ON THE RESOLUTION OF ^{14}C DATING ANOMALIES: CASE STUDIES FROM NEW WORLD ARCHAEOLOGY

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ABSTRACT. We submit that anomalies in radiocarbon data in archaeological studies should be viewed positively as a stimulus to undertake further targeted research. Additional analyses to resolve anomalies have the potential to provide important insights into heretofore unstudied or incompletely understood depositional or geochemical processes affecting ^{14}C values, particularly in certain types of samples and samples from certain types of environments. We consider 2 major categories or sources of ^{14}C dating anomalies that we posit are mostly responsible for the vast majority of problematic ^{14}C results: anomalous sample contexts and anomalous sample composition. Two additional sources of ^{14}C anomalies are much more rarely encountered. Six case studies taken from New World archaeological studies are briefly presented to provide examples of where questions concerning the validity of ^{14}C measurements generated additional and ultimately more accurate understandings of temporal relationships. AMS-based ^{14}C measurement technology has rendered detailed investigations of ^{14}C anomalies routinely feasible.

ANOMALOUS ^{14}C DETERMINATIONS

In this discussion, we will employ "anomaly" very broadly to designate any radiocarbon age determination that does not conform to an expected age. This term is here used in place of such expressions as "erroneous" or "incorrect" because it is our view that, in the majority of cases, an anomalous ^{14}C date may be considered "erroneous" primarily in the sense that there is some missing information that would provide an understanding of what the ^{14}C age determination is actually dating. We will consider 4 major categories or sources of ^{14}C dating anomalies, listed in the order which we suggest that they most responsible for anomalous results. These 4 sources are (1) anomalous sample contexts, (2) anomalous sample composition, (3) undetected systemic offsets, and (4) undetected measurement offsets.

We submit that 6 decades of ^{14}C studies in archaeological research have demonstrated that the overwhelming majority of what are we here calling ^{14}C dating anomalies are the result of the first source listed above. *Anomalous sample contexts* are a product of a failure to define accurately and precisely the physical relationship between the organic whose ^{14}C age has been measured and the target context, object, or phenomenon for which temporal placement is sought. Dean (1978) previously defined a very helpful taxonomy that sets out various types of dating events and the relationships among them. Two common examples of how anomalous sample contexts are generated include (i) inaccurate or incomplete geomorphological or stratigraphic analyses and (ii) undetected bioturbation, geoturbation, and/or anthroturbation effects in a localized depositional context from which the sample was obtained.

The second source of problematic ^{14}C values involves *anomalous sample composition*. Most often, this source is associated with the most common explanation of why the ^{14}C age of a sample is to be considered aberrant. This, to some, all-purpose explanation is *contamination.* A more formal manner of characterizing this factor would be to state that these are ^{14}C age offsets produced by the presence of carbon-containing components of heterogeneous ^{14}C activity contained in a sample matrix,

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which is then accompanied by a failure of physical and/or chemical pretreatment(s) to isolate the indigenous organics and/or successfully exclude exogenous organics in that sample. Examples of this type of anomaly-producing condition include (i) ineffective physical and/or chemical pretreatments and (ii) undetected natural or postexcavation organics that have come into contact and transferred or been applied to a sample. We will discuss briefly issues that arise when ^{14}C anomalies are explained by appealing to "contamination" in the next section.

The third and fourth sources of anomalous results are fortunately relatively infrequent, but have been experienced by the authors and reported by experienced researchers. The third source is *undetected systemic offsets*, which involve a failure to detect violations(s) of one or more of the physical assumptions on which the ^{14}C dating model rests as far as a specific sample is concerned. Examples of sources of undetected systemic offsets would be a failure to appropriately calibrate, correct, or normalize ^{14}C values obtained on a given sample. The fourth source, *undetected measurement offsets,* while extremely rare, do occur. Examples of this source for anomalies would include undetected laboratory contamination of samples, standards, or backgrounds, undetected instrument malfunction, and mislabeled samples. Fortunately, such problems are almost always immediately identified and corrected in most laboratories.

We wish first to consider briefly the use of "contamination" as an explanation for substantive ^{14}C anomalies and then examine 6 case studies divided into those derived from anomalous sample contextual problems and those arising as a consequence of anomalous sample composition issues. Our examples will be taken from New World archaeological contexts. Obviously, these case studies only touch on a few illustrations taken from a much larger pool of examples that could have been cited.

