Evidence for Temporal Fluctuations in Marine Radiocarbon Reservoir Ages in the Santa Barbara Channel, Southern California

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Differences in the 14C ages of closely associated marine shell and carbonized plant material from stratified archaeological deposits on San Miguel Island, California, suggest Holocene (10,000–present) fluctuations in marine 14C reservoir ages. These fluctuations coincide with δ18O and δ13C shifts measured in Mytilus californianus shells from the same stratigraphic contexts and general atmospheric/oceanic circulation models for the region. Based on these data we make three primary observations: (1) significant changes appear to have occurred in the radiocarbon reservoir during the Holocene; (2) these fluctuations appear to correlate with regional oceanographic changes; and (3) high resolution 14C dating of marine shells may require different ΔR values for different periods of time.

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Introduction

Radiocarbon dating is the primary method of defining chronologies for cultural and environmental changes over the past 40,000 years. In many coastal regions, environmental fluctuations seem to be closely correlated with shifts in human adaptations. Establishing such correlations, however, requires relatively precise dating. Charcoal and marine shell are the principal materials used to obtain radiocarbon assays on coastal archaeological and paleontological deposits. Two fundamental assumptions underlie the radiocarbon technique: (1) the initial 14C content of all samples of the same age is the same; and (2) the radiocarbon content of samples is not altered in the post-depositional environment. There are inherent problems associated with all datable materials depending upon geographical and depositional contexts (Dean, 1978; A rundale, 1981; Schiller, 1986; Hedges & Van Klinken, 1992). Recognizing sources of variability in the 14C content of all materials and developing reliable methods for correcting disparities are necessary for the comparability of radiocarbon dates between archaeological and paleontological chronologies.

Marine shell is the most abundant and well-preserved datable material in archaeological deposits along the California coast. Indeed, the predominant material used for radiocarbon dating prehistoric midden deposits is marine shell (Breschini, Haversat & Erlandson, 1996). Globally, marine shell can have radiocarbon ages up to 1000 years older than the...
actual (calendar) age of the shell (Taylor, 1987). This is
due, in part, to the slow mixing of deep ocean water
worldwide, leaving the marine radiocarbon reservoir
depleted in $^{14}$C relative to the atmosphere (Broecker &
Worldwide, 1982). The apparent $^{14}$C age of the water is
incorporated into the carbonate of marine mollusc
shells during growth. Large-scale variations in global
$^{14}$C reservoir ages are corrected with a model of oceanic
circulation (Stuiver & Pearson, 1986; Stuiver, Pearson
& Braziunas, 1986; Stuiver & Braziunas, 1993).

Regional differences (denoted as $\Delta R$) in the radiocarbon age between sea-surface water and average
surface water occur due to local anomalies in ocean
circulation (i.e. upwelling). $\Delta R$ is the difference be-
tween a particular region and the average world
ocean, which has an average reservoir age of 400 years
(MacFadgen & Manning, 1990). $\Delta R$ values are deter-
mined for a particular geographical region by radio-
carbon dating “prebomb” mollusc shells of known age
(Berger, Taylor & Libby, 1966; Robinson & Thompson,
1980; Taylor, 1987; Ingram & Southon, 1997). Along the coast of California, upwelling of
$^{14}$C-depleted deep oceanic water, originating in the
North Atlantic over 1000 years earlier, dilutes the
concentration of radiocarbon during spring and sum-
mer months. Based on the analysis of historical pre-
bomb shell samples, the $\Delta R$ value generally used for
the entire coast of California is 225 ± 35 years (Berger,
Taylor & Libby, 1966; Robinson & Trimble, 1981;
Stuiver, Pearson & Braziunas, 1986). Ingram &
Southon (1997) have recently refined reservoir age
estimates for eastern Pacific waters based on prebomb
mollusc shell $^{14}$C measurements. These reservoir esti-
mates are more constrained spatially and show an
increasing trend in $\Delta R$ from southern (220 ± 40) to
northern (290 ± 35) California. The $\Delta R$ for the Santa
Barbara Channel region is 233 ± 60, close to the average for the coast of California (Ingram &
Southon, 1997).

