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COMPILATION, CALIBRATION, AND SYNTHESIS OF FAUNAL AND FLORAL RADIOCARBON DATES, RANCHO LA BREA, CALIFORNIA

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ABSTRACT. This paper presents a compilation and synthesis of calibrated radiocarbon dates for the Rancho La Brea tar pits, Los Angeles, California. A literature survey yielded 188 dates, and 21 additional dates are presented here for the first time. These range in age from 185 to 50,000 radiocarbon years. Dating of Rancho La Brea fossils has been uneven; only from Pits 91 and 2051 have more than 30 dates been obtained. The depositional history of well-sampled pits was complex, with one or more episodes of major accumulation interspersed with lower background levels of entrapment. The most significant quantifiable source of error of Rancho La Brea ^{14}C dates is calibration error. Dates younger than 21,381 radiocarbon years can be calibrated using the IntCal04 calibration curve and yield an accurate estimate of age. Most older dates cannot be accurately calibrated at this time. Calibration of radiocarbon dates is important because raw radiocarbon dates consistently underestimate calendar dates, usually by several thousand years.

INTRODUCTION

The fossils of the Rancho La Brea tar pits in Los Angeles, California provide the type assemblage of the Rancholabrean Land Mammal Age (Savage, 1951) and present a unique window on the world at the end of the last ice age. The tar pits are a true lagerstätte, and intensive collection at intervals during the past century has resulted in the recovery of hundreds of thousands of exceptionally well-preserved mammalian bones ranging from saber-toothed cats to squirrels, plus large quantities of other vertebrates, invertebrates, and plant remains (Stock and Harris, 1992). The deposits represent a series of open asphalt seeps that acted as episodic animal traps (for a geological review see Quinn, 1992). The age range of the fossils from the deposits has been estimated by ^{14}C dating from more than 50,000 to less than 10,000 years ago, with each deposit recording one or more pulses of accumulation (Marcus and Berger, 1984; Friscia et al., 2008; Table 1). This time range brackets the end of the Wisconsin glaciation and includes the last glacial maximum, when global temperatures were 8°C or more below those of today (Jouzel et al., 2007). It also includes the Pleistocene–Holocene transition (Petit et al., 1999), the Younger Dryas cool interval (12,800–11,500 years before present), and the American megafaunal extinction event in which 33 genera of large mammals disappeared circa 12,700 years ago (Fiedel, 2009). The Rancholabrean assemblage thus accumulated during a very interesting time in Earth's climatic and ecological history. The number and quality of preserved fossils presents an excellent opportunity to investigate these events.

In recent years the synergy between detailed climate records and the fossil record has been applied to questions concerning changes to community structure, biogeography, and microevolution (MacDonald et al., 2008). The Rancho La Brea tar pits are a prime candidate for analysis of the impact of climate change on mammalian population parameters and Pleistocene–Holocene changes in community structure. Because carnivores far outnumber herbivores in the asphaltic deposits (Stock and Harris, 1992), they are a logical group to analyze for temporal trends, and indeed early studies focused on them. *Canis dirus* Leidy, 1858 and *Smilodon fatalis* (Leidy, 1868) are the two most common carnivorans from Rancho La Brea. Preliminary studies of these species (Nigra and Lance, 1947; Shaw and Tejada Flores, 1985; O'Keefe, 2008) have indicated chronological changes in body size that correlate with climate fluctuations. However, other studies have indicated stasis in the body size of late Pleistocene birds and mammals from Rancho La Brea (Prothero et al., 2009). Other recent work has addressed ecological processes. For instance, van Valkenburgh and Hertel's (1993) influential paper on premortem tooth breakage and wear documented nutrient stress in carnivoran populations at the terminal Pleistocene, while Binder et al. (2002) addressed breakage in *C. dirus* specif-

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Table 1 Summary tabulation of age estimates for Rancho La Brea (RLB) pits with more than six carbon dates. Error terms from carbon dating itself and from calibration may be derived from Table 2 and Figure 3. Outliers greatly increase the age range of each pit (see Figure 2 and Table 2).

RLB pit number	Number of dates	Mean age calibrated	Standard deviation	Age range, calibrated	Mean age, radiocarbon years
3	26	18,593	5,541	9,914–47,270	16,330
4	16	14,546	7,768	14,139–24,382	24,427
9	10	26,427	17,178	14,146–62,500	29,060
13	6	16,192	5,001	8,387–19,486	13,624
16	13	26,425	19,325	11,503–68,000	30,228
60	10	21,383	18,225	8,013–36,270	23,758
61–67	7	11,581	3,768	4,450–14,914	9,966
77	6	35,370	—	30,170–40,570	31,573
91	59	29,068	18,367	8,776–51,240	29,968
2051	33	21,349	4,571	5,765–26,000	22,692

ically. Anyonge (1996) used microwear to infer diet in *Smilodon*, while van Valkenburgh and Sacco (2002) focused on population dynamics in large Pleistocene carnivores. Additionally, stable isotope ratios of carbon can be used to discriminate between C_3- and C_4-dominated diets; stable isotope data from a range of Rancho La Brea taxa (Coltrain et al., 2004; Fox-Dobbs et al., 2006) show variability in N and C values, probably as a result of dietary shifts linked to climate-forced changes in community structure. Clearly, the fossils of Rancho La Brea have the potential to provide answers to a wide range of biological and ecological questions.

Most previous large-sample studies of Rancho La Brea fossils have been limited by weak chronological control. Stratigraphic position has been said to be an unreliable indicator of relative age within the asphalt deposits (Stock and Harris, 1992; Friscia et al., 2008; but see "Discussion" section). Available radiocarbon dates have allowed age bracketing of the different excavations from which collections have been made, producing a coarse chronological division for many (Marcus and Berger, 1984, and references therein; Tables 1 and 2). However, the reliability of individual dates within each excavation has yet to be established, which is important if the huge Rancho La Brea fossil sample is to be used in support of hypotheses concerning climate change. The various radiocarbon dates for Rancho La Brea are spread throughout the literature, have been measured using radically different protocols, and are usually not calibrated: (i.e., they are reported in radiocarbon years before present, not in calendar years before present). Sediment core, ice core, and dendrochronological ages, on the other hand, are usually reported as calendar years before present.

This paper gathers all published radiocarbon dates for Rancho La Brea and presents them in a single tabulation, along with reference, protocol, and error information. In addition, we present 21 new radiocarbon dates published here for the first time. All dates of the requisite age range (less than 21,381 radiocarbon years ago) have been calibrated using the IntCal04 calibration curve (Reimer et al., 2004) to express calendar years before present instead of radiocarbon years before present. Summary graphs and statistics are presented in an attempt to interpret the issues of precision, accuracy, and depositional history of the asphalt deposits.

MATERIALS AND METHODS

Of concern in this paper are the various methodologies devised for dating petroleum-saturated remains from Rancho La Brea, and the methods used to calibrate and report those dates. We first summarize the various dating techniques used for Rancho La Brea fossils and then briefly discuss the calibration methodology.

CARBON DATING

The early history of radiocarbon dating at Rancho La Brea was discussed thoroughly by Marcus and Berger (1984). Dating of both the organic and inorganic carbon components of Rancho La Brea fossils began shortly after the invention of radiocarbon dating techniques. Tests on bone-derived carbonate and apatite were deemed unsuccessful, perhaps due to diagenetic alteration by the surrounding petroleum (Marcus and Berger, 1984) or to contamination by the asphalt. However, because bone collagen does not exchange carbon with the environment (Hassan and Hare, 1978), collagen-derived carbon was used for most of the dates listed in the first survey of Rancho La Brea radiocarbon dating (Marcus and Berger, 1984). The initial step in the Marcus and Berger protocol (and all subsequent protocols) was a solvent wash using a Soxhlet distilling apparatus to remove hydrocarbons from a powdered bone sample (Berger and Libby, 1968). Amino acids were then extracted using a protocol devised by Ho et al. (1969), followed by burning of the amino acids and isotopic measurement of the resulting carbon dioxide. This method was effective but required from 75 to 300 grams of raw powdered bone for successful dating. The main improvement on this technique has been the use of accelerator mass spectrometry (AMS) for radiocarbon dating, allowing a radical decrease (three orders of magnitude) in the amount of bone needed for an accurate date. The lab used for most AMS dating presented here is the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory.