THE "CONTAMINATION" EXPLANATION

The use of the generic category of "contamination" as the reason for anomalous ^{14}C values can benefit from recognizing the constraints that exist when applying this explanation. The most straightforward manner of appreciating these constraints is to consider the effects of the introduction of known amounts of known-age contaminants into samples of known age. It becomes immediately obvious that the largest offset results from the addition of organics from contemporary or modern contexts to samples of Pleistocene age (>10,000 BP) particularly for those materials that have ages greater than ~40,000 yr. For example, the addition of 1% modern but pre-bomb ^{14}C to a sample exhibiting a finite ^{14}C age of ~50,000 yr will result in an apparent measured age of ~35,000 yr. (Of course, if bomb ^{14}C contamination is involved, the effect is much more severe.) By contrast, the effect of the contribution of "dead carbon," i.e. carbon of infinite ^{14}C age—e.g. coal, lignite, or carbonates from sedimentary limestone deposits—to relatively recent samples is much less severe. As an example, the introduction of 1% of "dead carbon" to a modern sample will result in an increase in the age by ~80 yr.

The effects of contamination on Holocene age (<10,000 BP) samples are significantly constrained to much smaller offsets than is sometimes assumed. Table 1 presents the change in age that would occur in samples whose true ages vary from 1000 to 10,000 BP when the amount of *modern* ^{14}C contamination ranges from 1% to 20%. For example, a 1% addition of modern ^{14}C to a sample with an actual age of 5000 yr will result in an apparent or composite age of ~4950 yr; a 5% addition would result in about a 350-yr decrease. A more typical situation is where carbon-containing compounds differing in age from the original sample material from a few hundred to a few thousand years are physically or chemically incorporated into a sample. Previous discussions (e.g. Olsson 1974; Taylor 1987: Figure 5.3) that have focused on this question provided plots that permit a quantitative estimation of expected effects.

Table 1 Effect of introduction of *modern carbon* to samples of varying Holocene age. Adapted from Table 5.3 in Taylor (1987).

	Approximate (±10 yr) apparent age (yr BP) with following percentage addition of modern carbon[a]			
Actual age (yr BP)	1%	5%	10%	20%
1000	990	950	900	800
2000	1950	1890	1750	1550
3000	2950	2800	2650	2300
4000	3950	3750	3500	3000
5000	4950	4650	4350	3700
6000	5900	5550	5150	4400
7000	6900	6450	5950	5050
8000	7850	7350	6750	5650
9000	8850	8200	7500	6200
10,000	9800	9050	8200	6800

[a]Modern carbon = ^{14}C activity of 0.95 OX-I ($\delta^{13}C$ = –19‰) or 0.7338 OX-II ($\delta^{13}C$ = –17‰).

Such data vividly illustrate that if the difference in age between a sample and any contaminant does not exceed 1 ^{14}C half-life and is limited to 1–2%, the errors introduced from contamination will generally not exceed a few hundred years. Appeal to contamination as an explanation of seriously anomalous ^{14}C values can be evaluated in terms of the strictures exemplified in the data presented in Table 1 and the studies of earlier researchers.

Although there are documented exceptions, especially when working with bone samples, routine sample chemical pretreatments by ^{14}C research laboratories are generally very efficient in removing all but, at most, 1–2% of the contaminating organics from sample types usually recovered from archaeological contexts. It is often not possible to remove all of the non-*in situ* organics from some sample types. However, the remaining contamination in the majority of Holocene age samples—again with the exception of some bone samples—will rarely be sufficient to alter the indicated age of the sample by more than, at most, several hundred years.

Such comments should not minimize the relatively rare instances where major contamination problems have been encountered. Investigators should be especially alert in cases where samples have been stored for long periods in museum collections or other types of curatorial environments where, for example, records that might indicate that chemical preservatives had been applied to samples had not been properly maintained. There are well-documented instances where anomalous dates exhibiting offsets of thousands of years have been measured before the nature of the contamination was recognized and various specialized chemical pretreatment techniques had to be applied to remove the contamination (e.g. Venkatesan et al. 1982).

