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Radiocarbon dating and the ‘‘old shell’’ problem: direct dating of artifacts and cultural chronologies in coastal and other aquatic regions

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Abstract

Archaeologists have long recognized the problem of the ‘‘old wood’’ effect in radiocarbon dating charcoal and wood samples, the age of which may be hundreds of years older than their use by humans. Such problems have resulted in significant changes in how most researchers select wood and charcoal samples for ^{14}C dating, with many now using relatively short-lived carbonized materials for dating. Despite the significant strides made in our understanding of the potential biases of the ‘‘old wood’’ effect, little emphasis has been placed on the possible impacts of dating ‘‘old shell’’ in archaeological deposits. The use of marine shell for ^{14}C dating is widespread in coastal areas around the world, including a growing emphasis on the dating of individual shell artifacts via Accelerator Mass Spectrometry (AMS). In dating shell artifacts, we have obtained several dates older than associated ^{14}C dates for short-lived subsistence remains from the same deposits, including great disparities (> 10,000 years) and more subtle differences (≥ 100 years). These discrepancies appear to be due to the use of old shells by humans to make beads and other artifacts, including shells collected from fossil deposits, older archaeological sites, and beaches. The problems caused by the use of old shells to make beads and other artifacts are surmountable through careful sample selection, analysis of multiple ^{14}C dates on a variety of materials, and proper calibration procedures.

Keywords: AMS radiocarbon dating; ‘‘Old shell’’ problem; Artifact chronologies; Shell beads; Shell fishhooks; California; Pacific Coast

1. Introduction

Archaeologists in coastal and other aquatic regions around the world rely heavily on radiocarbon (^{14}C) dating of shell, charcoal, and other materials for building artifact, site, and regional chronologies (see Refs. [2,8,31,32,36]). The use of marine and freshwater shell for ^{14}C dating has become increasingly popular as techniques for correcting and calibrating ^{14}C dates on shell have become more sophisticated, and significant strides have been made in understanding spatial and temporal variation in the marine reservoirs and other sources of bias [4,5,13,18,35]. Such studies have resulted in an increased confidence in the use of marine shell to date archaeological materials in many coastal areas, including North America.

Associated with the increased reliance on ^{14}C dating of marine shells and the growth of the accelerator mass spectrometry (AMS) technique, a number of archaeologists on the Pacific Coast of North America have initiated direct AMS dating projects of individual artifacts

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[9,10,21,22,23,26,27,37,38]. The direct dating of artifacts has proven to be a powerful tool for refining artifact, site, and regional chronologies in areas where sites were excavated before widespread use of ^{14}C dating and where bioturbation and other stratigraphic mixing pose a number of chronological problems [9,27]. In AMS dating shell beads from stratified California Channel Island sites, however, we have obtained several dates that are substantially older than other dates from non-artifactual materials from the same deposits. These include fossil examples that were tens of thousands of years too old, as well as more subtle examples that differ by a few centuries or less. After careful evaluation, in some of these cases we propose an "old shell" effect similar to the "old wood" effect long recognized by archaeologists [1,2,30,36]. Similar problems have also been noted for the Upper Paleolithic and Paleoindian use of fossil mammoth ivory to manufacture tools [40, p. 269].

To demonstrate the potential problems of the "old shell" effect, we present results obtained from our ongoing research efforts into the antiquity of shell artifacts in southern California (Fig. 1). We have identified anomalous dates on different types of shell, including *Olivella biplicata* (purple olive) and *Haliotis rufescens* (red abalone) suggesting that the "old shell" effect is not limited to a particular shell type. In discussing the "old shell" problem, we also describe other processes that can bias ^{14}C dating of shell samples, including dating of mixed shell specimens, the marine reservoir effect, conventional dating of relatively small artifacts, and other problems. We conclude by providing details on how to identify and avoid "old shell" dates, stressing the importance of using multiple lines of evidence when evaluating ^{14}C dates and chronologies from archaeological sites or individual specimens.

2. Radiocarbon dating on the California Coast

The archaeological record of the California Coast spans at least 13,000 to 12,000 calendar years [8,15]. During the last 40–50 years, archaeologists in coastal California have relied heavily on ^{14}C dating to build artifact, site, and regional chronologies. Orr [24], a pioneer of ^{14}C dating on the California Coast, dated numerous archaeological sites on Santa Rosa Island and demonstrated that people were on the Channel Islands throughout the Holocene. The growth and development of cultural resource management and academic research in California have created one of the largest radiocarbon records for any comparable region in the world. Over the last 20 years, California archaeologists have run thousands of ^{14}C dates, with an increasing number on marine shells [3].

