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MARINE CARBON RESERVOIR AGE ESTIMATES FOR THE FAR SOUTH COAST OF PERU

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ABSTRACT. In order to estimate the apparent age of seawater (R) and the corresponding local offset from the global marine radiocarbon calibration curve (ΔR) on the far south coast of Peru for 2 periods in the past, 6 pairs of associated marine shell and unburned wood samples from archaeological excavations at Loreto Viejo were ^{14}C dated. Three pairs from about cal AD 1280–1380 indicated larger and more variable ΔR estimates than have been obtained for other periods in nearby regions, suggesting that ΔR may vary considerably over space and/or time. Three pairs from about 1870–1680 cal BC yielded consistent shell dates, but only one reasonable terrestrial date and ΔR estimate, probably due to stratigraphic mixing in antiquity. The one early ΔR estimate falls slightly outside the range of the later ones, suggesting either still greater spatial variability in ΔR, or some temporal variability.

INTRODUCTION

In order to calibrate radiocarbon ages from archaeological marine shell excavated near Ilo, Peru (17°37′S, 71°20′W) (Figure 1), and to estimate how much a partially marine diet could have perturbed the apparent ^{14}C ages of human bones and tissue from this area, it is necessary to know the apparent age of local sea water (R) and the corresponding local offset from the global marine carbon calibration curve (ΔR) at the time of interest (Beavan and Sparks 1998; Beavan-Athfield 2001; Ingram 1998; Kennett et al. 1997, 2002; Molto et al. 1997; Stuiver et al. 1986; Stuiver and Braziunas 1993; Tauber 1983). Taylor and Berger (1967) assayed 4 shells collected at known times in the early 20th century on the coast of Peru and northern Chile, from about 10°S to about 33°S. The local reservoir ages indicated by 3 of these shells were in rough agreement, yielding ΔR estimates from 171 ± 34 to 307 ± 77. The shell from closest to Ilo (a gastropod collected around 15°S) indicated a much greater reservoir age (ΔR = 664 ± 45). This value, while not unprecedented, is very high and was excluded by Stuiver et al. (1986: Table 1) from their survey of regional ΔR estimates. The shell may have provided a false estimate because it was old when collected or was affected by geological carbonate (Dye 1994), or it may reflect a correct localized extreme value due to fluvial water depletion (Little 1993) or other factors.

Southon et al. (1995) estimated ΔR for a region south of Ilo (around 20°S) during roughly cal AD 200–900, reporting 4 tightly clustered values that were close to Stuiver et al.'s (1986) regional mean. This finding suggested that the regional value was correct, and that it was relatively constant during the last two millennia. Estimates by Southon et al. (1995) were based on composite archaeological artifacts made from marine bird tissues and terrestrial plant fibers, ensuring excellent contemporaneity of the samples. Because marine birds are mobile, their tissues may average out small-scale spatial variations in the marine carbon reservoir. This could contribute to the good agreement among the estimates, but might mask localized extremes.

Kennett et al. (2002) tried to estimate ΔR for the Ilo region during the Late Archaic Period (about 6000–4000 cal BC) using associated shell and charcoal samples from the site of Kilometer 4, but were thwarted because the ancient inhabitants apparently collected very old wood for fuel.

MATERIALS AND METHODS

Six pairs of marine shell and terrestrial plant samples were ^{14}C dated. Each pair was from a single archaeological stratum at the site of Loreto Viejo (17°36′8″S, 71°13′45″W) in the coastal Osmore valley, about 13 km inland from Ilo (Owen 1993). The samples were collected from 1/4 inch screens in the course of stratigraphic excavations. Extreme aridity and salty soil contribute to extraordinary preservation of plentiful desiccated plant material. Three sample pairs were from domestic middens that contained Chiribaya style ceramics and dated to cal AD 1280–1380 (1 σ; Table 1). The other 3 pairs were from a cooking area in a preceramic and early ceramic sector of the site, dating to 1870–1680 cal BC (1 σ; Table 1). Strata selected for sampling were well-defined by changes in soil texture and color, in order to reduce the chance of conflating samples from different depositional events. The selected strata were of low volume (Table 1), in order to ensure that each pair of samples was probably deposited within a relatively short period.

