Radiocarbon Dating of Cores Collected from Bear Lake, Utah and Idaho

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This report has not been reviewed for stratigraphic nomenclature.

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Introduction

The overall goal of our research on Bear Lake is to obtain records of past climate change for the region, including changes in precipitation (rain and snow) patterns during the last 10,000 years and longer. As part of the project, we are attempting to determine how the size of Bear Lake has varied in the past in order to assess the possibility of future flooding and drought. We also seek to understand human influences on sediment deposition, chemistry, and life in the lake.

Evidence of past environmental conditions comes from sediments deposited in the lake, so reconstructions of these conditions require accurate dating of the sediments. The study includes the upper Bear River watershed as well as Bear Lake. The Bear River is the largest river in the Great Basin and the source of the majority of water flowing into the Great Salt Lake. In this region, wet periods may produce flooding along the course of the Bear River and around Great Salt Lake, while dry periods, or droughts, may affect water availability for ecosystems, as well as for agricultural, industrial, and residential use.

Here we report the results of radiocarbon analyses of sediments in several cores from Bear Lake and compare the radiocarbon ages with independently estimated ages derived from amino acid analyses in ostracodes. We develop age models for each core to form the chronological framework for other paleoenvironmental studies.

Methods

Coring

Standard Kullenburg-type piston cores were obtained in September 1996 at three sites; BL96-1 (41.9527° N, 111.3160° W), BL96-2 (41.9527° N, 111.3333° W) and BL96-3 (41.9532° N, 111.3613° W) (fig. 1). The cores ranged in recovered length from 4 to 5 m and were collected from a portable barge and coring system.

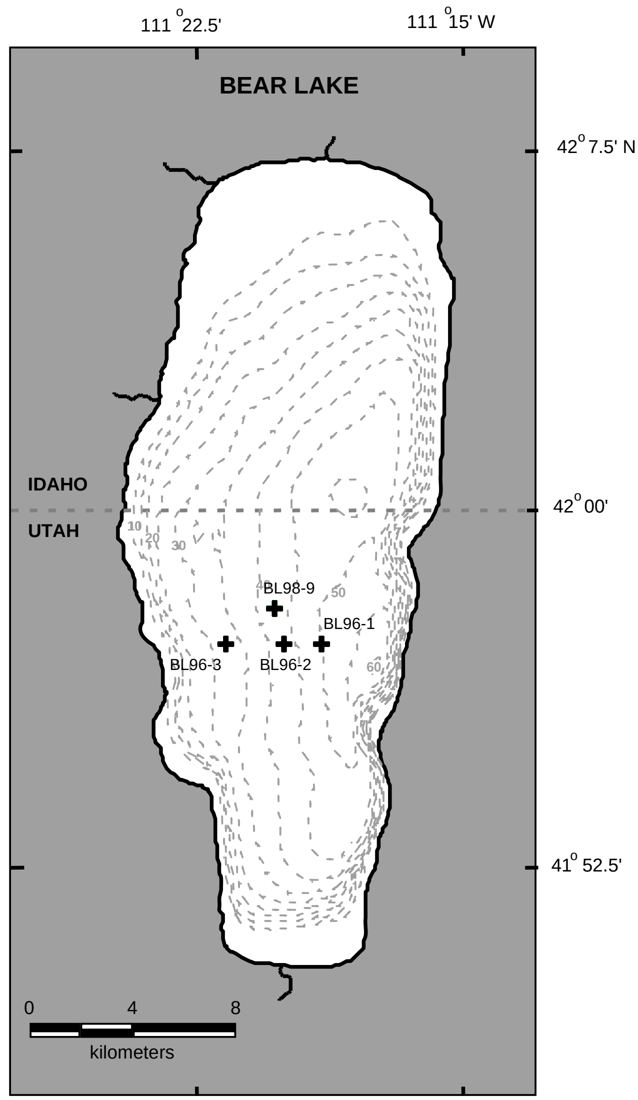

Figure 1. Map of Bear Lake showing the bathymetry of the lake and location of the core sites discussed here. Bathymetric contour interval 5 m, beginning at 10 m.

The inner diameter of the plastic liner of these cores was 7 cm. Locations of the core sites were determined by standard GPS methods. Additional short gravity cores were obtained in 1998, and samples from one of them, BL98-9 (41.9654° N, 111.3384° W), were analyzed.