CASE STUDIES: ANOMALOUS SAMPLE CONTEXT ISSUES

Chronological Placement of Folsom (North America)

The longest and most contentious debate within New World archaeological studies has revolved around questions concerning the nature of the earliest occupation of the New World by populations of *Homo sapiens* (Madsen 2004; Goebel et al. 2008; Meltzer 2009; Beck and Jones 2010). Contemporary discussions concerning this topic trace their origins to the second and third decades of the 20th century with the general acceptance of the direct association of 2 types of fluted projectile points—Folsom (Figgins 1927) and Clovis (Howard 1935)—with skeletal remains of Pleistocene North American megafauna, particularly mammoth and an extinct species of bison. On stratigraphic grounds, Clovis was demonstrated to have predated Folsom, but both the chronometric placement as well as the temporal offset between these 2 traditions were in dispute (Meltzer 1989). At that time, the age posited for the Clovis-Folsom cultures ranged between 25,000 and 10,000 yr ago (Wormington 1957).

In the pre-^{14}C era, this range in the ages assigned to the earliest evidence of the presence of New World human populations resulted primarily from differences among Pleistocene geologists with regard to the chronometric placement of the final phase of the terminal Pleistocene and the timing of the disappearance of the North American Pleistocene megafauna. In part, these diverging views were the product of varying understandings of whether inferences from the Scandinavian varve chronologies could be applied to North American sequences (e.g. Antevs 1928).

In part due to Libby's personal interest in the question of "Early Man" in the New World, one of the earliest samples dated by the Chicago ^{14}C laboratory concerned the resolution of the chronological status for Folsom materials. In pursuing this question, there unfolded a classic illustration of an anomaly caused by a failure to provide an accurate geological context for the dated organic sample.

A charcoal sample initially thought to be associated with a Folsom point recovered at the Folsom Site in New Mexico was initially described as deriving from a firepit situated *below* bison bones and artifacts collected in 1933 by Harold J Cook [1887–1962]. When this sample of charcoal was dated by the Chicago laboratory, the result was 4283 ± 250 BP (C-377), based on an average of 2 determinations of 4575 ± 300 and 3923 ± 400 BP. This result prompted the terse comment "surprisingly young" (Arnold and Libby 1950:10).

In response to this result, Cook revisited the Folsom type site in June 1950. His restudy of the geological context concluded that the original "sample [used for the ^{14}C measurement] had been taken from a hearth *in the fill of a secondary channel* (emphasis supplied) which had cut through the original deposit of bison bone and artifacts" (Roberts 1951:116). A ^{14}C value of 9883 ± 350 BP (C-558) was subsequently obtained on burned bison (*Bison antiquus*) bone from what was interpreted as the Folsom horizon at Lubbock Lake, Texas (Libby 1951:293). It might be noted that the term *burned bone* was then used to refer to a sample composed primarily of the carbonized skin and tissue adhering to a bone and only incidentally to sample of the bone matrix itself. Any ^{14}C determination on such a sample would represent a date on a composite sample insofar as the carbon source was concerned. Thus, the first ^{14}C determination concerned with a question associated with one of the most controversial issues in American archaeology was deemed unacceptable for what it was supposed to have dated, requiring reinterpretation of the geological context. A subsequent ^{14}C analysis on a sample in presumed direct contextual relationship with the cultural or technological tradition for which dating was being attempted was required (Roberts 1951:20–1; Haynes 1982:384; Meltzer et al. 2002).

Interestingly, later studies determined that even the Lubbock Lake bison bone used to obtain C-558 almost certainly did not, in fact, come from the Folsom level at this site (Haas et al. 1986; Holliday and Johnson 1986). The first ^{14}C age determination securely associated with Folsom materials was obtained on charcoal collected at the Lindenmeier site in Colorado. The value obtained on this sample was 10,780 ± 135 BP [I-141] (Haynes and Agogino 1960; Walton et al. 1961).