Due to their abundance in coastal sites and their utility in ^{14}C dating, archaeologists have long been interested in marine shell as a dating material. Because

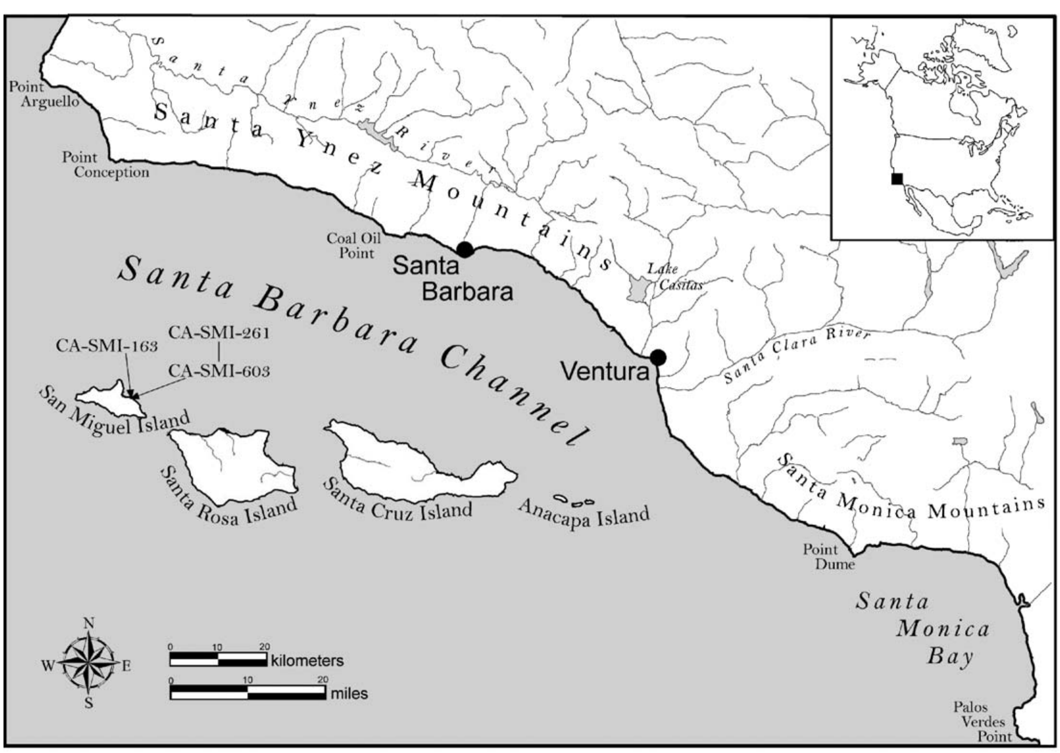

Fig. 1. Location of archaeological sites discussed in the text.

of differences in global atmospheric and oceanic carbon reservoirs, localized upwelling, the hard-water effect, and other problems (see Refs. [2,5]), however, shells are sometimes viewed as a problematic dating material. To help surmount these problems, scientists working on the California Coast have investigated regional differences in the marine reservoir effect, isotopic fractionation, and other biases in marine shell dating [6,8,12,13,18]. With recent refinements in shell dating, when proper reservoir corrections and calibration techniques are used and multiple dates are obtained, dating of marine shells can be more accurate than dating charcoal (e.g., Ref. [19]).

In a paper focused on refining marine reservoir corrections for the Eastern Pacific and California, however, Ingram and Southon [13] warned that the dating of old or reworked shell may bias some non-cultural samples. They noted several factors that can contribute to differences in the marine reservoir effect or other biases in ^{14}C dates, including seasonality, variability in freshwater input, and the feeding behavior of various shellfish species [13]. Our recent research suggests that the direct dating of shell artifacts can also be hindered by the human use of shells that are significantly older than the archaeological contexts in which they are found. In describing several anomalous dates obtained on marine shell artifacts from California's Channel Islands, we discuss some ambiguities associated with direct dating of shell artifacts and evaluate other possible sources of bias.

