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Stable Isotope Data and AMS ^{14}C Dates from Arctic Ocean Section 1994 Surface Sediment Transect and Box Core Samples from the Mendeleyev Ridge Area

by

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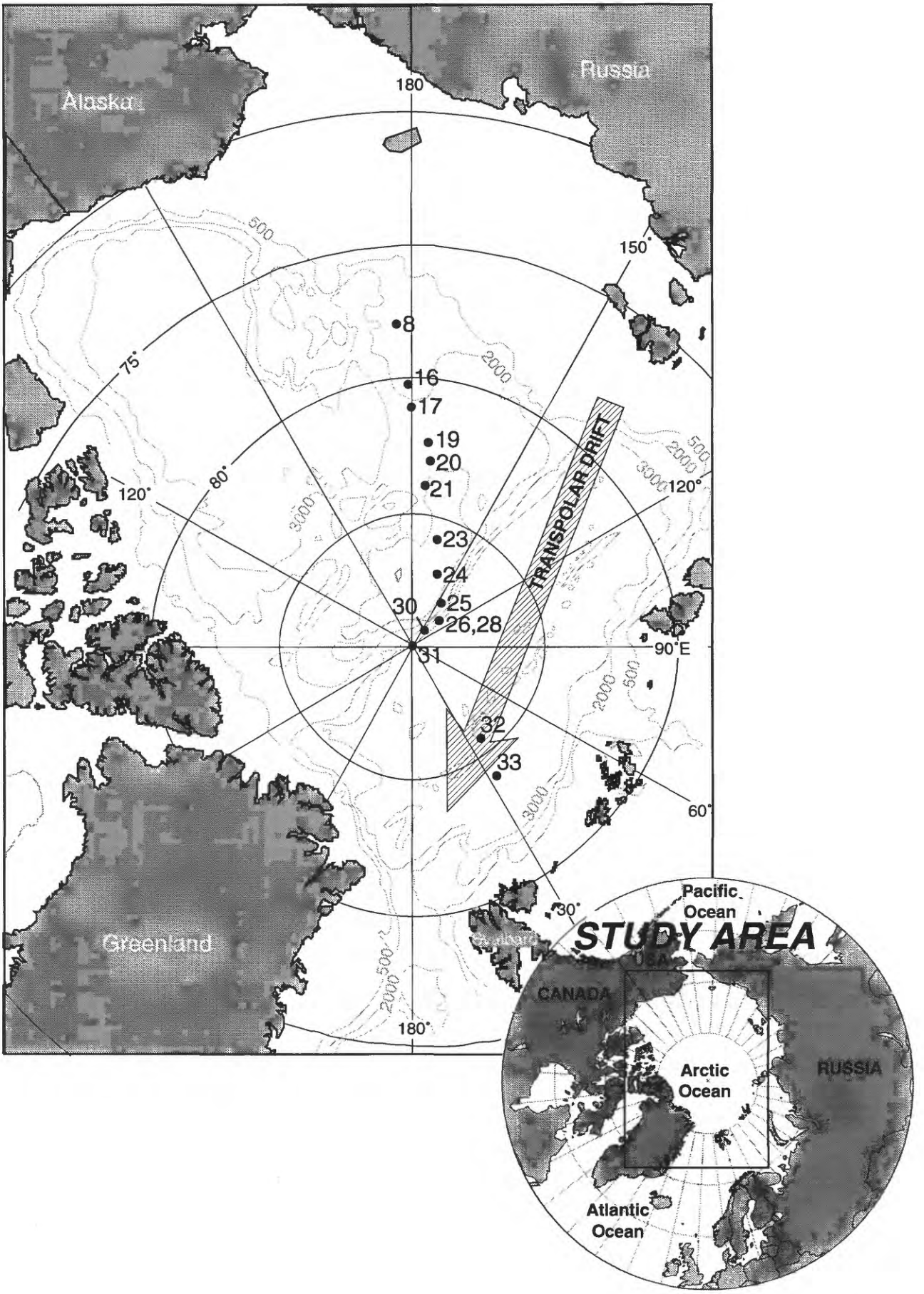
Introduction

During the summer of 1994 the United States and Canada conducted a joint oceanographic and sediment sampling program in the western Arctic Ocean (Aagaard and others, 1996). The experiment which was called the Arctic Ocean Section (AOS), recovered a series of piston and box cores along a transect of the Arctic that extended from the Chukchi Sea to the North Pole and into the eastern Arctic Basin (fig. 1, Table 1). In this report we present data on abundance of foraminifers, ice-rafted detritus, and oxygen and carbon isotope data from AOS box core surface sediment samples and for downcore samples from box cores B-8, B-16, B-17, and B-19 from the Mendeleyev Ridge area. AMS ^{14}C dates from the box cores are also provided. Additional information on ice rafted material and AMS ^{14}C dating of AOS box cores is available in Darby and others (1997). Census data on benthic foraminifer assemblages in AOS surface sediment samples are in L. Osterman and others (in press). Census data on box core samples are in L. Osterman (1998). Summaries and interpretations of water-column observations and measurements made at AOS stations are contained in Wheeler and others (1997) and Swift and others(1997).

