[RADIOCARBON, VOL. 34, NO. 3, 1992, P. 578–584]

RADIOCARBON DATING OF *ANODONTA* IN THE MOJAVE RIVER BASIN

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ABSTRACT. A 450-year correction is required to make *Anodonta* ^{14}C dates comparable to ^{14}C dates on other materials in the Mojave River basin. The internal stratigraphic consistency of 34 conventional ^{14}C dates on *Anodonta* in this drainage basin indicates that such dates are usually reliable. The validity of most conventional ^{14}C dates in the Mojave River basin may be a product of the basin's crystalline bedrock in a region usually typified by thick Paleozoic carbonate sections.

INTRODUCTION AND BACKGROUND

This paper presents the results of extensive radiocarbon dating, and the establishment of a correction term, for a freshwater pelecypod, *Anodonta californiensis*, in the Mojave River drainage basin of inland southern California (Fig. 1). During the late Pleistocene, *Anodonta* thrived in the pluvial lakes of the southwestern U.S., and extensive deposits of *Anodonta* shells have been found embedded in shoreline features and other lacustrine deposits throughout this region. Radiocarbon dating of these shells and associated sedimentary deposits has permitted paleoclimatologists to reconstruct some ancient lake-level fluctuations, and thus derive a proxy record of Pleistocene climatic shifts in the Mojave Desert (Ore & Warren 1971; Wells *et al.* 1989; Meek 1990).

Today, *Anodonta* are abundant in rivers of the northwestern U.S., and some remnant populations can be found locally in the southwestern U.S. (Ingram 1948). *Anodonta* prefer slightly alkaline waters with gentle currents, and live and burrow in sand or gravel flats at water depths of less than 2 m. They avoid locations with rooted vegetation. Most late Pleistocene *Anodonta* shells have been recovered from sites that experienced rapid burial, such as where a delta prograded into a basin during a flood, or in overwash deposits on beach ridges. Thus, fossil *Anodonta* sites often indicate approximate water levels at times of infrequent but rapid depositional events.

In this study, *Anodonta* shells were recovered from shoreline features of Lake Manix, a pluvial lake in the central Mojave Desert, that was the effective terminus of the Mojave River during most of the late Quaternary. Based on extensive paleontological and paleoecological evidence (Jefferson 1985, 1987; Steinmetz 1988), it appears that Pleistocene Lake Manix was much like the modern, shallow, marshy lakes in the rainshadow of the Cascades in northern California, Oregon and Washington. The complex Wisconsinan climate history generated by the new shell dates is beyond the scope of this paper, but has been reported by Meek (1990, and forthcoming).

Prior to this study, 14 finite ^{14}C age estimates had been published on materials associated with Lake Manix or post-lacustrine deposits in the Manix basin (Table 1). We collected 13 new ^{14}C samples, consisting of lustrous *Anodonta californiensis* shells and tufa from a variety of locations in the Manix basin (Table 2). Each sample was freed from external contamination by mechanical cleaning and subsequent washing in distilled water. Samples were then dissolved in dilute cold hydrochloric acid. The outer shell layer was removed by discarding the initial CO_2 fraction. The