Age of Early *Zea Maize* Cultigens (Mesoamerica)

It is well known that cave deposits often present unique challenges in the interpretation of ^{14}C results even from purportedly well-stratified and even apparently "sealed" levels. The relationship between the purported "associated" charcoal and artifacts or other features have been shown in many cases to be aberrant. A classic illustration in New World archaeological studies of this was vividly highlighted when ^{14}C ages obtained on charcoal seemly directly associated with individual *Zea maize* fragments from Coxcatlan Cave in Tehuacan Valley were compared with ^{14}C dates directly obtained on the maize specimens themselves. Table 2 presents that comparison. The ^{14}C ages obtained on the charcoal were obtained by decay counting (Johnson and MacNeish 1972), while the ^{14}C values on the maize specimens were obtained using accelerator mass spectrometry (AMS) technology (Long et al. 1989). It was determined that the *oldest* age obtained on a maize sample is almost 1000 yr younger than the *youngest* age obtained on the associated charcoal.

Table 2 Coxcatlan Cave, Mexico: comparison of ^{14}C ages on charcoal assumed to be stratigraphically associated with early domesticated maize (*Zea maize*).

(a) Charcoal[a] (^{14}C yr BP)		(b) Maize specimens[b] (^{14}C yr BP)	
I-594	4950 ± 200	AA-3314	450 ± 40
I-766	5250 ± 200	AA-3309	1860 ± 45
I-459	6235 ± 200	AA-3307	1900 ± 60
I-567	6925 ± 180	AA-3313	3740 ± 60
I-763	7950 ± 250	AA-3312	4040 ± 100
		AA-3307	4090 ± 50

[a]Coxcatlan Phase in Coxcatlan Cave ^{14}C values: Buckley and Willis (1969); Johnson and Willis (1970); Johnson and MacNeish (1972).
[b]Long et al. (1989); Long and Fritz (2001).

The age of the Coxcatlan Cave maize specimens had figured prominently in arguments dealing with an important question raised in New World archaeology—the chronology of the process of plant domestication in Mesoamerica that formed the subsistence basis on which the earliest sedentary village societies in the New World emerged (Smith 2005). AMS-based ^{14}C results on the maize samples generated an exchange of contrasting views including arguments that the maize specimens themselves had been contaminated with a preservative that had not been sufficiently removed before the AMS-based ^{14}C ages were obtained (Fritz 1994; Flannery 1997; MacNeish and Eubanks 2000; MacNeish 2001; Long and Fritz 2001). Although there was not a satisfactory resolution of the disagreements as far as the principals who were involved in the dispute were concerned, there came to develop a general understanding that the overall weight of the evidence strongly suggested that the AMS-based values more closely represented the actual ages of the maize fragments.

Human Presence at Tule Springs, Nevada (North America)

The degree of influence of ^{14}C dating on New World Paleoamerican studies can be further seen most clearly when it is noted that in a number of instances, a *single* ^{14}C age determination was the most important factor in directing greatly increased attention along, in some cases, with significant levels of funding and thus the allocation of significant resources, toward specific sites purported to contain evidence of archaeological materials presumed to be older than Clovis. For example, in the early 1960s, the decision to undertake large-scale excavations at Tule Springs, Nevada (Wormington and

Ellis 1967) was stimulated, in large part, by a single ^{14}C determination of >23,000 yr (C-914) obtained by Libby's Chicago laboratory (Libby 1952:121). The sample analyzed had been characterized as "charcoal" recovered from what had been labeled a "hearth-like feature" by excavators who associated its occurrence with sediments containing the bones of extinct fauna (Harrington 1954; Harrington and Simpson 1961).

The major excavations undertaken at Tule Springs resulted in the collection of a large suite of samples. ^{14}C measurements obtained on these samples determined that the original age assignments for the cultural materials had been significantly inflated. The only uncontested artifacts recovered during extensive excavations carried out in the early 1960s were associated with sediments dating in the 10,000 to 11,000 BP range. The features originally labeled as "hearths" containing "charcoal" were determined to be concentrations of decayed plant remains associated with water channel debris or spring deposits having no relationship to human activity (Haynes et al. 1966; Haynes 1988).

At this site, the detailed attention to the specifics of the geomorphological contexts of the purported archaeological materials and a critical evaluation of the ^{14}C values in the context of careful evaluation of stratigraphic contexts provided by the project geologist, C Vance Haynes Jr, provided a classic illustration, worthy of study by succeeding generations of archaeologists, of the need for geoarchaeological expertise if a critical and comprehensive evaluation of the integrity of site contexts are to be obtained for the samples used for ^{14}C analysis (Haynes 1967). It also vividly exemplifies the danger of relying on a single ^{14}C measurement to provide secure and conclusive evidence of age for any object or archaeological context.