The implicit assumption made when using regional
corrections ($\Delta R$) is that the radiocarbon reservoir in
any given region has remained stable through time.
However, oceanic circulation in the Santa Barbara
Channel region is complex (Hickey, 1992; Browne,
1994; Engle, 1994) and has apparently fluctuated
during the Holocene (Pisias, 1978, 1979; Dunbar, 1983;
Glassow et al., 1994; Ingram & Kennett, 1995). These
fluctuations in ocean circulation would have had a
direct impact on the marine radiocarbon reservoir.
In this paper, we report preliminary $^{14}$C data which define
temporal shifts in $\Delta R$ between 9250 and 3200 $\text{a}$ in the
Santa Barbara Channel region. The marine $\Delta R$
variations are determined with $^{14}$C measurements of marine shell and charcoal pairs from finely stratified
archaeological deposits at Daisy Cave (SMI-261) and
Cave of the Chimneys, located on San Miguel Island
(Figure 1). In addition, stable O and C isotopic
measurements of historical and archaeological shells,
from the same stratigraphic contexts, are used to
support the radiocarbon results. The methods used
in this study should be of use in other regions
where temporal shifts in the radiocarbon reservoir
undoubtedly occurred.

Oceanography of the Santa Barbara Channel
Regional ocean circulation has been recognized to
influence the $^{14}$C content, particularly in areas where
intense upwelling occurs. Contemporary oceanogra-
phical circulation in the Santa Barbara Channel
region is complex and a number of small and large-
scale phenomena can potentially have an impact on the
radiocarbon reservoir (Winant & Bratkovich, 1981). In
general, the Santa Barbara Channel is influenced by
two major current systems (Figure 2): (1) the south-
w ard flow of the cold, low salinity California current;
and (2) the relatively warm, saline northward-flowing
California counter-current (Hickey, 1992; Browne,
1994). The $^{14}$C-depleted California current and associ-
ated southern California Eddy are the dominant influ-
ence along the southern California Bight, including
the Santa Barbara Channel region (Wickham, 1975).
However, the California counter-current transports
$^{14}$C-rich equatorial water along the southern California
cost. As it moves north it interleaves with the
California current and the California Eddy, eventually
bifurcating. One branch travels north between the
Santa Barbara mainland and the northern Channel
Islands and the other runs south of the islands. In the
Santa Barbara Channel, the counter-current dominates
during the summer and early fall and sometimes
surfaces during the winter months. This northward
flow slows during the spring.

The localized upwelling of Pacific deep water along
the California coast during the spring and summer
months is driven by temperature differences between
air masses over land and water (Dorman & Palmer,
are generated during these months as air masses over
western North America heat up relative to air masses
over the Pacific. Near-shore waters are transported
offshore and replaced by cold, nutrient-rich, Pacific
depth water. Upwelling close to the coast can decrease
water temperatures in portions of the California
current below 8°C (Bernal & McGowan, 1981;
Brink, 1983; Huyer, 1983; O’Brien, 1983; Mooers
& Robinson, 1984).

Fluctuations in upwelling intensity along the sou-
thern California Bight are generally the result of
(1) fluctuations in summer insolation (Bakun, 1990;
van Geen et al., 1992; van Geen & Husby, 1996), or
(2) El Niño/Southern Oscillation (ENSO) events
(McGowan, 1984; Rasmussen, 1984; Ramage, 1986).
Increases in summer insolation result in warmer air
masses over western North America, increased
southerly winds and more intense upwelling along the
coast. Decreases in summer insolation are associated
with decreases in the intensity of upwelling. ENSO's are
Figure 1. Map of San Miguel Island. Archaeological shell and charcoal samples were collected from SMI-261 (Daisy Cave) and Cave of the Chimneys, located on the north-eastern shore of San Miguel Island. Inset: Map of the Santa Barbara Channel and northern Channel Islands. Historical *Mytilus californianus* shells were collected live from the Santa Barbara coast in 1936.