3. Methods

The artifacts described in this paper were dated by Beta Analytic, Inc., the National Ocean Sciences Accelerator Mass Spectrometry Laboratory (NOSAMS), the Center for Accelerator Mass Spectrometry (CAMS) at Lawrence Livermore National Laboratory, and the University of California Irvine AMS Lab (see below). Fragments of each artifact were removed for ^{14}C dating, trying to preserve as much of the artifact as possible. To remove contaminants, the specimens were etched in dilute hydrochloric acid to remove the outer layer most susceptible to diagenesis, then rinsed in distilled water. The pretreated shell samples were then dried and converted to CO_2 by reaction with phosphoric acid under vacuum. Subsamples were used to measure ^{13}C/^{12}C ratios and the remaining samples were converted to graphite before being dated.

Defining the antiquity of artifacts is often complicated by problems associated with comparing uncorrected ^{14}C dates based on shell, bone, and charcoal, since the measured ages of terrestrial and aquatic materials can differ by hundreds and even thousands of years. To standardize our results and increase the accuracy of our interpretations, all dates presented in this paper were calibrated with Calib 4.3 [33,34], applying a ΔR of 225 ± 35 years to compensate for local upwelling [35]. ^{13}C/^{12}C ratios were either determined by the radiocarbon labs, or an average of +430 years was applied [6]. The ΔR correction we used, an average value for the southern and central California Coast, has been confirmed by various researchers working in the Santa Barbara Channel area [6,8,18]. Due to variations in upwelling, sea surface temperature, and other climatic variables, however, there is spatial and temporal variability in the reservoir effect throughout California and beyond [4]. Ingram and Southon [13], for example, determined a ΔR estimate for the Santa Barbara Channel region of 233 ± 60, and demonstrate a range of 220 ± 40 for southern California to 290 ± 35 for northern California. Kennett et al. [18] demonstrated temporal variation in the ΔR for the Santa Barbara Channel area, noting a slightly diminished value of 210 ± 80 between 8440 and 4310 radiocarbon years before present (RYBP). It is likely that the artifacts in our study, also require slightly different ΔR adjustments. Using the Ingram and Southon [13] or Kennett et al. [18] estimates instead of the 225 ± 35 average, however, would only change our calibrated intercepts by roughly 10 years. These minor adjustments do not appear to affect our evaluation of the "old shell" effect in the Santa Barbara Channel area.

Kennett and Ingram [17] also noted variability in AMS ages obtained from different growth bands on marine shells from the southern California Coast. Their estimates indicate discrepancies between roughly 100 and 200 years per shell sample and appear to be closely linked to differences in upwelling and marine temperature at the time the shell added each new growth band. To compensate for this problem, we tried to obtain samples that spanned multiple growth lines and averaged seasonal and annual fluctuations in the intensity of upwelling and ΔR values. Nonetheless, possible short-term variations in ^{14}C content should be considered when evaluating AMS ^{14}C dates on marine samples. Despite these problems, the potential of direct ^{14}C dating of organic artifacts far outweighs any methodological difficulties. Below we present examples from our own research that highlight the need for caution when directly dating shell artifacts (Table 1).

4. Archaeological examples of the "old shell" problem

4.1. Cave of the Chimneys (CA-SMI-603)

Cave of the Chimneys is a large rock shelter about 10 m deep and up to 12 m wide. Located about 12 m above an isolated and rugged stretch of rocky coast on the northeast shore of San Miguel Island, the cave appears to have been formed during the Pleistocene by marine erosion associated with a high interglacial sea

Table 1
"Old shell" dates (noted by *), additional associated dates, and inferred ages of samples