Table 1 - Location and water depth of each box core sample locality

site	latitude N	longitude W/E	water depth (meters)
B 6	75° 21.45'	160° 05.54' W	1388
B 7	76° 39.99'	173° 23.09' W	2214
B 8	78° 07.68'	176° 44.67' W	1031
B 12	79° 59.32'	174° 17.32' W	1609
B 16	80° 20.33'	178° 42.71' W	1533
B 17	81° 15.91'	178° 58.05' E	2217
B 19	82° 26.80'	175° 45.50' E	2400
B 20	83° 10.20'	174° 06.36' E	3110
B 21	84° 05.72'	174° 57.82' E	3193
B 23	85° 54.40'	166° 41.00' E	3475
B 24	87° 09.70'	161° 02.20' E	3890
B 25	88° 03.30'	147° 40.80' E	2125
B 26	88° 48.60'	142° 58.90' E	1020
B 28	88° 52.40'	140° 10.80' E	1990
B 30	88° 59.97'	137° 29.70' E	3930
B 31	88° 58.85'	40° 30.39' E	4180
B 32	85° 43.04'	37° 44.52' E	3450
B 33	84° 16.14'	34° 44.39' E	3940

Figure 1. Location map showing cruise track and sediment sampling stations



Sediment sampling and processing

Bottom sediments were collected with 40 x 40 x 60 cm Mark III box cores. As soon as cores were recovered an approximately 50 cc sample of surface sediments was taken from the top of each box core as a surface sediment or "core top" sample. After the surface sediment samples were taken, the box cores were subsampled for downcore studies by pushing 10cm diameter core liner tubes through the box cores. Several push core subsamples were taken from each box core. The push cores were located away from areas disturbed by the surface sediment sampling. In our study the push cores were split into working and archive halves. The working half of each core was sampled at 1cm intervals taking care to avoid sediment along the edge of the core liner. About 3/4 of the surface sediment samples were processed. Sediment samples were oven dried at < 50°C, and weighted. Samples were then disaggregated by soaking in a beaker of deionized water with about 15 ml of dilute calgon solution (5 grams calgon /liter of deionized water) added to aid dispersal of clays and gently aggitated on an oscillating platform for about 1 hour. Disaggregated samples were wet sieved at 63μm and dried. In some cases two cycles were required to obtain fully disaggregated samples with clean foraminifers. The >63μm size fraction was weighed to obtain coarse fraction data and in several cores 63 - 2000μm and >2000 μ weight fractions were also obtained (Tables 2-6).

Foraminifer and ice-rafted debris abundance

The number of planktic and benthic foraminifers and ice-rafted detritus (= mineral grains and rock fragments) per gram of total sample dry weight was calculated for the >125μm fraction (Tables 2-6). A relatively small subsample (usually <1000 grain types) of the >125μm size fraction was obtained with a microsplitter to determine the abundance data for planktic foraminifers and ice-rafted detritus. Ice-rafted detritus and planktic foraminifers were tabulated in the splits but not sorted and glued down. Separate benthic splits yielding at least 300 specimens of benthic foraminifers were used to calculate the number of benthic foraminifers per gram (>125μm) and for benthic foraminifer assemblage census data (L. Osterman, 1998). The benthic foraminifers were sorted and glued in individual microslides. The entire sample was searched and all individuals picked and sorted in samples containing less than 300 specimens of benthic foraminifers.

Table 2 Surface-sediment sample foraminifer abundance, ice-rafted detritus abundance, and coarse fraction data. (na = not available)

site#	depth (meters)	# benthic foram per gram	# planktic foram per gram	# grains per gram	weight % 63 – 2000μm	weight % > 2000μm
B-6	528	46	144	364	1.00	0.70
B-7	2,241	182	7,309	914	na	na
B-8	1,031	338	8,227	1,082	na	na
B-12	1,609	290	24,848	3,035	na	na
B-16	1,533	172	22,276	1,498	na	na
B-17	2,217	52	5,730	212	4.00	0.77
B-19	2.400	120	9.453	691	8.80	1.40
B-20	3,110	94	11,359	1,042	8.41	0.01
B-21	3,193	103	10,682	751	9.45	0.60
B-23	3,475	32	7,306	819	7.20	0.03
B-24	3,890	16	7,434	1,568	8.00	0.00
B-25	2,125	87	5,926	6,729	na	na
B-26	1.020	563	8.666	3.890	na	na
B-28	1,990	59	4,651	405	4.10	0.17
B-30	3,930	3	2,197	198	0.90	0.00
B-31	4,180	5	2,301	154	1.60	0.00
B-32	3,450	61	9,033	4,236	14.70	0.50
B-33	3,940	15	6,139	885	5.60	0.00

Table 3 . Box Core 8 foraminifer abundance, ice-rafted detritus abundance, and coarse fraction data

sample depth cm	#benthic foram per gram	#planktic foram per gram	#grains per gram	weight% 63 – 2000µm	weight% >2000µm
0 - 1	307	12,533	4,178	12.74	1.38
1 - 2	271	10,581	2,794	9.13	0.26
2 - 3	205	10,491	2,932	8.91	0.04
3 - 4	251	11,528	2,907	9.28	0.87
4 - 5	219	11,434	2,096	7.09	1.68
5 - 6	215	10,582	1,802	8.18	0.49
6 - 7	174	7,892	1,127	6.80	0.00
7 - 8	126	5,117	1,190	4.69	0.02
8 - 9	81	4,215	983	3.27	0.00
9 - 10	86	3,773	903	3.69	0.00
10 - 11	81	3,081	918	2.88	0.00
11 - 12	101	5,002	1,236	3.97	0.00
12 - 13	109	4,777	1,314	4.68	0.00
13 - 14	39	1,169	381	1.27	0.00
14 - 15	19	422	213	0.56	0.00
15 - 16	3	125	119	0.95	0.00
16 - 17	5	28	227	0.21	0.00
17 - 18	3	83	65	0.08	0.00
18 - 19	8	156	173	0.25	0.00
19 - 20	40	1,544	1,282	2.33	0.09
20 - 21	39	850	741	5.45	1.54
21 - 22	40	814	655	6.23	4.89
22 - 23	2	70	791	4.19	4.87
23 - 24	9	378	1,197	3.84	0.00
24 - 25	20	838	2,324	5.31	11.23
25 - 26	41	2,124	5,345	21.66	3.02
26 - 27	38	3,016	4,568	10.81	0.93
27 - 28	33	2,020	2,997	6.53	0.00
28 - 29	15	905	1,279	2.60	0.00
29 - 30	5	244	383	0.80	0.00
30 - 31	12	629	933	1.81	0.00
31 - 32	10	326	469	1.14	0.00
32 - 33	6	205	332	2.14	2.65
33 - 34	26	1,111	736	5.13	13.94
34 - 35	405	12,665	5,889	21.71	0.00
35 - 36	181	6,366	3,831	10.05	0.00
36 - 37	244	5,671	5,217	12.72	0.00
37 - 38	273	25,372	28,523	12.45	0.02