Figure 2. Map of California coast indicating the primary offshore current systems (after Browne, 1994).
driven by oceanic and atmospheric anomalies in the equatorial Pacific causing an eastward movement of warm water that displaces cold water and reduces upwelling along the coast of California. During the El Niño of 1982–1983 sea-surface temperatures along the southern and central coast of California were elevated throughout the annual cycle. During this event, upwelling of cool nutrient rich water was reduced, causing low marine productivity.

Reconstructing the history of oceanic circulation patterns, paleotemperatures, climate, and human responses along the southern California coast has been a major focus of scholars. Given its geographical location, the Santa Barbara Channel region is sensitive to short and long-term climatic change (Pisias, 1978, 1979; Dunbar, 1983; Koerper et al., 1985; Arnold & Tissot, 1993; Glassow et al., 1994). These changes in ocean circulation must be considered and accounted for when correcting radiocarbon dates on marine shell for this region. In order to assess changes in $\Delta R$ over the past several thousand years in the Santa Barbara Channel region, we have collected closely associated charcoal-shell pairs from two archaeological sites on San Miguel Island. Radiocarbon differences between charcoal (reflecting atmospheric $^{14}$C) and shell (reflecting oceanic $^{14}$C) should allow the assessment of changes in the ocean $^{14}$C reservoir over the past 10,000 years.

Methods

Archaeological and historical samples

Shell and charcoal samples were collected from SM-I-261 (Daisy Cave) and Cave of the Chimneys, two finely stratified shell midden deposits on the north-east coast of San Miguel Island (Figure 1). The archaeological deposits at Daisy Cave and Cave of the Chimneys provide extremely well-preserved shell and charcoal samples spanning much of the Early and Middle Holocene (Erlandson, 1991, 1994; Erlandson et al., 1996). Compared with archaeological sites on the mainland coast, these midden deposits have not been disturbed by burrowing animals. Both deposits were excavated in naturally occurring cultural strata. Shell and charcoal samples were taken in close stratigraphic proximity. A variety of molluscan species were radiocarbon dated, including red abalone (Haliotis rufescens), black abalone (Haliotis cracherodii), California mussel (Mytilus californianus), and black turban (Tegula funebralis). Small charred twigs were preferentially selected to avoid the “old wood” problem (Blong & Gillespie, 1978; Schifer, 1986), but in some cases the use of large pieces of charcoal could not be avoided.

Historical Mytilus californianus shells were provided by the Santa Barbara Museum of Natural History. These shells were collected live from the mainland coast of Santa Barbara in 1936 (Figure 1). Two of these shells were radiocarbon dated for comparative purposes and stable isotopic measurements were done through the growth of the shell. Radiocarbon measurements of these historic shells were averaged with others for the region to derive the historic $\Delta R$ value (233 ± 60) for comparative purposes (Ingram & Southon, 1997).

Radiocarbon Analyses

Organic remains (twigs and charcoal) were selected for radiocarbon dating at the Center for Accelerator Mass Spectrometry (CAMS) at the Lawrence Livermore National Laboratory (Davis et al., 1990). Prior to analysis, organic carbon samples (1–2 mg) were rinsed sequentially in weak acid (1N hydrochloric acid) and base (1N sodium hydroxide), ending with a weak acid rinse to remove CO$_2$ absorbed during the alkaline bath. This procedure removes any adhering organic acids and secondary carbonate. The samples were then rinsed in deionized water three times, and oven-dried. Organic carbon samples were combusted in quartz tubes with cupric oxide wire at 900 °C for 3 h to generate carbon dioxide (CO$_2$). Carbonate samples (8–10 mg) processed at the Lawrence Livermore National Laboratory were evacuated in a 10 ml vacuum, then reacted with 0.5 mL phosphoric acid to release CO$_2$. In both cases the evolved carbon dioxide was reduced to graphite using a Cobalt catalyst powder and H$_2$ gas (Vogel et al., 1987).