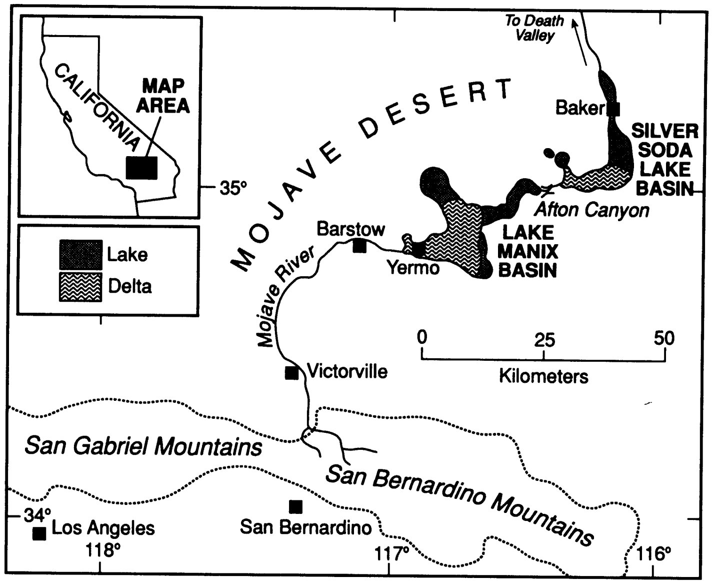

Fig. 1. Map of the Mojave River basin, California

TABLE 1. Published ^{14}C Dates (Uncorrected) From the Manix Basin

ID code	^{14}C age (yr BP)	Sample material	Lab no.	Reference
d1	30,950 ± 1000	Tufa	LJ-895	Hubbs, Bien & Suess (1965)
d2	20,050 ± ?	*Anodonta*	*	Bassett & Jefferson (1971)
d3	19,500 ± 500	Tufa	LJ-269	Hubbs, Bien & Suess (1962)
d4	19,300 ± 400	Tufa	UCLA-121	Fergusson & Libby (1962)
d5	19,100 ± 250	*Anodonta*	QC-1467	Jefferson (1985)
d6	16,750 ± 1000**	Tufa	UCLA-1079	Berger & Libby (1967)
d7	13,800 ± 600	*Anodonta*	LJ-958	Hubbs, Bien & Suess (1965)
d8	12,800 ± 900	Bone	GX-10417	Reynolds & Reynolds (1985)
d9	12,210 ± 430	Charcoal	GX-10420	Reynolds & Reynolds (1985)
d10	10,910 ± 425	Charcoal	GX-10421	Reynolds & Reynolds (1985)
d11	9050 ± 350	Charcoal	GX-10418	Reynolds & Reynolds (1985)
d12	7350 ± 115	Charcoal	QC-937	Reynolds & Reynolds (1985)
d13	2090 ± 105	Charcoal	QC-939A	Reynolds & Reynolds (1985)
d14	1570 ± 170	Charcoal	GX-10419	Reynolds & Reynolds (1985)

*Not available
**Artificial 2500-yr correction term removed

remaining bulk CO_2 was collected and extensively purified by washing in silver nitrate solution and chromic acid. After drying, the gas was treated with hot copper for removal of traces of electronegative impurities. All samples were then stored for at least one month to allow for radon decay. Thereafter, each sample was assayed in a proportional counter for at least 3000 min for good statistical precision. Table 2 presents these new ^{14}C dates.

TABLE 2. New ^{14}C Dates (Uncorrected) From the Manix Basin

ID code	^{14}C age (yr BP)	Sample material	Lab no.	UTM location (Zone 11) Easting	Northing
d15	30,650 ± 890	*Anodonta*	UCLA-2604	557500	3878300
d16	23,090 ± 445	*Anodonta*	UCLA-2600A	558800	3877300
d17	20,890 ± 345	Tufa	UCLA-2602	538350	3866450
d18	19,700 ± 260	Tufa	UCLA-2600B	558800	3877300
d19	18,150 ± 400	*Anodonta*	UCLA-2607	555950	3875900
d20	17,590 ± 1500	*Anodonta*	UCLA-2603	527600	3877400
d21	15,125 ± 270	*Anodonta*	UCLA-2608	528200	3879500
d22	15,025 ± 230	*Anodonta*	UCLA-2605	540550	3856200
d23	14,230 ± 1325	*Anodonta*	UCLA-2601	557650	3878300
d24	13,560 ± 145	*Anodonta*	UCLA-2609B	528700	3878600
d25	12,900 ± 120	*Anodonta*	UCLA-2606	522600	3874300
d26	11,810 ± 100	*Anodonta*	UCLA-2609C	528600	3878800
d27	480 ± 60	*Anodonta*	UCLA-2610A	(see text)	

DISCUSSION

Initial research on the reliability of ^{14}C age estimates on *Anodonta* in the Mojave Desert led Hubbs, Bien and Suess (1965: 69) to conclude that *Anodonta* provide reasonably reliable age estimates when solid, lustrous shells are dated. Consequently, in the literature, no previous ^{14}C dates on *Anodonta* have been corrected for variable ^{14}C uptake by the genus.

Without knowledge of the ^{14}C uptake of *Anodonta*, the chronologies of lake basins in the Great Basin, which depend heavily on shell dates, are not directly comparable to ^{14}C chronologies based on charcoal, *e.g.*, which have been thoroughly studied. For this reason, we conducted a study on the ^{14}C uptake of *Anodonta* in southern California.