While more recent protocols vary in detail, all retain the same basic approach, namely the gathering of a powdered bone sample, removal of contaminating hydrocarbons via solvent wash, extraction of bone collagen, and radiocarbon dating of the decalcified collagen. Three versions of the preliminary solvent wash have been used recently for petroleum removal prior to radiocarbon dating. The protocols are similar, but are successively less stringent.

The most stringent protocol, that of Stafford et al. (1991), was used to date 46 samples from Pit 91 (Friscia et al., 2008; see Table 2). A less stringent protocol presented in Fox-Dobbs et al. (2006) was used for dates in that paper and those provided by J. Harris in Table 2. Although the first of these protocols is more precise (Stafford et al., 1991), the second protocol calling for the dating of bulk collagen is more often used, as it is easier and cheaper to execute. A third protocol, developed by Fox-Dobbs and used to obtain the eight new bone dates reported by O'Keefe in Table 2, is as follows.

Raw bone samples from the University of California Museum of Paleontology (UCMP) *C. dirus* crania were collected using a handheld Dremel rotary tool. The samples were ground to a fine powder by mortar and pestle. Bone samples of 100–125 milligrams of bone powder were placed in test tubes and rinsed using three solvents: petroleum ether, acetone, and hexane. Five milliliters of each solvent was added to each test tube and agitated for five minutes; the solvent was then poured off. This process was repeated five times for each solvent; after the last rinse, the samples were left to soak for two hours in the last iteration of each solvent. Samples were then air-dried in preparation for demineralization. Demineralization was achieved using a 0.5 M HCl solution. Ten milliliters of acid was added, and the samples were put in a refrigerator (approximately 4.5°C) to slow the reaction. Demineralization was complete when the solution stopped producing CO_2 (about 12 hours). The demineralized material was then gelatinized by soaking in 0.01 M HCl for 14 hours at 58°C. The resulting solution was filtered through a Whatman 934-AH 25-millimeter glass microfiber filter, using a vacuum source to pull the solution. The filtered solution was decanted into a fresh test tube and dried under vacuum in a Jovan rotovap centrifuge evaporator. All glassware was precombusted, and ultrapure, millipore-filtered water was used for all solutions.

A protocol for dating wood α-cellulose was reported by Ward et al. (2005). Collagen- or cellulose-derived carbon is further processed for AMS by first oxidizing it to CO_2, then reducing this gas into a solid graphite target that is then subjected to a particle beam. The isotopic composition of the resulting gases is measured.

CALIBRATION

All initial results from radiocarbon dating are in radiocarbon years; a calibration of these dates is necessary to yield real calendar years (Reimer et al., 2004). All dates younger than 21,381 radiocarbon years were calibrated in this study (Table 2). Calibration was performed through use of the computer program CALIB 5.1, based on the IntCal04 calibration curve presented by Reimer et al., 2004 (the CALIB 5.1 program is available from www.calib.org; the primary references are Stuiver and Reimer, 1993, and Stuiver et al., 2005). Dates and radiocarbon error terms were entered from an Excel spreadsheet into the CALIB template, and the program was run to yield calendar dates before present and confidence intervals representing error associated with both the calibration and the radiocarbon date. The CALIB 5.1 program is also capable of calibrating dates greater than 21,381 radiocarbon years ago using the Taylor Dome ice core record (Beck et al., 2001); however, this calibration requires additional data on $\partial^{13}C$ values, and these data were available only for the wood cellulose dates reported by Ward et al. (2005) and collagen dates reported by J. Harris. Those dates have also been calibrated in Table 2 but other collagen dates older than 21,381 radiocarbon years ago have not.

RESULTS

The results of this study are summarized in Table 1 and presented fully in Table 2. We present a total of 209 radiocarbon dates for Rancho La Brea, 21 of which have not been reported previously. The overall depositional history of the Rancho La Brea complex spans from beyond the limit of accurate radiocarbon dating (circa 50 thousand years ago [kya]) to the Recent (Table 1). The mean ages of deposition for each site (="Pit") are also listed; these are broadly and evenly distributed throughout the last 50,000 years. The standard deviations listed in Table 1 are not measures of error, but measures of dispersion of actual dates around the mean date for each site.

A dire wolf innominate bone from Pit 91 dated by Stafford under blind test conditions yielded age estimates of 43,000±720 and 46,000±1,100. This result suggests there are limitations to the accuracy of radiocarbon age estimates based on fossil bone samples even when the same methodology is used. Marcus and Berger (1984:table 8.1) had previously shown how different methodologies produce different dates from the same sample. Some dates are clearly wrong. The date recorded by Marcus and Berger (1984) for bone fragments from the Page Museum Salvage excavation (QC 684) is 6,400±140 yet the faunal assemblage is clearly late Pleistocene in age with horse, dire wolf, and bison material as well as the only relatively complete *Smilodon fatalis* skeleton from Rancho La Brea. Subsequent attempts to date specimens from that locality were unsuccessful because of the poor preservation (low collagen content) of the bones. A date for a *Paramylodon* rib from Pit 60 placed it in the Holocene, approximately 20,000 years younger than other specimens from that locality. However, not all young dates are problematical; estimates for the historic sheep from caved strata in Pit 4 and for the domestic dog (originally described as a new species of coyote-like wolf, *Canis petrolei*) and archaeological artifacts from Pit 61–67 are certainly within the bounds of possibility.

Table 2 Compilation of published and new radiocarbon dates for Rancho La Brea. The dates are listed by pit number and, where possible, grid and depth below datum. The protocols used for each date can be found in its relevant reference; see also the "Materials and Methods" section of this paper. Calibrated dates older than 21,381 years before present (YBP) were calibrated using additional data on ∂ C13 values (for further discussion see text). Specimen numbers for each dated element are listed as they appear in original publications; their acronyms are as follows: **GEO**, geological sample processed by Les Marcus at Queens College; **GPMLBD** (Ward et al., 2005), George C. Page Museum of La Brea Discoveries; **LACMHC**, Page Museum Hancock Collection; **LACMRLP** (Friscia et al., 2008), Los Angeles County Museum-Pit 91; **LJ** (Hubbs et al., 1960; Marcus and Berger, 1984), Scripps Institute, University of California San Diego, La Jolla; **QC** (Marcus and Berger, 1984), Queens College, City University of New York; **QU** (Marcus and Berger, 1984), Centre de Recherches Minérales, Québec; **RLB** (Douglas, 1952; Harris, this study), Rancho La Brea; **UCLA** (Berger and Libby, 1966, 1968; Marcus and Berger, 1984), University of California, Los Angeles; **UCMP** (Fox-Dobbs et al., 2006, O'Keefe, this study), University of California Museum of Paleontology, Berkeley; **Y** (Deevey et al., 1959), Peabody Museum of Natural History, Yale University. **NA**, not applicable.