Beta Analytic dates are based on conventional (LSC) radiocarbon dating. At Beta Analytic, the external surfaces of the shell samples were etched with dilute HCl to remove portions of the shell most susceptible to contamination. The shell samples submitted were unusually well preserved, however, with little or no evidence for weathering or contamination. After pretreatment the remaining shell from each sample was dissolved in a second acid wash to produce CO$_2$. The charcoal samples were crushed and dispersed in deionized water and submitted to successive HCl-NaOH-HCl washes to eliminate carbonates, remove mechanical contaminants and secondary organic acids and neutralize the solution. According to correspondence from Beta Analytic, benzine synthesis and counting proceeded normally for all samples.

All radiocarbon ages are $^{13}$C/$^{12}$C adjusted according to Stuiver & Polach (1977) to correct for mass-dependent fractionation. $\Delta R$ determinations were calculated by converting the measured wood $^{14}$C ages from each stratigraphic level into equivalent marine model ages (figure 15; Stuiver & Braziunas, 1993). The corrected $^{14}$C age of the wood was then deducted from the radiocarbon age of shell for the same level to yield $\Delta R$.

Oxygen and carbon isotopic analysis

Studies of modern marine molluscs from known environments indicate that O and C isotopic analysis is
an effective method for reconstructing: (1) sea-surface temperature (Epstein, et al., 1951, 1953; Shackleton, 1969, 1973; Killoogley, 1981; Glassow et al., 1994); (2) changes in water salinity (Kennett & Voochies, 1995, 1996); and (3) fluctuations in upwelling (Killoogley & Berger, 1979; Wefer & Killoogley, 1980; Glassow et al., 1994). The ratio of $^{18}O$ to $^{16}O$ is highly sensitive to changes in water temperature and salinity and is preserved in calcareous fossils such as mollusc shells (Wefer & Berger, 1991). Fluctuations in $\delta^{13}C$ are thought to reflect changes in upwelling and overall marine productivity (Killoogley & Berger, 1979).

Analysis of incremental samples taken along the direction of shell growth enables the reconstruction of O and C isotopic ratios and hence annual fluctuations in water temperature, salinity and upwelling intensity through the life of a mollusc.

Well-preserved archaeological M ytilus californianus shells were selected from the same stratigraphical levels as the shell and charcoal pairs. The methods for cleaning and sampling California mussel shell (M. californianus) incrementally is detailed in Killoogley & Berger (1979) and Glassow et al. (1994). Briefly, all shells were cleaned and rinsed with deionized water to remove visible organic material, including the periostracum covering the historical samples. The outer surfaces of the shells were etched using a dilute solution of HCl (0.5 M) to remove any diagenetically altered carbonate (Bailey, Deith & Shackleton, 1983). Shells were sectioned longitudinally to expose the boundary between the exterior prismatic layer (calcite) and the interior, aragonitic nacreous layer (Glassow et al., 1994). Calcite samples were extracted from the exterior prismatic layer of the shell in 2 mm increments along the shell’s growth axis using a 0.5 mm drill. Powdered calcite samples (~ 0.3 mg) were heated at 375°C, under vacuum, for 1 h to remove organic compounds. After cooling to room temperature, the samples were reacted with orthophosphoric acid at 90°C (using a Fairbanks auto-sample device). The O and C isotopic ratios of the evolved CO$_2$ were measured using mass spectrometry (Finnegan/MAT251-Mass Spectrometer).

All measurements are expressed in $\delta$ notation as a deviation from an internationally accepted standard, PeeDee Belemnite (PDB), a carbonate fossil from South Carolina (Herz, 1990). The precision of the O and C isotopic ratios is 0.1‰. More negative $\delta$ values indicate higher proportions of the lighter $^{16}O$ and $^{12}C$ isotopes compared to the heavier $^{18}O$ and $^{13}C$ isotopes.