CASE STUDIES: ANOMALOUS SAMPLE COMPOSITION ISSUES

Human Presence at Lewisville, Texas (North America)

In the early 1950s, samples characterized as charcoal were recovered at the Lewisville site, Texas, from a series of hearth-like features containing extinct fauna that included mammoth and a Clovis-type point (Crook and Harris 1958). Two infinite age ^{14}C values were obtained on these samples, with 1 sample being designated specifically as coming from "hearth No. 8." The values were cited as >37,000 BP [O-235] and >37,000 BP [O-248] (Brannon et al. 1957).

It was initially suggested that the charcoal samples derived from ancient packrat middens (Heizer and Brooks 1965). It was also noted that there was nearby exposures of the Cretaceous age Woodbine Formation, which includes outcrops of lignite, a form of coal. This fossil carbon would, of course, yield infinite ^{14}C ages. Renewed excavations in the late 1970s recovered additional organic samples that had the appearance of being charcoal from a hearth feature. This sample, which yielded a ^{14}C age of 26,610 ± 300 BP, was determined to contain hematite (Fe_2O_3), one of the combustion products of pyrite or iron sulfide (FeS_2), a mineral often found in coal. The conclusion was that this result provided what was regarded as conclusive evidence that varying amounts of lignite was being burned in the hearths together with wood fragments, and this was responsible for significantly inflating the previously measured ^{14}C ages (Stanford 1982; Shiley et al. 1985).

Age of the Kennewick Skeleton (North America)

Over a period of several months, first a human skull, and then disarticulated postcranial human bones were recovered from a relatively small area in shallow water adjacent to an eroding embankment of the Columbia River near the community of Kennewick, Washington, USA (Nickens 1998; McManamon 1999; Chatters 2000).

Based primarily on various conventional skeletal morphological criteria, the Kennewick skeleton was initially thought to be that of a historic contact period Euro-American settler. This conclusion had to be modified with the receipt of the first of what would ultimately total 5 ^{14}C determinations on 3 different bones of Kennewick skeleton. The initial Kennewick ^{14}C value (UCR-3476/CAMS-29578) was 8410 ± 60 BP (Taylor et al. 1998). The presence of an early Holocene human skeleton in North America exhibiting both cranial and postcranial morphological features determined by several physical anthropologists with long experience evaluating North American aboriginal skeletal materials as being uncharacteristic of recent Native American populations, engendered both widespread scientific, then popular media interest, and ultimately, a bitter legal conflict pitting members of the scientific community against local Native American groups (Downey 1999; Thomas 2000; Chatters 2001). One important outcome of this discovery was that, in terms of the percentage of total skeletal elements recovered, this skeleton represents the best preserved of any early Holocene New World human skeleton recovered to date.

Our interest is focused on the range of ^{14}C age determinations obtained on these bones from this skeleton. Table 3 lists the ^{14}C determinations together with biogeochemical data for 3 of the bone samples. This later data can serve as a proxy for the degree of preservation of residual amounts of protein (primarily collagen) contained in the bone samples used for ^{14}C measurement. The carbon content contained in a total amino acid fraction isolated from these bones as a percentage of that present in modern bone is listed. Also, the constituent amino acids contained in total amino acid fractions of the bones were separated to determine quantitatively if any of the bones had retained a collagen-like amino acid profile. Two of the bones studied had been split into 2 portions and measured by 2 different ^{14}C laboratories. One of these laboratories reported the "amount of collagen extracted" and the second, "carbon yields."

Table 3 Radiocarbon, $\delta^{13}C$, and biogeochemical characteristics of 3 human bone samples from the Kennewick skeleton [CENWW.97], Columbia Park site, Washington, USA. Adapted from Table 1 in Taylor et al. (2001).