Radiocarbon dating

Three types of material were separated from the sediments and analyzed by accelerator-mass spectrometer (AMS) methods – total organic carbon (TOC), ostracodes hand picked from the sediments, and material remaining after mineralogic sediment was removed by standard pollen-preparation procedures (Faegri and Iverson, 1975), here called “pollen+.”

For total organic carbon, samples of bulk sediment were acidified with organic-free HCl and filtered through a nominal 1-µm diameter precleaned quartz-fiber filter. Pollen+ samples were prepared using standard methods (Faegri and Iverson, 1975). The prepared material contains charcoal and other refractory organic material in addition to pollen, but visual inspection indicated that nonpollen material was a minor component of the samples. Ostracodes were separated from the sediment by hand picking following the procedures described in Colman and others (1990).

The samples then were converted to CO_2 by combustion (TOC and pollen+) or dissolution in phosphoric acid using standard methods (Jones and others, 1989; Slota and others, 1987). Carbon dioxide from the samples was reduced to elemental graphite over hot iron in the presence of hydrogen (Vogel and others, 1984). The graphite targets were prepared and were analyzed at the NOSAMS facility in Woods Hole (OS- numbers in table 1), or they were prepared at the U.S. Geological Survey (WW- numbers in table 1) and run at the Lawrence Livermore Accelerator Facility. Ages were calculated according to the methods of Stuiver and Pollach (1977), using either measured $\delta^{13}C$ values or, in some cases, assumed $\delta^{13}C$ values (–25 for pollen or TOC, 0 for ostracodes, table 1). Calibrated ages were calculated with the CALIB 4.3 program (Stuiver and others, 1998) using the terrestrial calibration data set. Two sigma errors were used in the calibration procedure, and the midpoint of the age range with highest probability was selected.

Results

Radiocarbon ages were determined for four cores in Bear Lake (table 1). The three 1996 piston cores were the focus of this effort; data for the short (33 cm) BL98-9 core are given in table 1 but are not further discussed here.

Different fractions of the same samples allow comparisons among TOC, pollen+, and biogenic carbonate (ostracodes). On general principles, the pollen+ samples are thought to be the most reliable, even though they may contain fragments of refractory organic matter. In the glacial part of the section, however, this may not be true, as discussed in the next section. TOC samples contain all grain sizes of carbon and are likely to include detrital carbon that has been washed into the lake. Biogenic and authigenic carbonate samples are subject to reservoir effects, the size of which were not known *a priori*. Biogenic and authigenic carbonate samples share this limitation equally; authigenic carbonate was not analyzed because of the additional potential problem of contamination with detrital carbonate.

Two pairs of pollen+ and TOC samples (table 2) indicate a consistent difference between the two kinds of samples. Pollen+ samples average 560±120 years younger than corresponding TOC samples. This result is consistent with the assumption that TOC samples contain more detrital carbon than the pollen+ samples

Table 1. Radiocarbon measurements made in this study.