Pit	Grid	Depth in feet	Radiocarbon YBP	Radiocarbon SE	Calibrated YBP min. (2δ values)	Calibrated YBP max. (2δ values)
3	C-3	15	14,430	200	16,628	18,020
3	C-3	17.5	14,745	40	17,571	18,059
3	C-4	7	12,650	160	14,180	15,324
3	C-4	11.5	14,400	2,100	11,824	22,225
3	D-2	12	14,440	300	16,492	18,486
3	D-5	18.5	14,360	35	16,774	17,545
3	E-2	9	12,820	90	14,846	15,504
3	E-2	11.5	14,250	40	16,615	17,410
3	E-2	12	14,500	190	16,678	18,077
3	E-3	6	13,035	275	14,464	16,286
3	E-3	6	13,745	275	15,510	17,168
3	E-3	22–25	9,860	550	9,914	12,853
3	E-4	26	19,300	395	22,137	24,056
3	E-4	1–4.5	13,820	840	14,193	18,693
3	E-5	14	14,350	175	16,597	17,898
3	E-5	22	21,400	560	—	—
3			28,000	NA	—	—
3			13,890	280	15,716	17,483
3			14,110	420	15,674	18,463
3			14,500	210	16,649	18,447
3			14,500	140	16,879	17,985
3			15,200	150	18,067	18,816
3			15,390	230	18,052	19,041
3			36,840	430	36,410	47,270
3			19,555	820	21,253	25,494
3			20,500	900	22,563	26,000
4	A-5	9	22,000	1,200	—	—
4	B-5	18.5	12,760	150	14,319	15,544
4	B-5	23.5	29,600	1,100	—	—
4	C-2	11.5	15,200	800	16,149	19,929
4	Caved		185	30	—	300
4	D-2	8	28,600	190	—	—
4	D-2	15.5	28,000	1,400	—	—
4	D-2+4	8	26,700	900	—	—
4	D-3+4	10.5	13,500	170	15,474	16,625
4	F-4+5	15	26,995	4,000	—	—
4	F-4+5	18	35,500	2,200	—	—
4	F-4+5	20–22	36,000	NA	—	—
4	G-3	5	35,300	2,500	—	—
4		5	33,700	1,600	—	—
4		4.5–8.5	19,800	300	22,676	24,382
4			27,000	1,600	—	—
5			15,720	50	18,216	19,385
9		8.5	12,450	40	14,146	15,524
9		8.5	13,300	160	15,241	16,331
9		10.5	38,600	NA	—	—
9		16	35,820	380	35,440	46,200
9		16	40,000	NA	—	—
9			49,600	2,900	46,700	62,500
9			13,120	230	14,910	16,286
9			13,430	210	15,297	16,601

Table 2 Extended.

Calendar YBP	Institution	Catalog/sample number	Taxon	Element	Reference
17,324	UCLA	1292AA	*Mammut americanum*	Tibia	Marcus and Berger, 1984
17,900	LACMHC	28501	*Equus* sp.	Phalanx	Harris (this study)
14,752	UCLA	1292B	*Smilodon fatalis*	Femur	Berger and Libby, 1968
17,025	UCLA	1292E	*Smilodon fatalis*	Femur	Berger and Libby, 1969
17,489	LJ	55	*Cupressus* sp.	Wood	Hubbs et al., 1960
17,193	LACMHC	A883	*Smilodon fatalis*	Femur	Harris (this study)
15,140	LACMHC	Z4360	*Equus* sp.	Phalanx	Harris (this study)
17,018	LACMHC	Z4450	*Equus* sp.	Phalanx	Harris (this study)
17,378	UCLA	1292C	*Smilodon fatalis*	Femur	Berger and Libby, 1970
15,375	QC	279	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
16,339	QC	414	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
11,384	GEO	—	*Canis dirus*	Humerus	Marcus and Berger, 1984
23,097	UCLA	1292K	*Smilodon fatalis*	Femur	Berger and Libby, 1968
16,443	QC	401	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
17,248	UCLA	1292T	*Mammut americanum*	Tibia	Marcus and Berger, 1984
	UCLA	1292A	*Smilodon fatalis*	Femur	Berger and Libby, 1968
	LJ	89	Asphalt	Asphalt	Hubbs et al., 1960
16,600	Y	355B	*Cupressus* sp.	Wood	Deevey et al., 1959
17,069	Y	355A	*Cupressus* sp.	Wood	Deevey et al., 1959
17,548	Y	354A	*Cupressus* sp.	Wood	Deevey et al., 1959
17,432	QC	422B	*Cupressus* sp.	Wood	Marcus and Berger, 1984
18,442	QC	422A	*Cupressus* sp.	Wood	Marcus and Berger, 1984
18,547	Y	354B	*Cupressus* sp.	Wood	Deevey et al., 1959
41,840	GPMLBD	L-13	*Juniperus* sp.	Wood	Ward et al., 2005
23,374	QC	283	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
24,282	UCLA	1292J	*Smilodon fatalis*	Femur	Berger and Libby, 1968
	QC	412	*Equus* sp.	Femur	Marcus and Berger, 1984
14,932	UCLA	Femur_pit4	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292O	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
18,039	UCLA	1292L	*Smilodon fatalis*	Tibia	Berger and Libby, 1968
180	LACMHC	133499	*Ovis* sp.	Atlas	Harris (this study)
	LACMHC	Z4482	*Equus* sp.	Phalanx	Harris (this study)
	UCLA	1292D	*Smilodon fatalis*	Femur	Berger and Libby, 1968
	UCLA	1292G	*Smilodon fatalis*	Femur	Berger and Libby, 1968
16,050	UCLA	1292Q	*Bison latifrons*	Scapula	Marcus and Berger, 1984
	QC	386	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292S	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292M	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	QC	426	Wood	Wood	Marcus and Berger, 1984
	UCLA	773A	Wood	Wood	Berger and Libby, 1966
23,529	UCLA	1292R	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292Z	*Bison antiquus*	Axis	Marcus and Berger, 1984
18,801	GPMLBD	L-16	*Juniperus* sp.	Wood	Ward et al., 2005
14,835	GPMLBD	L-19	*Juniperus* sp.	Wood	Ward et al., 2005
15,786	UCLA	773D	Wood	Wood	Berger and Libby, 1966
	QC	423	Wood	Wood	Marcus and Berger, 1984
40,820	GPMLBD	L-22	*Juniperus* sp.	Wood	Ward et al., 2005
	UCLA	773F	Wood	Wood	Marcus and Berger, 1984
54,600	GPMLBD	L-4	*Juniperus* sp.	Wood	Ward et al., 2005
15,598	QC	429	Wood	Wood	Marcus and Berger, 1984
15,949	QU	724	Wood	Wood	Marcus and Berger, 1984

Table 2 Continued.