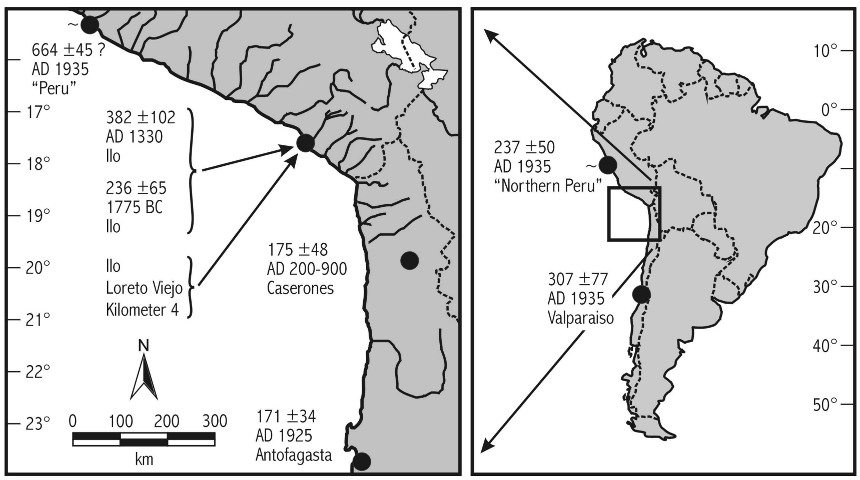

Figure 1 ΔR estimates for the Andean coast at various periods (with 40-yr Southern Hemisphere correction)

SAMPLES

Five of the 6 terrestrial samples were small unburned twigs of *Schinus molle* (California pepper tree, or molle) with bark. The remaining sample included twigs of both molle and unidentified species. The twigs ranged from 1 to 3 mm in diameter, which should ensure that they contain atmospheric carbon fixed during a period of no more than 2 or 3 yr. Such small twigs are unlikely to be "old wood" that was curated or collected from long-dead sources.

The marine samples were all fragments of *Choromytilus chorus* (choro mussel, or purple mussel) shell. Subtidal shellfish are preferable for marine carbon reservoir studies, because they are not exposed to atmospheric carbon during life (Goodfriend and Rollins 1998). Sandweiss et al. (1989) classify archaeological *C. chorus* from the nearby Ring Site as subtidal, and other sources treat *C. chorus* as primarily or entirely subtidal (Hancock 1969; Jaramillo et al. 1992; Soot-Ryen 1955). Intertidal *Choromytilus* are reported, but they are scarce, small, and of poor quality (Hancock 1969; Lasiak 1991). The archaeological specimens tend to be gigantic by modern standards, and they are ubiquitous in archaeological deposits, suggesting subtidal sources. If any of the samples were intertidal, ΔR estimates from them would be incorrectly low. Some grazing gastropods metabolize old carbon from seafloor minerals, exaggerating ΔR estimates based on their shells (Dye 1994; Phelan 1999). As a sessile bivalve, *C. chorus* should be less subject to this source of error. Since *C. chorus* shells in this region were rarely, if ever, worked, the mussels were probably collected live for food, making them contemporary with young twigs in the same contexts.