Core (bold), section (letter), and depth (cm)	Corrected total depth (cm)	Material	$\delta^{13}C$ (per mil)[a]	Age (^{14}C years)	Error (1σ, years)	Lab number[b]	Calibrated age (cal yr B.P.)[c]	Calibrated Range(cal yr B.P.)
BL96-1								
A11	7	ostracodes	-1.09	905	130	OS-19513	805	675-940
A16	12	ostracodes	0	890	130	OS-19507	800	670-930
A27	23	ostracodes	0	900	75	OS-19496	820	745-920
A37	33	ostracodes	0	14,500	1,700	OS-19509	17370	13130-21310
A52	48	ostracodes	-0.31	1,450	45	OS-18663	1325	1280-1365
A52	48	pollen	-25	1,070	40	WW-2774	970	880-1010
C55	252	pollen	-25	3,320	40	WW-1754	3545	3505-3620
E39	437	pollen	-25	5,260	40	WW-1752	6055	6015-6165
E95	493	TOC	-25	6,740	50	WW-1384	7555	7505-7580
BL96-2								
A13	3	pollen	-25	3,020	50	WW-1755	3205	3155-3325
A13	3	TOC	-25	1,620	50	WW-1758	1480	1430-1545
B9	99	pollen	-25	3,435	60	WW-2600	3690	3540-3900
B31	121	ostracodes	0	4,620	60	WW-2803	5320	5070-5590
B31	121	pollen	-25	4,230	40	WW-2775	4830	4800-5010
B61	151	ostracodes	0	5,460	50	WW-2799	6280	6180-6440
B61	151	pollen	-25	5,260	40	WW-2776	5990	5810-6050
B73	163	pollen	-25	5,810	50	WW-1756	6625	6575-6710
B85	175	pollen	-25	6,420	50	WW-1757	7300	7250-7380
B85	175	TOC	-25	6,970	50	WW-1759	7775	7725-7870
C10	201	pollen	-25	8,265	70	WW-2601	9170	8870-9310
C21	212	ostracodes	0	9,070	60	WW-2800	10220	10060-10280
C21	212	pollen	-25	8,580	40	WW-2777	9540	9480-9590
C55	246	pollen	-25	10,300	60	WW-1773	12135	12075-12280
D7	299	pollen	-25	12,710	50	WW-1774	14960	14910-15135
D7	299	TOC	-25	13,110	60	WW-1760	15605	15545-15750
D8	300	pollen	-25	12,545	90	WW-2602	14670	13760-15180
D15	307	rotifer	-29.20	12,400	80	OS-18559	14515	14435-14700

Table 1. Radiocarbon measurements made in this study–Continued.

Core (bold), section (letter), and depth (cm)	Corrected total depth (cm)	Material	$\delta^{13}C$ (per mil)[a]	Age (^{14}C years)	Error (1σ, years)	Lab number[b]	Calibrated age (cal yr B.P.)[c]	Calibrated Range(cal yr B.P.)
D21	313	pollen	-28.14	14,000	100	OS-35973	16790	16290-17330
D41	333	pollen	-27.92	16,200	75	OS-35624	19320	18720-19970
D61	353	pollen	-25.98	18,550	140	OS-35974	22025	21300-22810
D73	365	pollen	-25	8,380	40	WW-2783	9430	9340-9700
D81	373	pollen	-25.5	21,000	110	OS-35625	24750	24250-25250
D93	385	pollen	-25.34	21,300	150	OS-36022	25095	24595-25595
D101	393	pollen	-25	22,600	60	WW-2778	26600	26101-27101
BL96-3								
A18	5	pollen	-25.31	4,440	40	OS-36023	5010	4870-5290
A33	20	pollen	-25	10,940	75	WW-2607	12980	12800-13310
A46	33	pollen	-25.82	12,800	100	OS-35976	15440	15360-15900
A90	77	pollen	-25	19,980	60	WW-2779	23670	22910-24410
B85	172	pollen	-24.53	21,800	140	OS-36267	25675	25175-26175
C13	201	pollen	-25	21,850	230	WW-2605	25735	25235-26235
C89	277	pollen	-24.54	23,400	130	OS-35626	27520	27020-28020
D89	377	pollen	-25.04	26,700	170	OS-36024	31280	30780-31780
E15	403	pollen	-25	22,150	210	WW-2606	26080	25580-26580
BL98-09								
--	1	pollen	-25	1,510	40	WW-2771	1400	1310-1510
--	1	ostracodes	0	600	70	WW-2801	600	530-690
--	30	pollen	-25	980	40	WW-2772	925	790-990
--	30	ostracodes	0	1,350	50	WW-2802	1290	1240-1400

[a] Whole values indicated as “0” and “-25” were assumed for ostracodes and organic carbon, respectively; other values were measured.

[b] See text (Methods) for explanation.

[c] Calibrations from program CALIB 5.0 (Stuiver and others, 1998), using 2 σ errors and the midpoint of the range with highest probablility.

Table 2. Ages for pollen+ samples compared to those for TOC and ostracode samples. (Data from table 1; all values in cal yr BP.)

Pollen+	TOC	Ostracodes	TOC-Pollen	Ostracodes-Pollen
970		1,325		355
4,830		5,320		490
5,990		6,280		290
9,540		10,220		680
925		1,290		365
7,300	7,777		477	
14,960	15,605		645	
		Mean[a]	560	440
		St. Dev[a]**.**	120	150

[a] Rounded to nearest 10 years.