Local malacologists believe that *Anodonta* may have become extinct in the lower Mojave River drainage basin earlier this century because of human disturbances. Thus, it was not possible to obtain modern specimens from this drainage basin. However, before atmospheric atomic-bomb testing began in the 1940s, *Anodonta californiensis* shells were collected from the Mojave River drainage and in ponds in the Los Angeles basin. These shells were obtained through the courtesy of Dr. Clifton Coney, malacology collection manager at the Los Angeles County Museum of Natural History.

The inorganic fraction of a mixture of two *Anodonta californiensis* samples was ^{14}C dated. One sample of two specimens (4 valves; 25.8 g) was collected on 18 October 1934 in a Mojave River pool about 10 km east of Yermo, California, by W. Branaler. The other sample consisted of one specimen (2 valves; 9.5 g), collected in 1915 by E. P. Chase in East Lake Park, Los Angeles County. All of the specimens were adults, probably about 10 years old at the time of collection. Because these samples were collected prior to the discovery of ^{14}C dating, no data exist on the ^{14}C content of the water in which they were found. In the 50+ years since the shells were collected, the pools in the Mojave River have been highly disturbed by cattle ranching and offroad vehicles, and the ponds in the Los Angeles basin have experienced similar radical changes. Thus, we assume that the ^{14}C content of the water from which the samples were collected earlier this century was similar to the shallow, and probably well-mixed, water of Lake Manix.

^{14}C dating of the inorganic fraction of these shells provided an age of 480 ± 60 BP on specimens with a true age of *ca.* 30 ^{14}C years. Thus, this study suggests that age estimates on *Anodonta californiensis* in the Mojave River basin require an approximate 450-year correction term.

This correction term is substantially less than the approximate 1870 ± 240-year correction term required for specimens of *Anodonta californiensis* living in the Humboldt River at Dunphy, Nevada (Broecker & Olson 1959). The difference is probably attributable to large geochemical differences between the Mojave River and the Humboldt River basins. Unlike the Mojave River, the Humboldt River flows through a region of thick Paleozoic carbonates, which probably contribute significant amounts of dead carbon to the stream.

On the other hand, in the Cronese basin, which is just downstream from the Lake Manix basin, only a 350-year difference may exist between *Anodonta* and charcoal. Joan Schneider (written communication, 1989) reports an age of 910 ± 100 on *Anodonta* shells (UCR-2385) found in the upper playa clays, whereas charcoal in a nearby location provided an age of 560 ± 110 BP (UCR-767; Drover 1979). It is important to note that these two samples were not collected adjacent to each other, and so their age relationship is not firmly established.

Table 3 presents corrected *Anodonta* ^{14}C dates using the 450-year correction term for comparison with charcoal dates from the region. ^{13}C measurements were also completed, but only if ^{13}C corrections exceed the ^{14}C statistical error ranges have the error ranges been increased to accommodate the $\delta^{13}C$ variations.

TABLE 3. Corrected ^{14}C Dates From the Manix Basin

ID code	$\delta^{13}C$ ‰	Corr. (yr)	Sample material	Corrected ^{14}C age (yr BP)	Lab no.
d1	*	*	Tufa	30,950 ± 1000	LJ-895
cd2	*	*	*Anodonta*	19,600 ± ?	*
d3	*	*	Tufa	19,500 ± 500	LJ-269
d4	*	*	Tufa	19,300 ± 400	UCLA-121
cd5	*	*	*Anodonta*	18,650 ± 250	QC-1467
d6	*	*	Tufa	16,750 ± 1000	UCLA-1079
cd7	*	*	*Anodonta*	13,350 ± 600	LJ-958
cd15	−19.39	90	*Anodonta*	30,200 ± 890	UCLA-2604
cd16	*	*	*Anodonta*	22,640 ± 445	UCLA-2600A
cd17	+0.60	410	Tufa	20,890 ± 410	UCLA-2602
cd18	+1.29	420	Tufa	19,700 ± 420	UCLA-2600B
cd19	-8.03	270	*Anodonta*	17,700 ± 400	UCLA-2607
cd20	*	*	*Anodonta*	17,140 ± 1500	UCLA-2603
cd21	−1.54	375	*Anodonta*	14,675 ± 375	UCLA-2608
cd22	−8.76	260	*Anodonta*	14,575 ± 260	UCLA-2605
cd23	*	*	*Anodonta*	13,780 ± 1325	UCLA-2601
cd24	−6.96	290	*Anodonta*	13,110 ± 290	UCLA-2609B
cd25	−4.53	330	*Anodonta*	12,450 ± 330	UCLA-2606
cd26	−3.56	340	*Anodonta*	11,360 ± 340	UCLA-2609C
cd27	−16.21	140	Calib.	480 ± 140	UCLA-2610A