Results and Discussion

Radiocarbon ages for shell and charcoal samples from Daisy Cave and Cave of the Chimneys are listed in Table 1, along with calculated $\Delta R$ values. These data suggest that $\Delta R$ values in the Santa Barbara Channel region were not constant between 9470 and 3460 BP. Shifts in $\Delta R$ of up to 650 years occur between 9470 and 8910 BP, fluctuating from $-360$ (9470 BP) to $290$ (9070 BP) and back to $-10$ (8910 BP). This perturbation is followed by an increase in $\Delta R$ to $290$ (8440 BP). $\Delta R$ values show less variation between 8440 and 4310 BP, averaging $210 \pm 80$ and fluctuating ~230 years between 310 and 80 years. On average, $\Delta R$ values between 8440 and 4310 BP are slightly less than the average $\Delta R$ (225 ± 35) value currently used for the Santa Barbara Channel Region and smaller than the calculated $\Delta R$ based on two historic shells collected from the coast of California in 1936 ($233 \pm 60$). $\Delta R$ values at 3560 and 3460 BP are significantly smaller (~50 and $-30$) than the current value used for the region (225 ± 35).

Maximum, minimum and average $\delta^{18}O$ measurements of M ytilus californianus shells from the same stratigraphical levels as the shell and charcoal samples appear in Table 2. $\Delta R$ values for each stratum are plotted with $\delta^{18}O$ measurements in Figure 3. Between 9470 and 9070 BP $\delta^{18}O$ fluctuated 0.981‰ from 1.199 (9470 BP) to 0.218‰ (9070 BP). At 8910 BP average $\delta^{18}O$ values shift back to a more positive position (1.067‰). This perturbation correlates with a negative shift in $\Delta R$. With the exception of a positive jump at 3460 BP (1.134%), there was a gradual negative shift in $\delta^{18}O$ of 0.835‰ from 1.099 to 0.264% between 8440 and 3460 BP.

Maximum, minimum and average $\delta^{13}C$ measurements are plotted relative to $\Delta R$ values in Figure 4. Between 9470 and 8910 BP there was a sharp increase in $\delta^{13}C$ from $-0.013$ to $1.024\%$. This increase in $\delta^{13}C$ occurs as $\Delta R$ values fluctuate from $-360$ to 290 years and back to $-10$ years. Starting at 8910 BP the average $\delta^{13}C$ decreases from 1.024 to 0.434% and then remains relatively stable until 3460 BP, averaging ~0.267%. This parallels a period of relative stability in $\Delta R$ values.

Paleoceanographic implications

The radiocarbon ages of shell and charcoal from the same strata at Daisy Cave and Cave of the Chimneys fluctuate significantly between 9470 and 3460 BP. This variation may be due to changes in the marine radiocarbon reservoir ($\Delta R$) that occurred in the Santa Barbara Channel during this interval. Assuming the shell and charcoal samples are contemporary and the charcoal dates are accurate, we make five primary observations: (1) large-scale fluctuations occurred in the radiocarbon reservoir (~650 years) between 9470 and 8910 BP; (2) between 8910 and 4310 BP, $\Delta R$ values average 210 years and remain relatively stable; (3) at 3560 and 3460 BP, $\Delta R$ values decrease significantly (~50 and ~30); (4) $\Delta R$ values between 8910 and 4310 BP were on average (210) slightly less than the $\Delta R$ value currently used for the Santa Barbara Channel region (225 ± 30); and (5) $\Delta R$ values at 3560 and 3460 BP are significantly less than the current $\Delta R$ value used in the region. These observations
should be considered preliminary until they have been reproduced and higher temporal resolution is obtained.