Provenience	Lab number	Material	Uncorrected ^{14}C age	$^{13}C/^{12}C$ adjusted age	1 Sigma calibrated age range (cal BP)	Inferred age (cal BP)
CA-SMI-163						
Unit 2, 10 cm	OS-27183	Black abalone	–	655 ± 60	270 (150) 0	–
Unit 2, 110 cm	OS-33417	CA mussel	–	880 ± 30	320 (290) 270	–
*Unit 2, 70–80 cm	OS-34803	Red abalone bead	–	1010 ± 40	480 (440) 390	300–150
*Unit 2, 10–20 cm	OS-34802	Red abalone bead	–	1320 ± 30	680 (650) 630	300–150
CA-SMI-261						
Stratum F1	Beta-15623	CA mussel	8470 ± 120	8900 ± 120	9420 (9050) 8980	–
Stratum F1	CAMS-8867	Charred twig	–	8600 ± 60	9600 (9550) 9530	–
Stratum F3	Beta-49948	CA mussel	8940 ± 90	9360 ± 90	9920 (9810) 9590	–
Stratum F3	CAMS-8863	Charred twig	–	8810 ± 80	10,150 (9860) 9700	–
*Stratum F	UCIAMS-8674	*Olivella* bead	–	10,160 ± 25	11,120 (10,800) 10,550	9000–10,000
CA-SMI-603						
Stratum 7	Beta-122713	Marine shell	7220 ± 70	7650 ± 70	7950 (7870) 7790	–
Stratum 7	Beta-136696	Marine shell	7310 ± 80	7740 ± 80	8030 (7950) 7870	–
*Stratum 7	Beta-141221	*Olivella* bead	30,450 ± 100	30,900 ± 100	–	7800–8000

All dates were calibrated using Calib 4.3 [33,34], applying a ΔR of 225±35 years for all shell samples [18]. $^{13}C/^{12}C$ ratios were either determined by the ^{14}C labs, or an average of +430 years was applied [6]. OS-27183 is just beyond the calibration range of Calib 4.3, the closest possible calibrated age was used.

stand. Cave of the Chimneys faces due east and is sheltered from the strong northwesterly winds that buffet San Miguel Island much of the year. A skylight or "chimney" roughly 1.5 m wide and a large opening at the cave mouth illuminate the interior of the shelter. Although the floor of the cave slopes relatively steeply towards the ocean, archaeological deposits appear to be located beneath much of the cave floor. Seven discrete archaeological components, with up to two meters of midden accumulation, have been identified in the cave. Fourteen ^{14}C dates suggest that the site was occupied between about 8400 and 2300 cal BP [38,39].

Twenty-five *Olivella* spire-lopped shell beads associated with well preserved strands of woven sea grass cordage and knots were recovered in the Early Holocene deposits at the site [38]. Two *Olivella* spire lopped beads were directly dated by Beta Analytic and CAMS. One bead produced a calibrated age range of 7610 to 7480 cal BP and is consistent with the other Early Holocene dates obtained on food-related shell from the Early Holocene strata [38]. The second bead was dated to 30,900± 100 RYBP, however, more than 20,000 years older than any other dates from the cave. Although not visibly fossilized, this bead appears to have been made from a fossil *Olivella* shell, probably collected from a nearby deposit on the island. Due to the relatively large discrepancy between this date and associated dates, we could rule out other sources of error (e.g., reservoir effect, individual shell growth bands), making this a relatively clear case for the "old shell" effect.

4.2. Daisy Cave (CA-SMI-261)

Daisy Cave is a multicomponent archaeological site situated on the north side of Bay Point not far from Cave of the Chimneys. The site consists of a narrow fissure approximately 11 m deep and 1.5 m to 3 m wide, an outer rock shelter approximately 4 m×5 m wide, and a shell midden on the slope in front of the shelter [8]. Stratified archaeological deposits are located in all three areas, and prior to erosion covered an area of over 200 m^2. The cave was excavated in the 1960s by a team led by Charles Rozaire [28] and has been the subject of research by Erlandson and colleagues for over a decade. Fifty-one ^{14}C dates bracket the human occupation of the cave between about 11,500 and 700 cal BP [8].

Recently, several shell artifacts recovered by Rozaire and later excavations at the site were selected for direct AMS ^{14}C dating. Because Rozaire's team excavated the deposits in arbitrary levels that sometimes cross-cut the natural stratigraphy, the precise provenience and age of many artifacts and other materials is unknown. Several shell fishhooks and beads were dated [27] and most of the specimens produced ages similar to other ^{14}C dates from the same or surrounding strata. However, one *Olivella* spire lopped bead recovered by Erlandson from Stratum F of Unit 98-E6 was dated by the UC Irvine AMS lab. This bead produced an AMS date of 10,160±25 RYBP and a calibrated intercept of 10,800 cal BP, nearly 1000 years older than the other dates from this stratum obtained on charred twigs and closely associated food shell. This suggests that the age of this bead has been overestimated by the use of "old shell" by the people who made the bead, who may have collected it from a nearby beach. Because *Olivella* shells are reused by hermit crabs and other organisms, they can remain in use for a long time after the organism dies. A difference of 1000 years is also unlikely to result from the dating of individual growth bands or variability in the reservoir effect.