Pit	Grid	Depth in feet	Radiocarbon YBP	Radiocarbon SE	Calibrated YBP min. (2δ values)	Calibrated YBP max. (2δ values)
9			34,285	1,675	—	—
9			40,000	NA	—	—
10	F-11	4–5.5	15,700	530	17,521	20,000
10		5.5	5,270	155	5,662	6,391
10		6–9	9,000	80	9,792	10,370
13	E-11	11	14,950	430	16,807	18,968
13	F-10	14.5	15,300	200	18,059	18,932
13	F-11	20–23	14,310	920	14,667	19,331
13	G-10	13	15,360	480	17,134	19,486
13			7,665	35	8,387	8,537
13			14,160	50	16,505	17,486
16	Caved		29,860	190	—	—
16		4.5	12,275	775	12,766	16,586
16		6.5	40,000	NA	—	—
16		12	55,000	3,000	52,000	68,000
16		12	33,870	1,350	—	—
16		12–14	24,400	535	—	—
16		3–6	32,850	NA	—	—
16		8–12	10,710	320	11,503	13,251
16			18,430	500	20,516	23,199
16			19,485	275	22,475	23,950
16			37,310	NA	—	—
16			38,780	NA	—	—
16			40,000	NA	—	—
60	C-10	9–12	23,700	600	—	—
60	C-12	14	24,900	3,360	—	—
60	E-12	18	26,320	240	—	—
60	F-11	12	7,600	195	8,013	8,976
60		8–9	27,900	2,700	—	—
60		9–9.5	28,850	NA	—	—
60			24,460	NA	—	—
60			22,330	1,060	—	—
60			28,100	170	32,270	36,270
60			23,420	350	—	—
61–67	B-9	18–20	11,130	275	12,403	13,647
61–67	D-16	10	12,000	125	13,589	14,144
61–67	F-10	16–18.5	11,640	135	13,250	13,763
61–67	H-10	15–20	12,200	200	13,693	14,914
61–67	Caved		6,360	30	7,180	7,416
61–67			11,980	260	13,286	14,731
61–67			4,450	200	4,540	5,586
77	F-10	18.5–21	31,300	1,350	—	—
77	G-11	13–15	33,100	600	—	—
77		9–11	28,200	980	—	—
77			30,370	200	30,170	40,570
77			29,470	1,150	—	—
77			37,000	2,660	—	—
81			10,940	510	11,274	13,802
81			14,415	3,250	9,284	24,571
81			24,130	100	26,230	30,230
91	F-7	8.8–9	35,735	4,050	—	—
91	F-11	8.1–8.5	29,100	1,200	—	—
91	F-11	11.5	28,350	470	—	—
91	H-6	8.5–9	28,150	360	—	—
91	H-7	8.5–9	28,650	250	—	—
91	H-7	9.5–10	27,660	120	—	—
91	H-7	10.5–11	23,060	90	—	—
91	H-7	11.5–12	43,000	720	—	—
91	H-7	11.5–12	44,600	1,100	—	—
91	H-8	8.5–9	27,220	140	—	—
91	H-8	10.5–11	28,170	160	—	—
91	H-8	11.5–12	44,300	850	—	—
91	H-9	13.6	28,130	330	—	—

Table 2 Continued. Extended.

Calendar YBP	Institution	Catalog/sample number	Taxon	Element	Reference
	QC	424	Wood	Wood	Marcus and Berger, 1984
	UCLA	773B	Wood	Wood	Berger and Libby, 1966
18,761	UCLA	1292CC	*Equus* sp.	Femur	Marcus and Berger, 1984
6,027	QC	916R	*Ursus arctos*	Femur	Marcus and Berger, 1984
10,081	UCLA	1292BB	*Homo sapiens*	Femur	Marcus and Berger, 1984
17,888	UCLA	1292F	*Smilodon fatalis*	Femur	Berger and Libby, 1968
18,496	UCLA	1292I	*Smilodon fatalis*	Femur	Berger and Libby, 1968
16,999	QC	420	*Bison antiquus*	Femur	Marcus and Berger, 1984
18,310	QC	339	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
8,462	GPMLBD	L-5	*Juniperus* sp.	Wood	Ward et al., 2005
16,996	GPMLBD	L-18	*Juniperus* sp.	Wood	Ward et al., 2005
	LACMHC	X9982	*Canis latrans*	Ulna	Harris (this study)
14,676	QC	371	*Bison antiquus*	Metacarpal	Marcus and Berger, 1984
	UCLA	773G	Wood	Wood	Berger and Libby, 1966
60,000	GPMLBD	L-14	*Juniperus* sp.	Wood	Ward et al., 2005
	QC	428	Wood	Wood	Marcus and Berger, 1984
	QC	278	*Bison antiquus*	Metatarsal	Marcus and Berger, 1984
	QC	277II	*Bison antiquus*	Metatarsal	Marcus and Berger, 1984
12,377	GEO	GEO	*Canis dirus*	Humerus	Marcus and Berger, 1984
21,858	QC	427R	Wood	Wood	Marcus and Berger, 1984
23,213	QC	427	Wood	Wood	Marcus and Berger, 1984
	QU	725	Wood	Wood	Marcus and Berger, 1984
	QU	767	Wood	Wood	Marcus and Berger, 1984
	UCLA	773E	Wood	Wood	Berger and Libby, 1966
	UCLA	1292H	*Smilodon fatalis*	Femur	Berger and Libby, 1968
	QC	410	*Equus* sp.	Tibia	Marcus and Berger, 1984
	LACMHC	Z4579	*Equus* sp.	Metatarsal	Harris (this study)
8,495	QC	361	*Paramylodon harlani*	Rib	Marcus and Berger, 1984
	QC	280	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	QC	365	*Equus* sp.	Metapodial	Marcus and Berger, 1984
	QC	E_metapodial_60	*Equus* sp.	Metapodial	Marcus and Berger, 1984
	QC	E_Tibia_60	*Equus* sp.	Tibia	Marcus and Berger, 1984
34,270	GPMLBD	L-26	*Juniperus* sp.	Wood	Ward et al., 2005
	QC	G_Rib_60	*Paramylodon harlani*	Rib	Marcus and Berger, 1984
13,025	QC	413	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
13,867	UCLA	1292X	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
13,507	QC	302A	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
14,304	UCLA	1292Y	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
7,293	LACMHC	V5203	*Canis petrolei* (=*familiaris*)	Mandible	Harris (this study)
14,009	QC	302B	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
5,063	LJ	121	Wood	Atlatl shaft	Hubbs et al., 1960
	UCLA	1292V	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292U	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	UCLA	1292W	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
35,370	GPMLBD	L-25	*Juniperus* sp.	Wood	Ward et al., 2005
	QC	425	Wood	Wood	Marcus and Berger, 1984
	UCLA	773C	Wood	Wood	Berger and Libby, 1966
12,538	QC	E_Tibia_81	*Equus* sp.	Tibia	Marcus and Berger, 1984
16,928	QC	405	*Equus* sp.	Tibia	Marcus and Berger, 1984
28,230	GPMLBD	L-17	*Juniperus* sp.	Wood	Ward et al., 2005
	QC	658	Wood	Wood	Marcus and Berger, 1984
	UCLA	1738C	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	LACMRLP	42063	*Arctodus simus*	Cervical VI	Harris (this study)
	LACMRLP	R23755	*Smilodon fatalis*	Tibia	Friscia et al., 2008
	LACMRLP	R11704	*Puma concolor*	Humerus	Friscia et al., 2008
	LACMRLP	R28227	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R32497	*Canis dirus*	Tibia	Friscia et al., 2008
	LACMRLP	R49462	*Canis dirus*	Innominate	Friscia et al., 2008
	LACMRLP	R26494	*Canis dirus*	Innominate	Friscia et al., 2008
	LACMRLP	R22719	*Smilodon fatalis*	Humerus	Friscia et al., 2008
	LACMRLP	R34802	*Smilodon fatalis*	Humerus	Friscia et al., 2008
	LACMRLP	R42645	*Smilodon fatalis*	Metacarpal	Friscia et al., 2008
	LACMRLP	54077	*Arctodus simus*	Metatarsal	Harris (this study)

Table 2 Continued.