	Preservation indexes[a]				
Sample nr	AACC	AAC	Fraction measured	$\delta^{13}C$ (‰)	^{14}C age (BP)
a. 5th Left Metacarpal Bone					
UCR-3476/CAMS-29578	68.8%	Collagen	Total amino acids	–14.9	8410 ± 60
b. 1st Right Metacarpal Bone					
BETA-133993[b]	—[c]	—	Base-treated HCl-insoluble	–12.6	8410 ± 40
UCR-3807/CAMS-60684	14.3%	Non-collagen	Total amino acids	–10.8	8130 ± 40[d]
c. Left Tibial Crest					
UCR-3806/CAMS-60683	2.3%	Non-collagen	Total amino acids	–10.3	6940 ± 30
AA-34818[e]	—[f]	—	Gelatin	–21.9	5750 ± 100

[a]Indices of the degree of protein (mainly collagen) preservation in bone sample: AACC = % of amino acid carbon content of modern bone standard; AAC = collagen-like or non-collagen-like amino acid profile.
[b]Reported by D Hood in McManamon (1999).
[c]D Hood (Beta Analytic) reports that the "amount of collagen extracted" was 0.3% as a percent concentration, a "value is very low due to the high mineral content of the submitted bone."
[d]In Taylor et al. (2001), these values were cited as "apparent ^{14}C ages."
[e]Reported by D Donahue in McManamon (1999).
[f]D Donahue (University of Arizona) reports that the "carbon yield for this sample was 0.05% . . . well below the yield for which we would usually quote a result."

As the result of many decades of research, there is widespread agreement that an important factor in obtaining accurate individual bone ^{14}C values is the degree to which a bone sample had retained sufficient amounts of its principal protein component, collagen (Taylor 1987:53–61 for earlier studies; Brown et al. 1988; Hedges and van Klinken 1992; Bronk Ramsey et al. 2004). In the case of the Kennewick bone ^{14}C values, of the 3 bones dated by University of California facilities, only 1, the 5th left metacarpal bone (UCR-3476/CAMS-29578), retained both a significant fraction of its original collagen content and exhibited a collagen-like amino acid pattern.

An examination of the data in Table 3 exemplifies what is often assumed in the ^{14}C dating of bone, but rarely is there sufficient data available to be able to view the expected pattern in the results. At least 2 points stand out. First, it is clear that both different bones from the same skeleton and different parts of the same bone can exhibit a significant range not only in the amounts of collagen retained but also in terms of the biogeochemical status of the residual collagen, as reflected in the amino acid profile. Second, there is a general pattern in the ^{14}C values obtained from each bone sample from the same skeleton in which decreasing ^{14}C ages—in this case from 8410 ± 60 to 5750 ± 100 BP—are associated with a decline in the collagen content, in this case, as measured by the decreasing percentage of the amino acid-based carbon content and loss of a collagen-like amino acid profile. However, even in this data set, we can observe an exception in that essentially identical ^{14}C ages (8410 BP) have been obtained on 2 different bones from this skeleton (UCR-3476/CAMS-29578 and BETA-133993), which are reported as exhibiting significantly different collagen content.

In this case, the first ^{14}C determination obtained on this skeleton, corrected for a reservoir effect due to the amount of marine biomass (fish) contained in the bones, expresses the most probable age of this skeleton within the error terms assigned with the final reservoir-corrected ^{14}C age. Such a conclusion is entirely consistent with the results of geological and geomorphological analyses and the results of additional ^{14}C determinations obtained on organics contained in sediments whose lithology closely matched that which adhered to a number of the Kennewick human bone samples (Taylor et al. 2001:966–8).

Monte Verde, Chile

An example of the influence of a relatively small set of ^{14}C values from a single site on the course of archaeological discourse is illustrated by the implications of data from the site of Monte Verde located in the Lakes region of south-central Chile (Dillehay and Pino 1989, 1997). Excavations beginning in 1976 at this site recovered a wide-ranging cultural assemblage of wood, stone, fiber, and bone materials in what appears to be well-defined, multicomponent, stratigraphic contexts with associated wood and charcoal samples. The cultural attribution of much of this material appears to be well established. Eleven ^{14}C measurements on a range of sample types from the upper levels at the site ranged from 11,900 ± 120 BP [TX-5376] to 13,565 ± 250 BP [TX-3208] (Nagle and Wilcox 1982). The oldest date in the series [TX-3208] was later rejected by the excavators (Dillehay and Pino 1997:48), leaving the oldest value in this suite of values being 12,780 ± 240 BP (BETA-59082).