Table 1 Marine-terrestrial date pairs from Loreto Viejo (see notes on page 705)

Sample pair	Sample ID	Material and context	$\delta^{13}C$ (‰)	^{14}C age[a]	Apparent age of seawater[b]	Cal AD ±1σ[c] No SHC[e]	Model marine age[d] No SHC[e]	ΔR[f] No SHC[e]	Cal AD ±1σ[c] With SHC[g]	Model marine age[d] With SHC[g]	ΔR[f] With SHC[g]
Chiribaya midden, cal AD 1280–1380 (1σ)											
Unit 2505-5-6 midden, near top (279 liters)	Beta 51073	Small twigs of *Schinus molle* and other species	-26.3	730 ±60		1220–1390			1270–1390		
	AA37160	*Choromytilus chorus* shell	0.3	1358 ±46	628 ±76	640–770	1100 ±85	258 ±97	660–770	1070 ±70	288 ±84
Unit 2505-11-17 midden, near bottom (48 liters)	AA37161	Small twigs of *Schinus molle*	-27.7	701 ±38		1270–1390			1285–1390		
	AA37162	*Choromytilus chorus* shell	0.4	1428 ±56	727 ±68	560–665	1070 ±70	358 ±90	600–690	1060±60	368 ±82
Unit 2503-6-6 midden (44 liters)	AA40291	Small twigs of *Schinus molle*	-26.3	662 ±34		1285–1390			1300–1395		
	AA40292	*Choromytilus chorus* shell	0.0	1530 ±40	868 ±52	430–600	1060 ±60	470 ±72	535–620	1040 ±60	490 ±72
Weighted means[h]					772 ±36			384 ±49			393 ±45
Means w/ std dev[i]					**741 ±121**			**362 ±106**			**382 ±102**
Early cooking area, 1870–1680 cal BC (1σ)											
Unit 2513-5-4 around hearth, near top (36 liters)	AA37163[j]	Small twigs of *Schinus molle*	-27.3	1895 ±28[j]		65–135			125–220		
	AA37164	*Choromytilus chorus* shell	-0.8	3936 ±55	2041 ±62[k]	-2560–-2310	2250 ±30	1686 ±63[k]	-2470–-2300	2190 ±35	1746 ±65[k]
Unit 2513-14-33 pit fill, middle (9 liters)	AA40293[l]	Small twigs of *Schinus molle*	-25.7	1519 ±31[l]		440–610			540–620		
	AA40294	*Choromytilus chorus* shell	-0.1	3951 ±46	2432 ±55[k]	-2560–-2340	1885 ±75	2066 ±88[k]	-2470–-2310	1840 ±33	2111 ±57[k]
Unit 2513-11-18 ashy surface, near bottom (75 liters)	AA37165	Small twigs of *Schinus molle*	-26.7	3439 ±43		-1870–-1680			-1750–-1620		
	AA37166	*Choromytilus chorus* shell	-0.1	3961 ±47	**522 ±64**	-2570–-2350	3790 ±70	**171 ±84**	-2470–-2310	3725 ±45	**236 ±65**

Table 2 Marine-terrestrial date pairs from neighboring regions (see notes on page 705)