Considerable variation in the radiocarbon reservoir (ΔR), δ18O and δ13C values between 9470 and 8910 BP suggest either: (1) significant fluctuations in the strength of coastal upwelling, or (2) rapid changes in the source of Santa Barbara Channel waters. Based on a radiocarbon chronology of varved sediments in Poland, Goslar et al. (1995) have suggested that the published 14C calibration curves may require adjustment around 8800–9000 14C BP. Alteration of calculated global reservoir ages would affect the amplitude of calculated ΔR, but fluctuations in δ18O and δ13C suggest that changes in oceanographic circulation in the Santa Barbara Channel did occur. Sancetta et al. (1992) argue, based on lithology, diatoms and pollen in a core located 120 km off the coast of southern Oregon, that patterns of summer upwelling were well developed by 9000 BP, but there were years when winds

### Table 1. Shell and charcoal dates from SMI-261 (Daisy Cave) and Cave of the Chimneys

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample number</th>
<th>Material</th>
<th>14C age</th>
<th>Equivalent marine model age</th>
<th>ΔR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col. E-6, Str. A3</td>
<td>CAM S-9095</td>
<td>Charred twig</td>
<td>3110 ± 60</td>
<td>3460 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. A3</td>
<td>Beta-15619</td>
<td>Red abalone</td>
<td>3430 ± 90</td>
<td>3430 ± 90</td>
<td>−30</td>
</tr>
<tr>
<td>Col. E-6, Str. A1</td>
<td>CAM S-8864</td>
<td>Charred twig</td>
<td>3220 ± 70</td>
<td>3560 ± 80</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. A1</td>
<td>Beta-49997</td>
<td>Blk. abalone</td>
<td>3510 ± 80</td>
<td>3510 ± 80</td>
<td>−50</td>
</tr>
<tr>
<td>Chim. B: 15–20</td>
<td>CAM S-14364</td>
<td>Charcoal</td>
<td>3930 ± 60</td>
<td>4310 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Chim. B: 15–20</td>
<td>CAM S-12454</td>
<td>Shell</td>
<td>4430 ± 60</td>
<td>4430 ± 60</td>
<td>−120</td>
</tr>
<tr>
<td>Chim. B: 35–40</td>
<td>CAM S-14367</td>
<td>Charcoal</td>
<td>3940 ± 60</td>
<td>4310 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Chim. B: 35–40</td>
<td>CAM S-12455</td>
<td>Shell</td>
<td>4560 ± 60</td>
<td>4560 ± 60</td>
<td>250</td>
</tr>
<tr>
<td>Col. E-6, Str. C</td>
<td>CAM S-8862</td>
<td>Charred twig</td>
<td>6000 ± 70</td>
<td>6420 ± 70</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. C</td>
<td>Beta-52359</td>
<td>Blk. abalone</td>
<td>6500 ± 80</td>
<td>6500 ± 80</td>
<td>80</td>
</tr>
<tr>
<td>Col. E-6, Str. E1</td>
<td>CAM S-8866</td>
<td>Charred twig</td>
<td>7810 ± 60</td>
<td>8150 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. E1</td>
<td>Beta-15621</td>
<td>Blk. abalone</td>
<td>8460 ± 100</td>
<td>8460 ± 100</td>
<td>310</td>
</tr>
<tr>
<td>Col. E-6, Str. E4</td>
<td>CAM S-8865</td>
<td>Charred twig</td>
<td>8040 ± 60</td>
<td>8440 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. E4</td>
<td>Beta-15622</td>
<td>Blk. abalone</td>
<td>8730 ± 120</td>
<td>8730 ± 120</td>
<td>290</td>
</tr>
<tr>
<td>Col. E-6, Str. F</td>
<td>CAM S-8867</td>
<td>Charred twig</td>
<td>8600 ± 60</td>
<td>8910 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. F</td>
<td>Beta-15623</td>
<td>CA mussel</td>
<td>8900 ± 60</td>
<td>8900 ± 60</td>
<td>−10</td>
</tr>
<tr>
<td>Col. E-6, Str. F</td>
<td>CAM S-8863</td>
<td>Charred twig</td>
<td>8810 ± 80</td>
<td>9070 ± 80</td>
<td>—</td>
</tr>
<tr>
<td>Col. E-6, Str. F</td>
<td>Beta-49948</td>
<td>CA mussel</td>
<td>9360 ± 90</td>
<td>9360 ± 90</td>
<td>290</td>
</tr>
<tr>
<td>Cave A, IIc</td>
<td>CAM S-14366</td>
<td>Charred twig</td>
<td>9180 ± 60</td>
<td>9470 ± 60</td>
<td>—</td>
</tr>
<tr>
<td>Cave A, IIc</td>
<td>CAM S-12456</td>
<td>CA mussel</td>
<td>9110 ± 90</td>
<td>9110 ± 90</td>
<td>−360</td>
</tr>
</tbody>
</table>