Table 4. Box Core 16 foraminifer abundance, ice-rafted detritus abundance, and coarse fraction data.

sample depth cm	#benthic foram per gram	#planktic foram per gram	#grains per gram	weight% 63-2000µm	weight% > 2000µm
0-1	294	11,533	349.5	12.12	0.00
1-2	226	13,466	702.9	10.20	2.51
2-3	273	14,898	707.2	10.31	0.00
3-4	142	9,554	640.7	7.56	0.00
4-5	171	9,138	743.3	7.37	0.00
5-6	167	4,839	330.3	8.00	0.00
6-7	98	5,524	1275.0	6.64	0.00
7-8	44	2,353	996.1	4.39	0.64
8-9	20	1,222	445.9	3.61	0.49
9-10	11	494	337.4	3.58	1.95
10-11	15	913	540.7	2.29	0.00
11-12	16	917	929.3	4.12	0.00
12-13	13	778	1270.0	3.92	0.00
13-14	35	1,906	2391.0	6.28	0.00
14-15	19	1,558	3644.0	7.76	0.00
15-16	23	2,804	3778.0	8.36	0.00
16-17	13	1,406	2321.0	5.54	0.45
17-18	6	633	788.1	2.10	0.21
18-19	19	1,108	802.4	7.21	5.18
19-20	50	2,622	1884.0	10.02	2.50
20-21	105	7,205	3556.0	13.72	0.75
21-22	73	3,860	3884.0	16.60	4.22
22-23	123	4,718	3552.0	13.25	1.36
23-24	183	7,242	3390.0	14.14	0.14
24-25	260	8,940	3343.0	15.47	0.00
25-26	352	15,620	4866.0	19.75	0.01
26-27	347	13,588	4529.0	18.29	0.00
27-28	233	9,681	6549.0	20.53	0.00
28-29	77	3,477	8204.0	19.09	0.00
29-30	50	2,408	3782.0	19.44	0.00
30-31	95	3,624	6623.0	14.85	0.00
31-32	132	6,126	7069.0	16.15	0.00
32-33	115	4,666	4073.0	10.74	0.00
33-34	206	6,986	4710.0	13.56	0.00
34-35	56	2,557	2957.0	7.48	0.00
35-36	30	2,292	2769.0	6.97	0.00
36-37	22	923	1800.0	7.45	0.00
37-38	8	437	5717.0	9.94	0.00

Table 5. Box Core 17 foraminifer abundance, ice-rafted detritus abundance, and coarse fraction data

sample depth cm	#benthic foram per gram	#planktic foram per gram	#grains per gram	weight% 63-2000µm	weight% >2000µm
0 - 1	67	7,011	8,040	6.78	0.00
1 - 2	78	5,716	6,646	4.59	0.00
2 - 3	39	3,836	4,423	3.51	0.00
3 - 4	59	5,845	6,912	4.80	0.00
4 - 5	38	4,135	4,723	3.33	0.00
5 - 6	41	4,813	5,232	2.91	0.02
6 - 7	33	3,429	3,765	2.60	0.02
7 - 8	22	2,774	3,006	2.22	0.07
8 - 9	38	3,393	3,712	3.18	1.63
9 - 10	18	2,967	3,552	2.82	37.03
10 - 11	28	2,834	3,901	5.43	1.59
11 - 12	26	2,184	3,733	5.69	0.02
12 - 13	9	895	4,006	6.41	0.24
13 - 14	6	756	1,234	2.87	0.00
14 - 15	9	905	1,256	2.20	2.80
15 - 16	6	588	780	2.12	0.28
16 - 17	7	644	1,206	2.10	0.08
17 - 18	11	858	1,976	2.58	8.22
18 - 19	5	681	1,754	5.41	0.00
19 - 20	15	1,683	4,150	6.66	0.00
20 - 21	6	1,046	1,963	4.04	0.06
21 - 22	14	1,114	2,035	3.13	0.00
22 - 23	26	2,338	3,243	4.79	1.96
23 - 24	54	6,380	9,032	8.37	0.51
24 - 25	46	5,638	8,025	9.52	0.00
25 - 26	51	4,461	7,043	8.60	0.00
26 - 27	48	3,400	4,453	6.58	0.00
27 - 28	67	5,286	7,055	4.66	0.00
28 - 29	64	5,274	5,961	3.98	0.00
29 - 30	62	5,262	5,753	4.47	0.00
30 - 31	69	4,786	5,144	5.26	0.00
31 - 32	71	5,025	5,431	4.69	0.00
32 - 33	84	5,519	6,005	4.98	0.00
33 - 34	120	6,425	7,567	5.49	0.00
34 - 35	106	5,764	6,589	4.25	0.00
35 - 36	109	4,410	4,988	3.50	0.00
36 - 37	70	1,958	2,447	3.19	0.00