Pit	Grid	Depth in feet	Radiocarbon YBP	Radiocarbon SE	Calibrated YBP min. (2δ values)	Calibrated YBP max. (2δ values)
91	I-11	10–10.5	28,650	240	—	—
91	I-11	10.5–11	28,350	240	—	—
91	I-6	8.5–8.8	25,100	850	—	—
91	I-6	8.5–9	27,460	130	—	—
91	I-6	8.5–9	28,240	160	—	—
91	I-6	9–9.5	28,400	130	—	—
91	I-6	9.5–10	28,430	140	—	—
91	I-6	9.5–10	27,350	120	—	—
91	I-6	10.5–11	26,840	120	—	—
91	I-6	10.5–11	28,580	380	—	—
91	I-6	11–11.5	28,330	200	—	—
91	I-6	11.5–12	27,890	130	—	—
91	I-6	11.5–12	28,270	130	—	—
91	I-6	11.5–12	41,940	790	—	—
91	I-6	12–12.5	27,860	140	—	—
91	I-6	12.5–13	27,680	140	—	—
91	I-7	8.5–9	28,360	160	—	—
91	I-7	9.5–10	28,320	140	—	—
91	I-7	10.5–11	28,510	380	—	—
91	I-7	11–11.5	28,620	200	—	—
91	I-8	11–11.5	28,590	240	—	—
91	K-8	11.5–12	28,530	240	—	—
91	L-5	6–7	30,800	600	—	—
91	L-10	8–8.3	25,100	1,100	—	—
91	L-10	8.5–9	25,710	140	—	—
91	L-10	9.5–10	25,740	100	—	—
91	L-10	10.5–11	26,150	280	—	—
91	L-10	11.5–12	27,820	150	—	—
91	L-11	8.5–9	14,040	50	16,342	17,089
91	L-11	9.5–10	26,120	280	—	—
91	L-11	10.5–11	39,090	580	—	—
91	L-11	11.5–12	27,620	150	—	—
91	M-3+4	7.2–7.5	32,600	2,800	—	—
91	M-4	6.5–7	44,650	2,830	—	—
91	M-4	7–7.5	41,800	800	—	—
91	M-4	7.5–8	27,560	130	—	—
91	M-4	7.5–8	41,010	580	—	—
91	M-11	9.5–10	35,800	400	—	—
91	M-11	10.5–11	28,070	130	—	—
91	M-11	11.5–12	28,310	170	—	—
91	M-11	7.5–8	24,930	240	—	—
91	N-11	9	27,330	140	—	—
91	N-11	8.8–9	33,000	1,750	—	—
91		6–8	8,850	455	8,776	11,197
91			38,880	550	38,330	49,430
91			40,690	550	40,140	51,240
2050			30,470	1,090	—	—
2050			30,870	1,650	—	—
2051	D-7	16	20,900	2700	19,032	26,000
2051	D-7	17	17,630	1,400	17,837	24,617
2051	D-7	17	20,300	1,750	20,496	26,000
2051	D-13	15	19,480	550	21,899	24,781
2051	G-5	6.8	20,410	2,450	19,186	26,000
2051	H-19	15	23,850	1,200	—	—
2051	I-3	6	26,140	2,200	—	—
2051	J-13	11	22,355	3,400	—	—
2051	N-21	5	22,890	500	—	—
2051	Q-19	16	29,760	NA	—	—
2051	T-22	8	20,450	460	23,370	26,000
2051			6,160	530	5,765	8,024

Table 2 Continued. Extended.

Calendar YBP	Institution	Catalog/sample number	Taxon	Element	Reference
	LACMRLP	R54033	*Puma concolor*	Radius	Friscia et al., 2008
	LACMRLP	R22385	*Nothrotheriops shastenis*	Calcaneum	Friscia et al., 2008
	UCLA	1738A	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
	LACMRLP	R22420	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R22376	*Smilodon fatalis*	Radius	Friscia et al., 2008
	LACMRLP	R27065	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R41785	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R16695	*Smilodon fatalis*	Radius	Friscia et al., 2008
	LACMRLP	R29708	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R29823	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R30312	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R50952	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R39006	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R39004	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R50699	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R54035	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R23621	*Canis dirus*	Femur	Friscia et al., 2008
	LACMRLP	R26134	*Smilodon fatalis*	Tibia	Friscia et al., 2008
	LACMRLP	R39292	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R39320	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R36388	*Nothrotheriops shastenis*	Cuboid	Friscia et al., 2008
	LACMRLP	R38722	*Nothrotheriops shastenis*	Astragalus	Friscia et al., 2008
	UCLA	1718	*Smilodon fatalis*	Sacrum	Marcus and Berger, 1984
	UCLA	1738F	*Smilodon fatalis*	Tibia	Marcus and Berger, 1984
	LACMRLP	R25591	*Smilodon fatalis*	Tibia	Friscia et al., 2008
	LACMRLP	R27932	*Smilodon fatalis*	Caudal vertebrae	Friscia et al., 2008
	LACMRLP	R35212	*Smilodon fatalis*	Humerus	Friscia et al., 2008
	LACMRLP	R45830	*Smilodon fatalis*	Thoracic vertebrae	Friscia et al., 2008
16,716	LACMRLP	R14493	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R36301	*Smilodon fatalis*	Calcaneum	Friscia et al., 2008
	LACMRLP	R37351	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R48706	*Smilodon fatalis*	Astragalus	Friscia et al., 2008
	UCLA	1738D	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	LACMRLP	R15199	*Canis dirus*	Ulna	Friscia et al., 2008
	LACMRLP	R15408	*Canis dirus*	Tibia	Friscia et al., 2008
	LACMRLP	R16837	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R18896	*Canis dirus*	Radius	Friscia et al., 2008
	LACMRLP	R34667	*Canis dirus*	Thoracic vertebrae	Friscia et al., 2008
	LACMRLP	R36962	*Canis dirus*	Humerus	Friscia et al., 2008
	LACMRLP	R50546	*Canis dirus*	Tibia	Friscia et al., 2008
	LACMRLP	R21648	*Smilodon fatalis*	Astragalus	Friscia et al., 2008
	LACMRLP	19258	*Arctodus simus*	Humerus	Harris (this study)
	UCLA	1738B	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
9,987	QC	384	*Equus* sp.	Radius	Marcus and Berger, 1984
43,880	LACMRLP	L-24	*Juniperus* sp.	Wood	Ward et al., 2005
45,690	LACMRLP	1660 A	*Juniperus* sp.	Wood	Ward et al., 2005
	QC	349A	Wood	Wood	Marcus and Berger, 1984
	QC	349B	Wood	Wood	Marcus and Berger, 1984
22,516	QC	435	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
21,227	QC	442	*Camelops hesternus*	Metacarpal	Marcus and Berger, 1984
23,248	QC	442	*Camelops hesternus*	Metacarpal	Marcus and Berger, 1984
23,340	QC	381	*Paramylodon harlani*	Rib	Marcus and Berger, 1984
22,593	QC	436	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
	QC	440	*Smilodon fatalis*	Femur	Marcus and Berger, 1984
	QC	430	*Equus* sp.	Femur	Marcus and Berger, 1984
	QC	431	*Smilodon fatalis*	Rib	Marcus and Berger, 1984
	QC	443	*Paramylodon harlani*	Rib	Marcus and Berger, 1984
	QC	438	*Smilodon fatalis*	Ulna	Marcus and Berger, 1984
24,685	QC	390	*Paramylodon harlani*	Rib	Marcus and Berger, 1984
6,895		E_Femur_2051	*Equus* sp.	Femur	Marcus and Berger, 1984

Table 2 Continued.

