87/1006	156.21	56.452	bulk	0.09	1.66
S 87/964	156.32	56.459	bulk	0.12	1.68
S 87/1007	156.32	56.459	bulk	0.11	1.73
S 87/965	156.42	56.456	bulk	0.11	1.59

Table 2 (continued).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/1008	156.42	56.465	bulk	0.09	1.65
S 87/966	156.49	56.469	bulk	0.14	1.54
S 87/1009	156.49	56.469	bulk	0.09	1.66
S 87/967	156.58	56.474	bulk	0.12	1.59
S 87/1010	156.58	56.474	bulk	0.12	1.60
S 87/579	156.67	56.479	bulk	0.02	1.47
S 87/968	156.69	56.480	bulk	0.09	1.65
S 87/969	156.80	56.487	bulk	0.14	1.58
S 87/970	156.91	56.494	bulk	0.25	1.60
S 87/971	157.29	56.527	bulk	0.17	1.55
S 87/972	157.39	56.535	bulk	0.11	1.57
S 87/973	157.50	56.545	bulk	0.21	1.62
S 87/974	157.60	56.553	bulk	0.16	1.64
S 87/975	157.71	56.561	bulk	0.19	1.63
S 87/976	157.82	56.570	bulk	0.14	1.65
S 87/977	157.93	56.578	bulk	0.18	1.63
S 87/578	157.99	56.582	bulk	0.01	1.56
S 87/978	158.03	56.585	bulk	0.15	1.61
S 87/979	158.13	56.593	bulk	0.08	1.59
S 87/980	158.24	56.601	bulk	0.36	1.68
S 87/981	158.36	56.610	bulk	0.10	1.60
S 87/982	158.47	56.618	bulk	0.17	1.77
S 87/983	158.59	56.628	bulk	0.14	1.83
S 87/577	159.49	56.695	bulk	−0.13	1.28
S 89/547	159.86	56.723	bulk	−0.01	1.31
S 87/576	160.99	56.808	bulk	−0.11	1.47
S 87/575	162.49	56.921	bulk	−0.21	1.73
S 87/574	163.99	57.034	bulk	−0.03	1.66
S 87/573	165.49	57.147	bulk	−0.04	1.69
S 87/572	166.36	57.212	bulk	−0.37	1.50
S 87/571	167.69	57.313	bulk	−0.44	1.05
S 87/570	169.19	57.426	bulk	−0.46	0.50
S 89/548	169.55	57.454	bulk	−0.49	0.06
S 87/569	170.69	57.540	bulk	−0.18	1.37
S 87/568	172.19	57.654	bulk	0.06	2.04
S 87/567	173.69	57.767	bulk	0.07	2.69
S 87/566	175.07	57.869	bulk	1.01	3.37***
S 87/565	176.57	57.983	bulk	0.52	3.12
S 89/549	176.95	58.012	bulk	0.33	2.71
S 87/564	178.07	58.098	bulk	0.36	3.07
S 87/563	179.57	58.212	bulk	0.22	2.96
S 87/562	181.08	58.332	bulk	0.15	3.05
S 87/561	182.58	58.445	bulk	0.21	3.10
S 87/560	183.97	58.550	bulk	0.31	3.36
S 87/559	185.98	58.686	bulk	0.25	3.51
S 87/558	187.48	58.781	bulk	0.31	3.16
S 87/557	188.98	58.875	bulk	0.42	3.59
S 87/556	190.12	58.947	bulk	0.52	3.48
S 87/555	190.48	58.970	bulk	0.29	3.42
S 87/554	192.01	59.068	bulk	0.46	3.82
S 87/553	193.51	59.163	bulk	0.61	3.86
S 87/552	195.01	59.258	bulk	0.61	4.09
S 87/551	196.51	59.353	bulk	0.57	4.18
S 87/550	198.79	59.504	bulk	0.68	4.26
S 87/549	200.29	59.599	bulk	0.63	4.20
S 87/548	201.79	59.693	bulk	0.49	4.21
S 87/547	203.29	59.788	bulk	0.76	3.87
S 87/546	204.97	59.896	bulk	0.56	3.49
S 87/545	206.47	59.990	bulk	0.56	3.31
S 87/544	207.97	60.085	bulk	0.76	3.25
S 87/543	209.47	60.179	bulk	1.60	3.57***
S 87/542	210.97	60.274	bulk	0.90	3.46
S 87/541	212.47	60.368	bulk	0.72	3.12

*Denotes samples with evidence of significant reworking.
***Denotes intensive dissolution.

Table 3. Isotopic analyses for ODP Hole 690C. Ages estimates as in Stott et al. (this volume).

Lab reference	Depth (mbsf)	Age (Ma)	Sample	$\delta^{18}O$	$\delta^{13}C$
S 87/539	224.31	62.087	bulk	0.56	2.21
S 87/538	225.83	62.311	bulk	0.41	2.17
S 87/537	227.36	62.537	bulk	0.48	2.23
S 87/536	228.80	62.750	bulk	0.69	2.27
S 87/535	230.35	62.979	bulk	0.69	2.49
S 87/534	231.85	63.200	bulk	0.59	2.67
S 87/533	233.98	63.633	bulk	0.41	2.21
S 87/532	234.48	63.734	bulk	0.17	2.03
S 87/531	235.98	64.039	bulk	−0.16	2.37

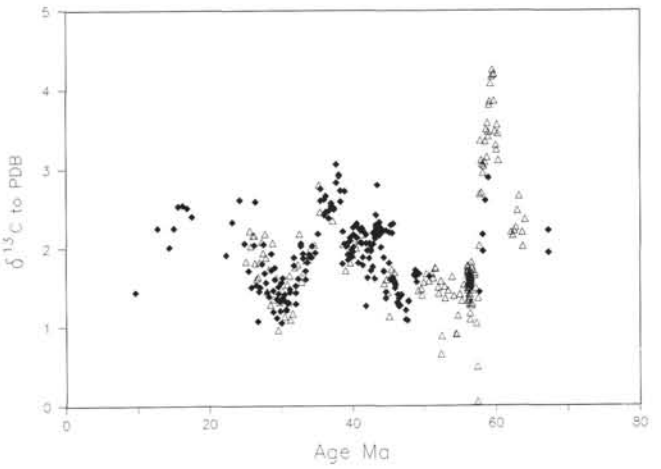

Figure 1. $\delta^{13}C$ data for bulk sediment in ODP Sites 689 and 690, using the time scale of Stott et al. (this volume). ♦ = ODP Site 689; △ = ODP Site 690.