Table 6. Box Core 19 foraminifer abundance, ice-rafted detritus abundance, and coarse fraction data

sample depth cm	#benthic foram per gram	#planktic foram per gram	#grains per gram	weight% 63-2000µm	weight% >2000µm
0-1	157	6,605	2,343	9.35	0.49
1-2	139	13,785	2,773	8.47	0.00
2-3	85	4,363	754	6.19	0.00
3-4	69	9,071	1,501	5.77	0.00
4-5	52	6,944	1,380	5.61	0.00
5-6	45	4,776	2,394	6.77	0.00
6-7	11	1,421	752	6.45	6.50
7-8	5	971	585	2.66	0.94
8-9	5	969	695	2.76	0.00
9-10	8	1,417	1,995	4.66	0.00
10-11	6	1,218	1,587	6.13	0.00
11-12	13	1,884	2,375	5.97	0.00
12-13	28	2,405	1,509	5.57	1.04
13-14	83	6,456	1,567	6.92	0.00
14-15	140	10,728	2,318	10.34	0.00
15-16	127	10,278	2,629	10.12	0.00
16-17	148	10,192	1,756	10.19	0.00
17-18	185	5,994	523	10.34	0.00
18-19	249	15,071	1,182	9.85	0.00
19-20	234	13,267	995	10.01	0.00
20-21	290	13,561	1,418	10.96	0.00
21-22	158	7,839	695	8.43	0.00
22-23	151	6,703	1,427	6.87	0.00
23-24	110	5,807	1,292	6.76	0.00
24-25	59	4,058	2,410	6.81	0.00
25-26	64	4,030	3,080	6.77	0.00
26-27	10	539	8,844	17.69	0.00
27-28	2	101	12,067	27.51	0.18
28-29	7	354	5,100	7.45	0.00
29-30	19	709	729	2.71	0.00
30-31	9	462	803	2.73	0.00
31-32	2	153	3,551	5.39	0.00
32-33	3	86	8,084	13.29	0.00
33-34	1	15	13,413	22.65	0.09
34-35	5	312	12,058	20.60	0.05
35-36	20	817	3,850	7.61	0.31
36-37	10	1,325	9,378	7.11	0.00

Oxygen and carbon isotope analyses.

We measured oxygen and carbon isotope ratios on the planktic foraminifer *Neogloboquadrina pachyderma* (sinistral) and the benthic foraminifers *Fonbotia wuellerstorfi*, *Oridorsalis umbonatus* and *Cassidulina teretis* (tables 7-11) using the Woods Hole Oceanographic Institution Finnigan MAT252 mass spectrometer equipped with a "Kiel" automated carbonate analytical device containing two parallel extraction lines. We used 1 specimen of *Fonbotia wuellerstorfi*, 6 specimens of *Oridorsalis umbonatus* and *Cassidulina teretis* and 8 specimens of *Neogloboquadrina pachyderma* for each analysis. The system is designed to analyze each sample in a separate reaction vessel which is placed on the vacuum system for the 10 minute reaction with 70° C, 100% phophoric acid made using a modified Coplen and others (1983) formula. During the ten minute reaction time, all evolved gases are trapped at liquid nitrogen temperatures. When the reaction is over, the non-condensibles are pumped away, the first trap is warmed to -100 °C, releasing the CO_2 but trapping the water. The pressure of evolved CO_2 is measured, recorded and the second trap temperature is lowered to -190 °C. At the end of the CO_2 transfer from the first trap to the second, the second trap is warmed to room temperature and the gas is introduced into the mass spectrometer through a capillary and expanded if necessary. All traps are baked at +130° C after each reaction to remove contaminating water vapor.

Isotopic values are reported relative to Pee Dee Belemnite (VPDB) in delta notation and expressed in per mil using the intermediate standard NBS19. The precision of 2,200 NBS19 analyses run during the interval between March 1993 and June 1998 (all sizes from 10 to 300 ug) is 0.07 for ^{18}O and 0.03 for ^{13}C. Small sample (10-20ug and under all laboratory conditions) precision is 0.14 for ^{18}O and 0.06 for ^{13}C. Since we only weigh standard material, we use the relationship between weight and voltage of standard material to assess unknown data based upon its mass 44 voltage. We only accept data which has a mass 44 sample voltage greater than 0.6 volts and whose ratio between sample and standard voltage (efficiency of bellows balancing) is between 0.8 and 1.

Table 7. Carbon and oxygen isotope values for *Neogloboquadrina pachyderma* (sinistral), *Cassidulina teretis, Oridorsalis umbonatus*, and *Fontbotia wuellerstorfi* in AOS 94 surface sediment ("core top") samples.

core	depth (cm)	species	^{13}C	^{18}O
B6	0-1	*N. pachyderma* (sinistral)	-2.045	1.665
B6	0-1	*N. pachyderma* (sinistral)	-0.943	1.888
B7	0-1	*N. pachyderma* (sinistral)	1.195	1.762
B7	0-1	*N. pachyderma* (sinistral)	1.104	1.493
B8	0-1	*N. pachyderma* (sinistral)	1.221	1.716
B8	0-1	*N. pachyderma* (sinistral)	1.259	1.799
B12	0-1	*N. pachyderma* (sinistral)	1.372	1.725
B12	0-1	*N. pachyderma* (sinistral)	1.211	1.696
B16	0-1	*N. pachyderma* (sinistral)	1.356	1.735
B16	0-1	*N. pachyderma* (sinistral)	1.172	1.893
B17	0-1	*N. pachyderma* (sinistral)	1.313	1.549
B17	0-1	*N. pachyderma* (sinistral)	1.189	1.620
B19	0-1	*N. pachyderma* (sinistral)	1.164	1.764
B19	0-1	*N. pachyderma* (sinistral)	1.062	1.657
B20	0-1	*N. pachyderma* (sinistral)	1.213	1.569
B20	0-1	*N. pachyderma* (sinistral)	1.154	1.767
B21	0-1	*N. pachyderma* (sinistral)	1.158	1.728
B21	0-1	*N. pachyderma* (sinistral)	1.189	1.572
B23	0-1	*N. pachyderma* (sinistral)	1.045	2.033
B23	0-1	*N. pachyderma* (sinistral)	1.015	1.900
B24	0-1	*N. pachyderma* (sinistral)	0.923	1.794
B24	0-1	*N. pachyderma* (sinistral)	1.027	1.943
B25	0-1	*N. pachyderma* (sinistral)	0.976	1.665
B25	0-1	*N. pachyderma* (sinistral)	1.086	1.623
B26	0-1	*N. pachyderma* (sinistral)	1.048	2.157
B26	0-1	*N. pachyderma* (sinistral)	1.073	1.801
B28	0-1	*N. pachyderma* (sinistral)	1.082	1.543
B28	0-1	*N. pachyderma* (sinistral)	1.008	1.391
B30	0-1	*N. pachyderma* (sinistral)	0.872	1.616
B30	0-1	*N. pachyderma* (sinistral)	0.761	1.518
B31	0-1	*N. pachyderma* (sinistral)	0.953	1.601
B31	0-1	*N. pachyderma* (sinistral)	0.866	1.443
B32	0-1	*N. pachyderma* (sinistral)	0.767	2.789
B32	0-1	*N. pachyderma* (sinistral)	0.870	2.653
B33	0-1	*N. pachyderma* (sinistral)	1.028	3.007
B33	0-1	*N. pachyderma* (sinistral)	0.924	3.121
B6	0-1	*C. teretis*	-1.013	3.484
B6	0-1	*C. teretis*	-0.967	3.561
B8	0-1	*C. teretis*	0.014	4.203
B8	0-1	*C. teretis*	-0.230	4.037
B26	0-1	*C. teretis*	0.080	4.196
B26	0-1	*C. teretis*	0.604	4.543
B7	0-1	*O. umbonatus*	-0.666	3.895
B7	0-1	*O. umbonatus*	0.620	2.011
B8	0-1	*O. umbonatus*	-1.213	3.864
B8	0-1	*O. umbonatus*	-1.196	3.906
B12	0-1	*O. umbonatus*	-1.077	3.871
B12	0-1	*O. umbonatus*	-1.237	3.852
B16	0-1	*O. umbonatus*	-1.375	3.927
B16	0-1	*O. umbonatus*	-1.501	3.868