Pit	Grid	Depth in feet	Radiocarbon YBP	Radiocarbon SE	Calibrated YBP min. (2δ values)	Calibrated YBP max. (2δ values)
2051			13,950	1,570	12,830	20,229
2051			18,475	320	20,978	22,609
2051			28,250	1,030	—	—
2051?			19,380	100	22,627	23,477
2051?			19,580	190	23,003	23,890
2051?			19,640	100	22,938	23,844
2051?			23,080	150	—	—
2051?			23,110	160	—	—
2051?			23,600	330	—	—
2051?			24,000	340	—	—
2051?			25,240	400	—	—
2051?			23,300	510	—	—
2051?			19,030	280	22,056	23,536
2051?			21,260	370	22,685	24,051
2051?			22,710	450	—	—
2051?			24,230	550	—	—
2051?			24,900	600	—	—
2051?			30,700	1,300	—	—
2051?			30,900	1,300	—	—
2051?			31,000	1,300	—	—
2051?			32,350	1,400	—	—
A			46,800	2,500	—	—
A			16,590	45	19,163	20,143
Page Salvage			6,400	140	6,997	7,569
La Brea samples of unknown provenance						
?			45,010	920	44,090	55,930
?			14,710	45	17,116	18,153
?			14,760	50	17,168	18,217
?			16,050	60	18,569	19,784
La Brea			16,250	2,000	14,192	24,141
La Brea			16,400	2,000	14,422	24,375
La Brea			>34,000	NA	—	—
La Brea			>34,001	NA	—	—
La Brea			>34,002	NA	—	—
La Brea adjacent						
1814	Sycamore & La Brea		46,500	NA	—	—
7247	Wilshire & Curson		23,630	4,560	—	—
Non-La Brea samples						
Lankershem			51,800	2,700	49,100	64,500
Universal			8,820	40	7,748	8,166

Floral and faunal dates for the Rancho La Brea deposits have been made opportunistically over several decades but there has not been a coherent sampling program, largely because of the expense involved for obtaining radiometric dates. The excavation of Pit 91 has been ongoing for the past 40 years, and was the subject of a detailed analysis of stratigraphic position by Friscia et al. (2008); Pit 91's age distribution is relatively well characterized with 58 dates of high precision. Many dates have also been obtained from Pit 2051, excavated both by the Los Angeles County Museum and the University of California at Berkeley. All other excavations are less densely dated. The Pit 61–67 complex has only eight dates and two of these are from post-Pleistocene archaeological materials. The large, productive Pits 3 and 4 have 26 and 16 dates respectively, but these also include post-Pleistocene materials. All but two excavations (Pits 91 and 2051) lack enough dates to characterize an age distribution, at least in the statistical sense. The age distributions for the four excavations with the most dates (n≥16) are plotted as frequency distributions in Figure 1. Individual dates for all of the major asphaltic deposits are presented in Figure 2.

In general, 73% of the dates in Table 2 come from *Smilodon*, *C. dirus*, and wood samples, with smaller but significant samples from taxa that have been the subject of targeted ecological studies. *Smilodon* and C. *dirus* were preferentially selected for many recent dates (a) because these are the most common mammalian species, (b) in order to provide consistency between the dates from different deposits, and (c) because the bones of these extinct species were unlikely to be confused with those of extant species. The 51 wood dates sample *Juniperus* (18), *Cupressus* (8),

Table 2 Continued. Extended.

Calendar YBP	Institution	Catalog/sample number	Taxon	Element	Reference
16,530		S_Humerus_2051	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
21,794		S_Humerus_2051_b	*Smilodon fatalis*	Humerus	Marcus and Berger, 1984
		S_ulna_2051_c	*Smilodon fatalis*	Tibia	Marcus and Berger, 1984
23,052	UCMP	24334	*Canis dirus*	Collagen	O'Keefe (this study)
23,447	UCMP	24346	*Canis dirus*	Collagen	O'Keefe (this study)
23,391	UCMP	24314	*Canis dirus*	Collagen	O'Keefe (this study)
	UCMP	24332	*Canis dirus*	Collagen	O'Keefe (this study)
	UCMP	24346	*Canis dirus*	Collagen	O'Keefe (this study)
	UCMP	24319	*Canis dirus*	Collagen	O'Keefe (this study)
	UCMP	24345	*Canis dirus*	Collagen	O'Keefe (this study)
	UCMP	24343	*Canis dirus*	Collagen	O'Keefe (this study)
	UCLA	737A	*Cupressus* sp.	Wood	Berger and Libby, 1966
22,796	UCMP	148877	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
23,368	UCMP	148880	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148878	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148875	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148885	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148881	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148876	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCMP	148884	*Gymnogyps californianus*	Collagen	Fox-Dobbs et al., 2006
	UCLA	737B	*Quercus agrifolia*	Leaves	Berger and Libby, 1966
	LACMHC	116501	*Canis latrans*	Dentary	Harris (this study)
19,653	LACMHC	L-3	*Juniperus* sp.	Wood	Ward et al., 2005
7,283	QC	684	Bone	Bone frags	Marcus and Berger, 1984
50,010	LACMHC	101800	*Juniperus* sp.	Wood	Ward et al., 2005
17,635	LACMHC	L-9	*Juniperus* sp.	Wood	Ward et al., 2005
17,693	LACMHC	L-8	*Juniperus* sp.	Wood	Ward et al., 2005
19,177	LACMHC	L-10	*Juniperus* sp.	Wood	Ward et al., 2005
19,167		Wood_La Brea_a	Wood	Wood	Douglas, 1952
19,399		Wood_La Brea_b	Wood	Wood	Douglas, 1952
		344	Asphalt	Asphalt	Marcus and Berger, 1984
		345	Asphalt	Asphalt	Marcus and Berger, 1984
		346	Asphalt	Asphalt	Marcus and Berger, 1984
	QC	504	Wood	Wood	Marcus and Berger, 1984
	QC	570	*Bison antiquus*	Metacarpal	Marcus and Berger, 1984
56,800		L-27	*Juniperus*	Wood	Ward et al., 2005
7,957		L-21	*Juniperus*	Wood	Ward et al., 2005

and wood of unspecified taxon (25); there is also one date from *Quercus* leaves. The 157 faunal dates are dominated by *Smilodon* (62), *C. dirus* (37), *Equus* (16), *Gymnogyps* (8), and *Paramylodon* (5).

A summary of the error terms associated with Rancho La Brea radiocarbon dates is presented in Figure 3. Only calibrated dates are plotted here, with radiocarbon years before present on the x axis and calendar years on the y axis. The error bars are two standard deviations above and below the calibrated date, and are an amalgam of the error arising from radiocarbon dating and the uncertainty intrinsic to the calibration curve; note that they do not contain contamination error. For dates within the range of the CALIB 5.1 program (i.e., younger than 21,381 radiocarbon years ago), the magnitude of the calibration error is small, so that the error associated with each date is driven by the magnitude of the radiocarbon dating error. Many of these dates are quite precise, with errors ranging from 200 to several hundred years (Table 2), although dates with large radiocarbon uncertainty have correspondingly wide error. For dates older than 21,381 radiocarbon years, calibration error is much larger, and when combined with the larger radiocarbon errors typical of dates this old, a very imprecise estimate results, with ranges of 10,000 or more years.

Figure 3 also reveals a critical point concerning the accuracy of Rancho La Brea radiocarbon dates. While a given radiocarbon date may be quite precise, it is not accurate unless calibrated. Uncalibrated radiocarbon dates are systematic underestimates of the true calendar date; the magnitude of this error is large, ranging from about 1,000 years for 10 kya dates, to 4,000 or more years for 20 kya dates. Radiocarbon dates