If these ^{14}C values are accepted as valid, this would indicate that the lithic artifact inventory from Monte Verde, which appears to have no developmental relationship to the Clovis assemblages of North America, was in place in a South American site approximately 1000 ^{14}C yr before the appearance of Clovis materials in North America. The widespread acceptance of the validity of this conclusion renewed active discussions concerning the route(s) used by the earliest human populations as they moved south from presumed entry points in eastern Beringia. If a human population was indeed present on the coast of Chile a millennium prior to Clovis, the earliest migration route could be more reasonably sought along the Pacific coastal zones and not immediately south below an ice-free Laurentide-Cordilleran corridor in the north-central interior of North America. Beck and Jones (2010) have provided a recent review of discussions examining the issues and problems associated with viewing the Pacific coastal route as the earliest path taken by the first inhabitants of the Western Hemisphere.

As would be expected with such an important site, there has been considerable discussion of the integrity of the artifact assemblage in terms of the quality of associations with some of the ^{14}C values at all levels in the site. We wish to focus our attention on a significant ^{14}C dating anomaly involving the dating of 2 mastodon bone fragments excavated from the Monte Verde site. The 6 ^{14}C determinations obtained on 2 fragments of the same mastodon bone are listed in Table 4.

Table 4 Radiocarbon and $\delta^{13}C$ data on 2 segments of a single Mastodon bone from Monte Verde, Chile. Initial measurements were reported in Dillehay and Pino (1997:43–4). Additional measurements were reported in George et al. (2005: Table 1).

		Preservation indexes[a]		Fraction ^{14}C	$\delta^{13}C$[b]	^{14}C age
Sample nr	Context	AACC	AAC	dated	(‰)	(BP)
a. Initial measurements						
BETA-7824	Surface	—	—	[Collagen][c]	Not reported	6550 ± 160
TX-3760	Subsurface	—	—	[Collagen][c]	Not reported	11,990 ± 200
b. Additional measurements						
UCR-4014/UCI-AMS-2765	Surface	20%	Collagen	Total amino acids	–25.5[d]	12,510 ± 60
UCIAMS-10737	Surface	—	—	Ultrafiltered gelatin	–22.5	12,450 ± 40
UCR-4015/ UCIAMS-2766	Subsurface	31%	Collagen	Total amino acids	–25.7[d]	12,450 ± 60
UCIAMS-10738	Subsurface	—	—	Ultrafiltered gelatin	–22.7	12,455 ± 40

[a]Indices of the degree of protein (mainly collagen) preservation in bone sample: AACC = % of *amino acid carbon content* of modern bone standard; AAP = collagen-like or non-collagen-like *amino acid profile*.
[b]$\delta^{13}C$ values were obtained using a Fisons NA-1500 elemental analyzer coupled to a Finnigan Delta Plus isotope ratio mass spectrometer.
[c]Characterized as "collagen" by Dillehay and Pino (1989:136).
[d]$\delta^{13}C$ values for these samples were obtained on a total organics [demineralized /acid insoluble] bone fraction.

In the publication reporting the first ^{14}C value on the mastodon fragment of 6550 ± 160 BP (BETA-7824), this value was listed under a category of "non-cultural deposits" (Dillehay and Pino 1989: 134). This sample had been recovered eroding out of the surface of the modern creek bed at the site location. In the same table under "cultural deposits," a determination of 11,900 ± 200 BP (TX-3760) was listed as being obtained on a bone from a subsurface unit of the excavation (Dillehay and Pino 1989:135). These 2 bone segments were determined by the excavators to be "long-bone fragments that, fitting together, [came] from the same femur of a mastodon" (Dillehay and Pino 1989:136). These 2 ^{14}C values are listed in Section a of Table 4. Although the literature reporting data from this site (e.g. Dillehay and Pino 1989, 1997) employs the term "mastodon" to refer to the type of megafauna from which this bone derives, currently the most appropriate taxonomic term at the family level would be "gomphotheres" (Prado et al. 2006).