*Not available

Two new ^{14}C dates (Table 2) were also measured on lithoid tufa in deposits where both *Anodonta* and tufa are found in the same outcrop. The Manix basin results, supplemented with the Silver/Soda Lake basin results, suggest that lithoid tufa usually provides reliable age estimates in the Mojave River drainage basin when compared with the corrected *Anodonta* dates. This is not surprising because of the relative absence of carbonate bedrock in the drainage basin, and the fact that the primary water source was in the San Bernardino Mountains, which are composed predominately of crystalline rocks.

Table 4 presents a sequential summary of all known finite conventional ^{14}C dates from the Manix basin and downstream areas. Because *Anodonta* correction terms were used in this study, the Manix basin dates were not directly comparable to unadjusted ^{14}C dates in downstream areas. We have corrected the *Anodonta* dates from a list of Silver/Soda Lake basin ^{14}C dates compiled by Wells *et al.* (1989). Only conventional ^{14}C dates on shells and tufa are reported in Table 4, although six additional AMS dates on the organic fraction of bulk sediments from cores have been reported in the Silver/Soda Lake basin.

One unusual aspect of the Manix basin is that it broke in what may have been a catastrophic flood about 13,800 BP, carving Afton Canyon and allowing the Mojave River to flow directly downstream into the Silver/Soda Lake basin (Meek 1989, 1990).

When combined, the conventional ^{14}C dates from the Manix basin correspond exceedingly well with ^{14}C dates from the Silver/Soda Lake basin. Of all the conventional ^{14}C dates yet published, only three dates from the Silver/Soda Lake basin overlap with dates on lacustrine features from Lake Manix, and the maximum overlap is 2040 ^{14}C years. Some overlap is to be expected, because during the late Wisconsinan glaciation, *Anodonta* should have been living in lakes downstream from Lake Manix before it drained. In other words, of the 57 conventional ^{14}C dates derived from the 2 basins, only 3 indicate that a lake existed downstream before Lake Manix broke, and no ^{14}C

TABLE 4. Sequential Summary of Conventional ^{14}C Dates From the Mojave River Drainage Basin

Manix Basin	Silver Basin	ID code (Meek 1990)	Corr. ^{14}C age (yr BP)	Sample type	Lab no.
X		d1	30,950 ± 1000	Tufa	LJ-895
X		cd15	30,200 ± 890	*Anodonta*	UCLA-2604
X		cd16	22,640 ± 445	*Anodonta*	UCLA-2600A
X		cd17	20,890 ± 410	Tufa	UCLA-2602
X		cd18	19,700 ± 420	Tufa	UCLA-2600B
X		cd2	19,600 ± ?	*Anodonta*	*
X		d3	19,500 ± 500	Tufa	LJ-269
X		d4	19,300 ± 400	Tufa	UCLA-121
X		cd5	18,650 ± 250	*Anodonta*	QC-1467
X		cd19	17,700 ± 400	*Anodonta*	UCLA-2607
X		cd20	17,140 ± 1500	*Anodonta*	UCLA-2603
X		d6	16,750 ± 1000	Tufa	UCLA-1079
	X	s1	15,820 ± 310	*Anodonta*	Beta-29553
	X	s2	14,900 ± 240	*Anodonta*	Y-1587
X		cd21	14,675 ± 375	*Anodonta*	UCLA-2608
X		cd22	14,575 ± 260	*Anodonta*	UCLA-2605
X	X	s3	14,100 ± 140	*Anodonta*	Y-1586
		cd23	13,780 ± 1325	*Anodonta*	UCLA-2601

TABLE 4. (Continued)