Sample pair	Sample ID	Material and context	δ^{13}C (‰)	^{14}C age[a]	Apparent age of seawater[b]	Cal AD ±1σ[c] No SHC[e]	Model marine age[d] No SHC[e]	ΔR[f] No SHC[e]	Cal AD ±1σ[c] With SHC[g]	Model marine age[d] With SHC[g]	ΔR[f] With SHC[g]
Composite artifacts from Caserones, northern Chile, cal AD 200–900 (Southon et al.											
CAS572	CAMS 10320	Plant fiber	-23.5	1270 ±60		660–860			690–890		
	CAMS 10321 and 10322	Fish vertebra and skin or stomach (mean)	-12.8 -14.5	1770 ±35	500 ±69	220–340	1640 ±95	130 ±101	250–390	1610 ±95	160 ±95
CAS512	CAMS 9372 and 9373	Wool yarn (mean of two samples)	-20 (est.)	1580 ±40		430–540			430–600		
	CAMS 7610 and 9374	Bird-skin cape (mean of two samples)	-13.4	2060 ±40	480 ±57	-160–1	1925 ±45	135 ±60	-90–60	1895±75	160 ±80
CASTr6/7	CAMS 10314	Wool yarn	-20.2	1690 ±60		250–430			260–530		
	CAMS 10315 and 10316	Feather and bird skin (mean of two samples)	-11.5 -12.2	2225 ±50	535 ±78	-380—200	2045 ±75	180 ±90	-360—170	2000 ±110	245 ±85
CAS93.031	CAMS 10317	Wool yarn	-20.4	1850 ±70		80–250			120–330		
	CAMS 10318 and 10319	Bird-skin cape (mean of two samples)	-13.1 -13.6	2295 ±50	445 ±86	-410—210	2195 ±70	100 ±86	-400—200	2145 ±85	135 ±110
Weighted means[h]					490 ±35			**136 ±40**			180 ±45
Means w/ std dev[i]					**490 ±38**			136 ±33			**175 ±48**
Historical shells, early 20th century (Taylor and Berger 1967; Stuiver et al. 1986, table 1)											
"Northern Peru"	UCLA 1282	*Strombus peruvianus* shell collected 1930–1940	-0.2	700 ±49	685 ±49		463 ±10	237 ±50			
"Peru"	UCLA 1279	*Oliva peruviana* shell collected 1930–1940	1.2	1127 ±44	1112 ±44[k]		463 ±10	664 ±45[k]			
"Antofagasta, Chile"	UCLA 1277	*Concholepas concholepas* shell collected 1925	0.1	626 ±34	601 ±34		455 ±4	171 ±34			
"Valparaiso, Chile"	UCLA 1278	*Tegula aler* shell collected 1930–1940	1.3	770 ±76	755 ±76		463 ±10	307 ±77			
Weighted means[h] excluding 1279					**643 ±26**			**206 ±27**			
Means w/ std dev[i] excluding 1279					680 ±21			238 ±21			

Table notes:

[a]Conventional radiocarbon age BP, including $\delta^{13}C$ adjustment, no Southern Hemisphere correction.
[b]Apparent age of seawater is the difference between the conventional ^{14}C ages of the marine and terrestrial samples (Stuiver and Braziunas 1993:137). The error estimate is $(\sigma_{marine}^2 + \sigma_{terrestrial}^2)^{½}$. This value is in ^{14}C yr and is independent of the Southern Hemisphere correction.
[c]Calibrated ±1 σ date range calculated by OxCal v3.5 (Ramsey 2000), atmospheric calibration data from Stuiver et al. (1998).
[d]The model marine age is the hypothetical age and error estimate that, when calibrated using OxCal v.3.5, the marine calibration curve (Stuiver et al 1998), and ΔR=0, produces the associated terrestrial calibrated 1 σ date range.
[e]"No SHC" indicates that no Southern Hemisphere correction has been included in the calculation.
[f]ΔR is the difference between the measured marine ^{14}C age and the model marine age. The ±1σ error estimate is $(\sigma_{measured}^2+\sigma_{model}^2)^{½}$.
[g]"With SHC" indicates that the Southern Hemisphere correction suggested by Stuiver and Braziunas (1993) has been included in the calculation by subtracting 40 yr from the conventional ^{14}C age of the terrestrial sample prior to calibration and determination of the model marine age.
[h]Weighted means and error estimates after Bowman (1990:59).
[i]Arithmetic mean and standard deviation of values.
[j]Weighted mean of one measurement on each of 2 graphite targets prepared from the same sample (Bowman 1990:59).
[k]Unreasonably large, presumably erroneous value.
[l]Weighted mean of 2 measurements on 1 graphite target and 1 measurement on a second target prepared from the same sample (Bowman 1990:59).

Eleven of the 12 samples were pretreated and assayed at the NSF–University of Arizona AMS Facility under the direction of George Burr. The remaining sample was measured conventionally by Beta Analytic. The wood samples were given AAA pretreatment. The shell samples were pretreated with an HCl bath to remove surface layers that could contain recrystalized calcium carbonate.