Table 7 continued

core	depth (cm)	species	^{13}C	^{18}O
B17	0-1	*O. umbonatus*	-1.332	4.067
B17	0-1	*O. umbonatus*	-1.649	3.965
B19	0-1	*O. umbonatus*	-1.196	4.088
B19	0-1	*O. umbonatus*	-1.101	3.953
B20	0-1	*O. umbonatus*	-1.230	4.086
B20	0-1	*O. umbonatus*	-1.213	3.807
B21	0-1	*O. umbonatus*	-1.013	3.948
B21	0-1	*O. umbonatus*	-1.242	3.868
B23	0-1	*O. umbonatus*	-0.817	3.917
B23	0-1	*O. umbonatus*	-1.359	3.823
B25	0-1	*O. umbonatus*	-1.092	4.024
B25	0-1	*O. umbonatus*	-1.541	4.131
B28	0-1	*O. umbonatus*	-1.719	4.001
B28	0-1	*O. umbonatus*	-1.332	4.062
B32	0-1	*O. umbonatus*	-1.089	4.041
B32	0-1	*O. umbonatus*	-1.081	4.170
B7	0-1	*F. wuellerstorfi*	1.340	3.720
B7	0-1	*F. wuellerstorfi*	1.485	3.688
B8	0-1	*F. wuellerstorfi*	1.649	3.673
B8	0-1	*F. wuellerstorfi*	1.643	3.706
B12	0-1	*F. wuellerstorfi*	1.586	3.786
B12	0-1	*F. wuellerstorfi*	1.310	3.866
B16	0-1	*F. wuellerstorfi*	1.293	3.709
B16	0-1	*F. wuellerstorfi*	1.583	3.736
B17	0-1	*F. wuellerstorfi*	1.593	3.788
B17	0-1	*F. wuellerstorfi*	1.473	3.773
B19	0-1	*F. wuellerstorfi*	1.681	3.708
B19	0-1	*F. wuellerstorfi*	1.655	3.686
B20	0-1	*F. wuellerstorfi*	1.389	3.730
B20	0-1	*F. wuellerstorfi*	1.620	3.739
B21	0-1	*F. wuellerstorfi*	1.385	3.785
B21	0-1	*F. wuellerstorfi*	1.391	3.733
B23	0-1	*F. wuellerstorfi*	1.026	3.739
B23	0-1	*F. wuellerstorfi*	1.453	3.710
B25	0-1	*F. wuellerstorfi*	1.272	3.912
B25	0-1	*F. wuellerstorfi*	1.577	3.700
B26	0-1	*F. wuellerstorfi*	1.665	3.630
B26	0-1	*F. wuellerstorfi*	1.787	3.680
B28	0-1	*F. wuellerstorfi*	1.341	3.711
B28	0-1	*F. wuellerstorfi*	1.721	3.793

Table 8 a-c Carbon and oxygen isotope analysis of *Neogloboquadrina pachyderma* (sinistral), *Oridorsalis umbonatus,* and *Fontbotia wuellerstorfi* in samples from AOS 94 box core 8

A) Box Core 8, *N. pachyderma* (sinistral)

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.149	1.708
0-1	1.153	1.786
1-2	0.926	1.893
2-3	1.196	1.814
3-4	1.066	1.792
4-5	1.174	1.757
5-6	1.145	1.718
6-7	1.085	1.655
7-8	0.467	1.561
8-9	0.376	0.606
9-10	0.942	1.451
10-11	0.778	1.194
10-11	0.865	1.671
11-12	0.912	1.377
12-13	0.824	1.688
13-14	0.473	1.520
14-15	0.186	0.970
15-16	0.139	0.966
16-17	0.188	0.417
17-18	0.540	0.629
18-19	0.119	0.850
19-20	0.083	0.686
20-21	0.159	0.664
21-22	0.132	0.102
22-23	0.070	-0.200
22-23	0.175	0.519
23-24	0.106	0.570
24-25	0.157	0.329
25-26	0.424	1.061
26-27	0.416	1.224
27-28	0.208	1.506
28-29	0.064	1.238
29-30	0.058	1.388
30-31	0.192	0.448
31-32	0.143	0.868
32-33	0.586	1.391
33-34	0.698	1.301
34-35	0.801	1.261
35-36	0.906	1.390
35-36	0.989	2.107
36-37	1.217	2.090
37-38	1.455	3.113