All samples are from Daisy Cave except for Chim B: 15–20 and Chim B: 35–40. Beta Analytic dates are based on conventional (LSC) radiocarbon dating. CAMS dates are based on accelerator mass spectrometry. All radiocarbon dates 13C/12C adjusted according to Stuiver & Polach (1977). The measured charcoal 14C ages were converted to equivalent marine model ages using the method of Stuiver & Braziunas (1993, Figure 15) and then deducted from the 14C age of shell from the same stratigraphic level to yield ΔR.

### Table 2. Maximum, minimum and average δ18O and δ13C measurements of historic Mytilus californianus shells and archaeological shells from Daisy Cave (SMI-261) and Cave of the Chimneys

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Site</th>
<th>Unit</th>
<th>Level</th>
<th>δ18O</th>
<th>M ax.</th>
<th>M in.</th>
<th>δ13C</th>
<th>M ax.</th>
<th>M in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC11</td>
<td>SMI-1-261</td>
<td>D5</td>
<td>A3</td>
<td>0.264</td>
<td>0.814</td>
<td>−0.267</td>
<td>0.434</td>
<td>0.989</td>
<td>−0.141</td>
</tr>
<tr>
<td>JE23</td>
<td>SMI-1-261</td>
<td>D5</td>
<td>A1</td>
<td>1.34</td>
<td>1.734</td>
<td>0.001</td>
<td>0.048</td>
<td>0.837</td>
<td>−0.655</td>
</tr>
<tr>
<td>JE30</td>
<td>Chim</td>
<td>B</td>
<td>35–40 cm</td>
<td>0.429</td>
<td>1.077</td>
<td>−0.330</td>
<td>0.342</td>
<td>0.872</td>
<td>−0.346</td>
</tr>
<tr>
<td>JE20</td>
<td>SMI-1-261</td>
<td>D6</td>
<td>C</td>
<td>0.838</td>
<td>1.206</td>
<td>0.208</td>
<td>0.078</td>
<td>0.396</td>
<td>−0.104</td>
</tr>
<tr>
<td>M C10</td>
<td>SMI-1-261</td>
<td>D6</td>
<td>E1</td>
<td>0.935</td>
<td>1.451</td>
<td>0.351</td>
<td>0.424</td>
<td>0.935</td>
<td>−0.385</td>
</tr>
<tr>
<td>JE21</td>
<td>SMI-1-261</td>
<td>D6</td>
<td>F1</td>
<td>1.099</td>
<td>1.496</td>
<td>0.730</td>
<td>1.024</td>
<td>1.713</td>
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</tr>
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<td>D6</td>
<td>F2</td>
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<td>0.055</td>
<td>0.718</td>
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</tr>
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<td>E6</td>
<td>F3</td>
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<td>0.638</td>
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<td>Ilc</td>
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<td>0.675</td>
<td>0.013</td>
<td>0.279</td>
<td>−0.510</td>
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</table>

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were too weak to support summer upwelling. Our data are consistent with these findings, but there is some evidence for persistent coastal upwelling during the early Holocene off the California coast (Anderson, Hemphill-Haley & Gardner, 1987). Alternatively, large-scale fluctuations in \( \Delta R \) during this interval may have resulted from changes in the source water entering the Santa Barbara Channel region.