4.3. CA-SMI-163

CA-SMI-163 is a village site just east of Cuyler Harbor that contains six visible house depressions and covers an area at least 50 m wide by 110 m long. The site contains shell midden deposits well over 1 m deep, with abundant evidence of bead making, marine fishing, and other activities. Fifteen ^{14}C dates suggest that the site was occupied primarily during the Protohistoric and Historic periods (ca. A.D. 1540–1800) and is probably the remnants of *Tuqan*, one of two historic Chumash villages on San Miguel [14,16,26]. Dating of two shell samples from the western site margin also identified a discrete component dated between ca. 1260 and 1130 cal BP.

Among the ^{14}C dates obtained for the site, two were for red abalone epidermis beads-in-production from Unit 2. Two dates from the top and bottom of Unit 2 (ca. 290–150 cal BP) were obtained from marine shells that represent food remains, the primary means of establishing the chronology for this unit [26]. Because most of the red abalone shells in the site deposits appear to have been used for making beads or fishhooks, dates were obtained on the beads to determine if people were using shells from "fresh" abalones or shells collected from nearby beaches or older archaeological sites. These beads yielded intercepts of 650 and 440 cal BP, roughly 500–100 years older than the dates obtained on subsistence remains from the same deposits. Because these dates are relatively similar, we cannot rule out the possibility that these differences result from dating individual shell growth bands. However, care was taken in sampling these beads to make sure multiple growth lines were dated, which should minimize this problem. Red abalone shells are generally subtidal and difficult to acquire in southern California. Although abundant in some Middle Holocene shell middens [11], they are much less common in Late Holocene sites, especially the larger shells required to make beads from the epidermis [16]. Collectively, these lines of evidence suggest that the discrepancy between dates for beads vs. subsistence remains is probably the result of people using older abalone shells to make beads. In developing high-resolution chronologies for distinctive artifacts or technologies, this example underscores the importance of analyzing multiple ^{14}C samples, including short-lived subsistence remains or other materials that were probably collected when they were alive.

5. Discussion

Our direct dating of shell artifacts from stratified Channel Island archaeological sites illustrates several potential problems in the ^{14}C dating of shell and other organic artifacts. Our intent in this paper is not to dissuade archaeologists from dating marine shell artifacts. We emphasize that most of the dates being obtained by archaeologists on shell artifacts probably provide relatively reliable age indicators. Vellanoweth's [37] recent analysis of numerous *Olivella* grooved rectangle beads from Oregon, Nevada, and California, for example, produced a tight cluster of dates around 5000 years old. The dates we described above, however, demonstrate that in some cases the apparent age of shell artifacts used by people can be thousands or hundreds of years older than their actual manufacture or use as beads. Although Fitzgerald et al. [10, p. 431] suggested that most "old shell" dates are from fossil deposits of great antiquity, our research suggests that "old shell" dates can be less dramatic, more difficult to detect, and result from a variety of processes.

The use of "old shell" in making shell artifacts can result from several factors. First, people can select specimens for making beads, ornaments, or other artifacts from fossil deposits. Last Interglacial fossil beach deposits containing unlithified *Olivella*, clam, and other shells used to make beads are found in a variety of areas of California [7, p. 183, 24, p. 22], including the Channel Islands, and Koerper [20] described fossil *Glycymeris* shell bracelets found in Orange County, CA archaeological sites. It is also possible that people may have obtained raw materials for making shell artifacts, or even finished artifacts, from nearby older archaeological sites, just as they appear to have done with chipped stone artifacts [7, p. 76]. Shell middens found throughout the coast today are a ready supply of shells and were undoubtedly in the past too. People may also have collected artifacts from older sites as curios. Finally, "old shell" can be collected off the beach. Because people do not need to collect living specimens when making artifacts, any shell washed on the beach or found in the intertidal zone is potentially a source of raw material. *Olivella* and other shells used by hermit crabs after their use by the original organism can also be a potential source of bias [9]. Many archaeological sites and fossil beach deposits found on raised marine terraces along the California Coast are also actively eroding from modern sea cliffs, which may mix shells of fossil, archaeological, and biological origin on the same beaches.