Five pairs of pollen+ and ostracode samples (table 2) show a remarkably consistent relation. Pollen+ samples average 440±150 years younger than the ostracode samples. The consistency of this result suggests that the difference is due to the fact that the radiocarbon content of the water is slightly out of equilibrium with that of the atmosphere, that is, that there is a reservoir effect of about 440 years. Although the magnitude of the reservoir effect likely varies with time, no consistent trend with time was seen in our data set.

Discussion

Age models for the Holocene and late glacial sections of each of the 1996 piston cores were developed using least-squares linear fits (fig. 2). For cores BL96-2 and -3, which exhibit changes in sediment accumulation rates, a local least-squares fit procedure was used producing multiple line segments (fig. 2). The end points of these line segments form the age models for these cores (table 3). This procedure produces a robust, objective fit to the data without the problems at the ends of the depth range that are common with polynomial fits. However, the local least-squares fit is not a single age-equation with an associated R^2 value, and depths must be converted to ages using the data in table 3.

Because of the relations between the ages of different types of samples discussed in the previous section, 440 years were subtracted from the calibrated ostracode ages and 560 years were subtracted from the calibrated TOC ages in figure 2. All ages are thereby adjusted to the timescale of the pollen+ samples. The apparent core-top ages (in cal yr BP) for each core are: 160 (BL96-1, from equation in fig. 2); 792 (BL96-2, from table 3); and 3,148 (BL96-3, from table 3). These ages probably are due mostly to the common failure of piston cores to recover the uppermost part of the sediment section, combined with different rates of sediment accumulation.