Manix Basin	Silver Basin	ID code (Meek 1990)	Corr. ^{14}C age (yr BP)	Sample type	Lab no.
Afton Basin Permanently Drained – (all of the following Manix basin ^{14}C dates are from sites that postdate the high stand of Lake Manix, and are related to Mojave River delta migration)					
X		cd7	13,350 ± 600	*Anodonta*	LJ-958
	X	s4	13,220 ± 550	*Anodonta*	LJ-933
	X	s5	13,190 ± 500	Tufa	LJ-931
	X	s6	13,190 ± 120	*Anodonta*	Beta-26456
	X	s7	13,170 ± 160	*Anodonta*	Y-1585**
X		cd24	13,110 ± 290	*Anodonta*	UCLA-2609B
	X	s8	13,040 ± 120	Tufa	Y-1588
	X	s9	12,840 ± 550	*Anodonta*	Y-1589
X		d8	12,800 ± 900	Bone	GX-10417
	X	s10	12,700 ± 350	*Anodonta*	I-443
X		cd25	12,450 ± 330	*Anodonta*	UCLA-2606
X		d9	12,210 ± 430	Charcoal	GX-10420
	X	s11	12,000 ± 160	*Anodonta*	Y-2408
	X	s12	11,630 ± 500	Tufa	LJ-934
	X	s13	11,570 ± 130	*Anodonta*	Beta-21299
	X	s14	11,520 ± 160	*Anodonta*	*
	X	s15	11,410 ± 95	*Anodonta*	DIC-2824
X		cd26	11,360 ± 340	*Anodonta*	UCLA-2609C
	X	s16	11,320 ± 120	Tufa	Y-1590
X		d10	10,910 ± 425	Charcoal	GX-10421
	X	s17	10,870 ± 450	Tufa	LJ-930
	X	s18	10,850 ± 75	Tufa	DIC-2823
	X	s19	10,250 ± 100	*Anodonta*	Y-1591
	X	s20	10,130 ± 100	*Anodonta*	Y-1593
	X	s21	9990 ± 100	Tufa	Y-1592
	X	s22	9960 ± 200	Tufa	Y-2410
	X	s23	9880 ± 120	*Anodonta*	Beta-21200
	X	s24	9820 ± 160	*Anodonta*	Y-2406
	X	s25	9810 ± 400	*Anodonta*	LJ-932
	X	s26	9550 ± 300	*Anodonta*	I-444
	X	s27	9190 ± 240	*Anodonta*	LJ-200
	X	s28	9160 ± 400	Tufa	LJ-935
X		d11	9050 ± 350	Charcoal	GX-10418
	X	s29	8940 ± 140	*Anodonta*	Beta-29552
	X	s30	8890 ± 140	*Anodonta*	Y-2407
	X	s31	8350 ± 300	Tufa	LJ-929
X		d12	7350 ± 115	Charcoal	QC-937
X		d13	2090 ± 105	Charcoal	QC-939A
X		d14	1570 ± 170	Charcoal	GX-10419

*Not available

**The error range of this date has been consistently misreported as ± 100 yr since the Ore and Warren (1971) publication; see Stuiver (1969).

dates exist on lacustrine materials in the part of Manix basin that was permanently drained after Afton Canyon had formed. We believe that this is a testament to the reliability of conventional ^{14}C dates on *Anodonta* in the Mojave River basin.

Conclusions

We believe that a genus-specific correction term of 450 years is required to make *Anodonta* ^{14}C dates in the Mojave River drainage basin comparable to ^{14}C dates on other materials.

Because of the relative absence of carbonate bedrock in the Mojave River drainage basin, conventional ^{14}C dates on *Anodonta*, as well as lithoid tufa dates, are usually reliable. This conclusion is based on the regional stratigraphic consistency of more than 50 conventional ^{14}C dates. Knowledge of the apparent reliability of conventional ^{14}C dates on *Anodonta* in the Mojave River drainage basin will greatly enhance future geomorphic and paleoclimatic studies of this important region.

Acknowledgments

We thank Dr. Clifton Coney, Los Angeles County Museum of Natural History, for help in obtaining pre-atomic-bomb *Anodonta* specimens. This research was funded by a NSF Dissertation Improvement Grant #SES-8719442.

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