B) Box Core 8, *O. umbonatus*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	-1.007	3.880
1-2	-1.530	4.179
2-3	-1.278	3.997
2-3	-1.858	4.118
3-4	-1.527	3.922
4-5	-1.363	4.021
5-6	-1.270	4.035
6-7	-1.379	3.951
7-8	-1.539	4.062
8-9	-1.476	4.088
9-10	-1.553	4.019
10-11	-1.662	4.096
11-12	-1.567	3.948
11-12	-2.048	4.159
12-13	-1.994	4.244
14-15	-1.568	3.965
16-17	-2.301	4.229
18-19	-1.745	4.135
19-20	-1.936	4.158
20-21	-1.631	4.175
21-22	-1.878	4.197
22-23	-2.494	4.070
23-24	-2.794	4.258
24-25	-2.280	4.181
25-26	-1.896	4.307
26-27	-1.733	4.376
27-28	-1.730	4.311
27-28	-2.375	4.408
28-29	-2.567	4.271
29-30	-2.443	4.066
30-31	-2.390	4.111
31-32	-2.480	4.110
32-33	-2.352	4.105
33-34	-1.584	4.105
34-35	-1.549	4.015
35-36	-1.334	4.294
36-37	-0.855	4.412
37-38	-0.828	4.532
37-38	-0.861	4.491

C) Box Core 8, *F. wuellerstorfi*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.612	3.649
1-2	1.482	3.773
1-2	1.707	3.730
2-3	0.938	3.639
3-4	1.129	4.033
4-5	1.000	3.553
5-6	0.925	3.727
7-8	1.056	3.871
8-9	1.657	3.810
10-11	1.675	3.715
11-12	1.137	3.996
14-15	1.019	3.726
19-20	1.091	3.900
20-21	1.316	3.969
21-22	1.052	3.825
21-22	1.431	4.077
32-33	1.395	4.116
33-34	1.578	4.162
34-35	1.491	4.127
34-35	1.530	4.137
35-36	1.596	4.215

Table 9 a-c Carbon and oxygen isotope analysis of *Neogloboquadrina pachyderma* (sinistral), *Oridorsalis umbonatus,* and *Fontbotia wuellerstorfi* in samples from AOS 94 box core 16

A) Box Core 16, *N. pachyderma* (sinistral)

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.165	1.646
1-2	1.334	1.353
2-3	1.132	1.013
3-4	1.115	1.582
3-4	1.154	1.869
4-5	1.107	1.415
5-6	0.887	1.340
6-7	0.943	0.478
7-8	0.635	1.032
8-9	0.436	0.036
9-10	0.165	0.488
10-11	0.256	0.345
11-12	0.116	1.065
12-13	0.219	0.553
13-14	0.343	0.434
14-15	0.372	1.040
15-16	0.091	1.235
15-16	0.112	1.375
16-17	0.206	1.269
17-18	0.351	1.537
18-19	0.547	1.591
19-20	0.620	1.221
20-21	0.846	1.265
20-21	0.896	1.566
21-22	1.026	1.951
22-23	1.353	2.795
23-24	1.134	2.752
24-25	1.257	3.018
25-26	1.245	2.937
26-27	1.056	2.738
26-27	1.120	2.734
28-29	1.130	2.859
29-30	0.976	2.344
29-30	1.043	3.180
30-31	0.948	2.390
31-32	1.127	3.138
32-33	0.864	3.085
33-34	0.983	3.077
34-35	0.596	1.715
35-36	0.927	2.695
36-37	0.789	2.360
36-37	0.801	2.242
37-38	0.576	2.401

B) Box Core 16, *O. umbonatus*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	-1.537	4.055
1-2	-1.513	3.974
2-3	-1.470	3.960
3-4	-1.454	4.055
4-5	-1.496	3.953
5-6	-1.782	4.212
6-7	-1.933	4.503
6-7	-2.105	4.304
7-8	-2.007	4.193
8-9	-2.171	4.295
9-10	-2.304	4.428
10-11	-2.029	4.257
11-12	-2.262	4.531
12-13	-2.546	4.307
13-14	-1.678	4.239
14-15	-2.099	4.344
15-16	-2.265	4.458
15-16	-2.298	4.402
16-17	-2.289	4.389
17-18	-2.254	4.381
18-19	-1.781	4.322
19-20	-1.184	4.262
20-21	-1.157	4.306
20-21	-1.412	4.407
21-22	-0.816	4.388
22-23	-0.588	4.490
23-24	-1.053	4.383
24-25	-0.823	4.402
25-26	-1.547	4.267
26-27	-0.849	4.049
28-29	-0.985	3.999
29-30	-1.323	4.075
30-31	-0.913	3.897
31-32	-1.053	4.081
32-33	-1.034	3.956
32-33	-1.244	3.981
33-34	-0.980	4.044
34-35	-1.018	4.019
35-36	-1.236	4.039
36-37	-1.275	3.909
37-38	-1.321	4.073

C) Box Core 16, *F. wuellerstorfi*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.770	3.793
1-2	1.600	4.016
1-2	1.637	3.777
2-3	1.600	3.950
3-4	1.682	3.902
4-5	1.386	4.112
5-6	1.592	3.923
7-8	1.289	4.130
8-9	0.813	3.707
9-10	1.344	4.126
10-11	1.168	4.149
11-12	0.826	4.020
12-13	1.151	4.222
13-14	1.206	4.116
14-15	1.404	4.034
14-15	1.535	3.846
17-18	1.449	3.962
18-19	1.536	4.180
19-20	1.539	4.052
20-21	1.623	4.346
21-22	1.624	4.184
22-23	1.584	3.950
23-24	1.532	4.290
24-25	1.347	3.927
24-25	1.581	4.353
25-26	1.419	3.840
26-27	1.548	3.884
27-28	1.406	3.884
28-29	1.425	3.944
29-30	1.543	3.879
30-31	0.027	2.686
30-31	0.449	3.111
31-32	1.171	3.815
31-32	1.217	3.816
32-33	1.393	3.850
33-34	1.340	3.759
34-35	1.332	3.834
35-36	1.278	3.779
36-37	1.132	3.885
36-37	1.171	3.638
36-37	1.329	3.761
37-38	0.146	2.824
37-38	0.243	2.977
37-38	0.298	3.040
37-38	0.668	3.241
37-38	1.387	3.874