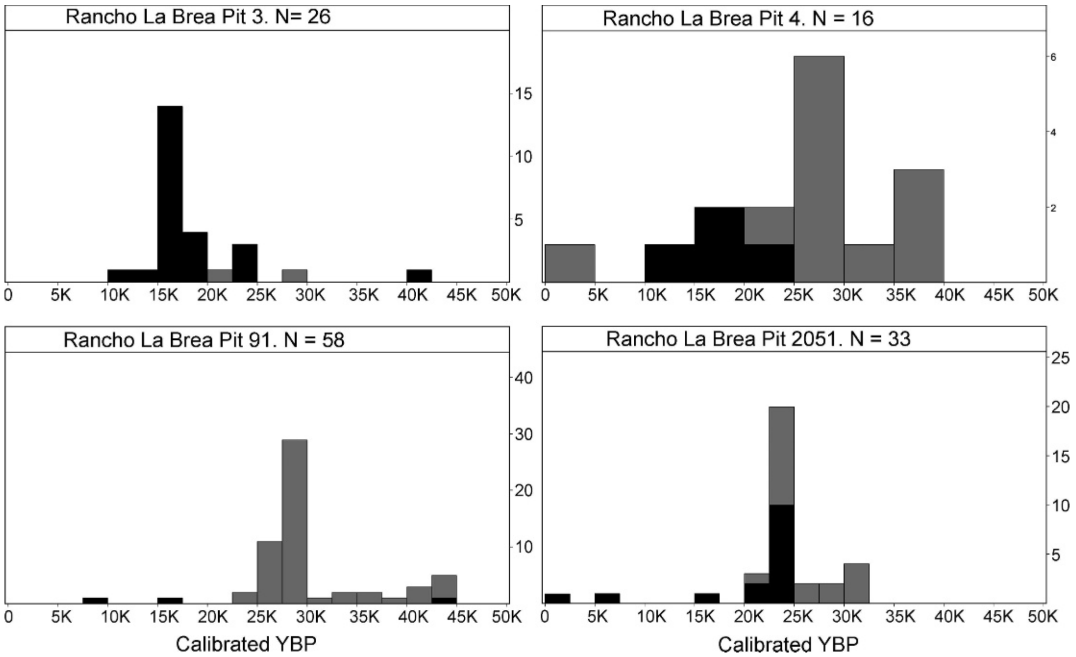

Figure 1 Frequency histograms of radiocarbon dates for Rancho La Brea asphaltic deposits with 16 or more dates. All dates with radiocarbon ages younger than 21 kya are calibrated, while most of those older than 21 kya are not. Calibrated dates are shown in black, uncalibrated dates are shown in gray. See text for discussion of error introduced by this and other factors. Heavily sampled pits (91, 2051) show a single peak of maximum accumulation with significant deposition at other times.

older than 21 kya underestimate the correct calendar age by 5,000 or more years. A systematic underestimate of this magnitude will obviously impact any inference concerning conditions at the calendar date when a given animal died and became fossilized. Hence, calibration is a necessary prerequisite to any inference concerning calendar date.

DISCUSSION

The Rancho La Brea asphaltic fossil accumulations resulted from the entrapment of animals and plant material in sticky asphalt seeps on the alluvial plain between the Hollywood Hills and the Pacific coastline. Hydrocarbon seepage from the underlying Salt Lake Oilfield was intermittent rather than continuous, and episodes of entrapment at a single locality may be separated by several thousand years. Because of the transitory nature of the alluvial plain surface, oscillating between erosional and depositional in nature, overall superposition provides no guide to geologic age. Even within the same seep complex, entrapment may have occurred at different times at the same level. Thus Pit 10 preserved both a late Pleistocene and an early Holocene assemblage at about the same stratigraphic level. A few yards away in Pit 91, a similar depth below ground has yielded both 27,000- and 40,000-year-old assemblages and geological evidence is consistent with there being at least four different seeps in the Pit 91 excavation. Yet, as is documented in Table 2, dates from individual three-feet-square grids within any given excavations seem to be governed by superposition and normally get older with depth.

Although the Rancho La Brea deposits have been the focus of radiocarbon dating efforts for decades, and 209 dates now exist, these are distributed unevenly among many sites, and many of the more productive excavation sites are not adequately dated. The distributions of dates for Pits 91 and 2051 (Figure 1) are complex, reflecting a low background entrapment rate with one or more episodes of increased entrapment at different times. Date distributions from other pits are too poorly known for any inferences of depositional pattern. Based on Pits 91 and 2051, however, asphaltic accumulation was complex and temporally variable and is imperfectly characterized.

The question of how many dates suffice to characterize the age ranges of the different assemblages within each of the asphaltic deposits is clearly a complex one. However, it seems safe

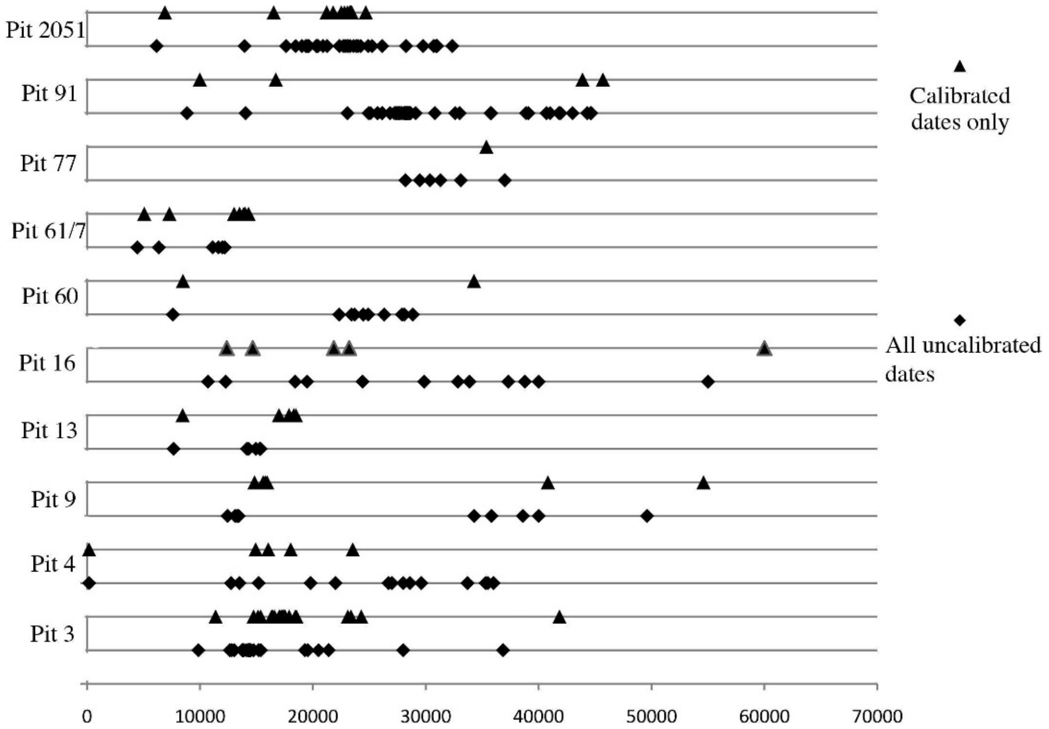

Figure 2 Plot of all calibrated radiocarbon dates from selected Rancho La Brea sites compared to all uncalibrated dates from those sites. Black triangles represent calibrated dates; black diamonds represent the subset of uncalibrated dates. Uncalibrated dates systematically underestimate calendar age; uncalibrated dates of more than 25 kya underestimate calendar age by about 5,000 years.

to say that currently there are too few dates to allow more than vague statements about the relative age of most of each deposit. Moreover, the age distribution of each accumulation has hitherto been further obscured by the inclusion of both calibrated and uncalibrated dates in the age estimates.

There are four potential sources of error pertaining to each calendar date: provenance, contamination, dating error, and calibration error. Any of these dates may compound least two error sources (dating and calibration error). The least significant source of error is probably provenance. In general, fossils collected from Rancho La Brea during the primary collection period (1913–1915; Stock and Harris, 1992) are well provenanced, and can confidently be assigned to a site and a grid reference within each site. However, the significant University of California collection that now resides at the UCMP in Berkeley (recovered between 1906 and 1913; Stock and Harris, 1992) was less well documented when collected but was reportedly made from the Pit 2050–2051 complex. A comparison of the Pit 2051 dates with dates from the UCMP collection is consistent with this, as almost all fall in the 20–25 kya primary deposition spike of this pit. The UCMP dates have therefore been provisionally assigned to Pit 2051 in Table 2. Friscia et al. (2008) state that the youngest date reported from Pit 91 was from a disturbed area of the deposit and may not belong in Pit 91. Clearly, each dated element should be evaluated for provenance before its date is included in a pit date distribution.