ANALYTICAL METHODS

ΔR is calculated here as outlined by Stuiver et al. (1986) and Stuiver and Braziunas (1993), except that instead of a graphical intercept method (Southon et al. 1995; Facorellis and Maniatis 1998), a probability distribution method is adopted, using OxCal v3.5 (Ramsey 2000) with atmospheric and marine calibration data from Stuiver et al. (1998). The model marine age and error estimate are determined by successive approximations as the values that, when calibrated with the marine calibration curve, produce the same 1-σ date range as the terrestrial sample produces when calibrated using the atmospheric calibration curve. The smooth shape of the marine calibration curve ensures that there is almost always a unique solution.

Stuiver and Braziunas (1993) recommend subtracting a 40-yr Southern Hemisphere correction (SHC) from the terrestrial date before calibration. Marine dates calibrated with the resulting ΔR are comparable to terrestrial dates that incorporate the 40-yr SHC. However, few Andean archaeologists apply the SHC. Using a ΔR that includes the SHC would produce calibrated marine dates that are biased 40 ^{14}C yr younger than terrestrial dates calibrated without the SHC. On the other hand, most ΔR estimates are based on historically dated marine shells, the age of which is independent of any SHC. Marine dates calibrated with ΔR estimates from historical shells are comparable to calibrated terrestrial dates only if the terrestrial dates are correctly adjusted for hemispheric and other reservoir offsets—whatever those actually are. Moreover, the appropriate value for the SHC is still under discussion (Stuiver and Braziunas 1998; McCormac et al 1998). Given these uncertainties, ΔR is calculated here both with and without a 40-yr SHC.

Multiple values are summarized as weighted means of the values and error estimates (Bowman 1990:59) and as simple means and standard deviations of the values. Following Stuiver et al. (1986: 982), the method that results in the larger error estimate in any given case is adopted.

RESULTS AND DISCUSSION

The results of the 6 date pairs are given in Table 1. Data from Southon et al. (1995), Taylor and Berger (1967), and Stuiver et al. (1986) are recalculated in the same manner in Table 2. The recalculated values differ only slightly from the originally published results.

The weighted mean terrestrial conventional age for the 3 Chiribaya contexts is 687 ± 23 BP, or cal AD 1280–1380 (1 σ) without SHC. This range is as expected for the Chiribaya ceramic style. The 3 ΔR estimates are of credible magnitudes and are roughly consistent, averaging 363 ± 106 without SHC or 382 ± 102 with SHC. These estimates are considerably higher and more variable than those from previous studies (Table 2).

The tight clustering of the terrestrial dates suggests that the archaeological deposits accumulated over a brief period, so the variability is probably not due to poor contemporaneity of the paired samples, nor to temporal variations in ΔR. If the variation reflects spatial clines in ΔR, these must occur over very small distances, since all the shell probably came from within walking distance of Loreto Viejo. Such small-scale variation might be caused by the contribution of fluvial water at the river's mouth (Little 1993).

Estimated ΔR near Ilo about cal AD 1330 is high compared to the general region in the early 20th century (Taylor and Berger 1967; Stuiver et al. 1986) and to northern Chile around cal AD 200–900 (Southon et al. 1995). This could indicate temporal or spatial variability in ΔR. Alternatively, some of the new or previous ΔR estimates could be inaccurate.

The results from the 3 earlier date pairs were erratic. The 3 shell dates were very close, suggesting that they correctly date the deposits. The weighted mean of the conventional ^{14}C ages of the marine shell is 3951 ± 28 BP, or 1860–1680 cal BC (1 σ) without SHC using the single ΔR estimate discussed below. The 3 terrestrial dates were wildly variable. Two were over 2000 yr younger than the shells, indicating such extreme reservoir ages that they must be in error. The third indicates a believable ΔR estimate of 171 ± 84 without SHC or 236 ± 65 with SHC.