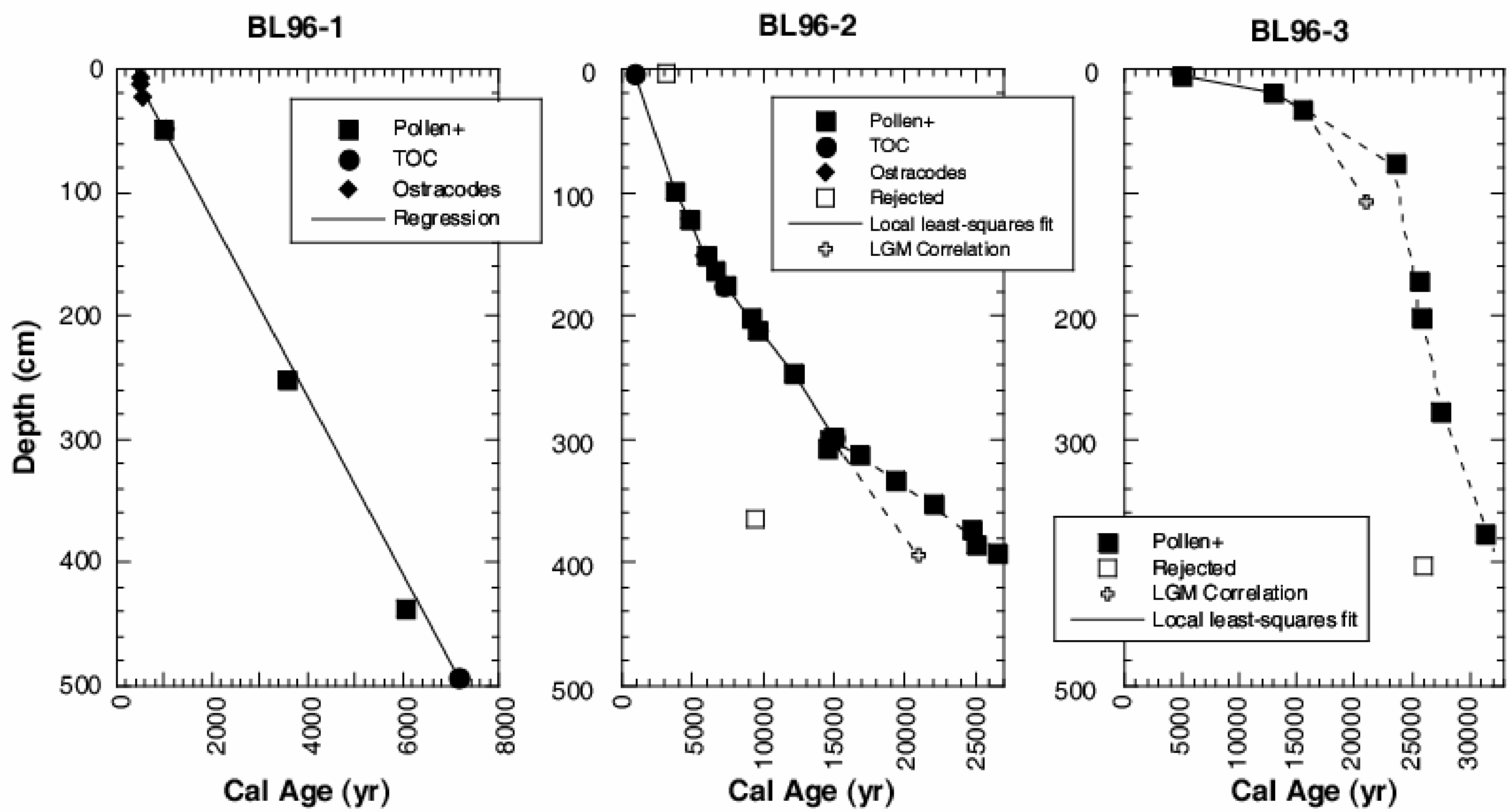

Figure 2. Radiocarbon ages for cores BL96-1, -2, and -3 plotted against depth in the sediment sequence. Data from table 1. Ostracode and TOC ages modified to account for reservoir effects and residence time (see text and table 2). One rejected age for core BL96-1 is off scale of plot. For BL96-2 and BL96-3, two options for the age models are shown as dashed lines for the interval >17 cal ka (see text).

Table 3. End points of local least-square line segments that form the age models for cores BL96-2 and BL96-3, for the option that passes through the correlated depth of the LGM at 21 cal ka.

BL96-2		BL96-3	
Depth (cm)	Age (cal yr BP)	Depth (cm)	Age (cal yr BP)
0	792	0	3,148
99	3,793	20	5,010
163	6,631	33	15,440
201	9,011	107	21,000
212	9,760		
246	11,845		
310	15,600		
393	21,000		

The age data are quite consistent internally. Only three outliers, defined by age reversals with depth, were observed in the Holocene to late glacial sections of the cores (fig. 2). These outliers (one in BL96-1 and two in BL-96-2) were disregarded in constructing the age models. The reasons for these outliers are unknown, but contamination is always a suspect.

Even though the ages for the glacial part of the section (> ca. 17 cal ka) in BL96-2 and -3 progressively get older, there is some reason to suspect the accuracy of these ages. First, organic carbon contents in these samples are very low, and the pollen+ samples from this interval that have been examined under the microscope contain little pollen. This suggests that the material is mainly refractory organic matter and, as such, may be significantly older than the sediment in which it was deposited. Second, the age of the local last glacial maximum (LGM), as indicated by geochemical and magnetic indicators of rock flour (Rosenbaum and others, 2002), appears to be about 25 cal ka years according to the radiocarbon ages. A cosmogenic-exposure age of 17.1 ± 1.6 ka has been obtained for terminal moraines on the south side of the Uinta Mountains (Laabs and others, 2003). Based on cosmogenic-exposure dating throughout the western United States, Licciardi and others (2004)suggested that there were two pulses at the LGM, at 17 and at 21 cal ka, although Pierce (2004) points out that the cosmogenic-exposure ages are consistently younger than comparable radiocarbon ages.

For the purposes of our age models for BL96-2 and -3, we used two different options for the sections of the cores >17 cal ka (fig. 2). The first simply uses the ages in the same way the younger ages were used. For the second option, we plotted a point at the depth of the LGM and an age of 21 cal ka (fig. 2) and connected it to the end of the age model for the ages <17 cal ka. The two options for the age models for BL96-2 and BL96-3 reflect the degree of uncertainty in the analyses for the time period > 17 cal ka.