Table 10 a-c Carbon and oxygen isotope analysis of *Neogloboquadrina pachyderma* (sinistral), *Oridorsalis umbonatus,* and *Fontbotia wuellerstorfi* in samples from AOS 94 box core 17

A) Box Core 17, *N. pachyderma* (sinistral)

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.282	1.375
1-2	1.130	1.766
2-3	1.222	1.900
3-4	1.117	1.490
4-5	1.063	1.859
5-6	0.895	1.756
6-7	0.780	1.665
7-8	0.930	1.159
8-9	0.897	0.801
9-10	0.438	1.056
10-11	0.087	0.746
11-12	0.115	0.764
12-13	0.196	0.049
13-14	0.211	0.229
14-15	0.203	-0.060
15-16	0.127	-0.175
16-17	0.296	0.571
17-18	0.171	0.784
18-19	0.142	1.629
19-20	0.152	0.958
20-21	0.106	0.677
21-22	0.508	-0.080
22-23	0.747	1.005
23-24	0.789	1.094
24-25	0.868	1.629
25-26	0.730	1.523
26-27	0.876	2.240
27-26	1.121	2.394
28-29	1.130	2.811
29-30	1.157	2.933
30-31	1.107	2.602
31-32	1.120	2.792
32-33	1.031	2.544
33-34	1.077	2.727
34-35	0.982	2.936
35-36	1.017	2.920
36-37	1.247	3.350

B) Box Core 17, *O. umbonatus*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	-1.065	3.801
1-2	-1.188	3.874
2-3	-1.107	4.002
3-4	-1.420	3.918
4-5	-1.493	3.918
5-6	-1.350	4.088
6-7	-1.702	4.006
7-8	-1.536	3.957
8-9	-1.773	4.346
9-10	-1.855	4.198
10-11	-1.569	4.319
11-12	-1.866	4.343
12-13	-1.953	4.392
13-14	-1.724	4.356
14-15	-1.701	4.340
15-16	-1.660	4.289
16-17	-1.929	4.384
17-18	-2.354	4.247
18-19	-2.504	4.317
19-20	-2.116	4.374
20-21	-2.197	4.444
21-22	-1.607	4.302
22-23	-1.405	4.245
23-24	-1.253	4.250
24-25	-1.124	4.246
25-26	-1.223	4.236
26-27	-1.148	4.252
27-26	-1.094	3.990
28-29	-0.560	-5.314
29-30	-0.896	4.162
30-31	-0.863	4.016
31-32	-0.950	4.124
32-33	-0.330	3.663
33-34	-0.859	4.008
34-35	-0.588	4.138
36-37	-0.631	4.197

C) Box Core 17, *F. wuellerstorfi*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.616	3.592
1-2	1.572	3.670
2-3	1.485	3.647
3-4	0.774	4.045
4-5	1.246	3.860
5-6	1.114	3.811
6-7	1.285	3.860
7-8	1.122	3.897
8-9	0.816	4.041
9-10	1.026	4.295
10-11	1.156	4.340
11-12	1.012	4.299
12-13	1.061	4.291
13-14	0.837	4.030
14-15	0.913	4.043
15-16	0.762	3.992
16-17	0.535	3.992
17-18	0.749	4.015
19-20	0.844	4.007
20-21	0.942	4.324
21-22	1.215	4.058
22-23	1.592	4.071
23-24	1.258	3.752
24-25	1.461	4.027
25-26	1.358	3.810
26-27	1.433	3.828
27-26	1.478	3.800
28-29	1.397	3.729
29-30	0.827	3.782
30-31	1.481	3.768
31-32	0.336	3.921
32-33	1.244	3.782
33-34	1.380	3.936
34-35	1.490	3.876
35-36	1.111	4.610
36-37	1.231	3.958

Table 11 a-c Carbon and oxygen isotope analysis of *Neogloboquadrina pachyderma* (sinistral), *Oridorsalis umbonatus,* and Fontbotia wuellerstorfi in samples from AOS 94 box core 19

A) Box Core 19, *N. pachyderma* (sinistral)

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	1.256	1.626
0-1	1.271	1.623
1-2	1.099	1.559
2-3	0.813	1.661
3-4	0.840	1.440
4-5	0.487	0.817
5-6	0.269	-0.207
6-7	0.160	0.718
6-7	0.174	0.701
7-8	0.168	0.668
8-9	0.244	0.112
9-10	0.086	1.017
10-11	0.101	1.124
11-12	0.264	0.778
12-13	0.690	1.043
13-14	0.625	1.218
14-15	0.902	1.395
15-16	0.888	1.470
15-16	0.966	1.722
16-17	1.024	2.330
17-18	0.982	2.031
18-19	0.945	2.839
19-20	1.026	2.607
20-21	1.175	3.086
21-22	1.116	2.546
22-23	0.927	2.567
23-24	1.020	2.397
24-25	0.949	2.126
25-26	0.759	1.275
26-27	0.721	1.040
27-26	0.682	1.884
28-29	0.303	1.004
29-30	0.464	1.744
29-30	0.611	1.525
30-31	0.424	0.915
31-32	0.391	-0.897
32-33	0.711	1.127
33-34	0.681	2.418
34-35	0.624	2.276
35-36	0.594	1.489
36-37	0.337	2.897
36-37	0.501	2.434