Both anomalous terrestrial dates were re-measured using new graphite targets prepared from remaining portions of the samples. One dated within 1 σ of the first target, and the other agreed within 2 σ, but both still suggested unreasonable reservoir ages. The twigs had been inspected under 10× magnification, and no decay or mold were noted. The discrepancy is probably not due to diagenetic changes or contamination of twigs that were contemporary with the shells, because an unreasonably high percentage of the carbon in the samples would have to be recent or modern to shift the apparent ages this much. The samples are unlikely to include post-occupation twigs, because the excavated area is on a barren desert hillside, over 200 m from the nearest irrigable land capable of sustaining a tree and 40 m above it. This is not an "old wood" problem, because the wood appears too *young*. It is unlikely to be an "old shell" problem, not only because the shell would have been collected fresh for food, but also because old shells collected on three different occasions would be unlikely to have such close ^{14}C ages.

The tightly clustered shell dates and the shallow cultural layers suggest that the entire sequence of deposits accumulated in a brief period, so there is no obvious source for drastically younger archaeological material. However, the stratum (2513-11-18) with a twig that gave a reasonable date is stratigraphically the earliest and best isolated from later deposits (Figure 2). The other 2 strata could contain twigs from a much more recent occupation, mixed in antiquity with shells from the earlier deposits that were brought up by digging the pit of 2513-14-33. Unfortunately, the material culture of this period is too simple and conservative to indicate on stylistic grounds whether the strata differ so significantly in time. This explanation implies exceedingly bad luck in sample selection, but it is possible. If it is correct, the sample pairs from 2513-5-4 and 2513-14-33 are not contemporary and cannot be used to estimate ΔR. On the other hand, this explanation gives no reason to reject the pair from 2513-11-18, providing one usable estimate of ΔR for the early period.

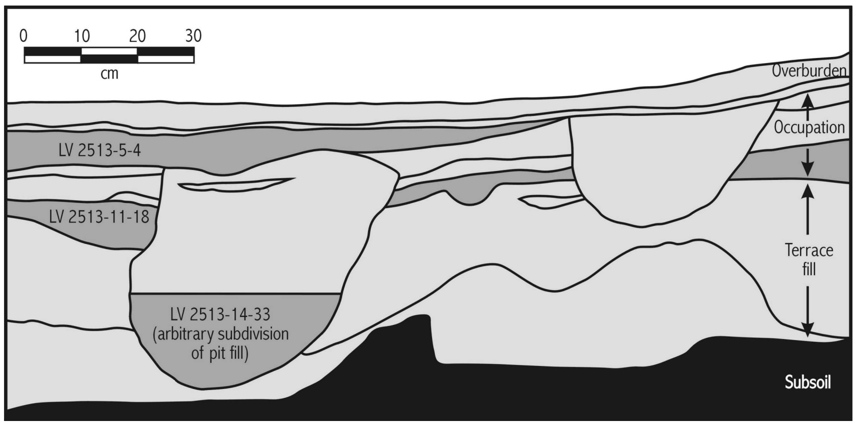

Figure 2 Strata sampled in the early cooking area at Loreto Viejo; north profile of unit LV 2513.

CONCLUSIONS

ΔR near Ilo, Peru, around cal AD 1280–1380 (1 σ) was about 362 ± 106 with no Southern Hemisphere correction, or 382 ± 102 with a 40-yr Southern Hemisphere correction. These values are higher than previous estimates for nearby regions at different times (Taylor and Berger 1967; Stuiver et al. 1986; Southon et al. 1995). This disagreement suggests that estimates of ΔR for this region should be used with caution, since there may be considerable spatial or temporal variation in marine ^{14}C reservoir depletion, or errors in some of the estimates.

One sample pair suggested a ΔR estimate for around 1870–1680 cal BC (1 σ) of about 171 ± 84 with no Southern Hemisphere correction, or 236 ± 65 with the 40-yr Southern Hemisphere correction. This estimate should be regarded as tentative, because 2 similar date pairs from nearby contexts gave erroneous results. While its lower magnitude is more in line with previously published estimates, it falls slightly outside the range of the other estimates reported here, accentuating the apparent variability of ΔR over short distances and/or over time.

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