The radiocarbon ages less than 17 cal ka compare well with age estimates based on amino acid racemization. We used an independently derived equation for racemization of aspartic acid in ostracodes (Kaufman, 2000), with an effective temperature of 4.6°C for the bottom of Bear Lake, to derive amino-acid age estimates (fig. 3). The two types of age estimates are entirely consistent, lending strong support for the <17-cal-ka part of the age models (fig. 2).

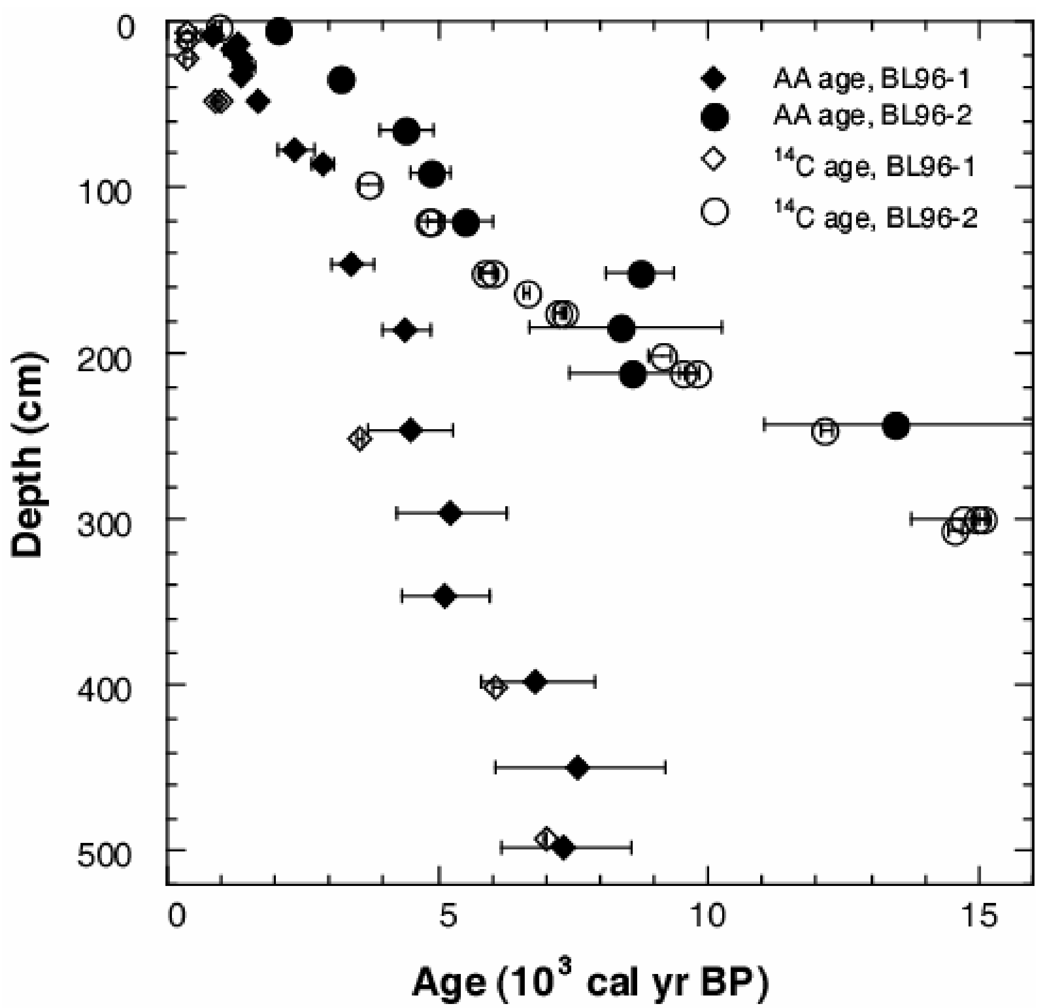

Figure 3. Comparison between ages estimated from radiocarbon (^{14}C) and amino

acid racemization (AA) methods. See text for explanation.

Conclusions

Radiocarbon analyses of total organic carbon, pollen, and ostracodes provide a reliable chronology of sediments deposited in Bear Lake. The differences in apparent age between TOC, pollen, and carbonate fractions are consistent and in accord with the origins of these fractions. The data also are in accord with ages independently estimated from aspartic acid racemization in ostracodes. The resulting age models are the backbone for reconstructions of past environmental conditions in Bear Lake.

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