B) Box Core 19, *O. umbonatus*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	-1.403	4.005
0-1	-1.489	3.955
1-2	-1.215	4.071
2-3	-1.159	3.993
3-4	-1.662	4.214
4-5	-1.344	4.157
5-6	-1.903	4.592
6-7	-2.092	4.473
7-8	-2.132	4.555
8-9	-2.014	4.426
9-10	-1.941	4.434
10-11	-1.989	4.420
11-12	-1.640	4.286
11-12	-1.789	4.495
12-13	-1.247	4.138
13-14	-1.657	4.270
14-15	-1.306	4.255
15-16	-1.119	4.381
16-17	-1.211	4.226
17-18	-0.806	4.135
18-19	-0.665	4.119
19-20	-0.833	4.091
20-21	-0.491	4.186
21-22	-0.758	4.256
22-23	-0.810	4.212
22-23	-0.936	4.199
23-24	-1.130	4.074
24-25	-0.858	4.149
25-24	-1.094	4.186
26-25	-1.568	4.073
27-26	-1.402	4.151
28-29	-1.262	4.063
29-30	-0.991	4.104
30-31	-1.503	3.706
31-32	-2.462	3.913
32-33	-1.433	4.061
32-33	-1.440	4.062
33-34	-1.452	4.129
34-35	-1.407	3.970
35-36	-1.315	4.039
36-37	-1.118	4.256

C) Box Core 19, *F. wuellerstorfi*

Depth (cm)	$\delta^{13}C$	$\delta^{18}O$
0-1	0.605	4.170
1-2	1.625	3.781
2-3	1.241	3.765
3-4	0.847	3.821
3-4	1.095	3.832
4-5	0.890	4.116
5-6	0.929	4.269
6-7	1.048	4.301
7-8	1.139	4.146
8-9	0.703	4.023
9-10	0.726	4.155
10-11	1.432	4.017
11-12	1.575	4.111
12-13	1.248	3.871
12-13	1.468	3.769
13-14	1.480	4.169
14-15	1.506	4.083
15-16	1.582	4.173
16-17	0.589	3.568
17-18	1.480	3.817
18-19	1.396	3.809
19-20	1.393	4.064
20-21	1.405	3.968
21-22	1.235	3.918
22-23	0.677	3.723
22-23	1.150	3.833
23-24	1.058	3.969
24-25	0.590	3.656
25-26	0.294	3.444
26-27	0.623	3.655
28-29	0.516	3.743
28-29	1.225	3.740
29-30	0.568	3.709
30-31	0.542	3.554
31-32	0.554	3.679
32-33	1.348	3.612
32-33	1.370	3.791
34-35	0.633	3.681
35-36	0.951	3.695
36-37	1.097	3.776

AMS ^{14}C Sample Handling and Processing

AMS ^{14}C dates were obtained on the planktic foraminifer *Neogloboquadrina pachyderma* (sinistral) (Table 12). Approximately 2,000 specimens of *N. pachyderma* were hand picked from the >125µm size fraction of processed samples. An effort was made to select larger specimens and to avoid specimens that appeared corroded or had obvious chamber infilling. Specimens were then placed in an ultrasonic bath to remove any remaining debris from apertures and sutures.

The 2000 specimen sample size was selected to provide the standard one-milligram of carbon for a ^{14}C age by accelerator mass spectrometry (AMS). The carbon from these samples was first captured as CO_2 by acidification of the entire sample with 85% phosphoric acid (H_3PO_4) in a vacuum chamber. The CO_2 was then dried by forcing the gas through a water trap cooled to ~ 80° C. The dried CO_2 was converted to pure carbon in the form of graphite by placing a measured volume (equivalent to 1mg carbon) in a chamber with iron powder, hydrogen, and zinc as a catalyst at 575° C for ten hours. The sample carbon (precipitated on the iron) was pressed into aluminum targets for AMS analysis. Dating was done at Lawrence Livermore laboratory ís Center for Accelerator Mass Spectrometry (CAMS) in Livermore, CA. (See Roberts, M.L., and others, 1997 for a detailed description of the CAMS facility and operation.) AMS ^{14}C dates are corrected by 440 years for reservoir effects (Keigwin and Jones, 1989; Darby, and others, 1997).

Table 12. AMS ^{14}C dates for AOS 94 box cores. Radiocarbon dates have been corrected by 440 years for water mass reservoir effects (Keigwin and Jones, 1989; Darby and others, 1997).

core	sample depth cm	^{14}C age	corrected age	error +/-
94 B-8				
	0-1	4,130	3,960	50
	2-3	5,580	5,140	50
	6-7	7,700	7,260	50
	8-9	7,760	7,320	50
	12-13	7,960	7,520	50
	14-15	10,630	10,190	50
	21-22	10,950	10,510	50
	24-25	21,740	21,300	100
	26-27	33,110	32,670	280
	30-31	35,580	35,140	350
	34-35	45,800	45,360	1,000
	36-37	39,250	38,810	510
	37-38	39,340	38,900	490

Table 12 continued.

core	sample depth cm	^{14}C age	corrected age	error +/-
94 B-16				
	2-3	4,680	4,240	50
	4-5	7,750	7,310	50
	6-7	10,050	9,610	50
	10-11	11,300	10,860	60
	13-14	12,250	11,810	60
	16-17	29,680	29,240	170
	17-18.5	41,250	40,810	850
	19.5-20	33,810	33,370	350
	19-20	31,930	31,490	280
	20-21	36,610	36,170	480
	21-22	36,890	36,450	570
	23-24	37,770	37,330	580
	26-27	42,310	41,870	980
	33-34	49,500	49,060	2,400
94 B-17				
	5-6	7,150	6,710	50
	10-11	11,690	11,250	50
	12-13	12,250	11,810	50
	16-17	13,040	12,600	50
	20-21	29,400	28,960	110
	27-28	36,970	36,530	280
	34-35	41,480	41,040	460
94 B-19				
	2-3	5,680	5,240	50
	5-6	12,120	11,680	60
	7-8	12,570	12,130	60
	10-11	25,410	24,970	190
	12-13	35,120	34,680	410
	15-16	40,260	39,820	780
	18-19	41,000	40,560	840
	21-22	41,680	41,240	930
	25-26	44,600	44,160	1,300
	29-30	49,400	48,960	2,400

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