The investigators explained the approximately 5000-yr offset in the ^{14}C ages of the 2 segments of the same bone as the result of the contamination of BETA-7824 "by modern animal waste and by detergents, pesticides, and other chemicals discarded by occupants and lumberjacks living upstream" (Dillehay and Pino 1989:136). Accepting that explanation at face value, it would mean that ~30% of the organics measured as BETA-7834 represented modern contamination. This is the approximate amount of pre-bomb modern carbon required to produce an apparent ^{14}C age of 6500 BP in a sample whose true age was about 11,400 BP. If the contaminants were derived from atmospheric CO_2 over the last 50 yr, then the percentage of contamination could be as low as ~20%, since this very recent carbon would contain bomb ^{14}C. Even so, such a relatively massive amount of contamination should have been largely removed by almost any standard bone pretreatment method used in any research-oriented laboratory over the last 2 decades. We recognize that these ^{14}C values were measured more than 2 decades ago when there was less experience with bone. Because of the importance of the site, there was an interest in resolving this 5000-yr anomaly. The explanation that "contamination" alone was responsible for BETA-7824 was considered highly improbable.

The redating of both segments of the bone was undertaken by measuring the ^{14}C and $\delta^{13}C$ values on 2 organic fractions of total amino acids and ultrafiltered gelatin (Table 4, Section b). To determine the biogeochemical integrity of the protein (largely collagen) constituents of the 2 gomphotheres fragments, profiles of the constituent amino acids of both bones were obtained and each was compared with standardized amounts of total amino acid obtained from modern bone. The percentage yields and amino acid profiles obtained during the procedures to isolate these 2 fractions indicated that both bones had retained a considerable amount of intact collagen. The same physically cleaned and sized bone segments on which the amino acid composition and profile data were obtained as well as the total amino acids fraction used to obtain the ^{14}C analysis for UCR-4014 and UCR-4015, respectively, were also used to obtain the ^{14}C values on the ultrafiltered gelatin fraction for UCIAMS-10737 and UCIAMS-10738. The ^{14}C values of all 4 of these ^{14}C measurements are statistically identical at the 1σ level and the 2σ range of the weighted average of these measurements lie within a 2σ range of TX-3760. Clearly, there is now sufficient evidence that the BETA-7824 ^{14}C value can be discarded and the 5000-yr discordance resolved.

CONCLUSION

The case studies presented here provide examples where anomalous ^{14}C results provided the stimulus to conduct additional investigations to resolve the discordant results and, if possible, understand what had caused the anomalous results. Also, the analysis of multiple samples from the same site or context revealed patterns in the ^{14}C values the permitted inferences to be made about what types of anomalies one could anticipate in similar situations. Several of the case studies also highlighted the well-known stricture of Frederick Johnson stated early in the history of the application of ^{14}C values in archaeological research: a ^{14}C determination ". . . does not date a site of building, or a grave or a level. The date is that of the sample and it is the task of the archaeologist to discover the true relationship between the sample and the area or place it came from" (Johnson 1965).

The use of "contamination" as an explanation of an anomalous ^{14}C result needs to be carefully considered on a case-by-case basis. The use of this explanation in a generic manner does not advance scientific understanding until further study is undertaken to define quantitatively the nature of the postulated contaminating organic. This is exemplified in our last case study, in which "contamination" seems not to have been the correct explanation for the anomalously young result obtained for 1 of the 2 initial ^{14}C measurements.

Having the ability to document both the nature and source of the carbon contained in a sample is a primary prerequisite to the application of ^{14}C data to the task of archaeological chronology building in a critical context. Here, the expertise of a geologist with experience and expertise dealing with the sometimes unique characteristics of Quaternary geomorphology and land-form development has proven to be of critical importance in understanding the relationship of ^{14}C values to specific archaeological expressions. We also suggest that the commitment of research-oriented ^{14}C laboratories in determining the source(s) of anomalous ^{14}C values should not be underestimated

As illustrated in 3 of our case studies, AMS-based ^{14}C measurement technology has made it feasible to undertake increasingly precise ^{14}C age determinations on submilligram amounts of carbon from an extended range of chemical components isolated from samples. This capability is especially important when working with bone samples (Taylor 1992; Bronk Ramsey et al. 2004; Beaumont et al. 2010). The routine ability to undertake AMS-based ^{14}C measurements on submilligram samples has created an experimental environment where it is now possible to resolve a greater percentage of ^{14}C dating anomalies.

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