Kennett, J. (1995) suggest that \(^{14}C\) age differences in planktonic-benthic foraminifera pairs from a core in the Santa Barbara region reflect changes in the age and thus the source of intermediate waters entering the Santa Barbara Basin.

The near stability of \( \Delta R \) values between 8440 and 4310 BP, on average slightly below contemporary levels, suggests that oceanic circulation was similar to today, and seasonal upwelling persisted through this interval. \( \delta^{13}C \) measurements of \( M. \) californianus shells from the same stratigraphical levels are consistent with this stability and the characterization of Anderson, Hemphill-Haley & Gardner (1987), who argued that upwelling along the California coast has remained strongly seasonal since the late Pleistocene. Smaller variations during this interval are undoubtedly related to changes in upwelling, possibly in response to the influence of El Niño/Southern Oscillation or other short-term changes in coastal upwelling. Other short-term fluctuations in the radiocarbon reservoir caused by these influences undoubtedly occurred, but the temporal resolution of our study does not allow us to comment on their relative influence.

The decrease in \( \Delta R \) values between 8440 and 3460 BP is consistent with general atmospheric circulation models predicting greater summer insolation in the northern hemisphere during the early Holocene than during the late Holocene (Heusser, Heusser & Peteet, 1985; COHMAP, 1988). Van Geen et al. (1992) argue that the decrease in summer insolation through the Holocene translates to decreases in coastal upwelling during this interval. Evidence for this is a decrease in the ratio of Cd/Ca in planktonic foraminifera in a core, spanning the last 4000 years, taken inside San Francisco Bay. Declining \( \Delta R \) values between 8440 and 3460 BP are consistent with this characterization. The negative shift in \( \delta^{18}O \) of \(-1.2\%\) through the Holocene is also consistent with this model and evidence for cooler sea-surface temperatures during the middle Holocene (Glassow et al., 1994). Prior to 6000 BP much of the shift in \( \delta^{18}O \) is related to changes in the O isotopic composition of the world ocean related to sea-level rise (Fairbanks, 1989). However, the negative shift in \( \delta^{18}O \) continues after the isotopic composition of the world ocean stabilizes (Figure 3).

Implications for correcting reservoir ages in prehistoric marine shell

Archaeologists continue to ask more complicated questions about prehistoric human behaviour, particularly how and why it changed through time. These questions require accurate radiocarbon dates so that archaeological patterns can be compared within and between time periods. Over the past 20 years, the reliability of marine shell for radiocarbon dating archaeological deposits has increased considerably. Dating historical shell from known contexts has been an extremely successful method for determining and refining
regional differences in $\Delta R$ (Berger, Taylor & Libby, 1966; Robinson & Thompson, 1981; Ingram & Southon, 1997). For some regions at least, $\Delta R$ values derived from historical shell may closely reflect $\Delta R$ values through the Holocene (Southon, Nelson & Vogel, 1990).

In the Santa Barbara Channel, where oceanic circulation is complex and sensitive to short- and long-term change, we argue that correcting fluctuations in the radiocarbon reservoir is not straightforward. Radiocarbon dating of paired shell and charcoal samples from Daisy Cave and Cave of the Chimneys suggests that $\Delta R$ values fluctuated through the Holocene Epoch. Between 9470 and 8910 14C yr, $\Delta R$ values are highly variable, as are $\delta^{18}O$ and $\delta^{13}C$ measurements of M. californianus shells from the same stratigraphic levels. Based on this observation we argue that the $\Delta R$ value currently used for the Santa Barbara region is unreliable for correcting marine shell dates that occur during this interval. If marine shell dates fall within this interval we suggest using $\delta^{18}O$ and $\delta^{13}C$ measurements of stratigraphically associated shells to characterize the marine environment at the time of deposition. Based on the stability of $\Delta R$ values between 8440 and 4310 14C yr, the current $\Delta R$ correction used for the Santa Barbara Channel region may be adequate (225 14C yr). However, this value appears to be too large for correcting dates between 3560 and 3460 14C yr.

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