Theoretically, at least, petroleum contamination could be a major issue; geologically old carbon contamination from the asphalt with which the fossils are impregnated could produce dates that are older than the fossils themselves. A second and often overlooked potential source of contamination is from recent carbon present in the environment during the solvent wash protocol; this carbon will give artificially young dates. The dating of cellulose and collagen should avoid or at least minimize these contamination sources, but it is entirely possible that that some of the dates reported here were derived from potentially contaminated specimens. Of particular note, contamination by recent carbon should yield a date distribution in which the main accumulation is accompanied by several younger dates—a pattern shown by many of the distributions in Figure 2. Some of the younger dates (for archaeological or historical materials) are perfectly feasible but others (e.g., Holocene dates for

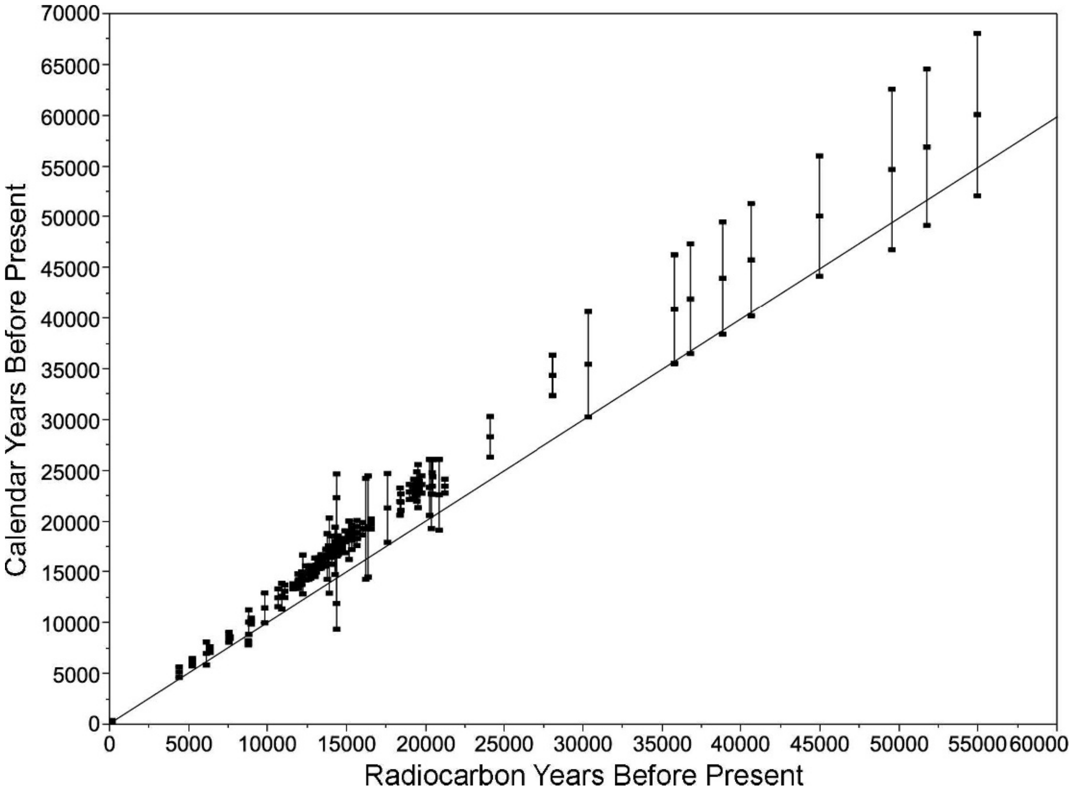

Figure 3 Summary plot of dating and calibration error terms affecting radiocarbon dating of La Brea deposits. Only calibrated dates are shown (n=95; bone dates older than 21 kya are not calibrated). Error bars around each date are two standard deviations positive and negative from the calendar date. This error is a combination of uncertainty intrinsic to the calibration curve and that arising from the radiocarbon dating itself. In practice, the magnitude of the calibration error is small, and overall error magnitude is driven by the dating error. The diagonal line is a line of isochrony; note that radiocarbon dates systematically underestimate the true calendar age of a given element.

extinct megamammals) are less so. Contamination by recent carbon is lab-specific, and is best mitigated by test dating of known carbon-dead bone samples in the same environment as the real samples are prepared (Fox-Dobbs, pers. com.).

The error associated with modern AMS radiocarbon dating is usually small, particularly for dates prepared with the stringent Stafford protocol reported in Friscia et al. (2008), although older dates become systematically less precise (Friscia et al., 2008; Figure 3). This error is often on the order of several hundred years, but can be up to several thousand years for dates that are geologically old, or performed using less-stringent protocols. These error terms are incorporated in the age calibration calculations in CALIB 5.1, so the error terms reported in Table 2 and Figure 3 around the reported calendar date are an amalgam of dating error and calibration error. As noted in the Results section, the impact of calibration error is small for dates younger than 21,381 radiocarbon years ago, but potentially large for geologically older dates. Uncalibrated radiocarbon dates significantly underestimate calendar dates, and should only be used with that understanding.

The effects, if any, of bias from sampling specific mammal species have not yet been investigated in detail. Dates reported in Marcus and Berger (1984) sample a wide variety of taxa but many specimens lacked precise stratigraphic provenance. Dates reported by Fox-Dobbs et al. (2006) for *Gymnogyps californianus* (=*G. amplus* Miller, 1911), Ward et al. (2005) for *Juniperus*, and O'Keefe (this study) for *C. dirus* were for taxon-specific investigations. Dates reported by Friscia et al. (2008) from Pit 91 were mostly the common species *Smilodon* and *C. dirus* that were selected to provide consistency during a stratigraphic investigation, although the rare species *Nothrotheriops shastensis* (Sinclair, 1905) and *Puma concolor* (Linnaeus, 1758) were dated to see if their bones represented a single individual. Most of the *Smilodon* and *Canis dirus* specimens from the same levels as the *Nothrotheriops* and *Puma* specimens were of similar age (26,150–28,650) but it would be interesting to sample a wide variety of taxa from the same (grid and depth) provenance to see if different species gave consistently different dates.

SUMMARY

A survey of published radiocarbon dates from Rancho La Brea, and the addition of 21 previously unpublished dates, provides a data set of 209 radiocarbon dates for this locality. The dates range in age from the present to more than 50,000 years before present. Radiocarbon dates are unevenly distributed among the excavations with most dates coming from Pit 91, excavation of which has been ongoing for the past 40 years, and Pit 2051—the source of the University of California, Berkeley, collections. The most frequently sampled genera are *Smilodon*, *Canis*, and *Juniperus*. Saber-toothed cat and dire wolf samples were used preferentially for many of the recent dates in order to provide consistency with past dates and to minimize potential variation from sampling different taxa. The fossil wood samples that were recently dated (Ward et al., 2005) turned out after the fact to be mostly juniper. Accumulations in the well-dated Pits 91 and 2051 appear to have a complex history, and full documentation of the history of individual deposits may not be possible from just a handful of dated samples.

The most important quantifiable source of error associated with La Brea dates arises from the calibration of radiocarbon year dates to provide calendar year dates. Use of calendar year dates is obviously desirable, as this allows direct comparison with dates from climate indicators such as ice cores and tree rings. Dates younger than 21,381 radiocarbon years can be confidently calibrated and a precise (within several hundred years) date obtained; older dates cannot be calibrated using the currently available calibration curves. This needs to be borne in mind because dates in radiocarbon years consistently underestimate the corresponding calendar dates. The magnitude of this error is large, ranging from about 1,000 years at 10 kya to 4,000 years or more at 20 kya. Calibration of radiocarbon dates is therefore critical to any detailed comparison between La Brea fossils and external climatic, ecological, or other factors.

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