Our "old shell" dates from Channel Island artifacts suggest that the old shell effect does not have site, geographic, or material type barriers. These dates come from a Late Holocene village and Early Holocene deposits in two stratified cave sites. The identification of "old shell" dates on different shell types, including *Olivella* and red abalone, also suggests that the old shell problem can affect virtually any shellfish species used for ornamental or technological purposes.

Another interesting variable in our research is that all of the examples we have identified are from shell beads, with no clear examples of "old shell" dates on shell fishhooks or other utilitarian items. Conventional ^{14}C dates obtained by Salls [29, p. 361, 372] for three shell fishhooks from the multicomponent Eel Point Site on San Clemente Island (4500 ± 350, 3950 ± 330, and 3380 ± 280 RYBP) have calibrated ages (ca. 4400 to 2900 cal BP) as much as 2000 years older than any directly AMS dated hooks in the Santa Barbara Channel region [27]. Although Raab et al. [25] suggested that 10 hooks and a blank from excavations at Eel Point may date to roughly 3200 cal BP or older, this age is based on associated ^{14}C dates with no direct dates on the hooks themselves. Salls' early fishhook dates may be accurate, but they could also result from the "old shell" effect or the large counting errors caused by conventional dating of small samples. This example demonstrates the importance of obtaining multiple dates, including dates for closely associated short-lived samples, and for direct AMS dating of the artifacts themselves, which would provide more accurate dates and allow the redating of samples that produce questionable dates.

Although we have yet to identify a clear case of the "old shell" effect on dates for more utilitarian artifacts, this remains a potential problem. It is possible, however, that fishhooks and other tools (shell adzes, etc.) may often have been made from relatively fresh shells that are generally more durable and less affected by weathering and other processes of disintegration. Such weathering may be less of a problem in making beads and other more ornamental artifacts since they do not need to be as strong or durable.

Fortunately, many of the problems we have identified with the "old shell" effect can be avoided, identified, or corrected. Most of our suggestions for surmounting the old shell problem also relate to ^{14}C dating in general, but several are unique to marine shells. The most important factor in identifying anomalously old dates for shell artifacts is obtaining multiple ^{14}C dates from associated site deposits, especially on short-lived materials (food shell, charred twigs, etc.). Dating of multiple specimens—even from the same provenience—is an ideal way to refine site chronologies and identify potential disturbances. Dating associated food remains (shells, charred seeds, etc.) also contributes to high resolution site chronologies since they are generally short-lived and were collected "fresh" for immediate processing or consumption. In some cases, artifacts are dated from museum collections for which there are no subsistence remains or additional samples to date. In these instances, we suggest that researchers look for well preserved shell specimens with limited weathering, abrasion, inclusions, or other marks that may indicate an "old shell" or poorly preserved specimen. Moreover, some museum specimens have been treated with chemicals that can result in anomalous ^{14}C dates. We recommend reviewing museum curation records to identify potential disturbances.

6. Conclusions

Direct AMS dating of shell, bone, and other artifacts is an important technique increasingly used by researchers along the Pacific Coast of the Americas and around the world. Dating artifacts via AMS is a powerful tool for refining the chronology of artifact, site, and regional chronologies, documenting site disturbances, and establishing the chronology of museum collections. Much of the recent research on direct AMS dating of artifacts, moreover, underscores the increased importance of the AMS technique for building higher resolution cultural chronologies. With increased reliability, competitive costs, and smaller sample requirements, we argue that in many cases AMS dates should be obtained rather than conventional dates.

Despite the utility of the direct AMS dating of artifacts, this technique is not without problems. Use of older materials (shell, bone, ivory, wood, etc.) for tool making by ancient peoples is a particularly problematic source of erroneous ^{14}C dates. We caution that "old shell" dates may also be obtained on specimens that were not made into artifacts [13], reiterating the importance of careful sample selection and use of multiple ^{14}C dates. Archaeologists should not assume that all dates that are inconsistent with other dates in a sequence are from "old shell." The dating of mixed shell samples and improper correction or calibration techniques are also potential sources of bias. Ultimately, determination of an "old shell" date should rely on multiple lines of evidence. Through careful sample selection, use of well preserved specimens, proper pretreatment (i.e., acid etching), use of established reservoir corrections and calibration curves, and the dating of multiple samples from a site, the "old shell" problem can be identified or avoided altogether. We hope researchers will continue to date shell, bone, and other artifacts, with continued attention given to refining and improving our chronological interpretations.

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